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SURFACE EROSION AND HYDROLOGY OF EARTH COVERS USED IN SHALLOW LAND BURIAL OF LOW-LEVEL RADIOACTIVE WASTE

by

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Gardner C. Bent

Gardner C. Bent

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

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LIST OF TABLES

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

ABSTRACT

Surface Erosion and Hydrology of Earth Covers Used in Shallow Land Burial of Low-Level Radioactive Waste

by

Gardner C. Bent, Master of Science

Utah State University, 1988

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Department: Watershed Science

Shallow land burial is the current method of disposal of low-level radioactive waste in the United States. The most serious technical problems encountered in shallow land burial are water-related. Water is reported to come into contact with the waste by erosion of earth covers or through infiltration of precipitation through the earth covers.

The objectives of this study were to: (1) compare and evaluate the effects of crested wheatgrass (_Agropyron desertorum_ (Fischer ex Link) Shultes) and streambank wheatgrass (_Elymus lanceolatus_ (Scribner and Smith) Gould spp. _lanceolatus_) on surface erosion of simulated earth covers at Idaho National Engineering Laboratory (INEL), (2) characterize the surface hydrology, and (3) estimate cumulative soil loss for average and extreme rainfall events and determine if the waste will become exposed during its burial life due to erosion.

Rainfall simulations consisted of a 60-minute run (dry soil surface), a 30-minute run (wet soil surface) 24 hours later, and a 30-minute run (very wet soil surface) 30 minutes later at a rainfall intensity of approximately 60 mm/hr. This series of rainfall simulations was applied during June and September of 1987 to three crested wheatgrass plots, three streambank wheatgrass plots, and one bare soil plot.

The streambank wheatgrass plots produced approximately twice as much total soil loss as the crested wheatgrass plots. However, the two grass species ability to control erosion appeared fairly similiar in September. Based on the data collected at present it appears that crested wheatgrass is the superior grass species relative to control of erosion.

Analysis of infiltration data with the Horton and the Green-Ampt infiltration equations showed streambank wheatgrass to control infiltration rates better than crested wheatgrass; although in September both grass species exhibited quite similiar ability to control infiltration.

The universal soil loss equation (USLE) was used to provide estimates of soil loss for different rainfall events at INEL. Cumulative soil loss curves for simulated and hypothetical rainfall events provide estimations of expected soil loss for different size storms. If an extreme rainfall event of 60 mm/hr occurred every year at INEL, it would take a minimum of 1200 years for a 1-m bare lakebed sediment earth cover to erode.

(124 pages)

INTRODUCTION

A conservative estimate of the total volume of federal and commercial low-level radioactive waste to be produced by the year 2000 is approximately eight million cubic meters (Daniel, 1983). Low-level wastes are materials such as contaminated clothing, tools, machinery, piping, laboratory apparatus, building debris, and ion-exchange resins produced by hospitals, laboratories, private industry, nuclear power plants, and the military (Daniel, 1983).

With the increased production rate of low-level radioactive wastes, Idaho National Engineering Laboratory (INEL), other Department of Energy (DOE) sites, and commercially operated low-level waste repositories are faced with the growing problem of finding new burial sites and environmentally safe methods for disposal of waste material (Nyhan et al., 1984). The method of disposal at these low-level waste repositories is shallow land burial. Design life of the shallow land burial is between 100-300 years, which allows adequate time for the decay of two important radionuclides (strontium-90 and cesium-137) each with half lives of about 30 years (Daniel, 1983).

At the INEL Subsurface Disposal Area (SDA), containers of low-level radioactive waste are buried in large pits, then covered with lakebed sediment material and revegetated with an equal mixture of crested wheatgrass (*Agropyron desertorum* (Fischer ex Link) Shultes) and streambank wheatgrass (*Elymus lanceolatus* (Scribner and Smith) Gould spp. lanceolatus). The objectives of this practice are to control soil erosion and possible exposure of the waste material and to minimize infiltration of water through the waste material zone by maximizing evapotranspiration while keeping roots from entering the waste-material zone.

The effectiveness of these management practices are of major concern to the DOE waste-management program because Jacobs et al. (1980) reports that the most serious technical problems encountered in the shallow land burial are water related. In six of the eleven commercial and federally operated low-level waste shallow land burial sites, including the INEL site, water coming into contact with the waste material has been reported (Jacobs et al., 1980). Water-management problems include water coming into contact with the disposed waste through infiltration and erosion of the trench cap leading to exposure of waste material. Nyhan et al. (1984) states that most management practices that reduce erosion of the trench caps will probably enhance infiltration, thus low-level waste repositories must ultimately determine techniques that will optimize control of both infiltration and erosion.

Several studies have been initiated to examine these processes. Nyhan et al. (1984) and Nyhan and Lane (1985; 1986) studied the erosion potential and hydrologic behavior of soil covers for buried low-level radioactive waste. A study of erosion and hydrology of simulated trench caps used in shallow land burial was performed at Los Alamos National

Laboratory (LANL). Both of these studies used the same methodology, and comparisons of the effects of different cover treatments on infiltration and erosion of earth covers can be evaluated. They found that a gravel and western wheatgrass (Agropyron smithii Rydb.) (sod-forming grass) treatment provided the best erosion and infiltration control. A study of evapotransporation abilities of several plants, including crested wheatgrass (bunchgrass) and streambank wheatgrass (sod-forming grass), at INEL by Nowak (1986) found that streambank wheatgrass has the most efficient root system in its ability to extract water from the soil profile. This is an important factor in keeping water out of the waste-material zone. Dadkhah and Gifford (1980) found that plots with sod-forming grass have a significantly higher infiltration rate than plots with bunchgrass.

This study will evaluate the potential of crested wheatgrass and streambank wheatgrass to provide control of both erosion and infiltration on shallow land burial covers at INEL. Also, the study will estimate cumulative soil loss for average and extreme rainfall events at INEL and determine if the waste will become exposed during its burial life.

The primary objectives of this study are:

1. To compare and evaluate the effects of crested wheatgrass and streambank wheatgrass on the surface erosion of lakebed sediment earth covers. The null hypotheses state there will

be no difference in the amount of erosion from: a) the effects of different vegetation, b) the effects of different soil moistures, and c) the effects of different seasons.

2. To characterize the surface hydrology of the plots.

3. To estimate cumulative soil loss for average and extreme rainfall events and determine if the waste will become exposed during its burial life due to erosion.

To study surface erosion and hydrology of simulated trench caps at INEL, a rainfall simulator was used to eliminate temporal and spatial uncertainties that occur in natural rainfall events throughout the Intermountain region. Rainfall simulation allows for efficient, rapid, and controlled soil-loss research (Meyer, 1965).

Both the Horton and the Green-Ampt infiltration equations were used to analyze infiltration data. These two infiltration equations were chosen because they are the most widely used in analysis of infiltration data.

Horton (1940) proposed an equation to describe infiltration rates of the form:

$$f = f_c + (f_o - f_c)e^{-kt}$$

where: f = infiltration rate (mm/hr),
f_c = steady state infiltration capacity constant (mm/hr),
f_o = initial infiltration rate at the start of the storm = rainfall intensity of the simulation (mm/hr),
t = time from start of runoff (min), and
k = constant (1/min).

Green and Ampt (1911) developed a physically based equation to describe infiltration rates of the form:

$$f = K_s(1 + ns/F)$$

where: f = infiltration rate (mm/hr),
K_s = saturated hydraulic conductivity = steady state infiltration capacity constant (mm/hr),
n = effective porosity,
s = wetted front capillary pressure head (mm), and
F = cumulative infiltration (mm).

To estimate cumulative soil losses for average and extreme rainfall events, the Universal Soil Loss Equation (USLE) was used. Numerous studies using the USLE have been done to estimate rangeland erosion throughout the western U. S. with various degrees of success. The USLE was developed for use in estimating cropland erosion and long-term average annual soil loss. Soil losses computed by the USLE must be recognized as the best available estimates, not absolute data (Wischmeier, 1970).

The USLE equation (from Wischmeier and Smith, 1978; Foster et al., 1981) is:

$$A = RKLSCP$$

where: A = estimated average annual soil loss (tons/ha/yr),
R = rainfall erosivity factor (EI units/yr) (EI = MJ·mm/ha·hr),
K = soil erodibility factor (tons·ha·hr/ha·MJ·mm),
LS = slope gradient-length factor,
C = cover and management factor, and
P = erosion control practice factor.

In this study, the USLE will be used mostly for estimates of soil loss for specific storms. Trieste and Gifford (1980) found that the USLE, on a per-storm basis, could not account for the variation in sediment yields as a function of soil condition, antecedent soil-moisture condition, season, and plant community. Nyhan and Lane (1985; 1986) state that the USLE is most successfully used in predicting long-term average soil losses from upland burial sites, not soil losses from specific rainfall events. They also stated that soil losses estimated by the USLE will be most accurate for medium-textured soils, slopes with gradients between 3 and 18% and lengths less than 120 m, and cover-management systems that have been used in erosion plot studies.

STUDY AREA

INEL Subsurface Disposal Area:

The INEL site encompasses 2312 km^2 in the upper Snake River Plain of southeastern Idaho. The area of concern at the INEL site is the Radioactive Waste Management Complex's (RWMC) Subsurface Disposal Area (SDA) (Figure 1). Since 1952, the SDA has been used for below-ground burial of radioactive waste generated by INEL activities and for burial of transuranic contaminated waste from the DOE's nuclear fabrication facility at Rocky Flats, Colorado (Arthur and Markham, 1978; Markham, 1978). The SDA occupies a 36-ha area in the southwest corner of the INEL site, of which 10 ha have been used for the disposal of transuranic waste and 17.5 ha have been used for disposal of activation and fission-product waste (Arthur and Markham, 1978).

Past practices at the SDA have used both pits and trenches for the disposal of low-level radioactive waste. The trenches averaged 275 m long, 2 m wide and 4 m deep. The pits were of variable lengths averaging 30 m wide and 4 m deep. Both were covered with 0.9 m of lakebed sediment material (Markham, 1978). The lakebed sediment was taken from a flood plain area of the Big Lost River at the INEL site. This soil was chosen because of its ability to act as a hydraulic barrier. No trenches have been constructed since 1977; only pits 10 m deep, 50 m wide, and 250 m long are now constructed to maximize storage volumes (J. Bower, personal communication, Radioactive Waste Management Complex, INEL,

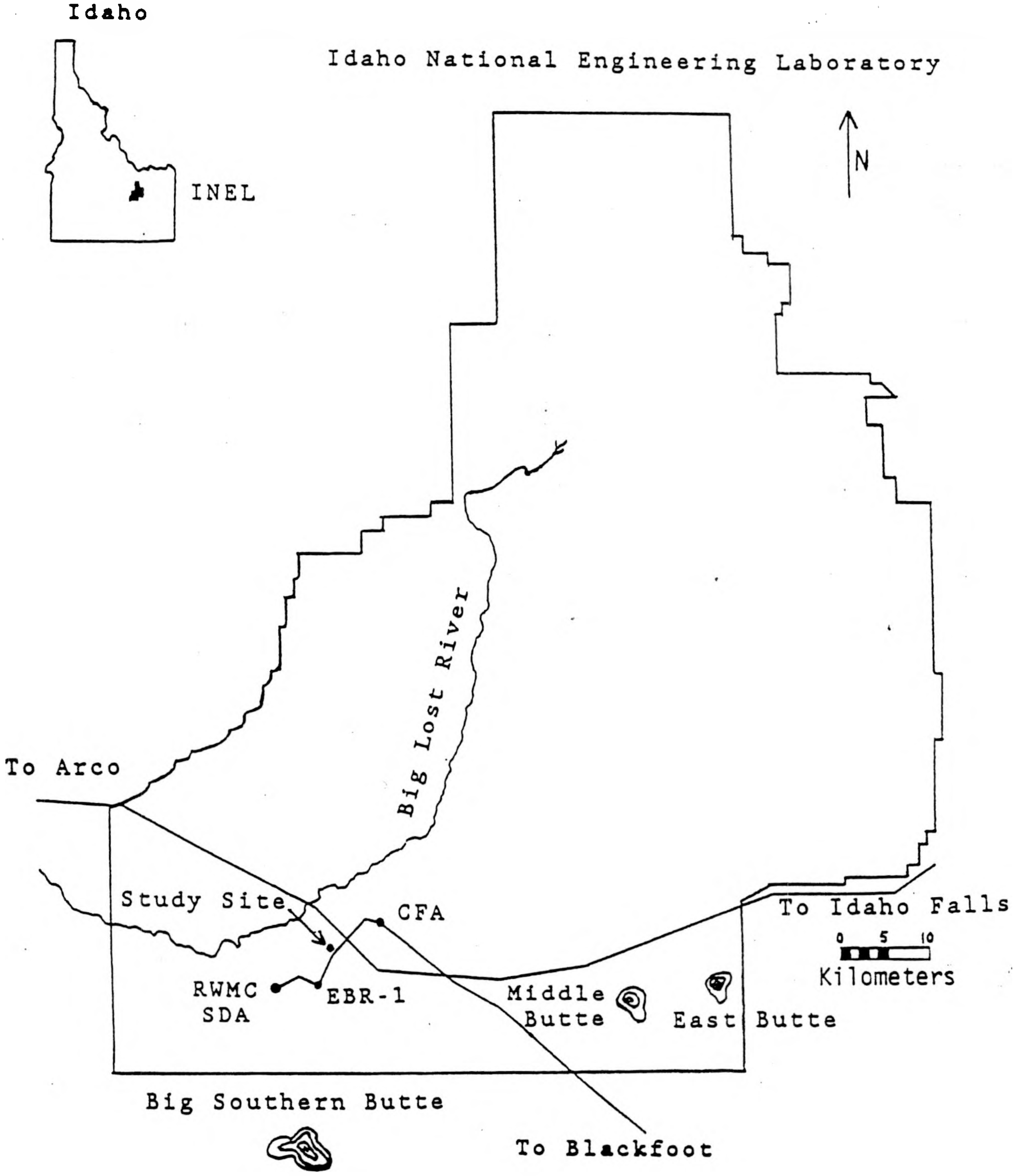

Figure 1. Location of the study site and the Subsurface Disposal Area (SDA) at Idaho National Engineering Laboratory (INEL).

1987). The waste in steel drums is stacked in the pits and then covered with 1 m of lakebed sediment to insure a 1-m barrier between the soil surface and the waste. The soil is compacted with a vibrating sheep's foot and then the surface is contoured to keep precipitation from ponding on the cover and drill seeded in the fall (R. Devries, personal communication, Radioactive Waste Management Complex, INEL, 1988). Since 1983, seeding of the covers at the SDA has been accomplished with a 50-50 mixture of Ephraim crested wheatgrass and Sodar streambank wheatgrass (C. Miller, personal communication, Radioactive Waste Management Complex, INEL, 1987). The Ephraim crested wheatgrass is an introduced bunchgrass species and the Sodar streambank wheatgrass is a sod-forming (rhizomatous) grass species. Prior to 1983, seeding of the covers was done only with crested wheatgrass.

Study Site:

The seven runoff plots are located on the study site approximately 5 km northeast of the SDA on Van Buren Boulevard, 1 km north of EBR-1 (Experimental Breeder Reactor-1) (Figure 1). EBR-1 is located 29 km east of Arco, Idaho and 80 km west of Idaho Falls, Idaho on the INEL site. The study site is at an elevation of 1524 m and the native soil texture is a sandy loam. The sandy loam soil is predominately coarse-silty, mixed, frigid xerollic calciorthids, probably in the Polatis-Tenno complex (Soil

Conservation Service, 1973). Both the study site and the SDA are located within a cool desert ecosystem, composed primarily of big sagebrush (*Artemisia tridentata* Nutt.), bluebunch wheatgrass (*Agropyron spicatum* (Pursh) Scribn. and Smith), and green rabbitbrush (*Chrysothamnus viscidiflorus* (Hook.) Nutt.) (McBride et al., 1978).

Climate:

Weather data from INEL (1951 to 1986) shows that the average yearly precipitation is 22.4 cm with extremes of 12.5 and 36.6 cm. The months of May and June account for more than 25% of the yearly precipitation, and December and January represent another slight peak in precipitation. The maximum recorded one-day rainfall event during the 36-year period at INEL was 4.19 cm. Precipitation events causing runoff at INEL are the spring snowmelt, rain on snow, and short-duration, high-intensity convection storms during the summer. The average annual temperature at the site is 5.6°C with extremes of -43°C and 38°C. Winds are predominantly from the SW and NE with the strongest and most frequent winds being from the SW.

MATERIALS AND METHODS

Plot Construction:

During the spring of 1985 the plot locations were determined at the study site. Seven plots 3.05 x 10.7 m in size were installed during the summer of 1985. The areas were first excavated to 1.5 m in depth and then backfilled with the same lakebed sediment material that is used at the SDA. Then a rubber-tired front end loader compacted the soil by backing over it several times. Steel plate borders 20 cm in depth were placed along the two 10.7-m borders and the upper 3.05-m border. The bottom end of the plot was delineated by a 3.4-m long collection trough with a 10-cm lip extending onto the plot. The trough slopes down from its ends to the center where it drains into a 5.1-cm pipe, which sends runoff to a collection tank with a diameter of 1.1 m and depth of 0.9 m. Lakebed sediment was filled in the plot area to allow only 10 cm of the steel plot border to show. The plots were rototilled to a 10-cm depth and raked to remove large clods in the soil. Then the plots were leveled to a uniform 6% slope.

In October 1985, crested wheatgrass was transplanted onto plots 2, 3 and 5 and steambank wheatgrass was sown on plots 1, 4, and 6 (Figure 2). Crested wheatgrass was taken from the surrounding area and transplanted in an offset diagonal pattern on 43-cm centers and on rows 43 cm apart with a 1-m buffer strip on all sides outside the plot. The offset diagonal pattern was used to create barriers to slow

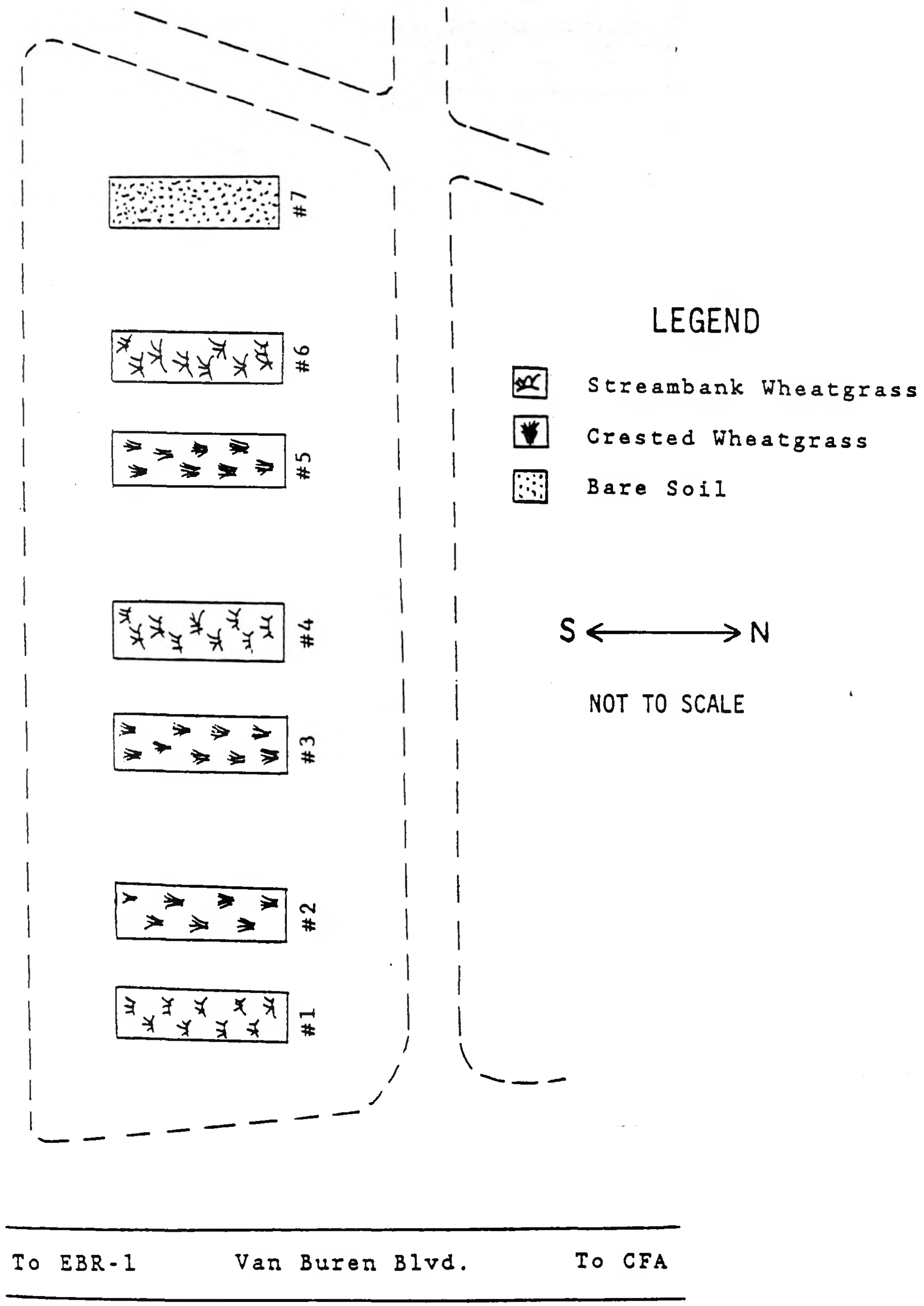

Figure 2. Layout of the seven lakebed sediment plots and their treatment.

downslope movement of surface runoff. Streambank wheatgrass was planted in rows 15 cm apart on the contour with a hand drill and then the drill furrows were tamped. Streambank wheatgrass was planted on the contour to make a barrier to slow downslope flow of surface runoff.

Crested wheatgrass and streambank wheatgrass were chosen for the study by the Radiological Environmental Science Laboratory (RESL) personnel at INEL. These species were chosen because they are the two grass species which are used in revegetation of the trench caps at the SDA and because they represent examples of bunchgrasses (crested wheatgrass) and rhizomatous grasses (streambank wheatgrass). Bunchgrasses and rhizomatous grasses exhibit distinctively different rooting characteristics. The streambank wheatgrass rhizomes grow radially and form a sod-like grass, whereas crested wheatgrass tends to be caespitose (Dr. J. Dobrowolski, personal communication, Range Science Department, Utah State University, 1987).

One plot was left bare to serve as a control plot and to represent the worst-case situation of seeding failure. This plot provides additional information on natural revegetation of trench caps at SDA.

During June and July of 1986, the plots seeded with streambank wheatgrass were irrigated with approximately 125 mm of water to insure survival of the grass. To provide comparable data between plots it was necessary to fill holes and cracks in the lakebed sediment plots caused by subsidence during June of 1987.

Rainfall Simulator:

To simulate episodic (or extreme) rainfall events, a rainfall simulator was used in this study. The rainfall simulator allows erosion and surface hydrology measurements from rainfall events that have a set rainfall intensity and duration at predetermined times. The simulator, built by the U. S. Agriculture Research Service (ARS), was trailer-mounted with a rotating boom similar to the design described by Swanson (1965) (Figure 3).

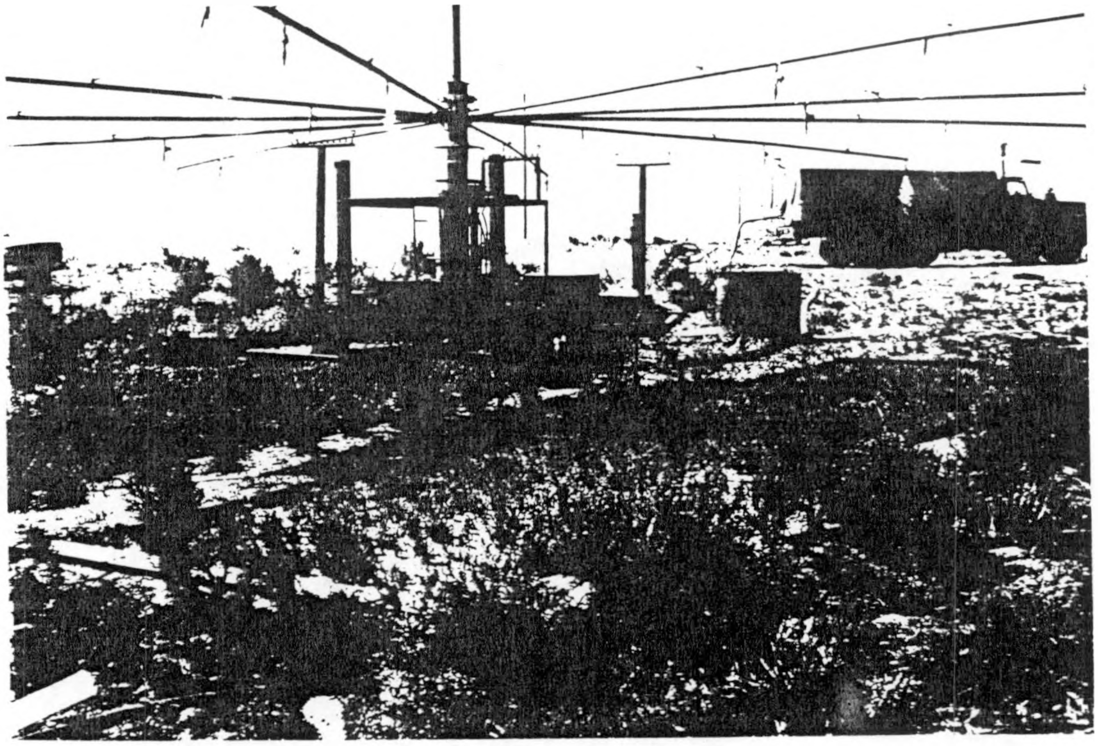

Figure 3. Trailer mounted rotating-boom rainfall simulator.

The rotating-boom rainfall simulator is capable of applying either 60 or 120 mm/hr rainfall rates at approximately 80% of the energy of natural rainfall (Swanson 1965; 1979). Ten booms radiate from the central stem of the simulator to support 30 nozzles. The nozzles are positioned along each boom at 1.5, 3.0, 4.6, 6.1, and 7.6 m from the center, with 2, 4, 6, 8, and 10 nozzles. Either 15 or 30 nozzles are used depending on whether a 60 or 120 mm/hr rainfall rate is desired. In this study a rainfall intensity of only 60 mm/hr was used. By using this simulator, paired plots 3.05 x 10.7 m in size and 3.05 m apart could be rained on simultaneously. The nozzles spray downward from a height of 2.4 m and during windy conditions all the outer nozzles at the 7.6 m radius were opened to insure that each entire plot would be covered. Water was pumped to the simulator from a 5000-gallon water truck provided by the DOE.

This project included three rainfall simulations on the seven plots during the study period of 1986 through 1987. Each of the rainfall simulations included three runs on each pair of plots at a rainfall intensity of 60 mm/hr. The initial run was for 60 minutes on a dry soil surface followed by a 30-minute run 24 hours later on a wet soil surface and finally a 30-minute run 30 minutes later on a very wet soil surface. The rainfall simulation during August 1986 involved only a run of 30 minutes on a dry soil surface, because it was believed that the streambank wheatgrass was not mature enough to withstand a full series of simulations, and the grass seedlings could possibly be washed out. In 1987, the two rainfall simulations followed the originally planned procedure of a dry, wet, and very wet run.

Measurement of Soil Characteristics:

Before each rainfall simulation run during 1986 and 1987 three soil samples were taken from each plot using a soil probe for determination of soil moisture percent. The samples were weighed wet and then oven dried at 105°C for 24 hours to determine average gravimetric soil moisture.

In October 1987 three soil samples of lakebed sediment were analyzed by the Utah State University (USU) Soil Testing Lab for soil texture classification and organic matter percent. Three soil samples was determined to be a sufficient number of samples, as the lakebed sediment material is mixed and uniform throughout. The soil texture analysis was done using the hydrometer method described by Bouyoucos (1962) to determine percent sand, silt, and clay. Also, the sand was sieved into very fine through very coarse fractions to help estimate the lakebed sediment's soil erodibility (K) value using the soil erodibility nomograph in Wischmeier and Smith (1978). In addition, the mineralogy of the different particle size fractions of the lakebed sediment material was analyzed by X-ray diffraction in October 1987 by Dr. Peter Kolesar of the USU Geology Department.

In September 1987, bulk density samples were taken on all seven plots at three locations on the plots (lower, middle, and upper) and at three depths (0-6, 6-12, and 12-18 cm) to determine an average bulk density of the lakebed sediment material. The samples of a known volume were then oven-dried at 105°C for 24 hours and weighed. The bulk density was then calculated by dividing the dry weight by the known volume.

Measurement of Vegetation Characteristics:

Before each of the rainfall simulations during 1986 and 1987 plot surface characteristics and vegetation cover were measured. Characteristics measured were bare soil, litter, vegetative basal cover, and vegetative crown cover. Soil had only one classification since no stones greater than 2 mm were found. Litter had only one classification, as only fine grass litter existed. A 3.05-m long vertical point frame with holes spaced 6 cm apart was used. The vertical point frame was placed perpendicular to the plot slope at five locations at 2-m increments along the plot borders. At each of the five locations, 48-point measurements of surface and canopy cover were made by dropping a pin through each of the 48 holes. Thus a total of 240-point measurements were used to describe that plot's surface and canopy characteristics.

In September 1987 standing crop estimates for the seven plots were made. To get a general estimate of standing crop, but keep destructive sampling to a minimum, only four or five random samples were taken on each plot. The number of samples taken differed for the two grass species due to their dissimiliar growth forms. Standing crop estimates for the streambank wheatgrass plots were done by selecting four random locations on each plot. At these locations a 30-x-60-cm frame was placed and all standing vegetation within the frame was clipped. The grass was oven-dried at 65°C for 24 hours and then weighed. The average dry weight of the clipped material was then expressed for the entire area of the plot. The same procedure was used on the bare plot except five random samples were collected. Standing crop estimates for the crested wheatgrass plots were done by selecting five random locations on each plot. At these locations the closest crested wheatgrass plant was clipped to the ground, bagged, and oven-dried as before. That average plant weight was multiplied by the number of plants on each plot and divided by the plot area to determine the estimated standing crop for each crested wheatgrass plot.

Measurement of Runoff and Erosion:

Before each rainfall simulation six wedge-shaped raingauges were placed evenly throughout each plot with two raingauges in the upper, middle, and lower portions of the plots. The average rainfall depth for the run was then divided by the duration of rainfall for the run to determine rainfall intensity on each plot for each run.

During the September 1987 rainfall simulations runoff velocity measurements were made using dye. The dye was spread across the plot during the rainfall simulation at either the top or the mid-point of the plot and the travel times were recorded with a stopwatch. Also, water temperatures in the water truck and in the runoff tank were recorded for some of the runs during 1987.

Runoff samples were collected in 1-liter plastic bottles. Sampling started on the first full minute after runoff began and continued at 1-minute intervals until the runoff rate had reached an equilibrium. At this time samples were taken at 2-minute intervals until rainfall was stopped. Then sampling returned to 1-minute intervals until runoff stopped. When the runoff rate exceeded 1-liter per 5 seconds a 6-liter graduated cylinder was used to get the discharge rate at that time and the 1-liter plastic bottles were used to sample the runoff for sediment concentrations. After each run, the lip of the collection trough and the trough were cleaned of all sediment. This sediment was then oven-dried at 105°C for 24 hours and added directly to the final calculations of soil loss. This was done because it was not known when deposition of this sediment in the trough occurred. Plot observations were made for rills, holes, and cracks in the soil surface and the amount of rainfall in each raingauge was recorded following each run.

Lab work was completed at RESL, at INEL and at USU in Logan, UT. The 1-liter runoff samples were weighed for determination of volume using 1 gm = 1 cm^3. Aluminum sulfate was then added to the samples to speed up the settling process of the sediment in solution. After the sediment had settled, the supernatant was suctioned off. Each sample was then filtered to catch all the sediment. The sediment and filter paper were then placed in small manilla envelopes, oven-dried at 105°C for 24 hours, and then weighed.

Infiltration Analysis:

For analysis of infiltration data, data were fitted to both the Horton (1940) and the Green-Ampt (1911) infiltration equations. The Horton and the Green-Ampt infiltration equations were selected because they are the most commonly used in analysis of infiltration data. A nonlinear curve-fitting computer program was used to fit the rate form infiltration data to the Horton equation. Least squares curve fitting was used in fitting the cumulative infiltration data to the Green-Ampt equation.

Statistical Design:

The statistical design used in this study to analyze the infiltration, runoff, and soil loss data was a split-split plot analysis of variance. The three treatments were grass species, season, and antecedent soil moisture condition. The blocks were the replications of the paired plots. In the split-split plot design the whole plot analysis was grass species, the subplot analysis was season, and the subsubplot analysis was soil moisture level. A significance level of $\alpha = 0.10$ was used to evaluate p-values of the null hypotheses.

To analyze vegetation (canopy cover, plant basal cover, litter cover, bare soil cover, and standing-crop amount) data the statistical design used was a split-plot analysis of variance. The treatments were grass species and season. The blocks were replications of the paired plots. In the split-plot design the whole plot analysis was grass species and the subplot analysis was season. To evaluate significant differences a significance level of $\alpha = 0.10$ was used to evaluate p-values. The SPSSx Inc. (1986) computer package was used for both statistical design analysis of variances.

RESULTS AND DISCUSSION

Soil Characteristics:

The soil texture of the lakebed sediment material was determined to lie at the boundary between clay loam, silt loam, and loam in the soil textural triangle with an average of 23% sand, 50% silt, and 27% clay. The average organic matter was determined to be 0.8% and the soil erodibility (K) factor was estimated to be 0.058 (t•ha•hr/ha•MJ•mm) using the soil erodibility nomograph in Wischmeier and Smith (1978). Individual results of each sample and a breakdown of the sand fraction are in Appendix A.

In September 1987 bulk density samples were taken at three depths at three locations on each plot to determine an average value for the lakebed sediment material. The bulk density was calculated to be 1.46 g/cm^3 with a standard deviation of 0.10 g/cm^3.

In both 1986 and 1987, surficial macropores were noticed on the soil surface of the plots (Figure 4). The macropores were caused by cracking and subsidence of the lakebed sediment material. The volume and number of cracks (macropores) on each plot was recorded in September 1986 and June 1987. The crack volumes were estimated by using length, width, and depth measurements. In 1986 the streambank wheatgrass plots had an average of 11 cracks per plot with an average volume of 261 cm^3 per crack and the crested wheatgrass plots had an average of 26 cracks per plot with an average volume of 677 cm^3 per crack.

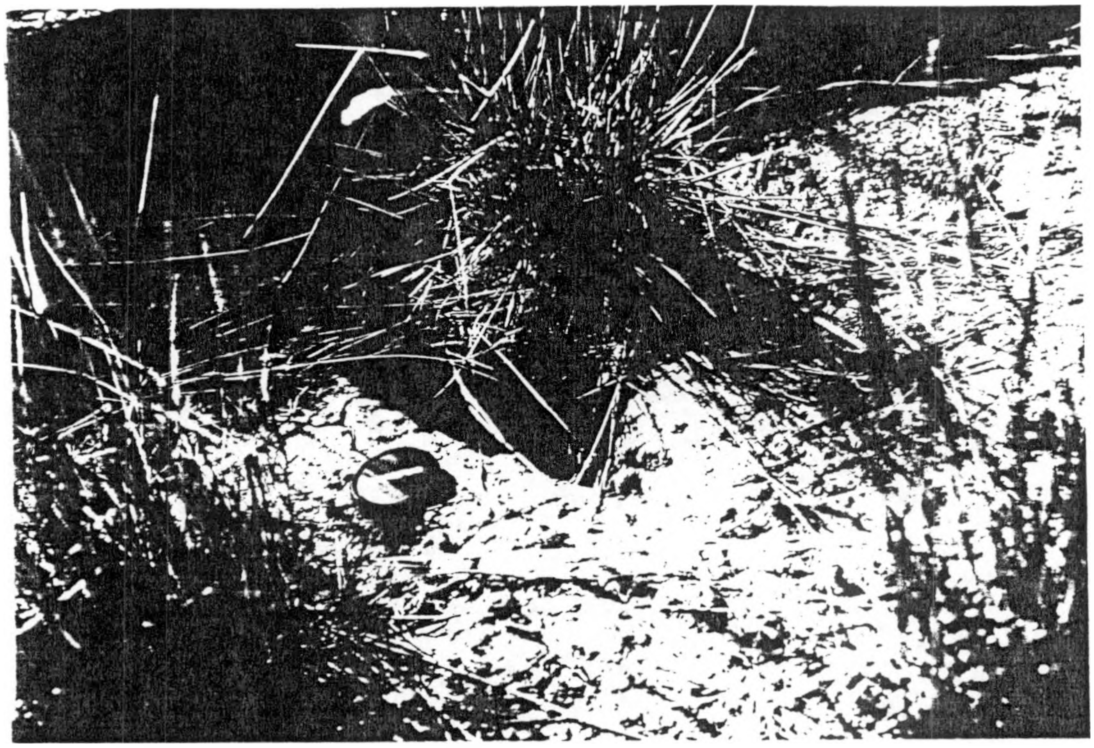

Figure 4. Macropore in surface of lakebed sediment plot.

Consequently in the fall of 1986 the crested wheatgrass plots had approximately 2.5 times as many cracks and 2.5 times as much crack (macropore) volume as the streambank wheatgrass plots. The reasons for these differences in crack numbers are not known. One possible explanation is the application of 125 mm of water during the summer of 1986 on the streambank wheatgrass plots. This additional water could have sealed some of the cracks. In June 1987 streambank wheatgrass plots had only an average of one crack per plot. Crested wheatgrass plots had an average of 15 cracks and an average volume of 564 cm^3 per crack. During the winter of 1986-1987 some natural sealing of the surficial macropores on the plots must have taken place. In June 1987 the macropores were filled with lakebed sediment to insure that comparable data could be collected from the plots.

It should be mentioned that the subsidence and cracking of the lakebed sediment could have an overwhelming effect on the amount and rate of infiltration in this soil. Since the soil is uniform to a 1 m depth, cracking of the soil may extend to this depth, which would allow precipitation and runoff to directly enter the waste material zone. For this reason the mineralogy of the different soil size fractions was analyzed. The results (Appendix A) showed that the clay particle size fraction was mainly made up of montmorillonite clay (Dr. P. Kolesar, personal communication, Geology Department, Utah State University, 1987). Montmorillonite clay is a 2:1 clay, or shrink-swell clay, which undergoes intense cracking from wetting and drying periods. This should be of major concern to the DOE waste-management program.

Vegetation Characteristics:

Cover is an important factor in controlling soil loss, thus surface characteristics were measured before each rainfall simulation. The data were placed into two categories, one group being canopy cover, which is similar to running an imaginary plane a few centimeters above the soil surface. The other group is surface cover, which relates to running an imaginary plane along the soil surface. Surface cover includes litter and plant basal cover, so the sum of percent of litter and plant basal cover and percent of bare soil equals 100%.

As seen from Table 1, both canopy and surface cover (litter and plant basal) increased for both grass species from August 1986 to August 1987. The canopy and surface cover increased dramatically, over 20% and 50%, respectively, for the streambank wheatgrass plots from August 1986 to August 1987. By August of 1987 the average values of canopy cover, surface cover, and bare soil percents were almost identical between the two grasses. Also, natural revegetation occurred in the bare plot forming a limited canopy and surface cover.

To further quantify cover for the seven plots, standing crop was estimated in September 1987 (Table 2). Crested wheatgrass plots had approximately 35% more standing crop than the streambank wheatgrass plots. This is most likely attributable to the difference in canopy height, with 65 cm the average for crested wheatgrass and 35 cm the average for streambank wheatgrass.

A split-plot analysis of variance (Appendix B) was done on percent canopy cover, percent litter cover, percent bare soil, and amount of standing crop to determine if differences existed between grass species, season, and the interaction of grass species and season. No significant differences between the two grass species were found for percent canopy cover and amount of standing crop data. Percent litter cover increased significantly for both grass species between June and September. Percent bare soil

Table 1. Canopy and surface cover percents for 1986 and 1987.

CANOPY COVER (%)

Plot (treatment)	August 1986	June 1987	August 1987
1 Streambank Wheatgrass	31.60	49.58	46.25
4 Streambank Wheatgrass	18.60	48.95	50.00
6 Streambank Wheatgrass	23.20	30.58	42.08
AVG.	24.47	43.04	46.11
2 Crested Wheatgrass	38.75	52.94	45.42
3 Crested Wheatgrass	34.79	38.08	51.25
5 Crested Wheatgrass	35.63	49.37	46.25
AVG.	36.39	46.80	47.64
7 Bare Soil	0.00	2.08	22.92

SURFACE COVER (%)

Plot (treatment)	August 1986	June 1987	August 1987
Plant Basal Cover (%)			
1 Streambank Wheatgrass	1.20	7.50	6.25
4 Streambank Wheatgrass	1.00	6.69	10.00
6 Streambank Wheatgrass	2.20	2.07	6.25
AVG.	1.47	5.42	7.50
2 Crested Wheatgrass	9.38	11.34	7.92
3 Crested Wheatgrass	7.29	11.30	9.17
5 Crested Wheatgrass	9.17	12.97	10.83
AVG.	8.61	11.87	9.31
7 Bare Soil	0.00	0.83	0.42
Litter Cover (%)			
1 Streambank Wheatgrass	1.40	31.25	46.25
4 Streambank Wheatgrass	1.00	33.06	44.58
6 Streambank Wheatgrass	0.80	22.31	47.08
AVG.	1.07	28.87	45.97
2 Crested Wheatgrass	25.42	31.10	42.91
3 Crested Wheatgrass	29.58	33.89	40.83
5 Crested Wheatgrass	31.04	32.64	44.17
AVG.	28.68	32.54	42.64
7 Bare Soil	0.00	0.00	9.58

Table 1. Canopy and surface cover percents for 1986 and 1987 (continued).

SURFACE COVER (%)

Plot (treatment)	August 1986 Bare Soil (%)	June 1987	August 1987
1 Streambank Wheatgrass	97.40	61.25	47.50
4 Streambank Wheatgrass	98.80	60.25	45.42
6 Streambank Wheatgrass	97.00	75.62	46.67
AVG.	97.73	65.71	46.53
2 Crested Wheatgrass	65.20	57.56	49.17
3 Crested Wheatgrass	63.13	54.81	50.00
5 Crested Wheatgrass	59.79	54.39	45.00
AVG.	62.71	55.59	48.06
7 Bare Soil	100.00	99.17	90.00

Table 2. Standing crop estimates for September 1987.

Plot (Treatment)	Standing Crop (g/m2)	Standing Crop (g/plot)
1 Streambank Wheatgrass	124.38	4070.90
4 Streambank Wheatgrass	155.50	5007.15
6 Streambank Wheatgrass	125.95	4053.03
AVERAGE	135.95	4377.03
2 Crested Wheatgrass	204.10	6559.80
3 Crested Wheatgrass	117.65	3793.01
5 Crested Wheatgrass	227.46	7269.60
AVERAGE	183.07	5874.14
7 Bare Soil	100.22	3254.17

decreased as expected with the increase in litter cover. The analysis on percent plant basal cover and percent bare soil showed a significant difference between the interaction of grass species and season. Since percent plant basal cover increased from June to September, percent bare soil decreased.

The cover factor (C) in the Universal Soil Loss Equation (USLE) can be obtained from canopy and surface cover data by using a table in Wischmeier and Smith (1978). This cover-factor estimate is useful because erosion is then proportionalto rainfall energies in the USLE, and expected soil loss can be calculated for each rainfall event. Before this is done, the estimated table values of the cover factors for the vegetation types should be checked for their reasonability. This is done by using the actual data collected form the rainfall simulations and backcalculating for (C). The table values are based on the average estimated C values using canopy and surface-cover data for each treatment during 1987. The computed values are the averages of all the rainfall simulations for each treatment during 1987. The average table and computed cover-factor (C) values for the three cover types are shown in Table 3.

Table 3. Cover factor (C) in the USLE for the three cover types.

Cover Type	Table Value	Computed Value
Crested Wheatgrass	0.06	0.08
Streambank Wheatgrass	0.07	0.16
Bare Soil	0.39	0.49

The crested wheatgrass cover factor from the table was very close to the computed value and, thus, could be used for calculation of the expected soil loss under differing rainfall events. The streambank wheatgrass and bare soil cover factors from the tables were not as close to the computed values.

Nyhan and Lane (1986) state that the most difficult factor to estimate in the USLE is the C factor. This can be seen in the results of Table 3. If the estimated C factors determined by using a table by Wischmier and Smith (1978) were used to predict soil loss using the USLE, average soil loss would be underestimated by 25, 54, and 22% for crested wheatgrass, streambank wheatgrass, and bare soil cover, respectively. For the 42 rainfall simulations done in 1987, it was determined that the USLE underestimated soil loss 71.4% of the time and overestimated it 28.6% of the time, when C factors were estimated using a table by Wischmeier and Smith (1978). These results are similar to those of Trieste and Gifford (1980), who found that on a per-storm basis the USLE underestimated observed soil loss 67.5% of the time and overestimated it 32.5% of the time. Because of these findings, it is recommended that the computed average C factors be used for predicting soil losses for different rainfall events for these cover types at INEL.

Infiltration:

Infiltration of surface water into radioactive waste is one of the major problems faced by waste-management programs that use shallow land burial. In this study both the Horton (1940) infiltration equation and the Green-Ampt (1911) infiltration equation were used to fit actual infiltration data collected from all rainfall simulations during 1987. Data collected during 1986 was considered unusable for this analysis because of insufficient runoff data.

The results of nonlinear curve fitting of the Horton infiltration equation to actual data collected are shown in Tables 4 and 5. Figure 5 is an example of nonlinear curve fitting of the Horton equation to rate form-infiltration data. The R^2 values for the fitted infiltration curves of each of the runs were all above 90% except for two of the 42 runs. To determine if there were a difference in the calculated infiltration capacity constants (f_c) between grass species, season, or antecedent soil-moisture condition, a split-split plot analysis of variance was done (Table 6). Results of the analysis of variance with a significance level of $\alpha = 0.10$ indicated significant differences in infiltration capacity constants for antecedent soil moisture condition (dry > wet > very wet), the two grass species (crested wheatgrass > streambank wheatgrass), and the interaction of grass species and season.

Horton (1940) and Aboulabbes et. al. (1985) found that almost invariably infiltration rates show differences between the initial and wet runs at the same intensity and duration of rainfall with a one-day break between runs. They

Table 4. Results of non-linear curve fitting with the Horton infiltration equation in June 1987.

JUNE 1987

Plot	f_c (mm/hr)	f_o (mm/hr)	k (1/min)	R^2	s.e.(mm/hr)
1D	14.86	61.95	0.2245	0.9797	1.94
1W	15.00	57.61	0.6311	0.9687	2.01
1VW	13.11	60.25	1.1900	0.9858	1.42
2D	32.21	53.62	0.1163	0.9304	1.75
2W	29.14	55.72	0.3778	0.9304	2.03
2VW	24.93	59.68	0.9242	0.9815	1.21
3D	24.56	61.04	0.0543	0.9353	2.65
3W	27.88	62.18	0.3414	0.9598	2.16
3VW	28.92	68.55	0.4982	0.9479	2.57
4D	19.00	49.27	0.1845	0.9227	2.36
4W	23.44	60.78	1.4910	0.9668	1.75
4VW	19.12	61.74	0.9832	0.9834	1.41
5D	35.82	53.62	0.0571	0.9594	1.08
5W	30.70	55.11	0.6287	0.9394	1.71
5VW	26.10	57.25	0.7704	0.9596	1.37
6D	19.59	50.59	0.1430	0.9303	2.48
6W	16.65	55.57	0.5971	0.9586	2.28
6VW	15.46	60.55	1.0170	0.9831	1.68
7D	19.62	56.47	0.2120	0.9491	2.35
7W	11.10	58.13	1.6700	0.9585	2.27
7VW	10.68	58.19	2.2150	0.9756	1.78

Note: D - Dry Run, W - Wet Run, and VW - Very Wet Run.

Plots 1, 4, and 6 are streambank wheatgrass.
Plots 2, 3, and 5 are crested wheatgrass.
Plot 7 is bare soil.

Table 5. Results of non-linear curve fitting with the Horton infiltration equation in September 1987.

SEPTEMBER 1987

Plot	f_c (mm/hr)	f_o (mm/hr)	k (1/min)	R^2	s.e.(mm/hr)
1D	19.89	55.74	0.1770	0.9718	1.77
1W	16.34	66.27	0.8896	0.9788	2.11
1VW	18.10	65.41	1.3140	0.9796	1.69
2D	17.53	40.61	0.0745	0.9514	1.65
2W	24.52	60.98	1.5450	0.8914	3.22
2VW	23.04	61.11	1.2330	0.9691	2.00
3D	33.73	63.27	0.3216	0.9574	2.07
3W	21.97	55.81	0.4364	0.9748	1.70
3VW	20.36	59.29	0.8913	0.9793	1.73
4D	30.95	61.28	0.3447	0.9575	1.91
4W	23.13	58.54	0.3958	0.9781	1.78
4VW	20.24	63.78	0.6899	0.9447	2.78
5D	31.17	58.20	1.0760	0.6619	3.98
5W	21.24	53.80	0.7464	0.9724	1.64
5VW	16.52	54.08	1.4540	0.9807	1.56
6D	18.10	56.42	0.7860	0.9392	1.94
6W	21.90	63.37	1.4380	0.9773	1.64
6VW	20.81	65.73	1.6480	0.9949	0.81
7D	16.05	61.98	0.0473	0.9797	2.11
7W	20.47	60.16	0.0485	0.9632	2.35
7VW	19.39	63.96	1.2280	0.9687	1.97

Note: D - Dry Run, W - Wet, and VW - Very Wet Run.

Plots 1, 4, and 6 are streambank wheatgrass.
Plots 2, 3, and 5 are crested wheatgrass.
Plot 7 is bare soil.

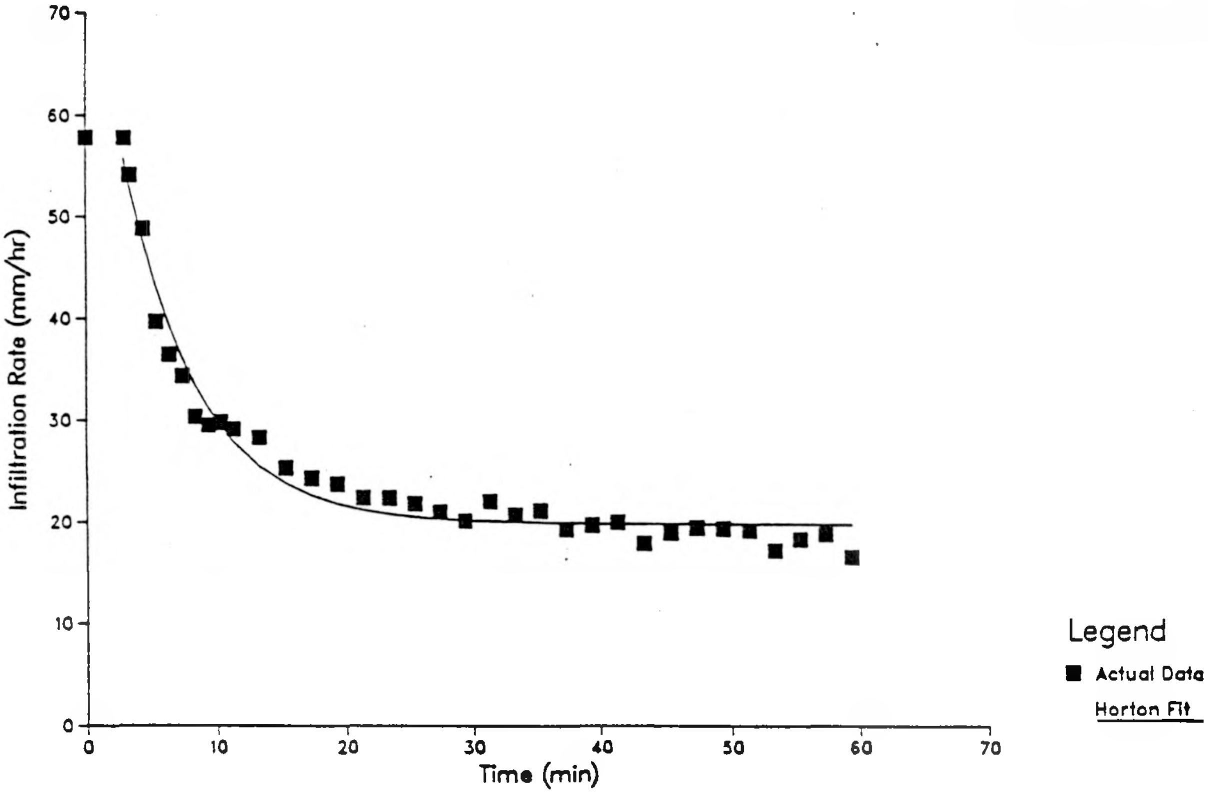

Figure 5. Example of nonlinear curve fitting of the Horton equation to actual infiltration data.

Table 6. Results of analysis of variance on f_c values.

Source of Variation	SS	DF	MS	F	p-value
Blocks	83.52	2	41.76	1.63	0.380
A: Grass Species	431.60	1	431.60	16.89	0.054
Error (A)	51.10	2	25.55		
B: Season	7.98	1	7.98	0.93	0.389
A x B	193.26	1	193.26	22.54	0.009
Error (B)	34.29	4	8.57		
C: Soil AMC	107.11	2	53.55	2.98	0.079
A x C	16.83	2	8.41	0.47	0.634
B x C	16.17	2	8.09	0.45	0.645
A x B x C	1.71	2	0.86	0.05	0.945
Error (C)	287.49	16	17.97		

also stated that the infiltration capacity constant value for the wet run was often considerably lower than that which was attained for the initial dry run.

The seasonal differences of the different cover types' (interaction of grass species and season) infiltration capacity constants observed during 1987 are shown in Figure 6. The infiltration capacity constants of bare soil and streambank wheatgrass increased between June and September, while crested wheatgrass's decreased. This seasonal change in infiltration capacity has been noted in other infiltration studies (Horton 1933, 1940; Simanton and Renard 1982; and Simanton et al. 1985). The reasons are attributed to both physical and biological processes.

Table 7 shows that during June 1987, the rainfall simulations on a very wet soil surface had an average f_c value for crested wheatgrass that was more than 10 mm/hr greater than for streambank wheatgrass and more than 15 mm/hr greater than for bare soil. In September, rainfall simulations on a very wet soil surface showed that the average f_c values of the three cover types were within 1 mm/hr of each other. Table 7 also shows that with increased soil moisture the infiltration capacity constants decreased and that crested wheatgrass had the highest f_c and bare soil the lowest f_c.

The results of least squares curve fitting of infiltration data with the Green-Ampt infiltration equation are shown in Tables 8 and 9. Figure 7 is an example of

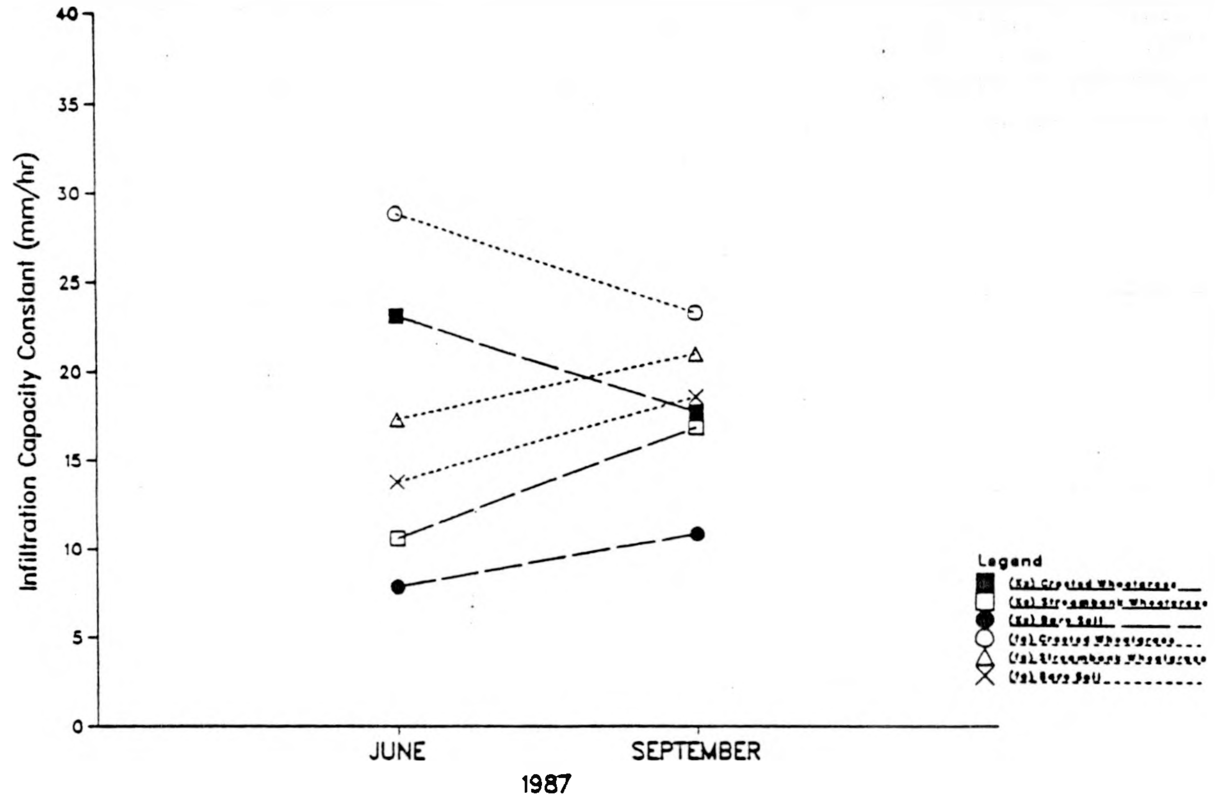

Figure 6. The seasonal trends of f_c and K_s for the three cover types in 1987.

Table 7. Average f_c values for the different treatments, seasons, and antecedent soil moisture conditions.

JUNE 1987

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	30.9	29.2	26.7
Streambank Wheatgrass (3)	17.8	18.4	15.9
Bare Soil (1)	19.6	11.1	10.7

SEPTEMBER 1987

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	27.5	22.6	20.0
Streambank Wheatgrass (3)	23.0	20.5	19.7
Bare Soil (1)	16.1	20.5	19.4

Table 8. Results of least squares curve fitting with the Green-Ampt infiltration equation in June 1987.

JUNE 1987

Plot	K_s (mm/hr)	ns (mm)	R^2	s.e.(mm/hr)
1D	8.51	10.89	0.8860	4.60
1W	5.30	13.83	0.9189	1.03
1VW	12.27	0.44	0.1000	1.44
2D	24.52	8.42	0.9587	1.35
2W	21.56	4.45	0.9453	1.10
2VW	21.97	1.18	0.5451	1.48
3D	17.80	18.96	0.9417	1.24
3W	22.08	3.29	0.9658	0.67
3VW	25.86	1.36	0.6900	1.36
4D	11.22	12.53	0.9478	1.23
4W	18.79	2.00	0.8071	1.00
4VW	20.79	-0.46	0.3713	0.96
5D	29.74	11.80	0.9675	0.87
5W	23.02	4.10	0.9028	1.12
5VW	22.09	1.81	0.7122	1.15
6D	8.25	28.16	0.9507	2.09
6W	3.87	28.21	0.9305	1.17
6VW	10.22	3.13	0.4761	2.67
7D	10.46	14.02	0.9645	1.96
7W	2.17	19.33	0.7942	1.79
7VW	10.89	-0.02	0.0003	1.97

Note: D - Dry Run, W - Wet Run, and VW - Very Wet Run.

Plots 1, 4, and 6 are streambank wheatgrass.
Plots 2, 3, and 5 are crested wheatgrass.
Plot 7 is bare soil.

Table 9. Results of least squares curve fitting with the Green-Ampt infiltration equation in September 1987.

SEPTEMBER 1987

Plot	K_s (mm/hr)	ns (mm)	R^2	s.e.(mm/hr)
1D	12.57	10.47	0.9889	1.11
1W	14.10	1.20	0.4558	1.21
1VW	19.41	-0.30	0.1470	1.30
2D	11.78	13.47	0.9688	1.32
2W	17.34	3.06	0.8867	1.43
2VW	18.92	1.63	0.6560	1.80
3D	21.36	8.89	0.9140	2.94
3W	12.92	7.42	0.9440	1.13
3VW	18.32	0.85	0.6151	1.11
4D	21.85	5.56	0.8870	1.60
4W	12.71	8.94	0.9548	1.36
4VW	20.57	0.09	0.0033	2.73
5D	29.44	1.02	0.0592	4.11
5W	15.74	2.96	0.8595	0.95
5VW	14.26	1.00	0.2595	1.58
6D	13.12	4.87	0.8644	1.00
6W	17.36	2.10	0.7048	1.26
6VW	20.35	0.18	0.0843	0.95
7D	5.32	94.23	0.9700	1.78
7W	11.33	7.28	0.9257	1.49
7VW	15.93	1.28	0.7233	1.66

Note: D - Dry Run, W - Wet Run, and VW - Very Wet Run.

Plots 1, 4, and 6 are streambank wheatgrass.
Plots 2, 3, and 5 are crested wheatgrass.
Plot 7 is bare soil.

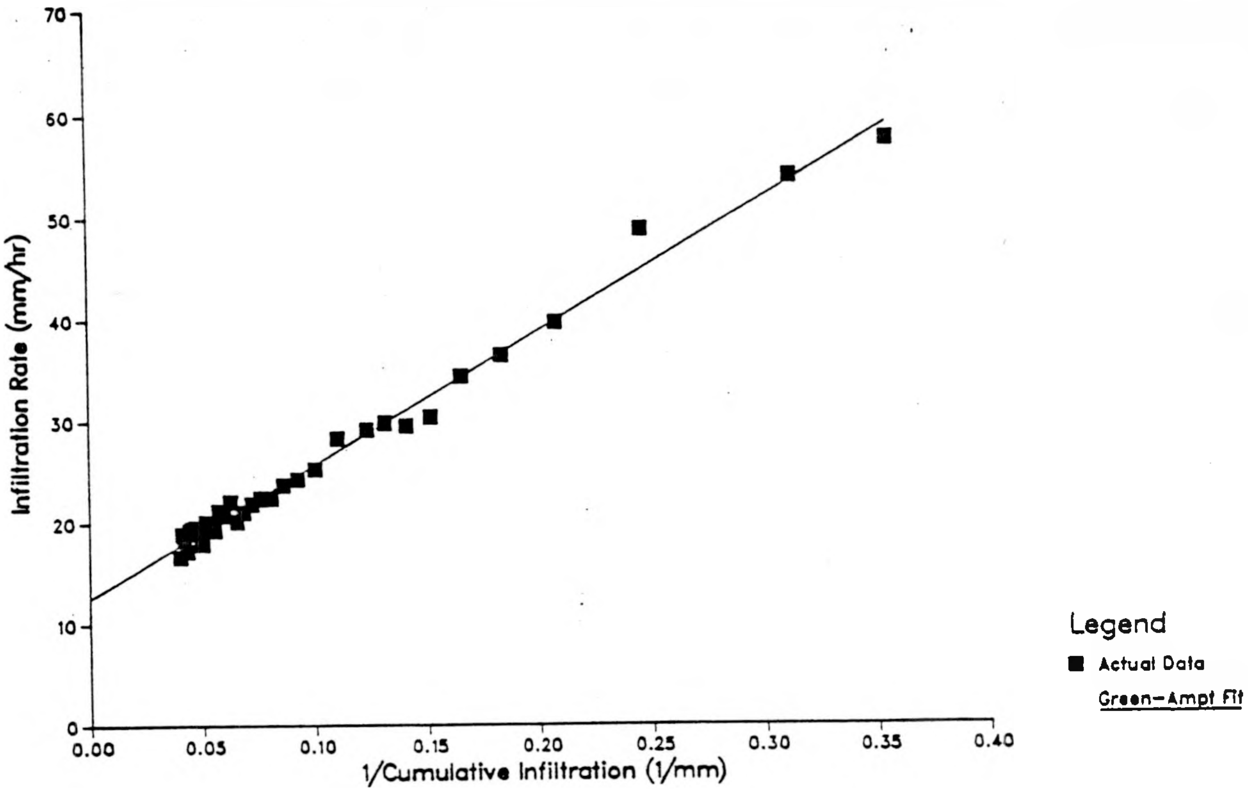

Figure 7. Example of least squares curve fitting of the Green-Ampt equation to cumulative infiltration data.

least squares curve fitting of the Green-Ampt equation to cumulative infiltration data. The term K_s (saturated hydraulic conductivity) produced by this analysis is considered equal to the steady-state infiltration capacity constant, which is equivalent to the f_c term in the Horton equation. The R^2 values produced by the least squares curve fitting procedure for the dry and wet runs were above 70% except for two of the runs. The very wet runs produced mostly low R^2 values. Three runs had negative ns values, which means that the infiltration rate was increasing during these runs.

A split-split plot analysis of variance with the K_s

values for all the rainfall simulations during 1987 showed a significant difference only for the interaction of grass species and season (Table 10). Figure 6 shows the same general trends for the three cover types for K_s and f_c values during 1987. The infiltration capacity constants of streambank wheatgrass and bare soil increased between June and September, while crested wheatgrass's decreased. Also, the average K_s for the very wet runs of the three cover types were all within 5 mm/hr in the September results, unlike the very wet run results during June (Table 11).

Since the actual steady-state infiltration capacity constant of the lakebed sediment material is not known, it cannot be determined if the Horton or Green-Ampt infiltration equation is the better predictor of the constant. In a general comparison of (Horton) f_c and (Green-Ampt) K_s values; they were plotted against each other (Figure 8). In all but 4 of the 42 rainfall simulation runs the Horton equation predicted a higher infiltration capacity constant that the Green-Ampt equation. Kotansky (1985) found that the Horton equation predicted higher infiltration rates, in his study, than the Green-Ampt equation.

Ideally $f_c = K_s$, as shown by the solid line in Figure 8. The predicted values of f_c and K_s for the very wet runs during 1987 were very close to each other (Figure 8). As a result it appears that when the antecedent soil moisture condition reaches the very wet stage, the Horton and Green-

Table 10. Results of analysis of variance on K_s values.

Source of Variation	SS	DF	MS	F	p-value
Blocks	67.79	2	33.89	0.64	0.612
A: Grass Species	408.85	1	408.85	7.66	0.110
Error (A)	106.73	2	53.37		
B: Season	1.83	1	1.83	0.12	0.744
A x B	307.07	1	307.07	20.49	0.011
Error (B)	59.94	4	14.98		
C: Soil AMC	68.01	2	34.01	1.72	0.211
A x C	86.15	2	43.07	2.18	0.146
B x C	16.45	2	8.22	0.42	0.667
A x B x C	0.61	2	0.31	0.02	0.985
Error (C)	316.65	16	19.79		

Table 11. Average K_s values for the different treatments, seasons, and antecedent soil moisture conditions.

JUNE 1987

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	24.0	22.2	23.3
Streambank Wheatgrass (3)	8.0	9.3	14.5
Bare Soil (1)	10.5	2.2	10.9

SEPTEMBER 1987

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	20.9	15.4	17.2
Streambank Wheatgrass (3)	15.8	14.7	20.1
Bare Soil (1)	5.3	11.3	15.9

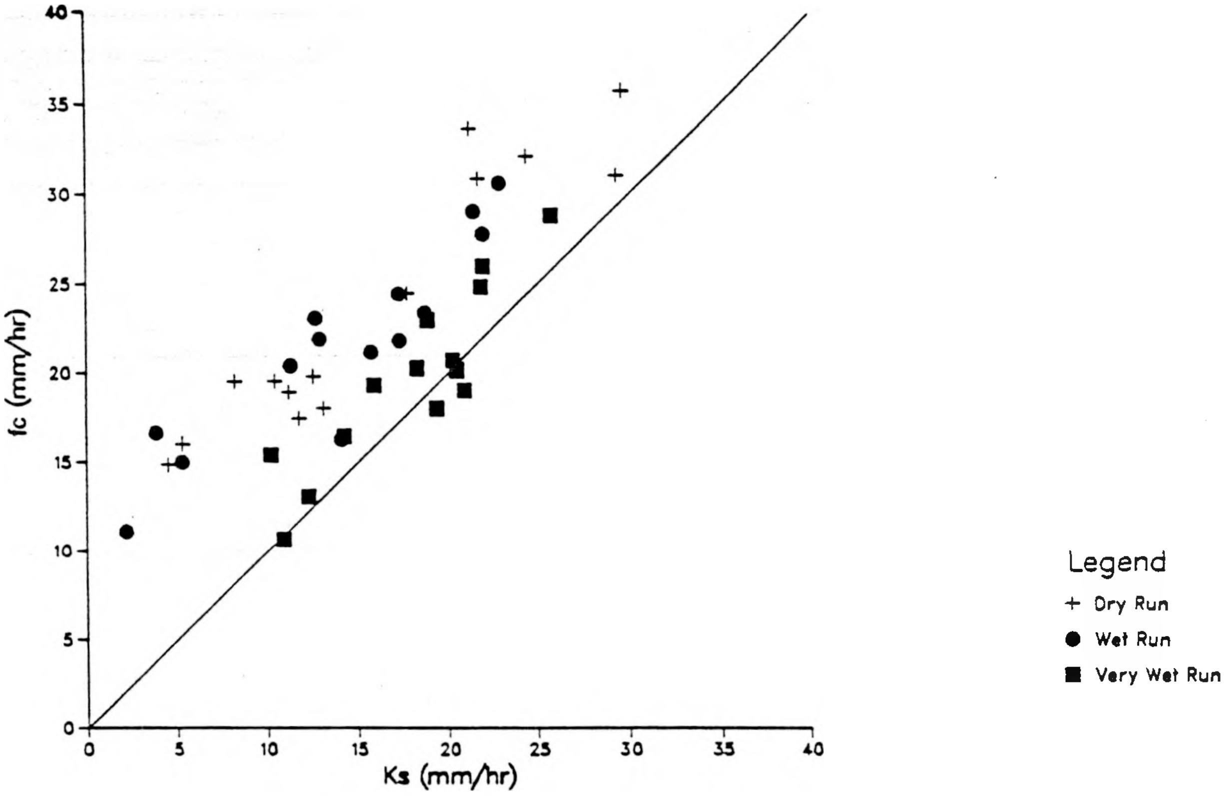

Figure 8. Plot of f_c vs. K_s for all rainfall simulations in 1987.

Ampt infiltration equations are predicting similar values of the steady state infiltration capacity constant. This provides some evidence that these values are the best estimates of the actual infiltration capacity constants for the lakebed sediment material for the three cover types.

Figures 9, 10, and 11 are examples of actual infiltration curves for the three cover types during the dry, wet, and very wet runs, respectively, for September 1987. The series of curves show each cover type approaching an infiltration capacity constant of between 15-20 mm/hr, which are similar to the results of the Horton and Green-Ampt infiltration equations for the September data. Infiltration curves for rainfall simulations on each plot

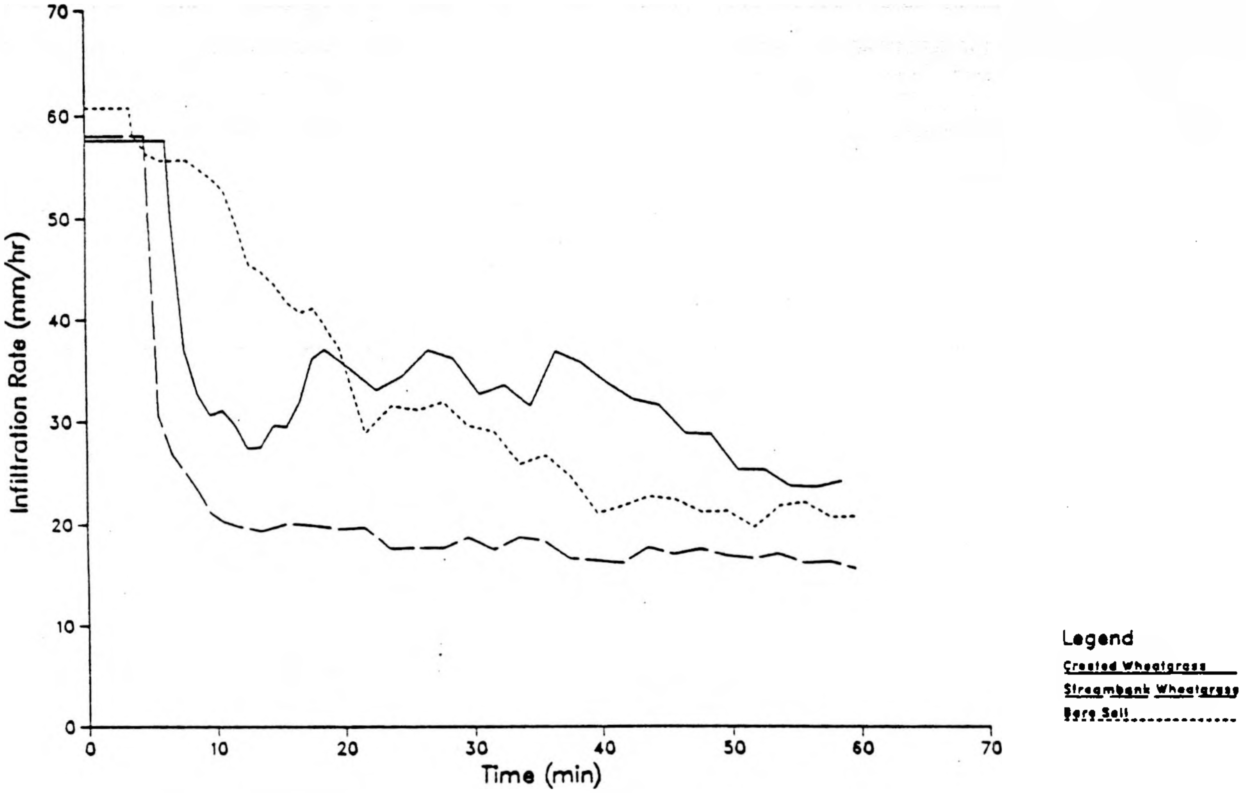

Figure 9. Infiltration curves for the dry run on the three cover types in Sept. 1987.

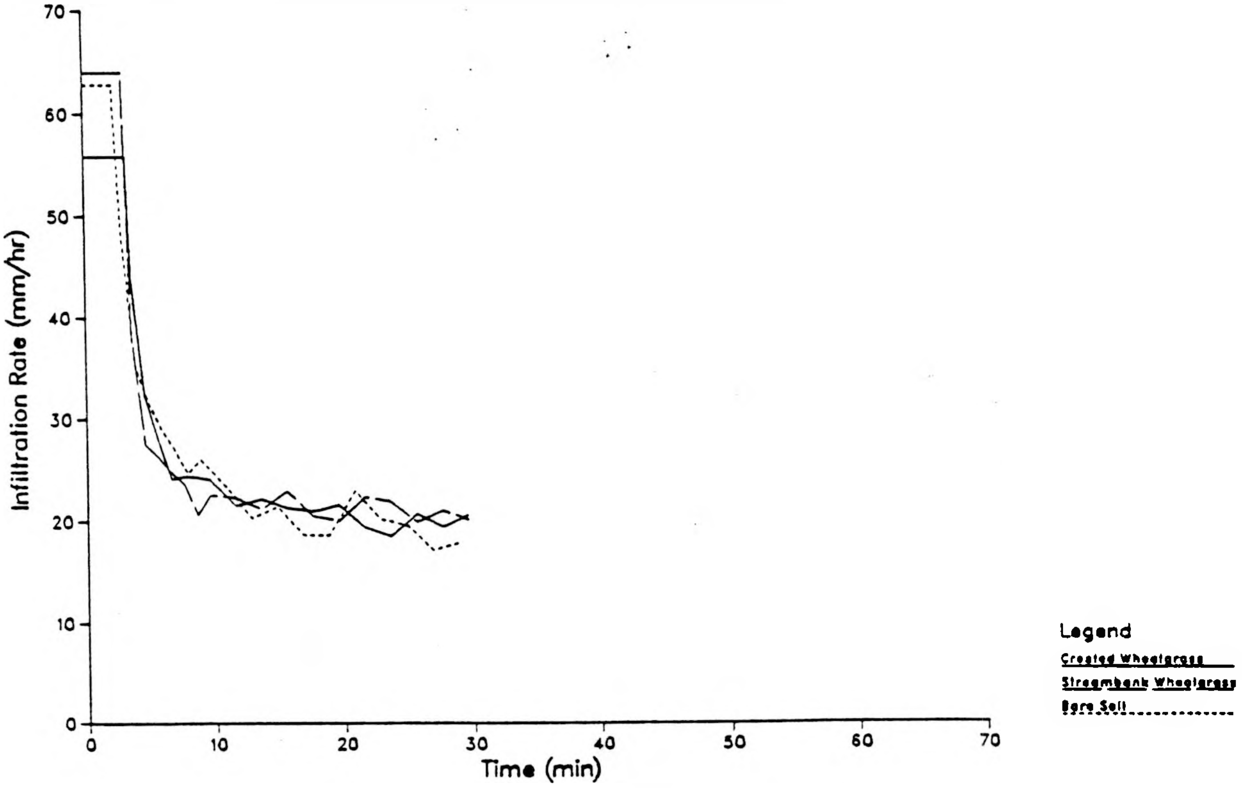

Figure 10. Infiltration curves for the wet run on the three cover types in Sept. 1987.

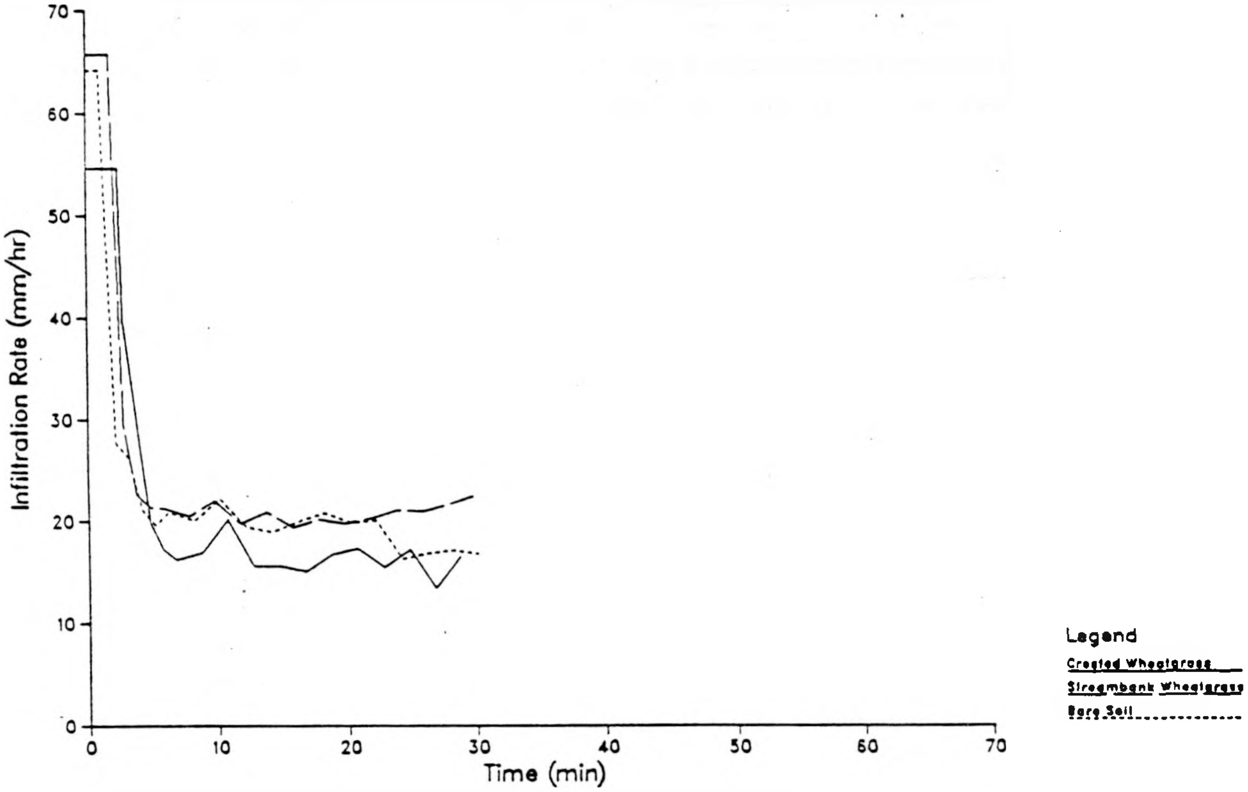

Figure 11. Infiltration curves for the very wet run on the three cover types in Sept. 1987.

during 1987 are shown in Appendix D.

Runoff and Erosion:

The data collected from rainfall simulations from August 1986 were not used in the comparison of the two grass species, because there was only a 30-minute dry run and water infiltrated into surficial macropores which developed on the crested wheatgrass plots leading to very little runoff. A general summary of 1986 data is presented in Table 12 and Appendix C.

Rainfall simulations were done on all seven lakebed sediment plots during June and September of 1987. A general summary of the data is presented in Table 12 and Appendix C.

Table 12. General summary of 1986 and 1987 rainfall simulations.

Treatment	Cover		Dry Run (60 min)				Wet Run (30 min)				V.Wet Run (30 min)			
(# of plots)	Canopy (%)	Surface (%)	S.M.	EI	RO	S.L.	S.M.	EI	RO	S.L.	S.M.	EI	RO	S.L.
AUGUST 1986														
CWG (3)	36	37	4	369	0.0	0.02								
SWG (3)	24	3	4	362	7.2	1.19								
Bare (1)	0	0	-	-	-	-								
JUNE 1987														
CWG(3)	47	44	9	619	14.4	0.57	22	361	12.1	0.49	30	399	15.5	0.78
SWG (3)	43	34	8	598	28.9	2.21	18	371	17.8	1.63	28	393	21.1	2.05
Bare (1)	2	1	14	765	35.5	7.15	21	369	22.2	6.94	26	355	22.9	6.88
SEPTEMBER 1987														
CWG (3)	48	53	7	522	18.8	0.95	18	365	15.5	0.91	27	364	18.0	1.02
SWG (3)	46	54	6	623	28.1	1.72	17	429	19.2	1.33	25	442	21.1	1.44
Bare (1)	23	10	10	785	27.5	4.19	20	423	18.6	3.74	26	458	22.5	3.88

Note: (1) All rainfall simulations had an intensity of approximately 60 mm/hr.
(2) In August 1986 only a 30 min. dry run was conducted on the six vegetated plots.
(3) S.M. - soil moisture (%), EI - rainfall energy (MJ·mm/ha·hr), RO - total runoff (mm), and S.L. - total soil loss (MT/ha).

The series of rainfall simulations done on each of the plots twice during 1987 consisted of an initial 60-minute run (dry surface), a 30-minute run 24 hours later (wet surface), and another 30-minute run after a 30-minute delay (very wet surface), all performed at a nominal target rainfall intensity of 60 mm/hr. Average rainfall intensities for 1987 were 57.5, 59.9, and 61.3 mm/hr for the dry, wet, and very wet runs, respectively. The duration of the rainfall for each of the rainfall simulations went the required time except for the dry runs on two plots in both June and September, which were cut short due to equipment problems. The average total rainfall amount and average rainfall energy for the dry runs reflect those situations. Average total rainfalls for 1987 were 51.2, 30.1, and 30.8 mm for the dry, wet, and very wet runs, respectively. Average rainfall energies for 1987 were 617, 383, and 401 MJ·mm/ha ·hr for the dry, wet, and very wet runs, respectively.

Ponding on the plots began almost immediately after rainfall started. The average amount of time between the start of rainfall and runoff was observed to be 5.23, 3.07, and 1.68 minutes for the dry, wet, and very wet runs, respectively. Less time to runoff from the dry to wet to very wet runs was due to the increased moisture in the soil profile.

Overland flow velocities were measured using dye for all runs in September. No noticeable changes in the velocities were observed between the dry, wet, and very wet runs. All plots exhibited their own individual overland flow velocities, which remained fairly constant throughout the series of runs. Average overland-flow velocities for each individual plot are listed in Table 13.

Table 13. Average Overland Flow Velocities in September 1987.

Plot #	Treatment	Velocity (m/sec)
1	Streambank Wheatgrass	0.089
2	Crested Wheatgrass	0.103
3	Crested Wheatgrass	0.095
4	Streambank Wheatgrass	0.109
5	Crested Wheatgrass	0.056
6	Streambank Wheatgrass	0.092
7	Bare Soil	0.137

Water temperatures were measured in the water truck and in the runoff. The average water temperature in the water truck was 16.4°C and the average runoff water temperature was 18.8°C. An average rise of 2.4°C occurred as the water became rain, overland flow, and then runoff.

Runoff equilibrium was generally reached during the final 30 minutes of the dry run on all the plots. In the successive wet and very wet runs the runoff equilibrium was achieved more promptly after the start of the rainfall event than previous runs, due to the increased antecedent soil moisture. In successive runs between dry, wet, and very wet the constant runoff rates increased, reflecting the decreasing infiltration rates of the plots. Figures 12, 13, and 14 are example hydrographs for the three cover types during the dry, wet, and the very wet runs.

Sediment concentrations and sediment loss rates during

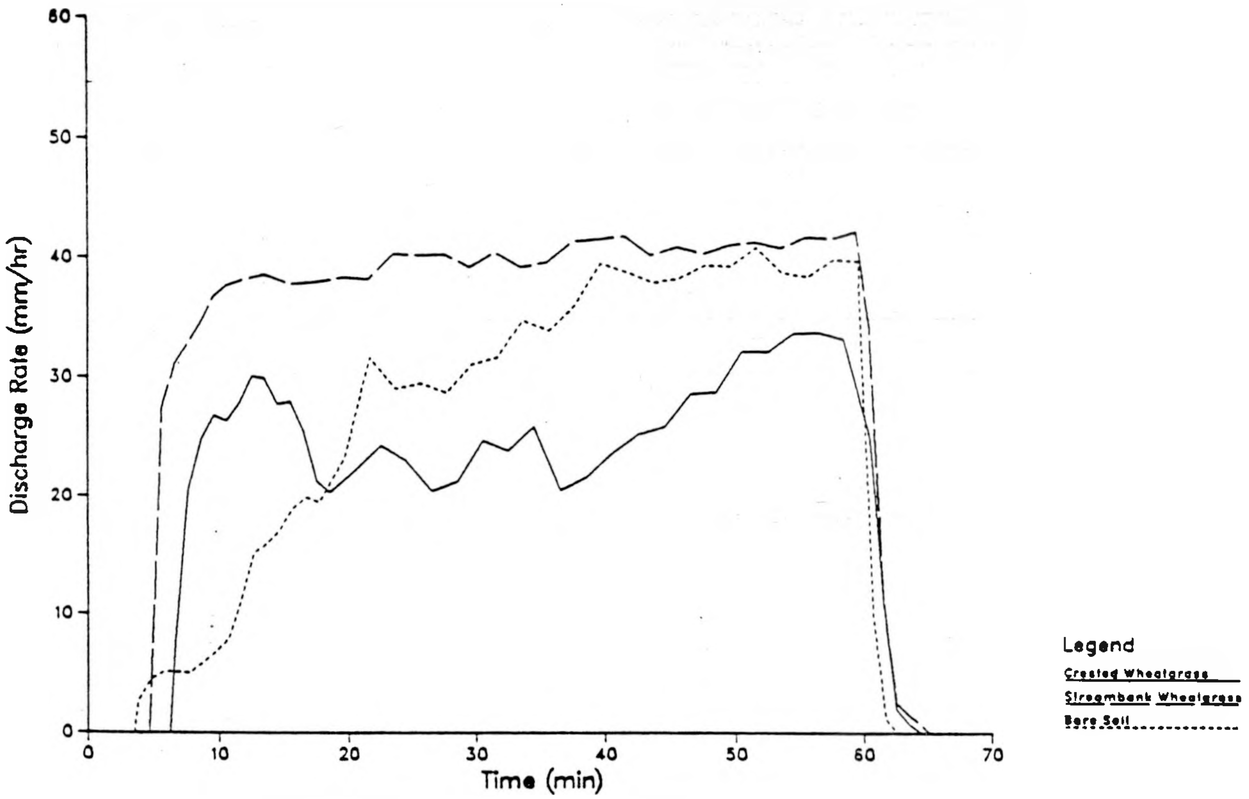

Figure 12. Hydrographs for the dry run on the three cover types in Sept. 1987.

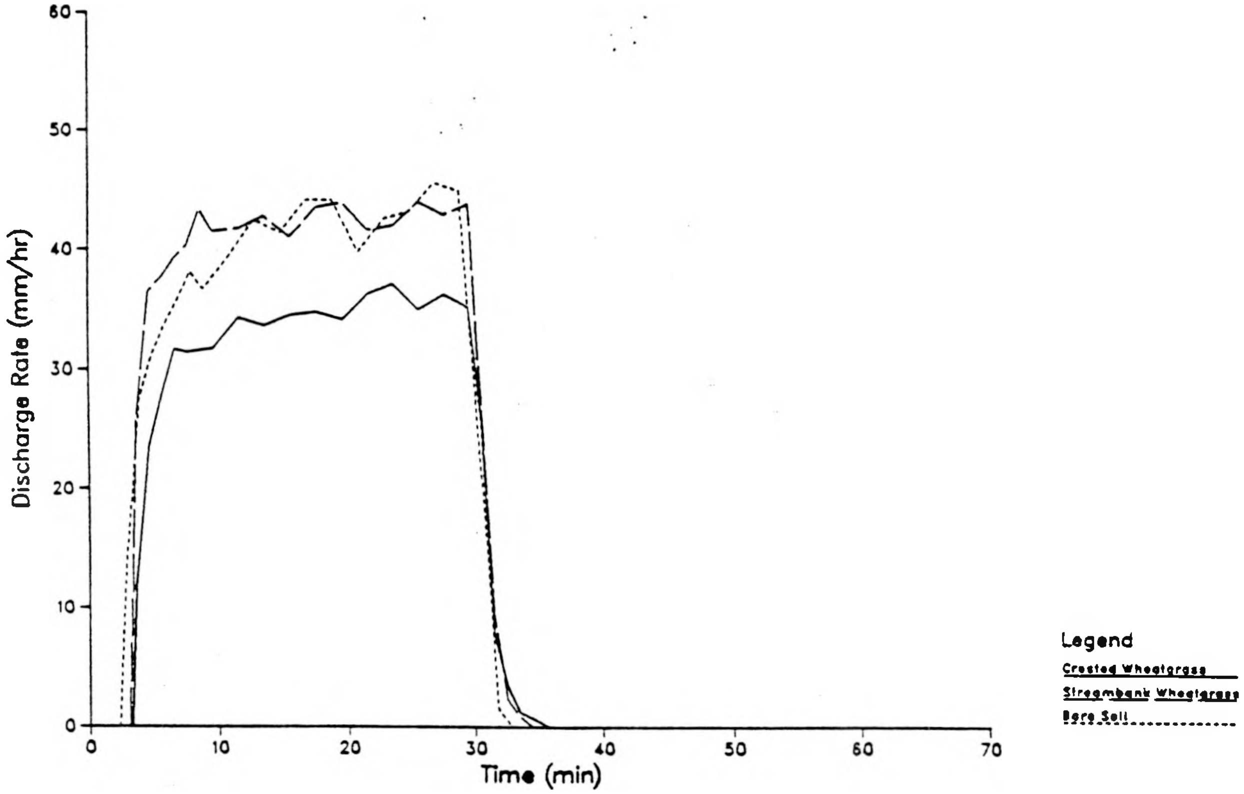

Figure 13. Hydrographs for the wet run on the three cover types in Sept. 1987.

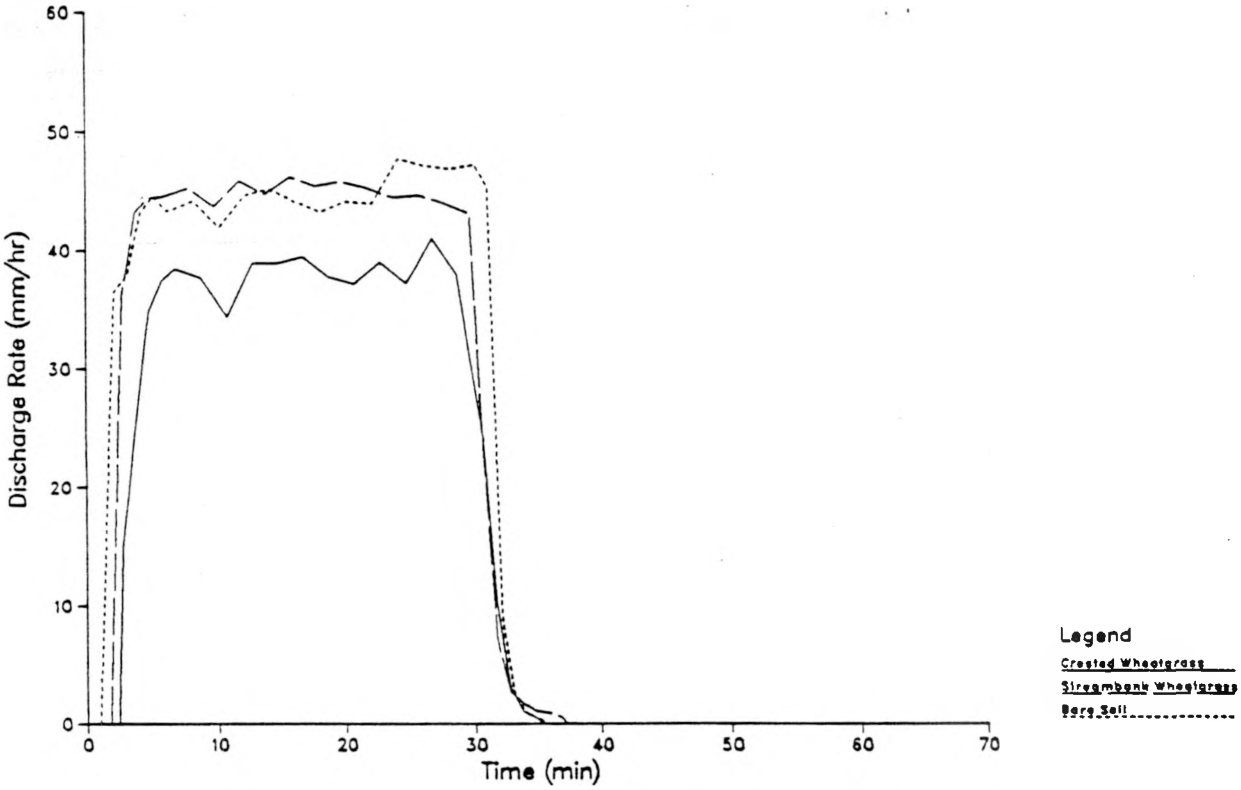

Figure 14. Hydrographs for the very wet run on the three cover types in Sept. 1987.

the dry runs generally reach equilibrium in the initial 30 minutes of the 60-minute run. Equilibrium constants were reached sooner after the start of the rainfall event in successive runs with increased soil moisture. Sediment concentration curves (Figure 15, 16, and 17) for the three cover types show the effects of the different covers. Figures 18, 19, and 20 are example sedigraphs for the three cover types during the dry, wet, and very wet runs.

The hydrographs, sediment concentration curves, and sedigraphs were made with data collected from plot #5 (crested wheatgrass), plot#6 (streambank wheatgrass), and plot #7 (bare soil) during September 1987. Time in each of

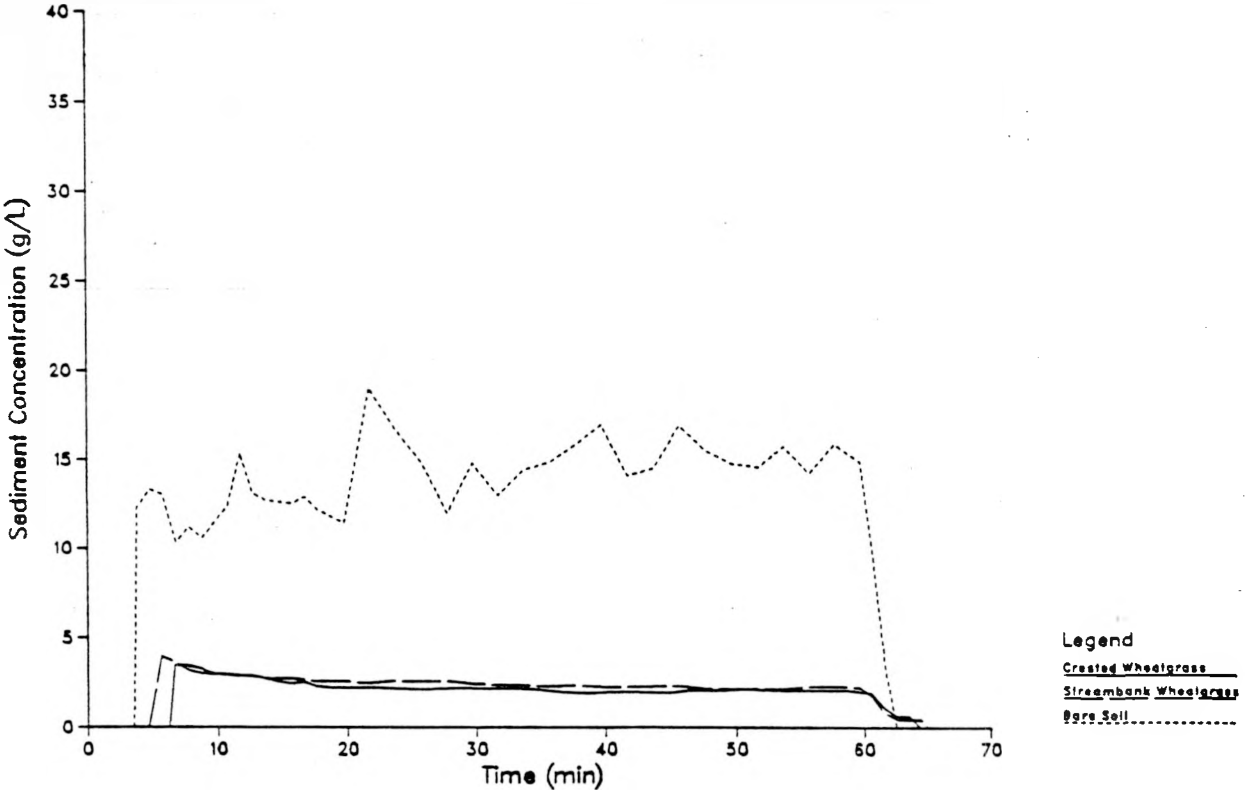

Figure 15. Sediment concentration curves for the dry run on the three cover types in Sept. 1987.

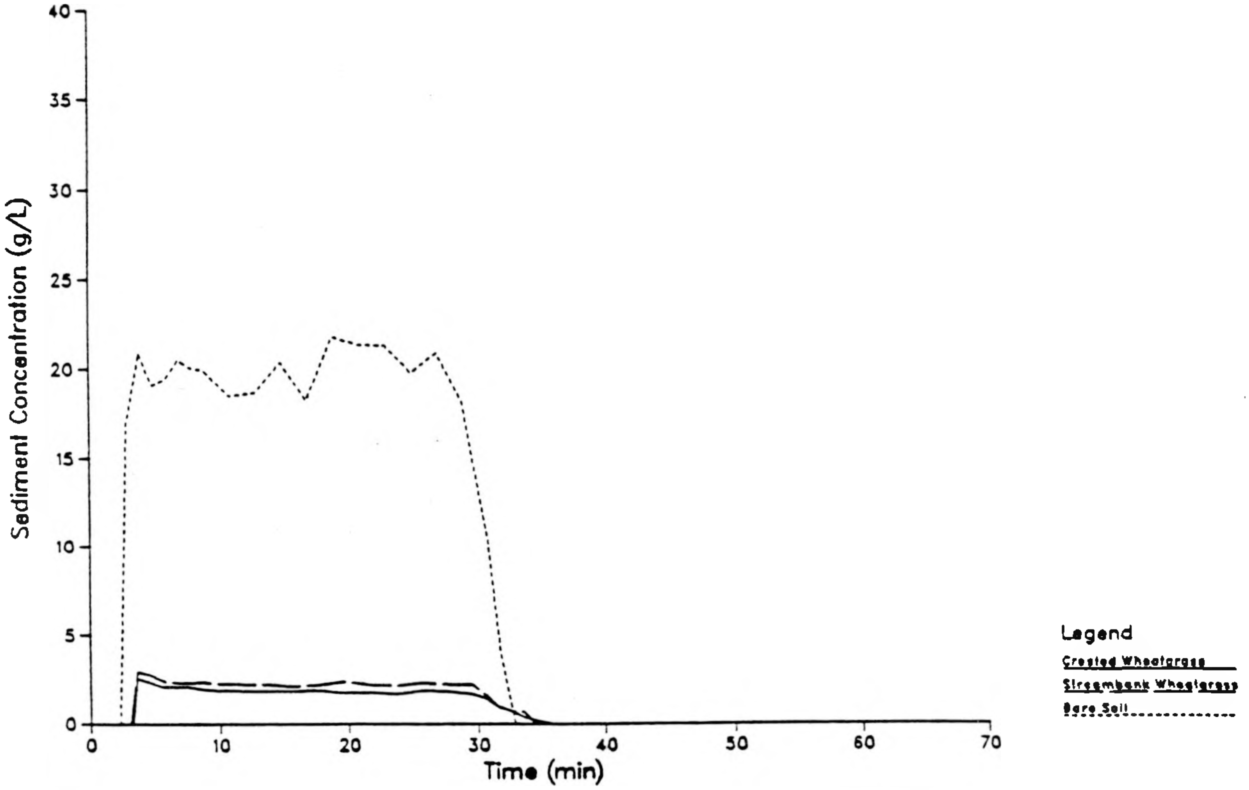

Figure 16. Sediment concentration curves for the wet run on the three cover types in Sept. 1987.

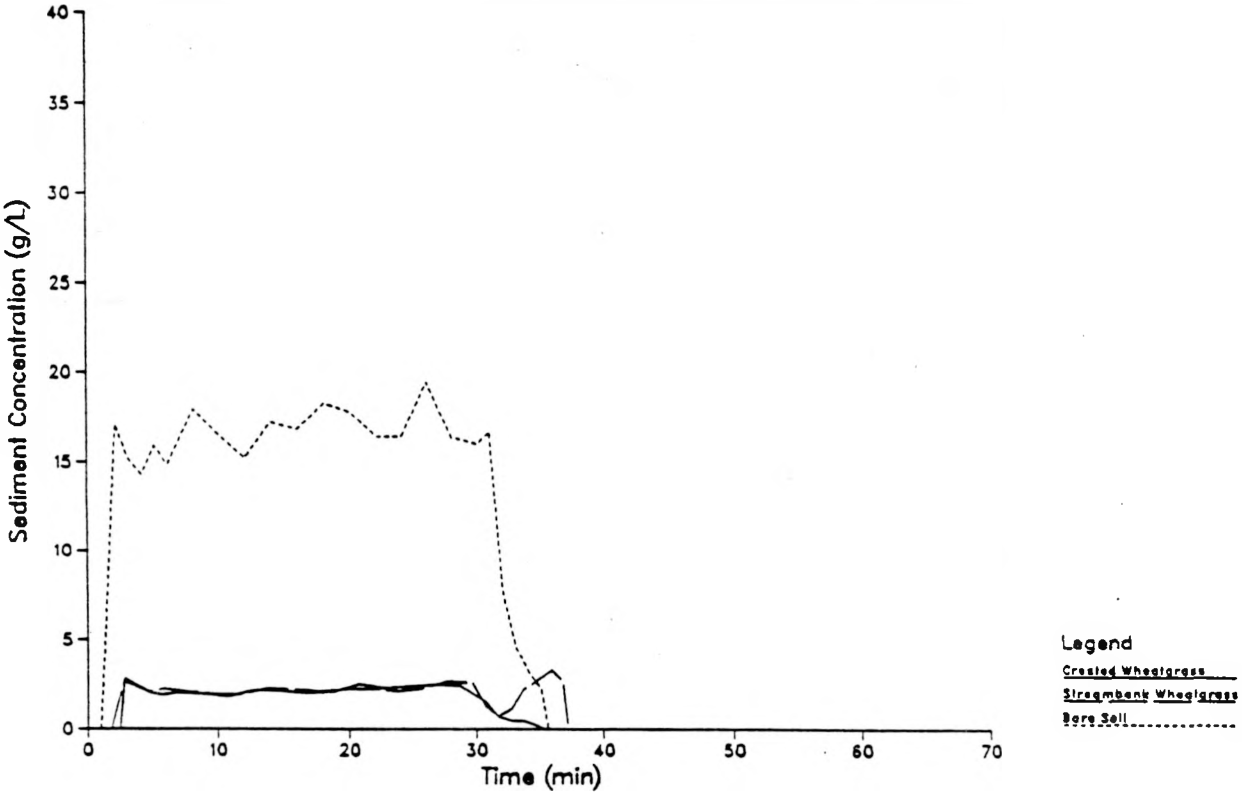

Figure 17. Sediment concentration curves for the very wet run on the three cover types in Sept. 1987.

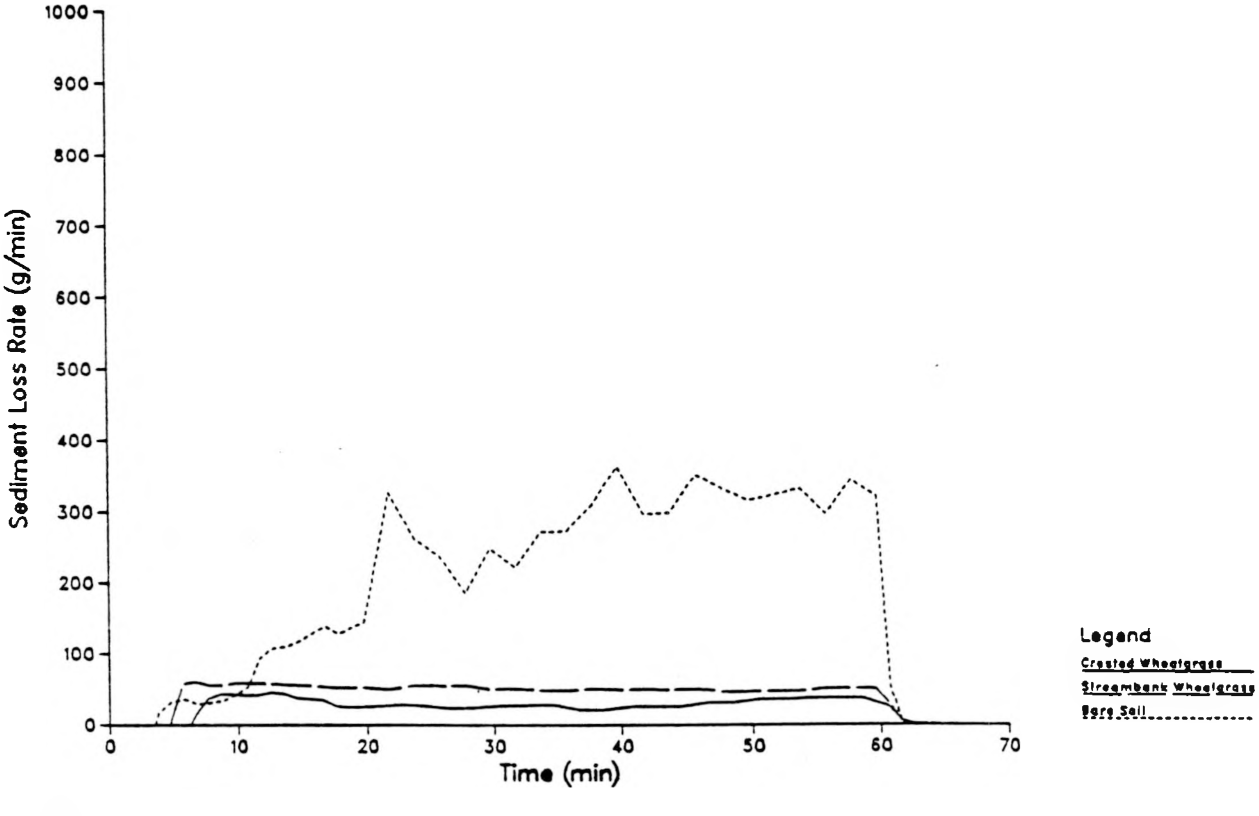

Figure 18. Sedigraphs for the dry run on the three cover types in Sept. 1987.

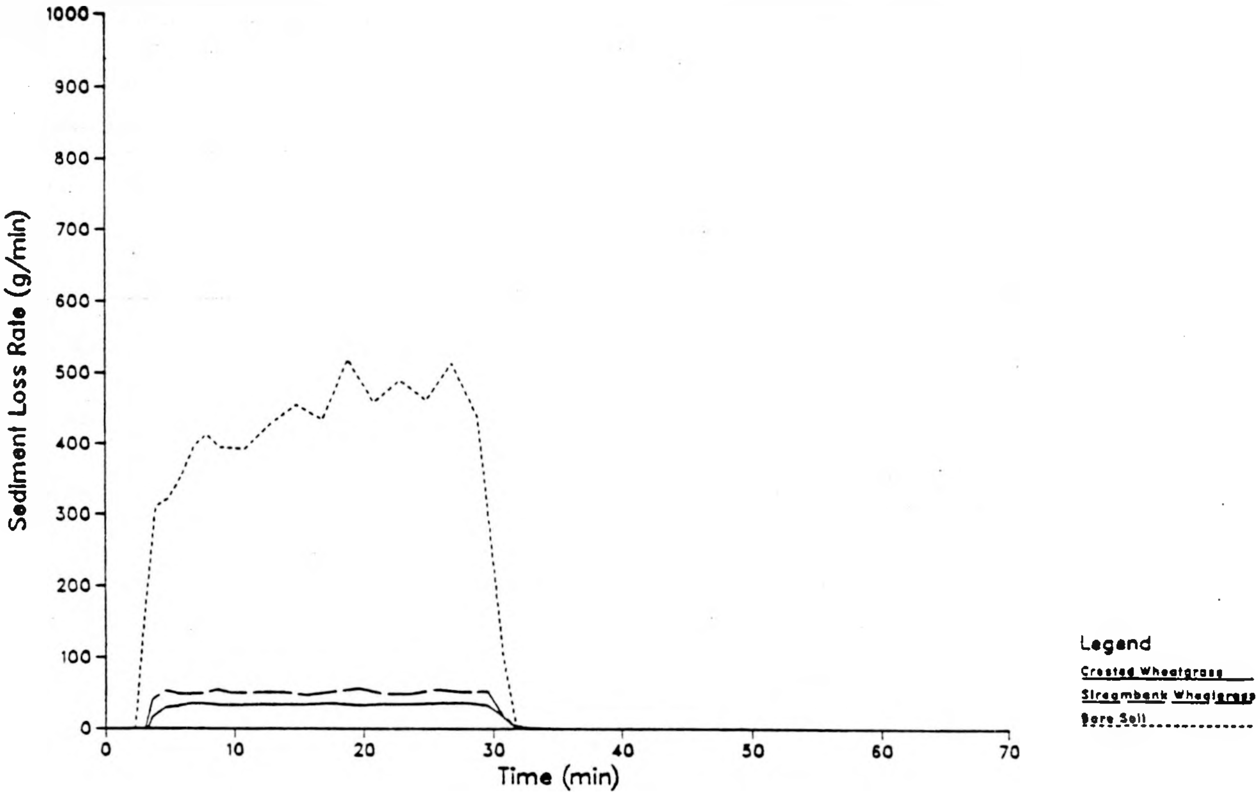

Figure 19. Sedigraphs for the wet run on the three cover types in Sept. 1987.

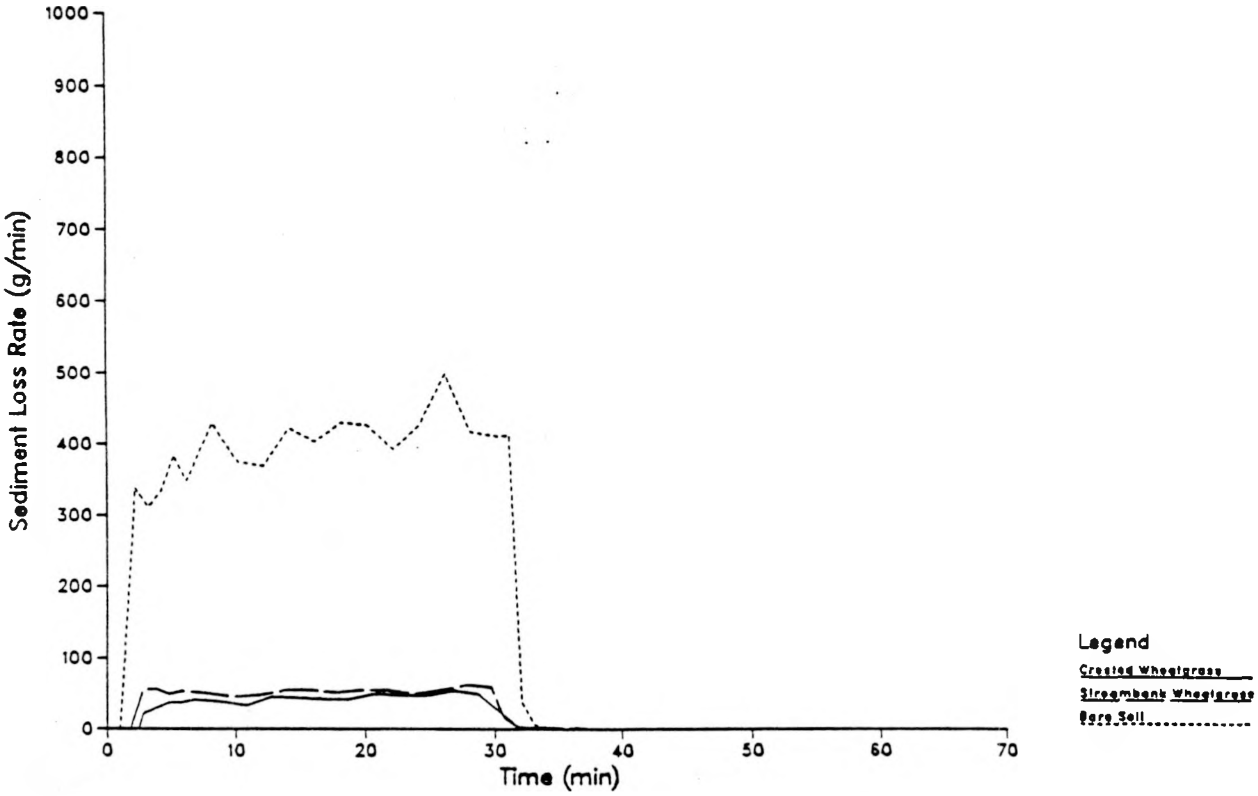

Figure 20. Sedigraphs for the very wet run on the three cover types in Sept. 1987.

these figures is from the start of the rainfall simulation event. Discharge rate curves (hydrographs), sediment concentration curves, and sediment loss-rate curves (sedigraphs) for rainfall simulations on each plot during 1987 are shown in Appendices E, F, and G, respectively.

Table 14 shows the average peak discharge rate, sediment concentration, and sediment loss rate for the dry, wet, and very wet antecedent soil moisture condition for the three cover types during 1987. For all three cover types the average peak discharge rate increased with increased antecedent soil moisture. This was the result of decreased infiltration rates with the increase of moisture in the soil profile. Discharge rates were quite similar for streambank wheatgrass cover and bare soil, with crested wheatgrass about 10 mm/hr less (Table 14).

Average peak sediment concentration for the three cover types remained relatively unchanged between the dry, wet, and very wet runs (Table 14). The average peak sediment concentration was more than 1.5 times greater for streambank wheatgrass than crested wheatgrass. Bare soil showed average peak sediment concentrations three times greater than streambank wheatgrass and five to six times greater than crested wheatgrass.

Sediment loss rate is the product of discharge rate and sediment concentration. The average peak sediment loss rate is greatest for bare soil and lowest for crested wheatgrass, with streambank wheatgrass in between (Table 14). The rate

Table 14. Average peak discharge rate, sediment concentration, and soil loss rate for the three cover types for the three antecedent soil moisture conditions in 1987.

Average peak discharge rate (mm/hr)

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	29.4	35.2	38.7
Streambank Wheatgrass (3)	40.2	44.3	47.1
Bare Soil (1)	42.9	48.4	49.7

Average peak sediment concentration (g/L)

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	4.9	4.6	4.9
Streambank Wheatgrass (3)	8.2	8.5	8.3
Bare Soil (1)	24.0	28.5	28.1

Average peak soil loss rate (g/min)

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	60.9	77.9	96.4
Streambank Wheatgrass (3)	158.0	187.0	196.4
Bare Soil (1)	508.2	730.2	758.7

increased successively with increased soil moisture. Since average peak sediment concentration remained fairly constant between antecedent soil moisture conditions, the average peak sediment loss rate is more dependent on discharge rate than sediment concentration, because discharge also increased with soil moisture.

Figure 21 displays soil loss from the three cover types for the three antecedent soil moisture conditions during 1987. Soil loss is expressed as kg/ha/EI. EI is a rainfall erosion index based on the product of rainfall storm energy (E) and the maximum 30-minute rainfall intensity (I_{30}). For

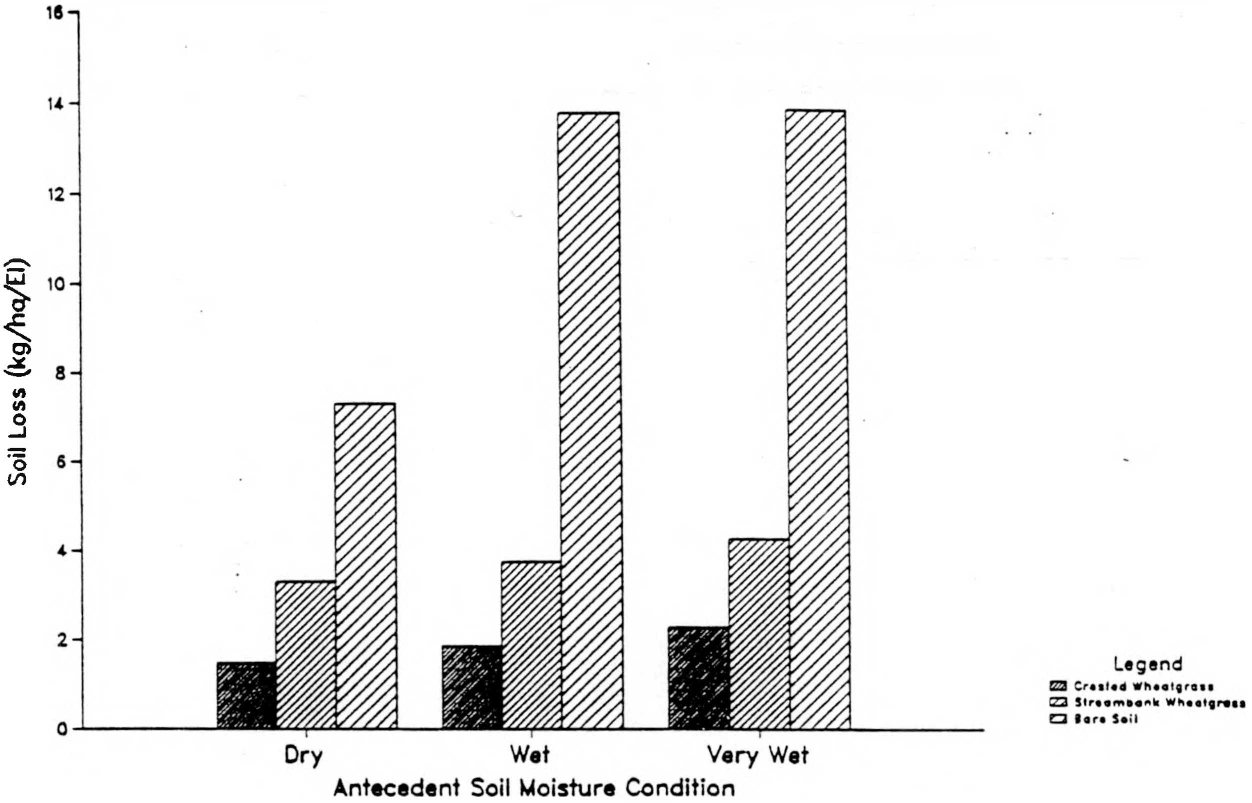

Figure 21. Soil loss for the three cover types for the three antecedent soil moisture conditions in 1987.

each run EI was calculated and expressed in units of (MJ·mm/ha·hr). Soil loss in kg/ha is divided by EI as a normalizing procedure to take into account differences in rainfall energy due to the duration of rainfall and minor differences in rainfall intensity. This normalizing procedure helps more correctly compare soil loss differences between treatments.

Data shown in Figure 21 are from six rainfall simulations for each antecedent soil moisture condition for the two grass species. Data for the bare soil cover types is based on only two rainfall simulations for each antecedent soil moisture condition. There is a distinct difference in soil loss between cover types. In all three antecedent soil moisture conditions streambank wheatgrass produced approximately twice as much soil loss as crested wheatgrass. The bare plot as expected produced much greater soil losses than the two grasses.

Soil loss (Figure 21) increased somewhat with increasing soil moisture from dry to wet to very wet. There was a marked increase in soil loss on the bare plot between the dry and wet soil condition. The two grass species showed a gradual increase in soil loss with increased soil moisture.

A split-split plot analysis of variance was done on total runoff and soil loss to determine if differences existed between grass species, season, and antecedent soil moisture. Both total runoff and soil loss were normalized by dividing normal units by EI to allow for equal comparison.

Results of the analysis of variance on total runoff data showed that there were significant difference between grass species (streambank wheatgrass > crested wheatgrass), antecedent soil moisture condition (dry < wet < very wet), and the interaction of grass species and season (Table 15). Although a significance level of $\alpha = 0.10$ was used, all three of these differences had p-values less than 0.05. Table 16 is presented to show the average total runoff values by treatments, season, and antecedent soil moisture condition. The seasonal differences between treatments are

Table 15. Results of analysis of variance on runoff (mm/EI) data.

Source of Variation	SS	DF	MS	F	p-value
Blocks	0.00	2	0.00	7.10	0.124
A: Grass Species	0.00	1	0.00	61.53	0.016
Error (A)	0.00	2	0.00		
B: Season	0.00	1	0.00	2.65	0.179
A x B	0.00	1	0.00	18.20	0.013
Error (B)	0.00	4	0.00		
C: Soil AMC	0.00	2	0.00	9.14	0.002
A x C	0.00	2	0.00	2.55	0.109
B x C	0.00	2	0.00	0.04	0.957
A x B x C	0.00	2	0.00	0.18	0.838
Error (C)	0.00	16	0.00		

Table 16. Average runoff (mm/EI) values for the different treatments, seasons, and antecedent soil moisture conditions.

JUNE 1987

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	0.024	0.033	0.039
Streambank Wheatgrass (3)	0.049	0.048	0.054
Bare Soil (1)	0.046	0.060	0.065

SEPTEMBER 1987

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	0.036	0.043	0.050
Streambank Wheatgrass (3)	0.043	0.045	0.048
Bare Soil (1)	0.035	0.044	0.049

shown in Figure 22.

The analysis of variance on total soil loss data showed that there were significant differences between blocks, grass species (streambank wheatgrass > crested wheatgrass), antecedent soil moisture condition (dry < wet < very wet), the interaction of grass species and season, and the interaction of season and antecedent soil moisture condition (Table 17). The average total soil loss values by treatment, season, and antecedent soil moisture condition are presented in Table 18. The seasonal differences between treatments are shown in Figure 23. It appears that two grass species are becoming more similar in their ability to control soil loss and infiltration over time (Figures 6 and 23). This is also seen in the closeness of the canopy and surface cover data in August 1987 (Table 1).

The common significant differences found by the analysis of variance on erosion and runoff data were differences between grass species, antecedent soil moisture condition, and the interaction of grass species and season. The differences found between antecedent soil moisture condition (ie., greater runoff and soil loss with increased soil moisture) can be explained by the fact that as the soil profile becomes more saturated, infiltration rates decrease and runoff increases. With the increase in runoff, more soil erosion occurs. All the data (Tables 16 and 18) showed this trend as the antecedent soil moisture condition went from dry to wet to very wet during the rainfall simulations.

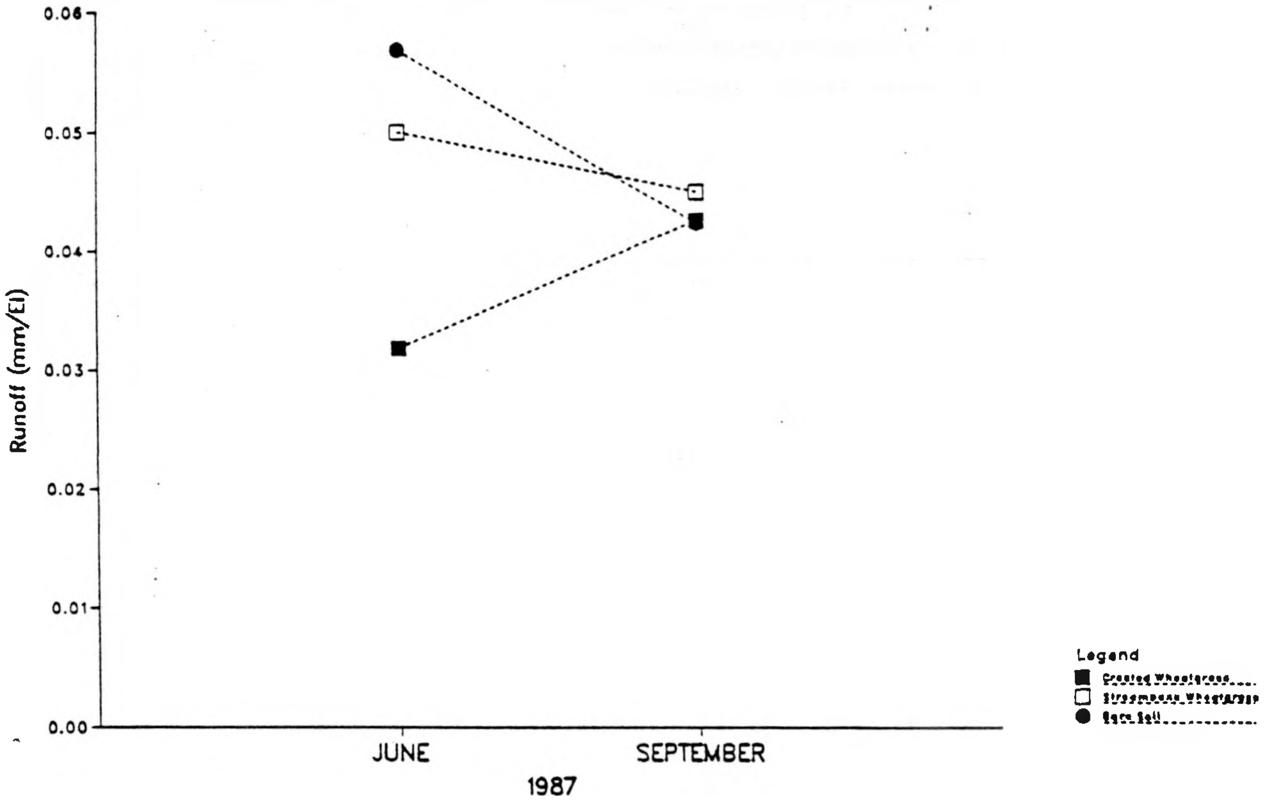

Figure 22. Seasonal differences in runoff for the three cover types in 1987.

Table 17. Results of analysis of variance on soil loss (kg/ha/EI) data.

Source of Variation	SS	DF	MS	F	p-value
Blocks	52.42	2	26.21	9.52	0.095
A: Grass Species	32.53	1	32.53	11.82	0.075
Error (A)	5.51	2	2.75		
B: Season	0.65	1	0.65	0.26	0.638
A x B	12.58	1	12.58	5.00	0.089
Error (B)	10.06	4	2.51		
C: Soil AMC	4.81	2	2.41	39.48	0.000
A x C	0.04	2	0.02	0.34	0.717
B x C	0.67	2	0.33	5.48	0.015
A x B x C	0.15	2	0.07	1.21	0.324
Error (C)	0.98	16	0.06		

Table 18. Average soil loss (kg/ha/EI) values for the different treatments, seasons, and antecedent soil moisture conditions.

JUNE 1987

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	0.99	1.34	1.96
Streambank Wheatgrass (3)	3.84	4.41	5.28
Bare Soil (1)	9.34	18.82	19.39

SEPTEMBER 1987

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
Crested Wheatgrass (3)	1.98	2.41	2.64
Streambank Wheatgrass (3)	2.78	3.10	3.30
Bare Soil (1)	5.34	8.84	8.48

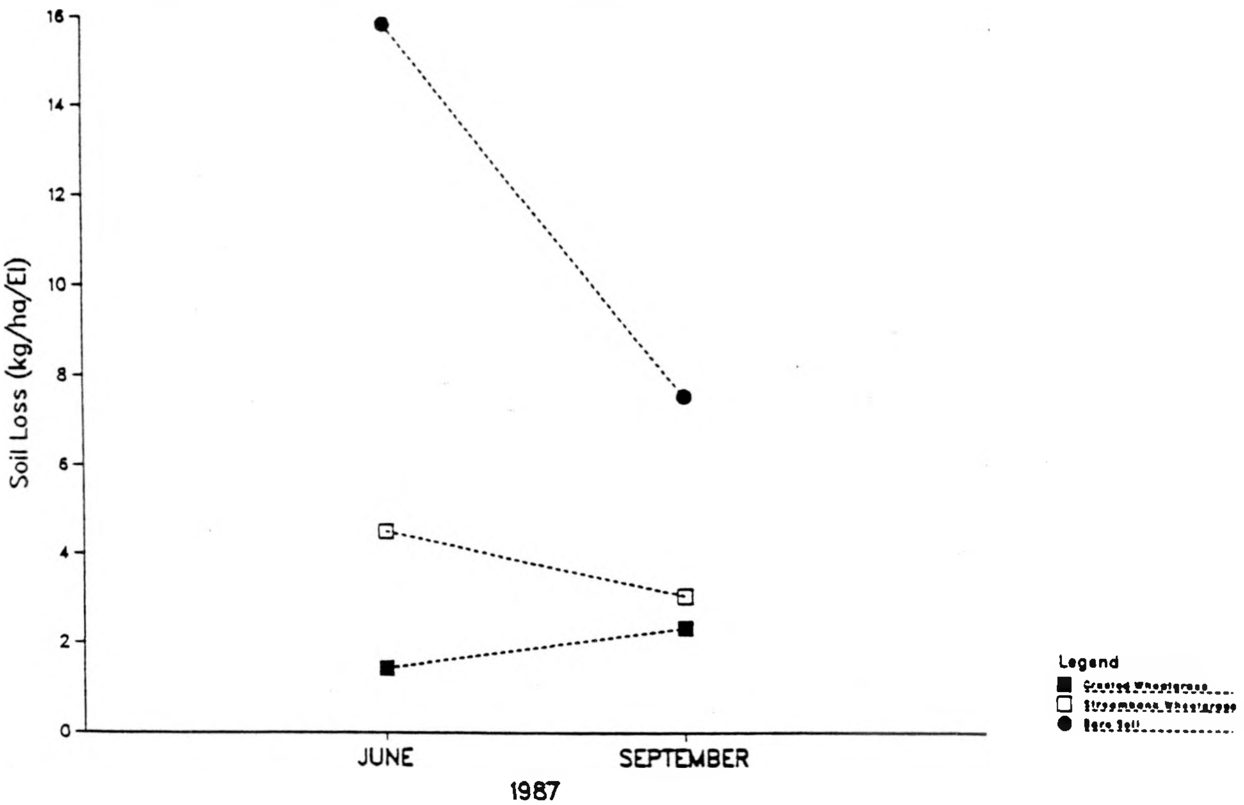

Figure 23. Seasonal differences in soil loss for the three cover types in 1987.

This same pattern has been shown in other studies (Nyhan et al.,1984; Nyhan and Lane, 1985; Nyhan and Lane, 1986; Simanton and Renard, 1982; Simanton et al., 1985).

Differences in soil characteristics were examined to see if they might account for differences found between grass species and the interaction of season and grass species for runoff and soil loss data. Since the lakebed sediment material is a uniformly mixed material and was used on all the plots, no difference in soil texture between plots was assumed. The soil moisture data was examined and no noticeable differences could be found between plots and between June and September runs.

The analysis of variances done on vegetation characteristics (canopy cover, plant basal cover, litter cover, bare soil cover, and amount of standing crop) (Appendix B) were then examined to see if they might account for significant differences found on runoff and soil loss data. The significant interaction of grass species and season for runoff and soil loss data can be explained by the increase in percent plant basal cover and the decrease in percent bare soil.

The decrease in erosion and runoff between June and September for streambank wheatgrass (Figures 22 and 23) can be explained by the increase in percent plant basal cover and litter cover. Also, the decrease in runoff and soil loss on the bare soil plot between June and September (Figures 22 and 23) can be explained by the increase in canopy and surface cover by natural regeneration processes during this time period.

The crested wheatgrass plots showed increases in runoff and soil erosion between June and September during 1987 (Figures 22 and 23). Simanton and Renard (1982; 1985) found seasonal changes in runoff and erosion in similar studies on rangeland in the west. They partially attributed lower runoff and erosion during spring to winter freeze-thaw processes in the soil, which loosen the soil surface and consequently allow more infiltration. During the summer, they felt the soil surface became compacted again from summer thunderstorms, causing higher fall runoff and erosion rates.

At INEL loosening of the soil due to intense freeze-thaw conditions during the winter and spring could be expected due the high diurnal temperature fluctuations. This would lead to higher infiltration rates during the spring rainfall simulations. The exposed bare soil during the summer months has been observed to become baked by high soil temperatures, causing it to become a hard claypan surface. This would lead to higher runoff rates during the fall rainfall simulations. These are some possible explanations as to why the crested wheatgrass plots exhibited increased runoff and soil erosion in September. This phenomena did not occur on the streambank wheatgrass and bare soil plots, primarily because of the increase in canopy and surface cover.

Differences in soil loss and surface runoff between the two grass treatments could not be explained by any of the analyse on vegetation characteristics. Also, the significant difference found between the blocks in soil loss could not be explained by any of the analysis on vegetation characteristics.

More years of spring and fall rainfall simulation data are necessary to determine if seasonal changes in runoff and soil loss exist and if the two grass species are fairly similar in their abilities to control infiltration and soil loss, as was shown by the September 1987 data. Simanton and Renard (1985) found that to adequately define relatively long-term responses of rangeland runoff and soil loss, at least two years of spring and fall rainfall simulation runs are necessary to reach an equilibrium rate. This data would be valuable to recommend a grass species that best controls infiltration and soil loss at INEL at the time of the spring snowmelt runoff and the May-June precipitation peak.

Comparison to Other Studies:

The data collected from the rainfall simulations on simulated trench caps during 1987 at INEL can be compared to a similar study at Los Alamos National Laboratory (LANL), New Mexico during 1982 and 1983 by Nyhan et al. (1984) and Nyhan and Lane (1985; 1986). The study at LANL was done using the same methodology as at INEL, but different treatments were used on the simulated trench caps plots.

Plot treatments at LANL were gravel, gravel plus western wheatgrass (sod-forming), barley, and bare soil. Table 19 shows the average runoff, runoff/precipitation (Q/P) ratio, and soil loss for the different cover types for the studies at INEL and LANL.

The estimated soil erodibility (K) values at INEL and LANL were 0.058 and 0.079 (t·ha·hr/ha·MJ·mm), respectively. By this classification the soil at LANL is more erodible than the soil used at INEL. Evidence of this is shown by the bare soil plots at LANL, which had two to three times as much soil loss as the bare soil plot at INEL. Also, the average runoff and Q/P ratio values were higher for the bare plots at LANL.

Comparison of results from plots with different cover types showed the barley cover type producing significantly greater amount soil loss than any of the other vegetated plots. The gravel and gravel plus western wheatgrass plots at LANL produced runoff and Q/P ratio values anywhere from 30-150% greater than similar values for crested and streambank wheatgrass plots at INEL.

Comparison of the average soil loss for the cover types (excluding barley) showed streambank wheatgrass with the highest soil loss during all three antecedent soil moisture conditions. During the dry run both the gravel and gravel plus western wheatgrass plots produced 1.5 to 2 times as much soil loss as the crested wheatgrass plots. But, during both the wet and very wet runs the gravel and gravel plus

Table 19. Comparison of average runoff, Q/P ratios, and soil loss from the 1987 study at INEL to the 1982 and 1983 studies at LANL.
Note: LANL data (Nyhan and Lane 1985; 1986)

Average Runoff (mm)

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
	INEL 1987		
Crested Wheatgrass (3)	16.6	13.8	16.8
Streambank Wheatgrass (3)	28.5	18.5	21.1
Bare Soil (1)	31.5	20.4	22.7
	LANL 1982		
Barley (4)	37.9	26.5	27.6
Bare Soil (2)	46.7	26.8	28.4
	LANL 1983		
Gravel (2)	46.2	23.3	28.3
Gravel + W. Wheatgrass (2)	47.2	25.8	29.0
Bare Soil (2)	51.1	23.6	27.2

Average Q/P Ratio

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
	INEL 1987		
Crested Wheatgrass (3)	0.34	0.47	0.56
Streambank Wheatgrass (3)	0.56	0.60	0.68
Bare Soil (1)	0.52	0.67	0.73
	LANL 1982		
Barley (4)	0.75	0.92	0.95
Bare Soil (2)	0.90	0.92	0.99
	LANL 1983		
Gravel (2)	0.84	0.80	0.97
Gravel + W. Wheatgrass (2)	0.82	0.85	0.99
Bare Soil (2)	0.90	0.79	0.92

Average Soil Loss (kg/ha/EI)

Treatment (# of plots)	Dry Run	Wet Run	Very Wet Run
	INEL 1987		
Crested Wheatgrass (3)	2.44	2.25	2.90
Streambank Wheatgrass (3)	6.39	4.80	3.68
Bare Soil (1)	18.40	17.34	17.46
	LANL 1982		
Barley (4)	30.56	23.43	24.84
Bare Soil (2)	70.55	41.88	44.58
	LANL 1983		
Gravel (2)	5.08	1.92	2.37
Gravel + W. Wheatgrass (2)	3.91	1.55	1.55
Bare Soil (2)	60.23	26.69	33.27

western wheatgrass plots produced less soil loss than the crested wheatgrass plots, with the gravel plus western wheatgrass being the lowest.

From this comparison of results at INEL and LANL it appears that the combination of gravel plus a western wheatgrass (sod-forming) wheatgrass would provide the best cover treatment for earth covers at these low-level radioactive waste burial sites. For not only did the gravel plus western wheatgrass cover provide excellent erosion control, but it also provided high average runoff and Q/P ratio values. This means that infiltration of precipitation into the earth cover is also being controlled. The gravel plus western wheatgrass appears to best meet the objective of optimizing control of both erosion and infiltration problems at low-level radioactive waste burial sites in the west.

Cumulative Soil Loss Estimates:

Shallow land burials for low-level radioactive waste are designed for a life of 100-300 years (Daniel, 1983). To help determine if the shallow land burial earth covers will erode during this period and lead to exposure of the waste material, cumulative soil loss estimates were made for average and extreme rainfall events at INEL.

First, the 1951-1986 rainfall records from the INEL Central Facility Area (CFA) were used to estimate maximum storm sizes. Unfortunately, the rainfall data available were recorded in mm/day, not intensity, so it was not possible to determine the rainfall erosivity factor (EI) in the USLE for particular storms at INEL. The Log Pearson Type III (Water Resources Council, 1967) procedure was selected to analyze rainfall frequency. This analysis calculated the following daily rainfalls for various recurrence intervals in years (Table 20).

Table 20. Recurrence intervals and their associated total daily rainfall amounts.

Recurrence Interval (years)	Total Daily Rainfall (mm/day)
2	18.5
5	26.2
10	31.2
25	37.8
50	42.4
100	47.2
200	52.1

Our rainfall simulations were applied at approximately 60 mm daily for two consecutive days. Our applications exceeded both the 100- and 200-year events in daily amount. The U.S. Department of Commerce (1973) estimates the 2-year and 100-year, one-hour storm intensity as 4.3 mm/hr and 27.9 mm/hr respectively. The 100-year, 27.9 mm/hr storm has a rainfall erosivity factor (EI) of 191.5 MJ·mm/ha·hr. The expected cumulative soil loss versus time for this storm can be estimated using the USLE.

In the USLE, the relation of soil loss to rainfall erosivity over time will be linear. The USLE also predicts immediate soil loss and it cannot take into account different antecedent soil moisture conditions. During rainfall simulations the threshold amount of rainfall needed to initiate soil loss on previously dry soils was observed to be approximately 5 mm. To reach this threshold point for soil loss for the estimated 100-year, 1-hour storm it would take approximately 10 minutes. Therefore, a linear relationship from this threshold point to the total predicted soil loss for this storm will be assumed. Soil loss versus time curves for the 100-year, 1-hour (28 mm/hr) storm were estimated for the three different cover types using the USLE. The factors used in the USLE were the estimated soil erodibility (K) value, plot length-slope (LS) value, the rainfall energy (EI) value of the storm, and the computed cover (C) value determined from rainfall simulation data.

Curves of soil loss versus time of the 100-year, 1-hour storm (28 mm/hr) at INEL for the three different cover types used in this study were compared to the actual curves of soil loss versus time observed during the September 1987 rainfall simulations, on a dry soil surface at approximately 60 mm/hr (Figures 24, 25, and 26). The actual curves of cumulative soil loss from rainfall simulation data are examples of the range (shaded area) of soil loss expected on dry soil at an intensity of 60 mm/hr.

The soil loss versus time curves from the rainfall simulation data for the crested wheatgrass and streambank wheatgrass cover types showed an approximately linear relationship. The curves from actual data for the bare soil

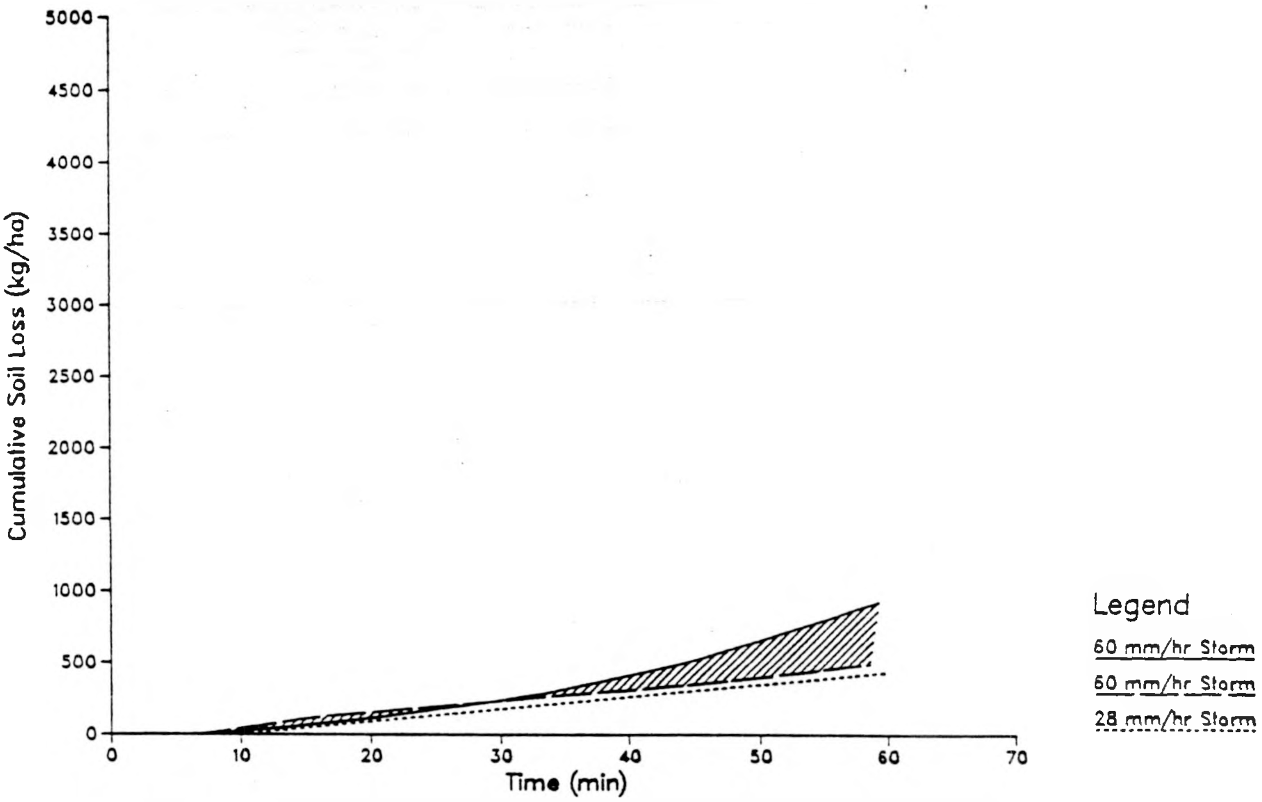

Figure 24. Cumulative soil loss curves for different rainfall intensities on a crested wheatgrass cover.

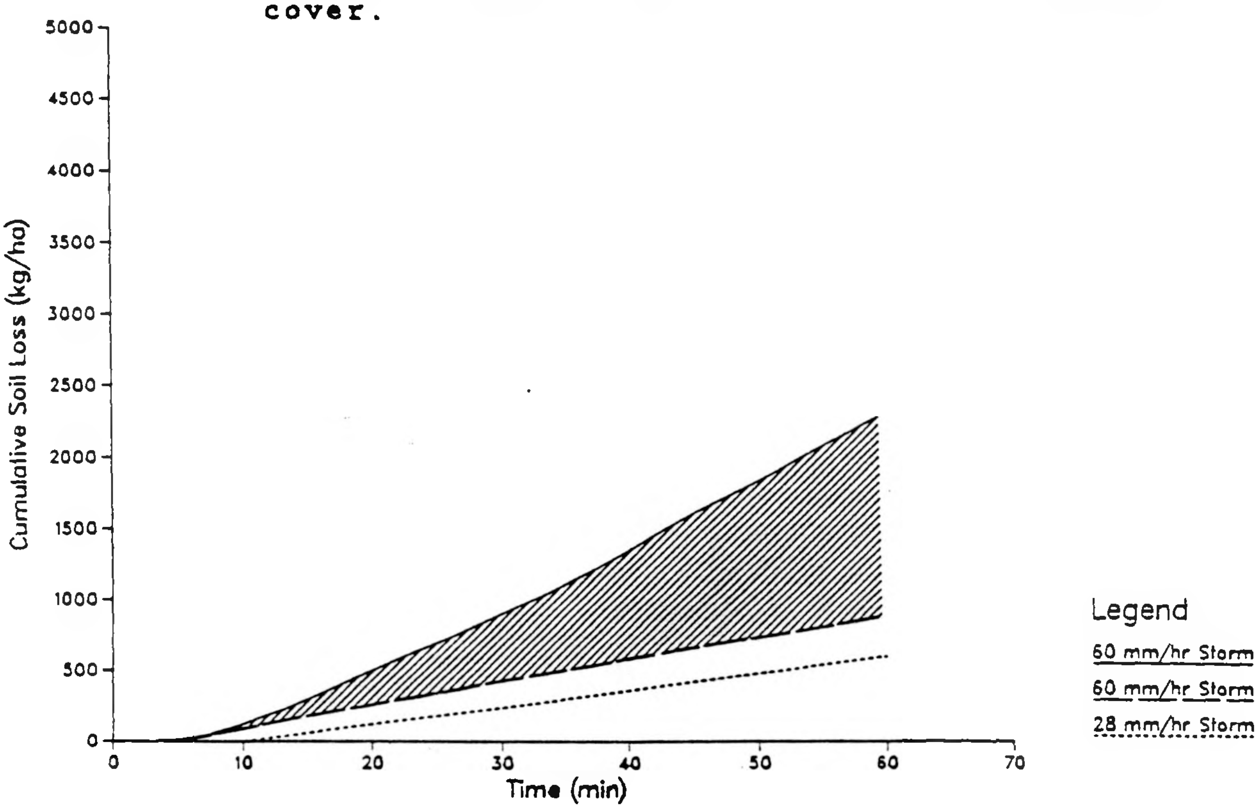

Figure 25. Cumulative soil loss curves for different rainfall intensities on a streambank wheatgrass cover.

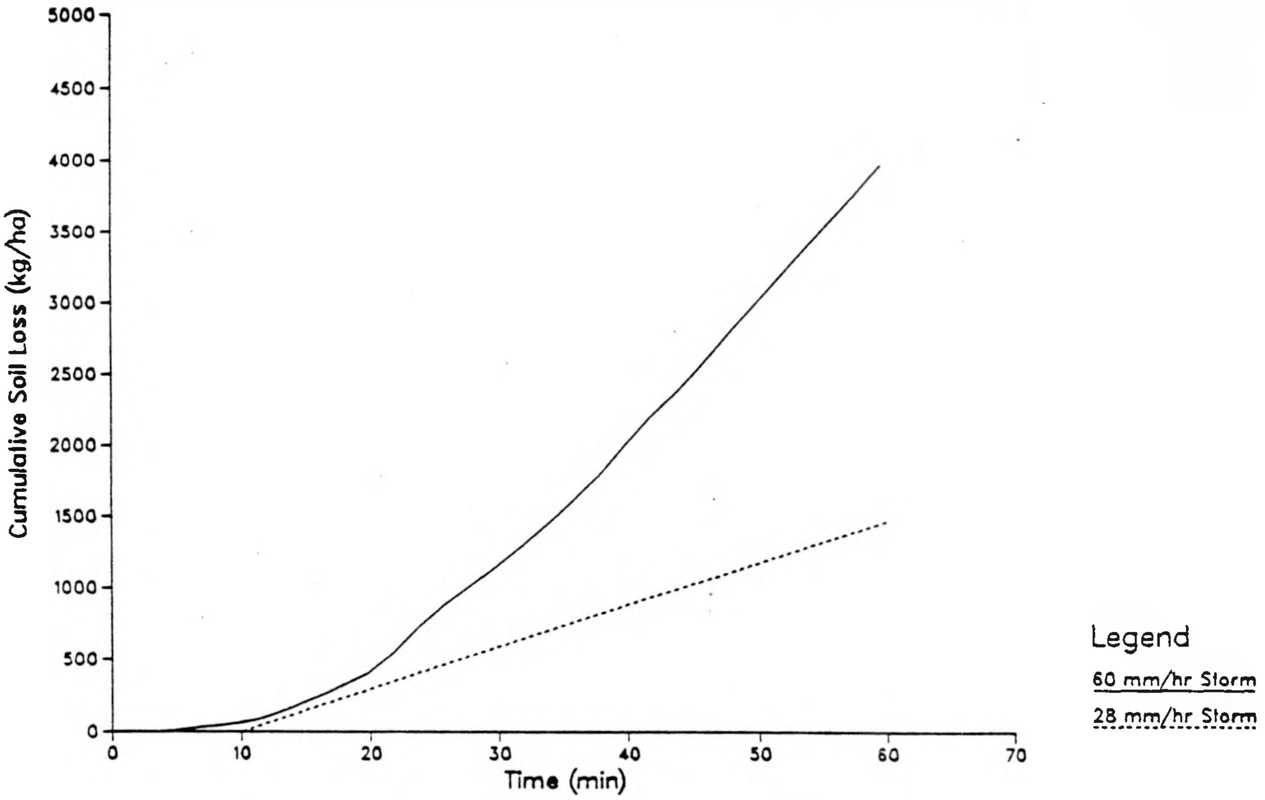

Figure 26. **Cumulative soil loss curves for different rainfall intensities on bare soil.**

cover type showed a more exponential soil loss rate over time. It appears that the expected soil loss for the 100-year, 1-hour storm on streambank and crested wheatgrass cover types are fairly good representations of what would be expected for that event.

The DOE waste management program is concerned with whether or not the low-level radioactive waste will become exposed during its burial life. The time for 1 m of soil to erode was estimated using the USLE and the bulk density of the lakebed sediment material, assuming: (1) permanent canopy and surface cover data for the two grass species similiar to that of August 1987, (2) a 6% slope and slope length of 10.7 m, (3) similiar soil texture and bulk density, and (4) no new soil formation. Estimations were performed for three conditions: (1) if the average annual rainfall erosivity (R) value of 250 MJ·mm/ha·hr as estimated by Wischmeier and Smith (1978) occurred every year, (2) if the 100-year, 1-hr storm occurred every year, and (3) if the simulated 60 mm/hr rainfall occurred every year. The results of approximately how many years for 1 m of lakebed sediment to erode for the three above situations is present in Table 21. The results in Table 21 suggest that soil erosion from rainfall events may not be a significant factor on shallow land burial earth covers at INEL, because under the most extreme rainfall conditions it would take a minimum of approximately 1200 years for the waste to become exposed.

Table 21. Number of years to erode burial earth covers at INEL under different rainfall situations.

Average annual R value occurring every year
(R = 250 MJ·mm/ha·hr·yr)

Cover	Years
Crested Wheatgrass	25500
Streambank Wheatgrass	18900
Bare Soil	3600

100-year 1-hour storm occuring every year
(EI = 191 MJ·mm/ha·hr)

Cover	Years
Crested Wheatgrass	33300
Streambank Wheatgrass	24700
Bare Soil	4700

60 mm/hr storm occurring every year
(EI = 760 MJ·mm/ha·hr)

Cover	Years
Crested Wheatgrass	8400
Streambank Wheatgrass	6200
Bare Soil	1200

SUMMARY AND CONCLUSIONS

The rainfall simulations conducted at INEL applied greater rainfall intensities and total precipitation than natural rainfall events in the area. Calculations using the average annual rainfall erosivity factor, the rainfall erosivity factor of the 100-year, 1-hour storm, and that of a 60 mm/hr storm showed that if they occurred every year the earth covers for the shallow land burials would not become exposed during its expected life (Table 5). These results indicate that soil erosion from rainfall events is not a significant factor on shallow land burial earth covers at INEL. Perhaps more emphasis is needed on infiltration characteristics and surficial macropores development on earth covers, since water entering the waste material zone could lead to leaching of radioactive pollutants into the groundwater.

The use of the USLE in erosion prediction for rainfall events on shallow land burials at INEL showed that it underestimates soil loss. Problems in applying the USLE to this study included: (1) it could not account for antecedent soil moisture condition; (2) soil loss was predicted immediately after rainfall started (ie., no threshold point of rainfall before runoff and erosion occur); and (3) cover factor values were questionable.

Data collected from 1986 and 1987 shows that crested wheatgrass controls erosion better than streambank wheatgrass. Since crested wheatgrass was transplanted and streambank wheatgrass was seeded, it appears that as streambank wheatgrass matures its ability to control soil loss approaches that of crested wheatgrass. The main conclusion for control of soil loss is that some type of vegetative cover is necessary. This can be seen in the comparison of total soil loss for both grass species to that of the bare soil plot (Figure 21).

Infiltration data indicated that streambank wheatgrass plots had a lower infiltration capacity constant than did crested wheatgrass plots, although the September 1987 data shows very similar infiltration capacity constants between the two grass species. At present, streambank wheatgrass could be recommended as the best choice in controlling infiltration. Another positive attribute of streambank wheatgrass is its ability to extract water from the soil profile better than crested wheatgrass (Nowak, 1986). For all plots the Horton infiltration equation generally predicted a higher infiltration capacity constant than the Green-Ampt infiltration equation. However, for very wet antecedent soil moisture conditions both equations predicted similar values of the infiltration capacity constant, which are thought to be representative of the actual infiltration capacity constants.

Several more years of data may be needed to allow streambank wheatgrass to reach maturity and give a reasonable indication of the grass species ability to control both infiltration and erosion. Further study would also differentiate the ability of the two grass species to control infiltration and soil loss during the period of spring snowmelt runoff and the May-June precipitation peak.

Future Recommendations:

To make a more comparable study, it is suggested that the grass species both be seeded similarly to the actual burial area at the SDA. The study should include equal replications of bare and grassed plots. Rainfall should be simulated for a number of years during the spring and fall to allow the plots to reach an equilibrium rate and allow the grasses to mature. Also, since the gravel plus wheatgrass plots at the LANL showed excellent erosion and runoff control, perhaps a study of the addition of gravel to the plots should be undertaken.

Finally, a better understanding of natural rainfall event characteristics and spring snowmelt runoff is necessary to characterize the naturally recurring erosion and runoff events at INEL. Also, a general estimate of wind erosion is necessary, because it appears to be a significant factor in soil loss at INEL.

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APPENDICES

Appendix A. Additional Soil Information:

Results of soil textural analysis done by USU Soil Testing Lab on lakebed sediment material.

Hydrometer Method

Sample #	% O.M.	% Sand	% Silt	% Clay	Textural Classificatio
1	0.7	23	49	28	clay loam
2	0.9	24	50	26	loam
3	0.7	23	51	26	silt loam

Sand Sieving (Breakdown of sand fraction)

Sample #	%V.Coarse	%Coarse	%Medium	%Fine	%V.Fine	Tota
1	1.5	2.2	1.0	3.7	11.9	20.
2	1.4	1.6	0.8	3.7	12.6	20.
3	1.3	1.5	0.9	3.7	12.2	19.6

Results of X-ray diffraction analysis of mineralogy of lakebed sediment samples done by Dr. Peter Kolesar, USU Geology Department.

Sample #	Size Fraction	Mineralogy
1	Sand	Quartz, feldspar (probably K-rich), calcite, dolomite
	Silt	Quartz, calcite, trace of feldspar
	Clay	Montmorillonite, illite, kaolinite, trace of calcite and quartz
2	Sand	Quartz, feldspar (probably K-rich), calcite, dolomite
	Silt	Quartz, calcite, trace of feldspar
	Clay	Montmorillonite, illite, kaolinite, trace of calcite and quartz

Appendix B. Additional Vegetation Information:

Results of split plot design analysis of variance on vegetative factors collected in 1987.

CANOPY COVER (%)

Source of Variation	SS	DF	MS	F	p-value
Block	92.19	2	46.09	0.68	0.595
A: Grass Species	20.99	1	20.99	0.31	0.634
Error (A)	135.54	2	67.77		
B: Season	11.51	1	11.51	0.26	0.637
A x B	3.73	1	3.73	0.08	0.786
Error (B)	176.85	4	44.21		

PLANT BASAL COVER (%)

Source of Variation	SS	DF	MS	F	p-value
Block	3.62	2	1.81	0.18	0.846
A: Grass Species	51.13	1	51.13	5.13	0.152
Error (A)	19.94	2	9.97		
B: Season	0.18	1	0.18	0.08	0.795
A x B	16.17	1	16.17	7.14	0.056
Error (B)	9.06	4	2.26		

LITTER COVER (%)

Source of Variation	SS	DF	MS	F	p-value
Block	5.58	2	2.79	0.30	0.772
A: Grass Species	0.09	1	0.09	0.01	0.933
Error (A)	18.86	2	9.43		
B: Season	554.47	1	554.47	40.57	0.003
A x B	36.79	1	36.79	2.69	0.176
Error (B)	54.66	4	13.67		

BARE SOIL COVER (%)

Source of Variation	SS	DF	MS	F	p-value
Block	15.74	2	7.87	0.20	0.830
A: Grass Species	55.38	1	55.38	1.44	0.353
Error (A)	76.92	2	38.46		
B: Season	534.93	1	534.93	27.53	0.006
A x B	101.73	1	101.73	5.24	0.084
Error	77.73	4	19.43		

STANDING CROP (g/plot)

Source of Variation	SS	DF	MS	F	p-value
Block	3396885.16	2	1698442.6	0.30	0.769
A: Grass Species	6726440.59	1	6726440.6	1.19	0.389
Error (A)	11292673.80	2	5646336.9		
B: Season	0.00	1	0.00	.	.
A x B	0.00	1	0.00	.	.
Error (B)	0.00	1	0.00		

Cover factor (C) values for 1986 and 1987. (Tabular Values are from a table in Wischmeier and Smith, 1978 and Computed Values are from backcalculating with actual data collected using the USLE).

	AUGUST 1986		JUNE 1987		AUGUST 1987	
Plot	Tabular	Computed	Tabular	Computed	Tabular	Computed
1D	0.3110	0.3360	0.0738	0.2830	0.0495	0.1566
1W			0.0738	0.2945	0.0495	0.1808
1VW			0.0738	0.3470	0.0495	0.1763
2D	0.0970	0.0011	0.0647	0.0638	0.0530	0.1372
2W			0.0647	0.0716	0.0530	0.1589
2VW			0.0647	0.1069	0.0530	0.1710
3D	0.0934	0.0011	0.0684	0.0397	0.0522	0.0589
3W			0.0684	0.0512	0.0522	0.0777
3VW			0.0684	0.0798	0.0522	0.0785
4D	0.3486	0.0602	0.0708	0.1305	0.0445	0.1108
4W			0.0708	0.1624	0.0445	0.1490
4VW			0.0708	0.2137	0.0445	0.1669
5D	0.0815	0.0048	0.0602	0.0171	0.0448	0.0418
5W			0.0602	0.0408	0.0448	0.0540
5VW			0.0602	0.0513	0.0448	0.0688
6D	0.3315	0.0394	0.1445	0.0682	0.0494	0.0680
6W			0.1445	0.0955	0.0494	0.0631
6VW			0.1445	0.1024	0.0494	0.0719
7D	0.4500	NA	0.4396	0.3916	0.3250	0.2238
7W			0.4396	0.7887	0.3250	0.3710
7VW			0.4396	0.8134	0.3250	0.3554

Note: D - Dry Run, W - Wet Run, and VW - Very Wet Run.

Plots 1, 4, and 6 are streambank wheatgrass.
Plots 2, 3, and 5 are crested wheatgrass.
Plot 7 is bare soil.

Appendix C. Summary of 1986 and 1987 Rainfall Simulations:

AUGUST 1986

Plot #	AMC	#1	#2	#3	#4	#5	#6	#7
Area (m^2)		32.73	32.14	32.24	32.20	31.96	32.18	32.47
Slope		6.24	6.59	6.10	6.01	6.13	6.38	6.16
LS value (USLE)		0.417	0.447	0.406	0.398	0.407	0.428	0.412
Soil Moisture (%)	D	4.7	4.9	4.1	4.7	3.2	3.2	-
Total Rainfall (mm)	D	28.2	29.7	30.5	30.7	29.5	30.0	-
Duration of Rainfall (min)	D	30.4	30.4	30.7	30.7	30.8	30.8	-
Rainfall Intensity (mm/hr)	D	55.6	58.7	59.7	59.9	57.4	58.4	-
Rainfall Energy (MJ•mm/ha•hr)	D	328	367	384	389	355	368	-
Time to Runoff (min)	D	2.43	23.25	30.83	3.50	21.65	4.17	-
Amount of Rainfall to Runoff (mm)	D	2.3	22.8	30.7	3.5	20.7	4.1	-
Total Runoff (mm)	D	11.0	0.1	0.0	6.0	0.0	4.5	-
Q/P Ratio	D	0.39	0.00	0.00	0.20	0.00	0.15	-
Peak Discharge Rate (mm/hr)	D	44.4	0.7	1.9	25.5	0.1	16.9	-
Peak Sediment Concentration (g/L)	D	32.4	1.4	2.3	10.6	1.9	7.9	-
Peak Sediment Loss Rate (g/min)	D	627	1	2	100	0	46	-

AUGUST 1986 (continued)

Plot #	AMC	#1	#2	#3	#4	#5	#6	#7
Calculated Sediment Loss (g)	D	7470	2	1	1466	0	746	-
Flushed Sediment (g)	D	1224	15	20	286	117	427	-
Total Sediment Loss (g)	D	8694	17	20	1752	117	1173	-
Total Soil Loss (MT/ha)	D	2.66	0.01	0.01	0.54	0.04	0.36	-

JUNE 1987

Plot #	AMC	#1	#2	#3	#4	#5	#6	#7
Area (m^2)		32.73	32.14	32.24	32.20	31.96	32.18	32.47
Slope		6.24	6.59	6.10	6.01	6.13	6.38	6.16
LS value (USLE)		0.417	0.447	0.406	0.398	0.407	0.428	0.412
Soil Moisture (%)	D	7.6	7.7	10.4	8.1	8.1	7.4	14.4
	W	17.7	21.4	24.1	18.6	19.6	17.2	20.7
	VW	25.7	27.0	30.0	28.2	31.7	29.2	25.6
Total Rainfall (mm)	D	43.6	41.7	57.2	55.5	57.4	54.5	60.3
	W	29.4	29.4	30.5	30.9	28.2	28.9	29.9
	VW	29.8	29.9	33.0	30.8	29.0	30.7	29.0
Duration of Rainfall (min)	D	44.5	44.5	60.9	60.9	59.8	59.8	60.3
	W	30.3	30.3	30.3	30.3	30.0	30.0	30.6
	VW	29.8	29.8	30.2	30.2	29.9	29.9	29.9
Rainfall Intensity (mm/hr)	D	58.8	56.2	56.4	54.7	57.5	54.7	60.1
	W	58.4	58.4	60.5	61.3	56.3	57.8	58.6
	VW	60.1	60.2	65.7	61.3	58.2	61.7	58.2
Rainfall Energy (MJ•mm/ha•hr)	D	540	490	674	632	693	621	765
	W	361	361	390	401	332	351	369
	VW	378	379	464	400	355	402	355
Time to Runoff (min)	D	1.52	7.23	3.62	4.85	15.05	5.97	3.13
	W	2.87	3.90	2.40	3.10	5.47	3.70	1.92
	VW	1.52	2.43	1.53	1.45	3.12	1.82	0.83

JUNE 1987 (continued)

Plot #	AMC	#1	#2	#3	#4	#5	#6	#7
Amount of Rainfall to Runoff (mm)	D	1.5	6.8	3.4	4.4	14.4	5.4	3.1
	W	2.8	3.8	2.4	3.2	5.1	3.6	1.9
	VW	1.5	2.4	1.7	1.5	3.0	1.9	0.8
Total Runoff (mm)	D	28.0	12.0	19.7	30.5	11.7	28.4	35.5
	W	18.7	12.1	13.9	17.2	10.3	17.6	22.2
	VW	21.9	16.0	16.3	19.8	14.3	21.6	22.9
Q/P Ratio	D	0.64	0.29	0.34	0.55	0.20	0.52	0.59
	W	0.64	0.41	0.45	0.56	0.37	0.61	0.74
	VW	0.74	0.54	0.49	0.64	0.49	0.70	0.79
Peak Discharge Rate (mm/hr)	D	46.3	28.0	31.2	37.9	21.7	38.4	44.8
	W	46.3	34.2	34.3	40.7	28.2	44.6	51.2
	VW	48.7	37.9	38.0	43.5	34.0	48.6	51.4
Peak Sediment Concentration (g/L)	D	14.1	4.7	5.8	6.8	2.0	5.2	29.0
	W	14.9	4.4	4.3	11.7	3.1	4.4	35.1
	VW	15.1	5.6	6.0	10.8	3.0	4.8	36.6
Peak Sediment Loss Rate (g/min)	D	338	67	49	131	20	69	652
	W	374	81	62	185	40	92	939
	VW	394	107	122	321	42	100	1018
Calculated Sediment Loss (g)	D	10925	1487	1857	5429	646	2812	22601
	W	7623	1541	1351	4202	861	2190	21964
	VW	9269	2240	2550	5369	985	2319	21825
Flushed Sediment (g)	D	1142	1104	165	674	259	577	599
	W	788	627	152	635	151	480	584
	VW	1106	1147	262	973	386	976	501
Total Sediment Loss (g)	D	12066	2591	2021	6103	905	3389	23200
	W	8410	2168	1503	4836	1013	2670	22548
	VW	10374	3387	2813	6342	1371	3296	22326
Total Soil Loss (MT/ha)	D	3.69	0.81	0.63	1.90	0.28	1.05	7.15
	W	2.57	0.67	0.47	1.50	0.32	0.83	6.94
	VW	3.17	1.05	0.87	1.97	0.43	1.02	6.88

SEPTEMBER 1987

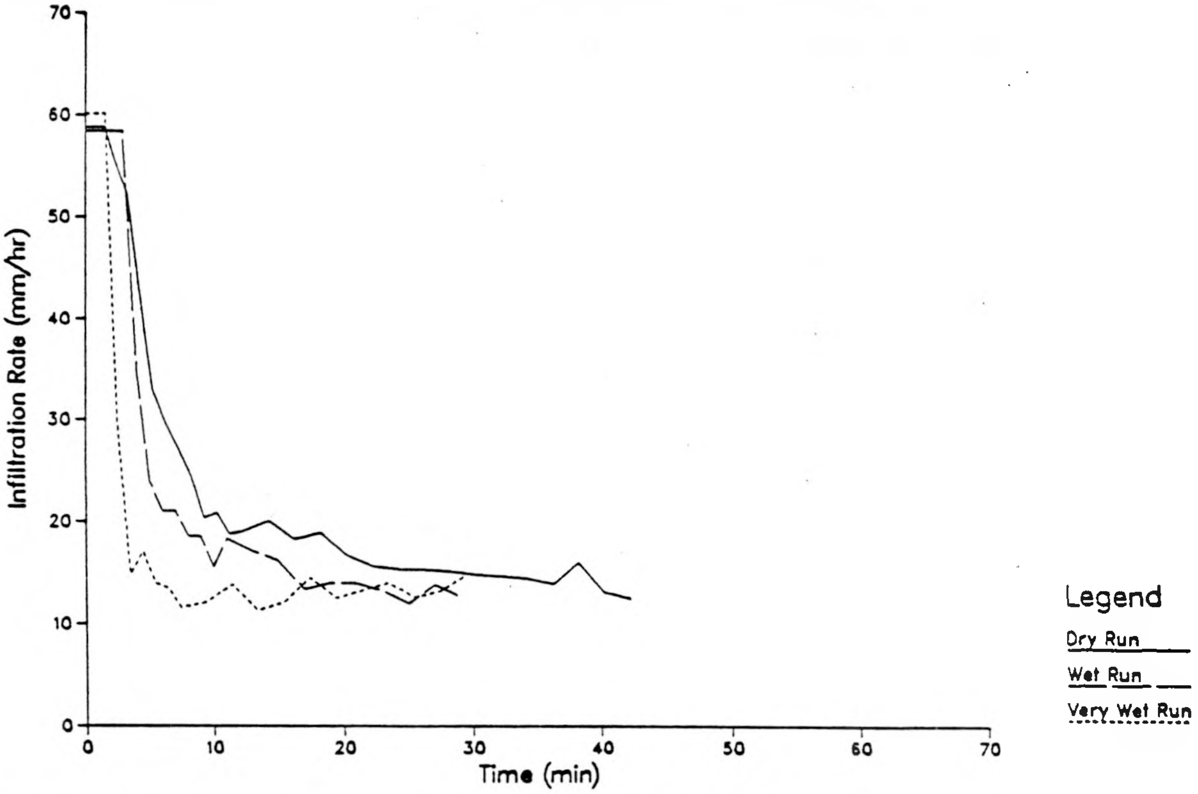
Plot #	AMC	#1	#2	#3	#4	#5	#6	#7
Area (m^2)		32.73	32.14	32.24	32.20	31.96	32.18	32.4
Slope (%)		6.24	6.59	6.10	6.01	6.13	6.38	6.1
LS value (USLE)		0.417	0.447	0.406	0.398	0.407	0.428	0.41
Soil Moisture (%)	D	5.9	6.5	8.3	6.9	6.8	6.6	9
	W	19.9	20.1	16.1	13.2	19.0	17.5	20
	VW	22.8	25.5	27.6	28.2	26.2	24.8	25
Total Rainfall (mm)	D	58.1	46.6	32.2	33.0	57.9	58.4	61
	W	32.3	31.0	27.8	31.0	28.2	32.4	31
	VW	32.6	31.9	28.9	31.2	27.6	33.2	33
Duration of Rainfall (min)	D	60.4	60.4	31.0	31.0	60.4	60.4	60
	W	30.3	30.3	30.3	30.3	30.4	30.4	30
	VW	30.2	30.2	30.3	30.3	30.3	30.3	31
Rainfall Intensity (mm/hr)	D	57.8	46.3	62.4	64.0	57.6	58.0	60
	W	64.0	61.4	55.1	61.6	55.8	64.0	62
	VW	65.1	63.5	57.3	61.8	54.7	65.8	64
Rainfall Energy (MJ·mm/ha·hr)	D	706	439	426	450	700	712	7
	W	439	403	361	405	329	441	4
	VW	453	431	347	408	314	466	4
Time to Runoff (min)	D	2.92	6.23	4.67	3.80	6.20	4.60	3.
	W	1.80	2.57	3.67	3.08	3.22	3.00	2.
	VW	1.33	2.03	1.43	0.90	2.43	1.75	0.
Amount of Rainfall to Runoff (mm)	D	2.8	4.8	4.9	4.1	6.0	4.5	3
	W	1.9	2.6	3.4	3.2	3.0	3.2	2
	VW	1.4	2.2	1.4	0.9	2.2	1.9	1
Total Runoff (mm)	D	33.3	21.2	11.3	13.9	23.8	37.0	27
	W	22.1	17.5	13.6	16.3	15.5	19.2	18
	VW	22.5	19.2	17.1	19.5	17.6	21.4	22
Q/P Ratio	D	0.57	0.46	0.35	0.42	0.41	0.63	0.
	W	0.68	0.56	0.49	0.53	0.55	0.59	0.
	VW	0.69	0.60	0.59	0.63	0.64	0.65	0.
Peak Discharge Rate (mm/hr)	D	41.1	30.2	31.5	35.1	33.9	42.4	41
	W	49.9	41.4	35.8	40.4	37.2	44.0	45
	VW	48.6	42.6	38.2	46.8	41.2	46.3	4
Peak Sediment Concentration (g/L)	D	8.7	6.5	7.1	10.4	3.5	3.9	1
	W	9.0	7.6	5.5	8.2	2.6	3.0	2
	VW	8.3	7.9	4.3	7.9	2.6	2.8	1

SEPTEMBER 1987 (continued)

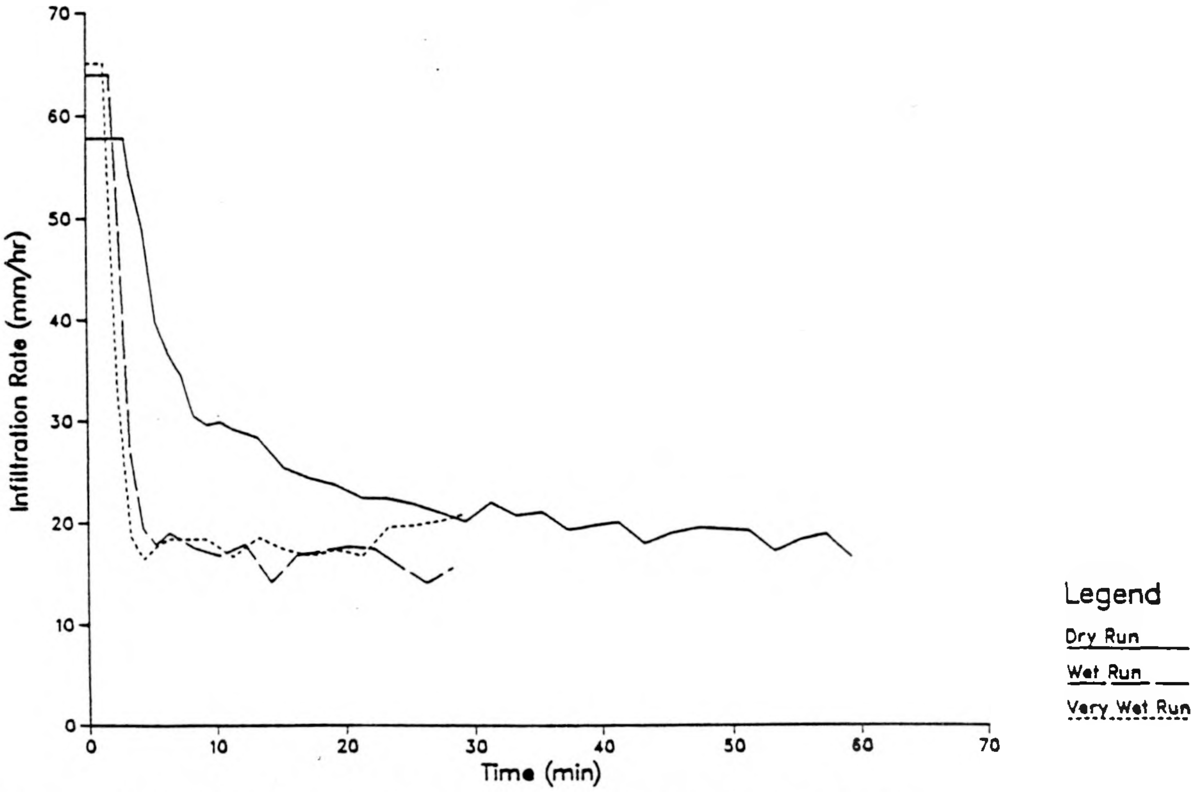
Plot #	AMC	#1	#2	#3	#4	#5	#6	#7
Peak Sediment Loss Rate (g/min)	D	180	103	80	170	46	60	365
	W	243	162	87	171	36	56	522
	VW	210	178	75	181	54	62	500
Calculated Sediment Loss (g)	D	7701	3069	1626	3294	1661	2873	13154
	W	5476	3609	1878	3734	903	1380	11770
	VW	5342	3777	1777	4075	1213	1488	12032
Flushed Sediment (g)	D	1052	1955	271	864	547	997	449
	W	813	1733	262	734	433	770	368
	VW	971	2353	276	997	454	1169	566
Total Sediment Loss (g)	D	8753	5024	1897	4159	2208	3870	13603
	W	6289	5342	2140	4468	1335	2150	12138
	VW	6312	6130	2053	5071	1667	2657	12599
Total Soil Loss (MT/ha)	D	2.67	1.56	0.59	1.29	0.69	1.20	4.19
	W	1.92	1.66	0.66	1.39	0.42	0.69	3.74
	VW	1.93	1.91	0.64	1.57	0.52	0.83	3.88

Note: (1) AMC - antecedent moisture condition.
(2) D - dry run, W - wet run, and VW - very wet run.
(3) Plots 1, 4, and 6 are streambank wheatgrass.
(4) Plots 2, 3, and 5 are crested wheatgrass.
(5) Plot 7 is bare soil.

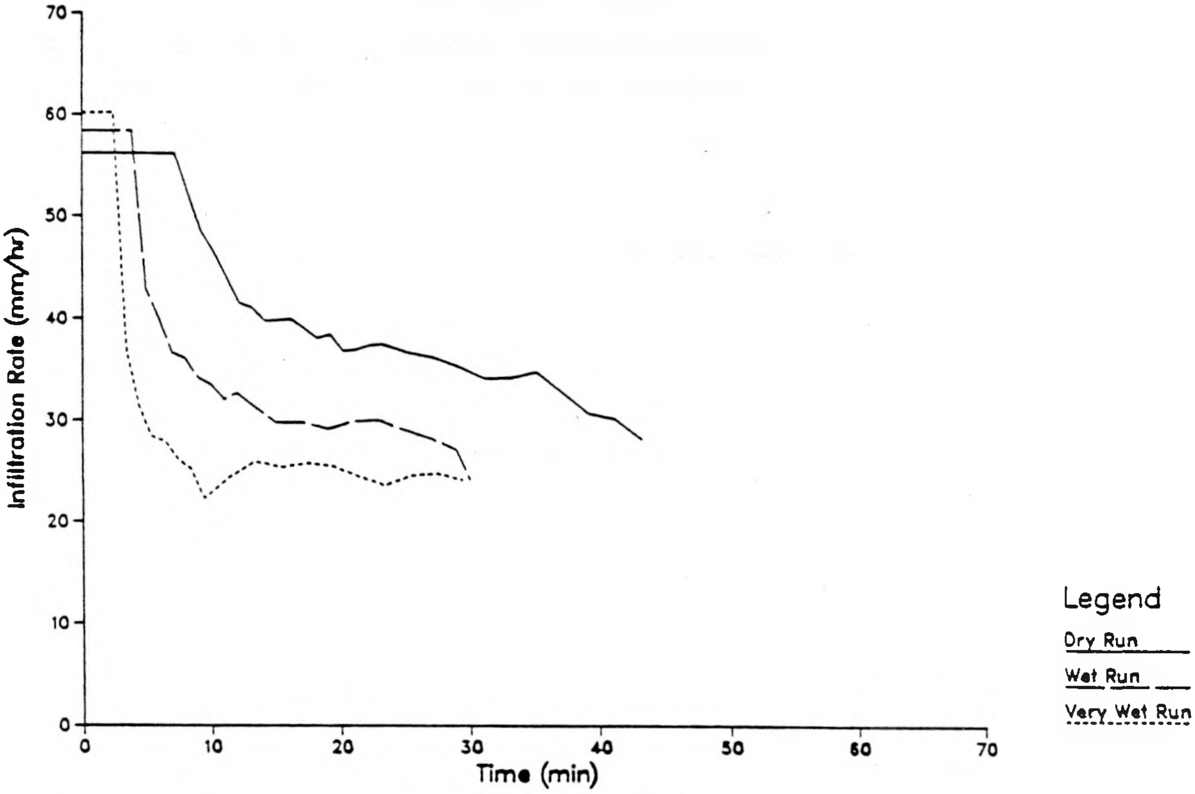
Appendix D. Infiltration Curves From 1987:



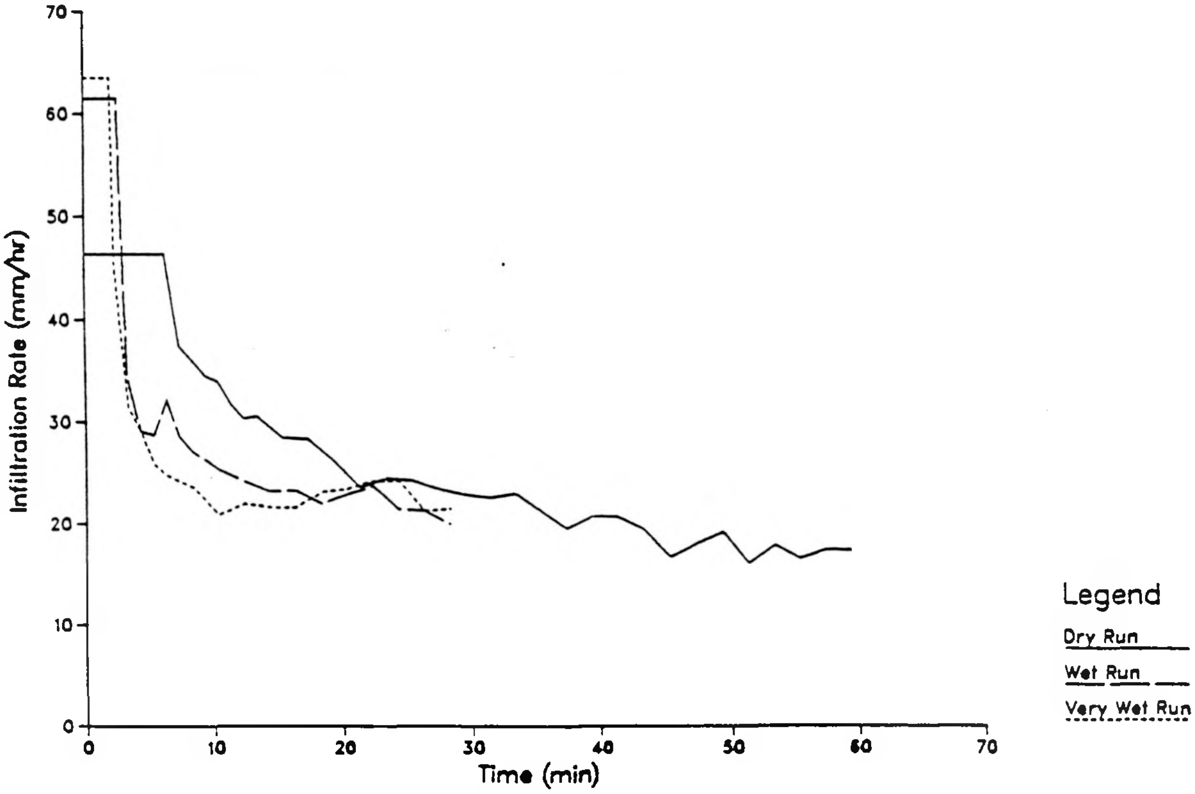
Plot #1 Streambank Wheatgrass June 1987.



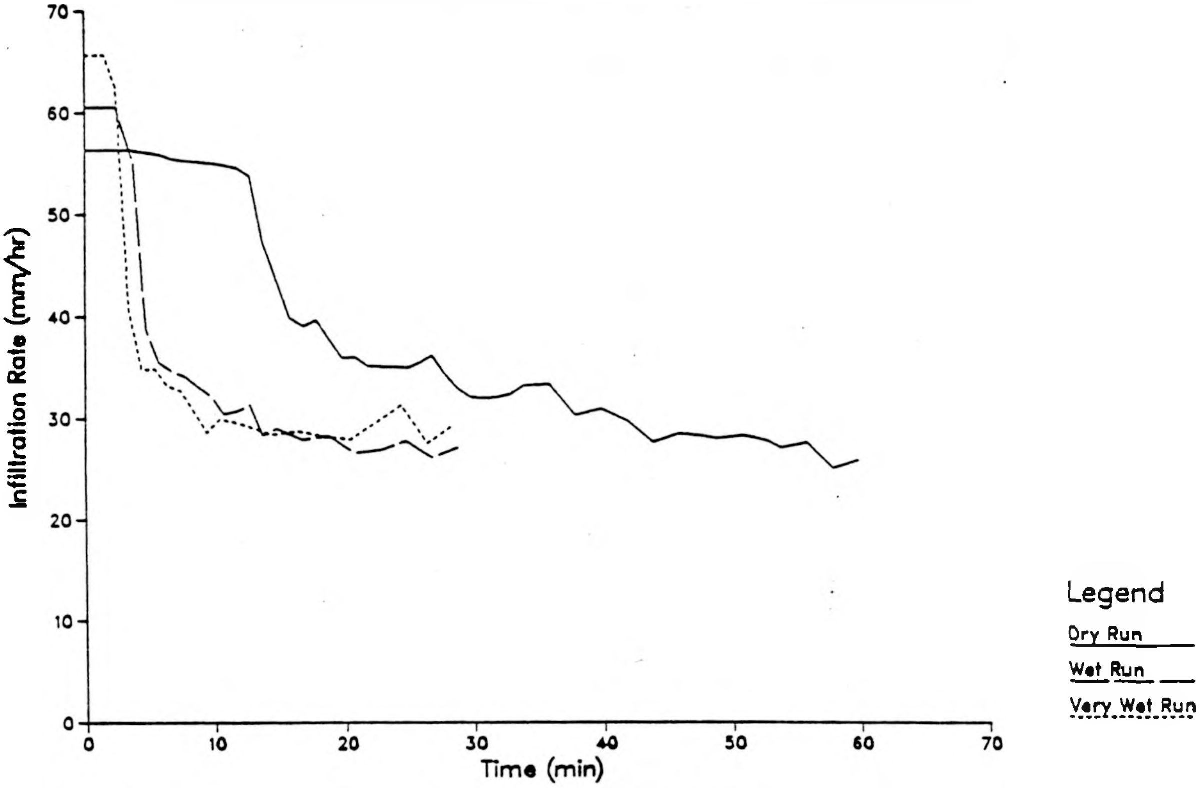
Plot #1 Streambank Wheatgrass September 1987.



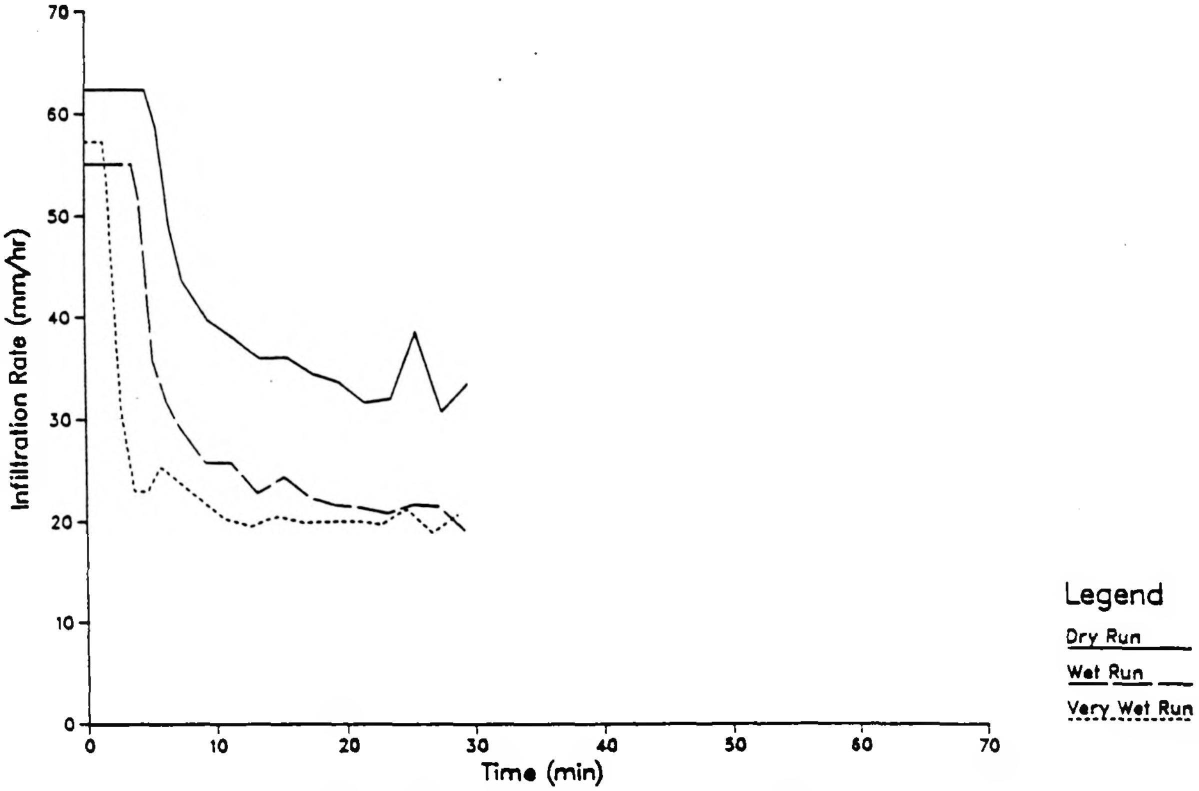
Plot #2 Crested Wheatgrass June 1987.



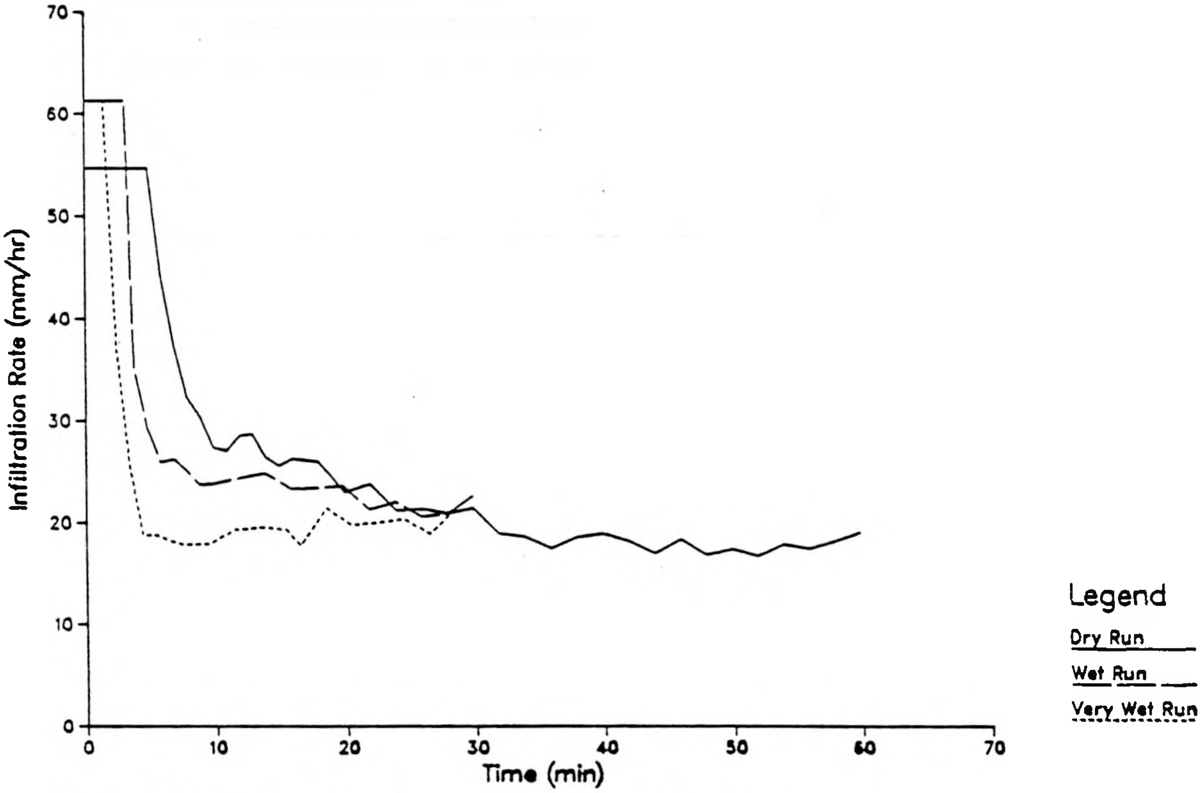
Plot #2 Created Wheatgrass September 1987.



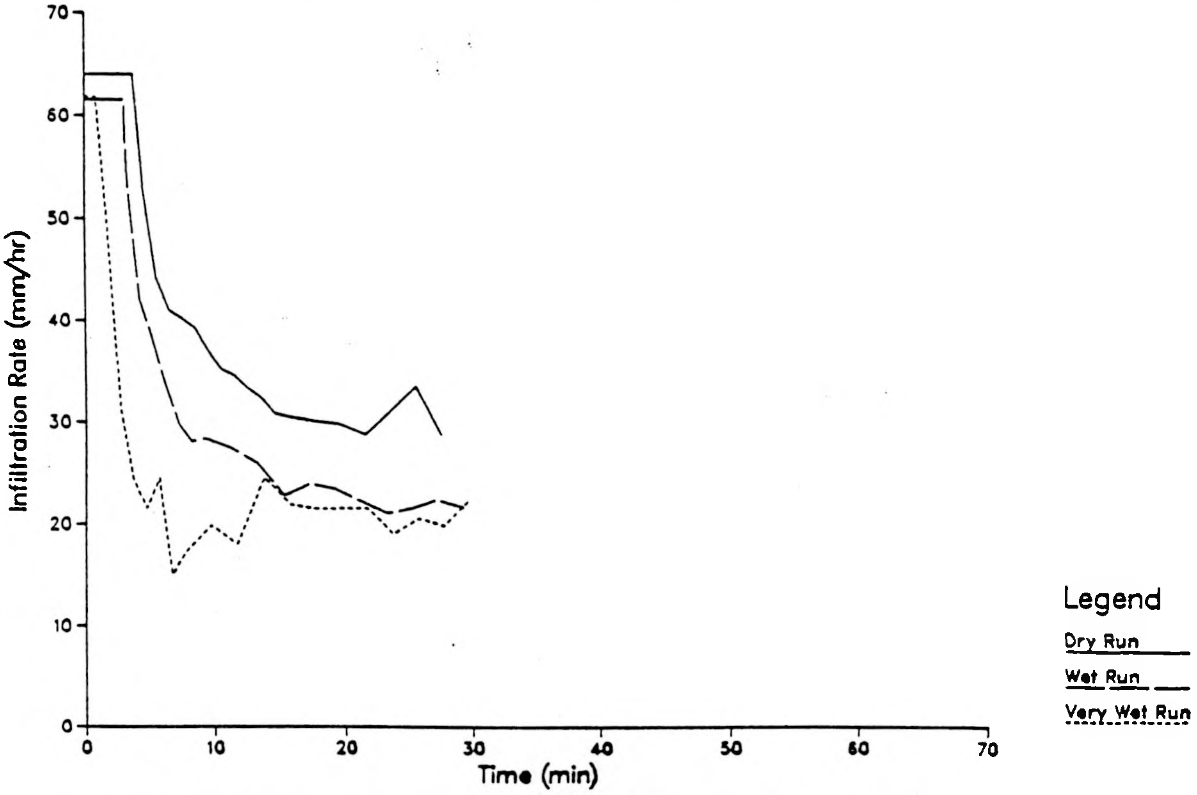
Plot #3 Crested Wheatgrass June 1987.



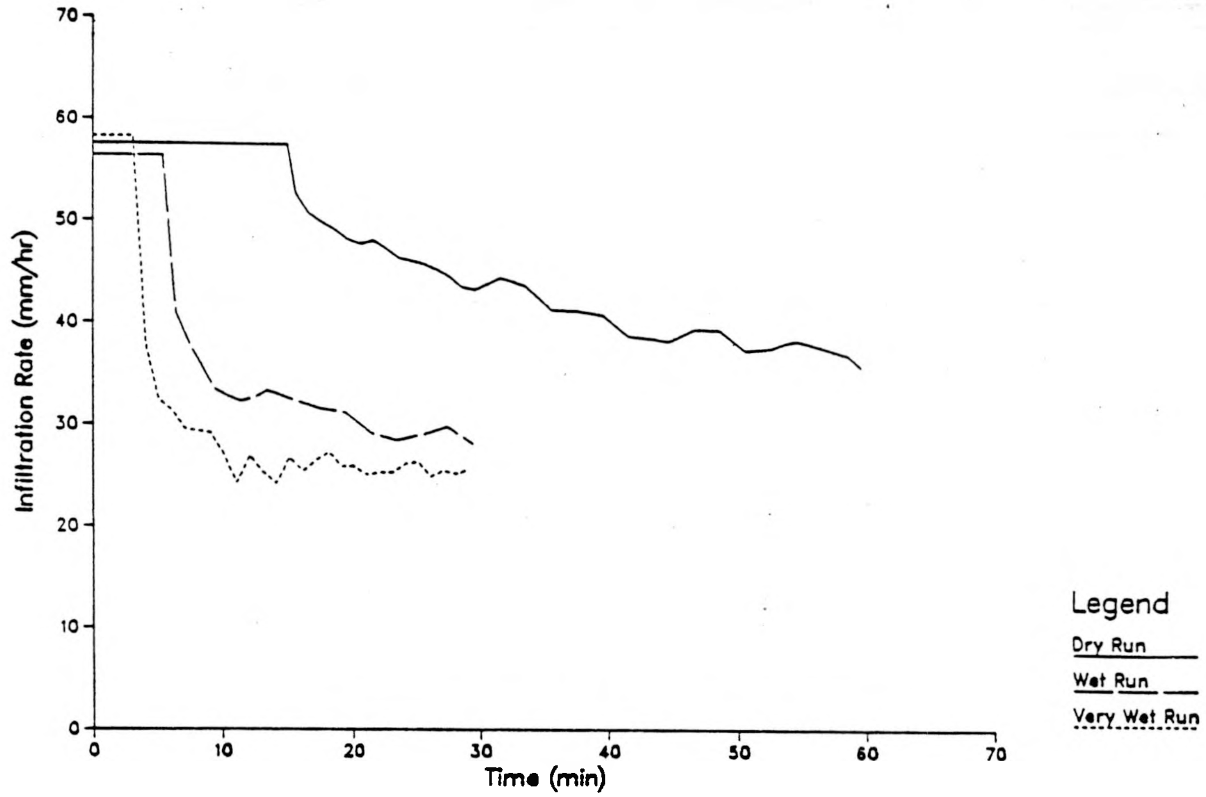
Plot #3 Crested Wheatgrass September 1987.



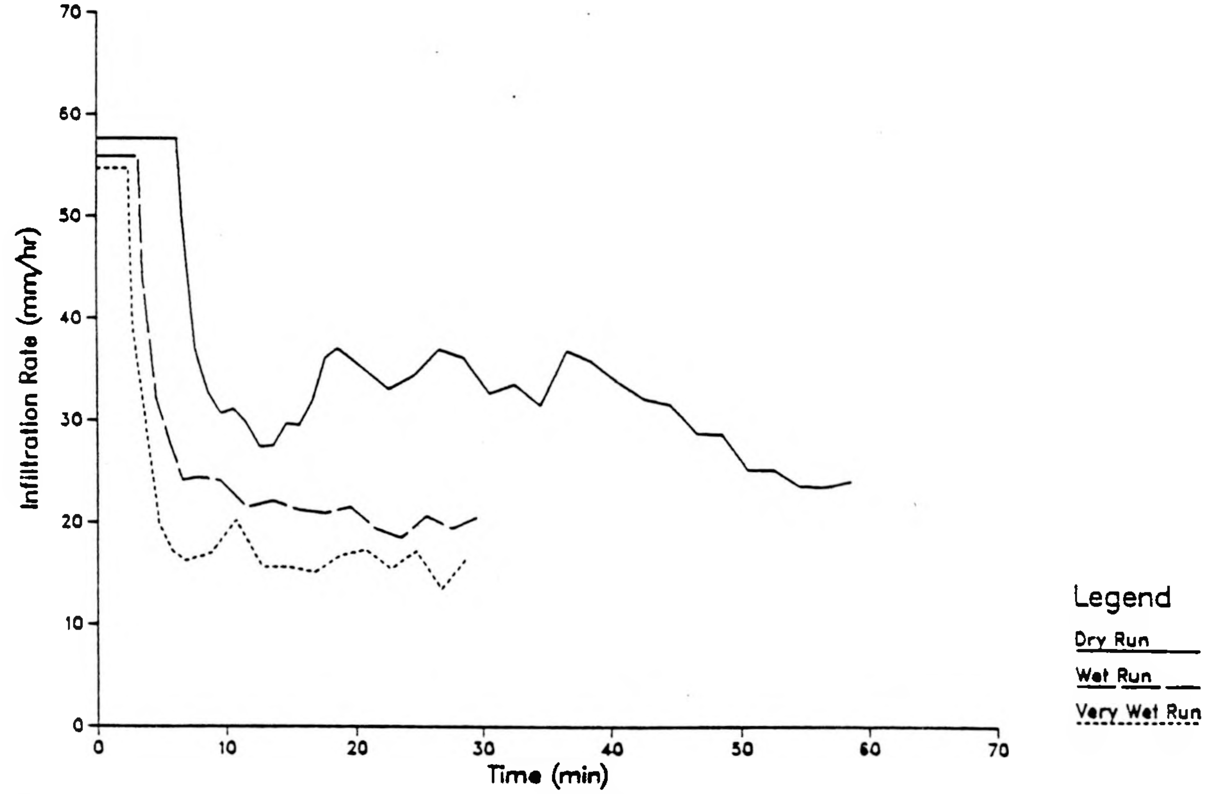
Plot #4 Streambank Wheatgrass June 1987.



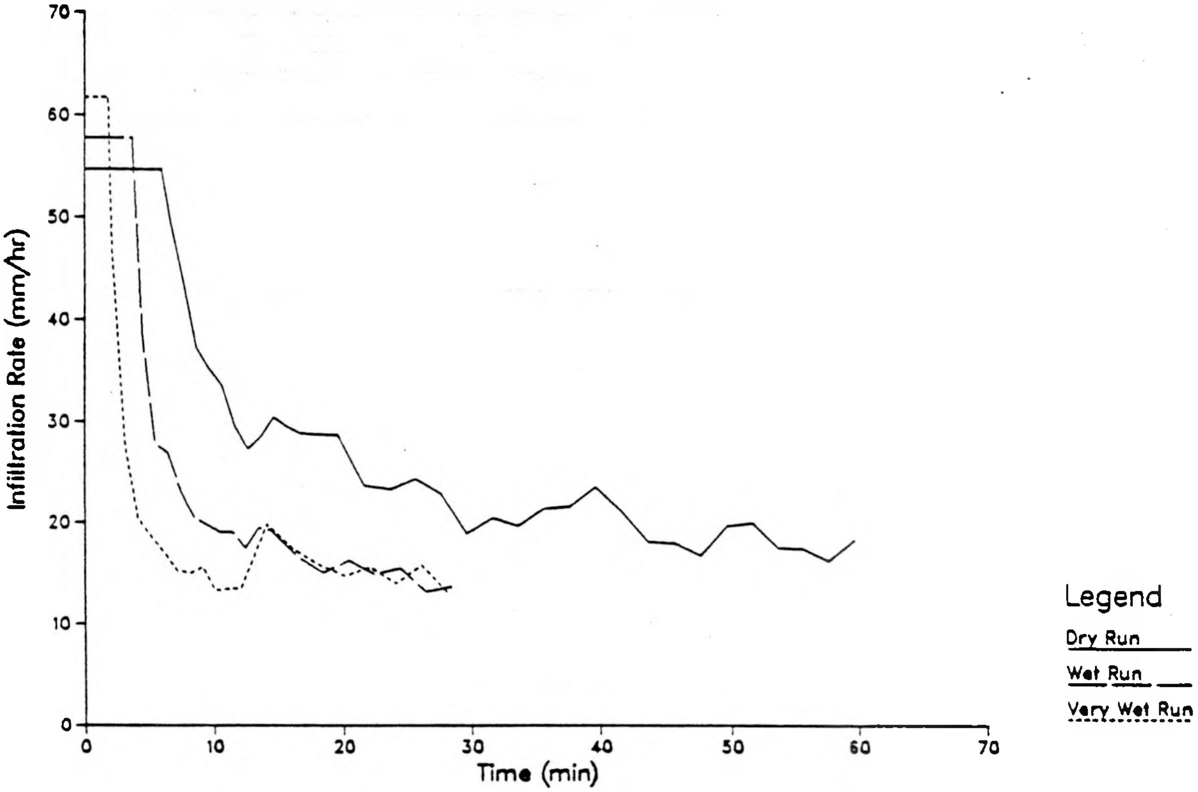
Plot #4 Streambank Wheatgrass September 1987.



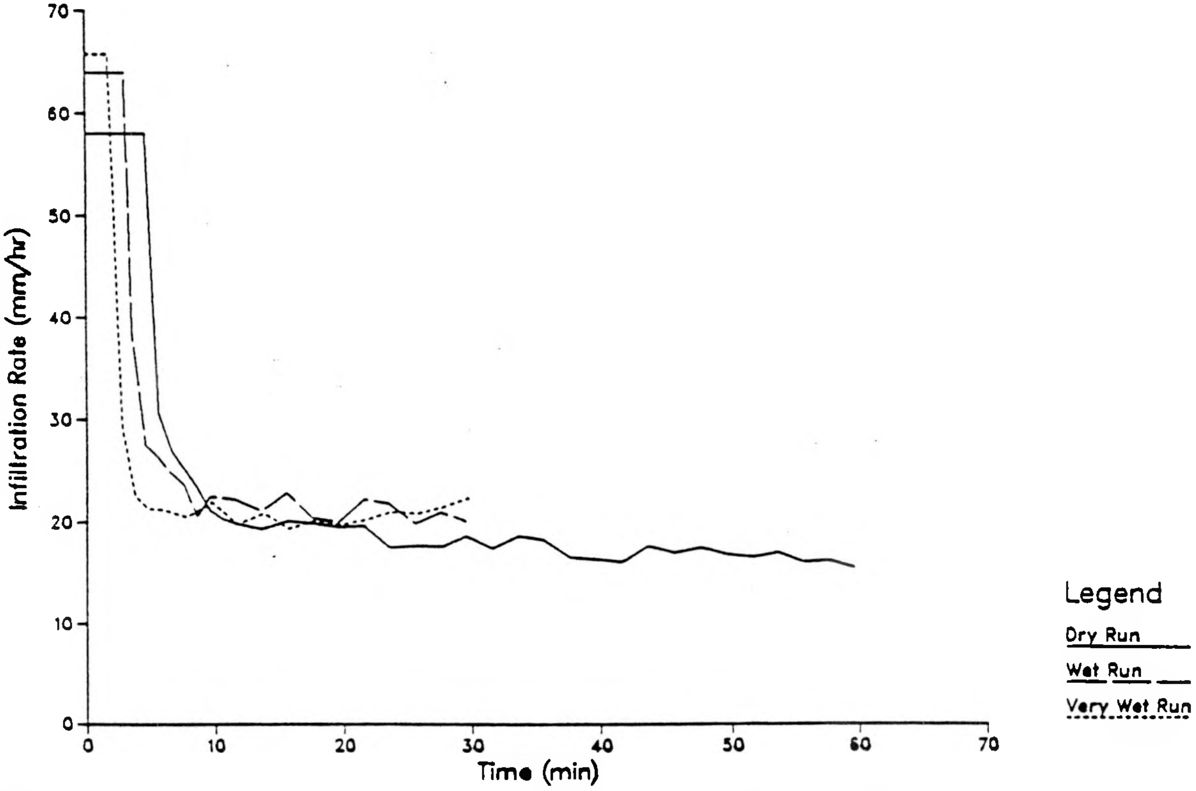
Plot #5 Crested Wheatgrass June 1987.



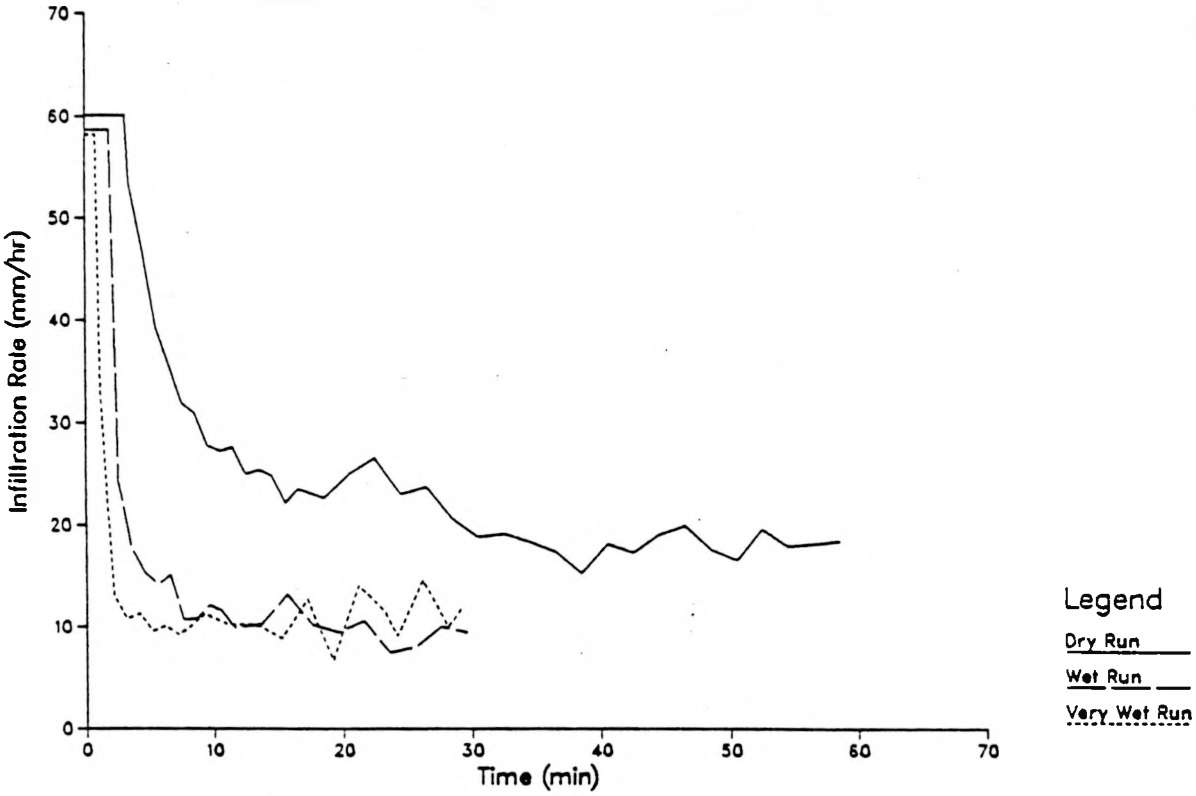
Plot #5 Crested Wheatgrass September 1987.



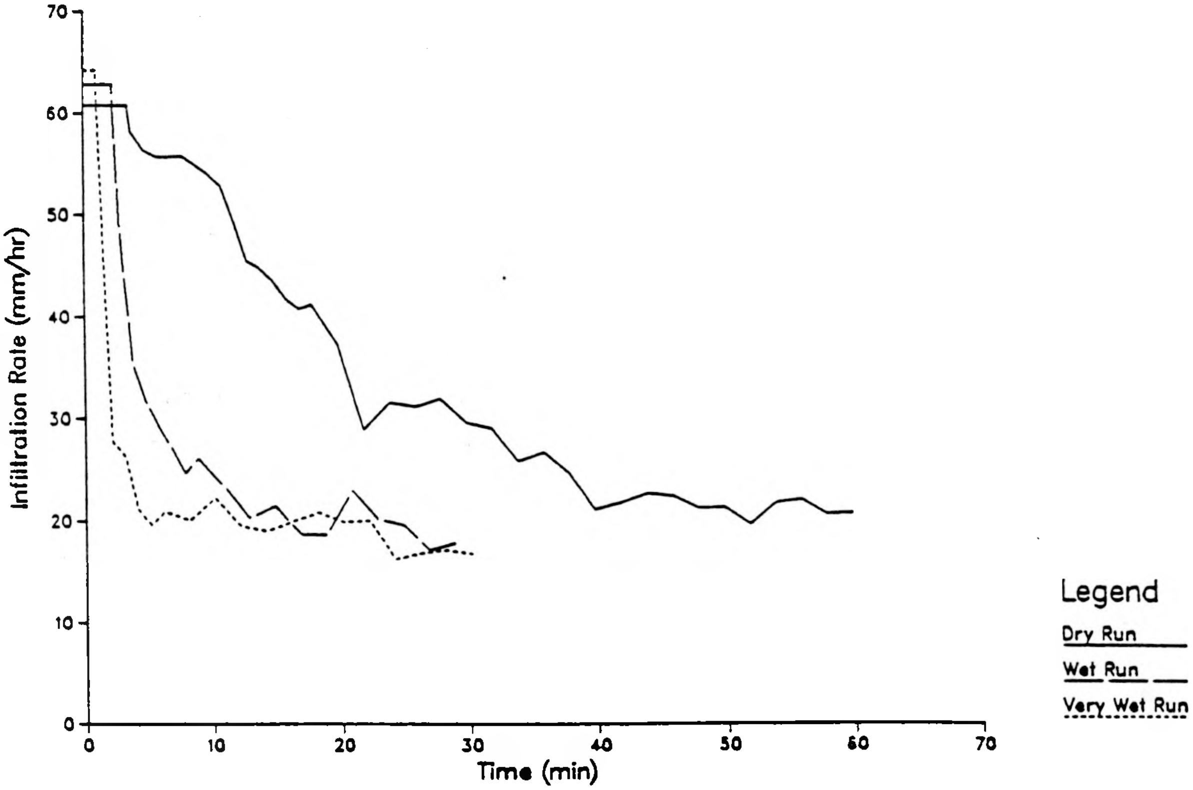
Plot #6 Streambank Wheatgrass June 1987.



Plot #6 Streambank Wheatgrass September 1987.

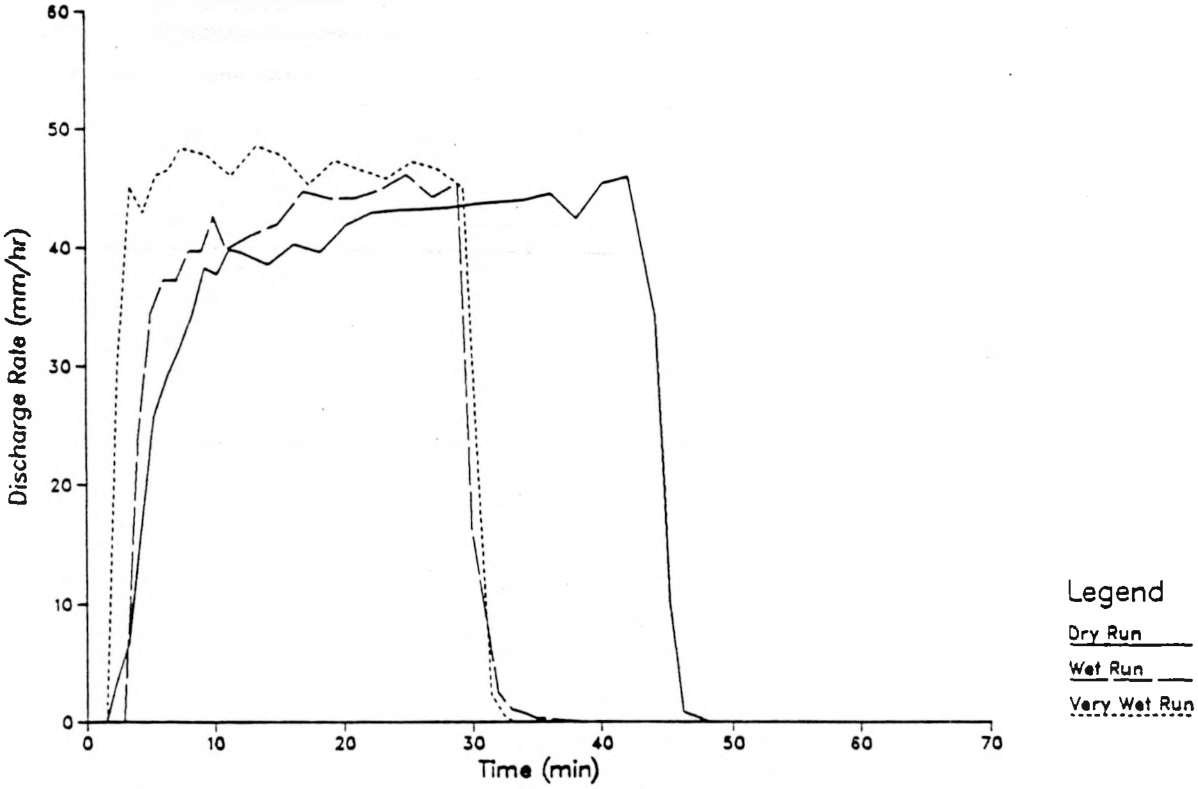


Plot #7 Bare Soil June 1987.

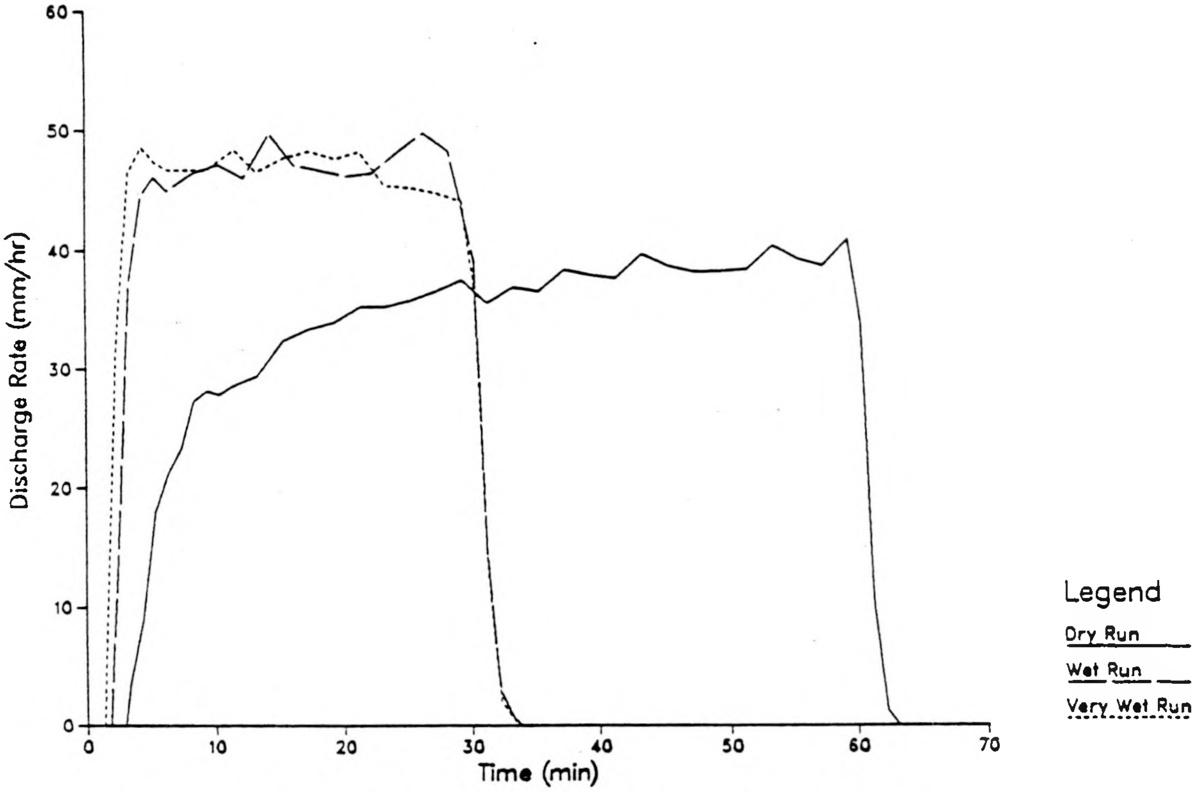


Plot #7 Bare Soil September 1987.

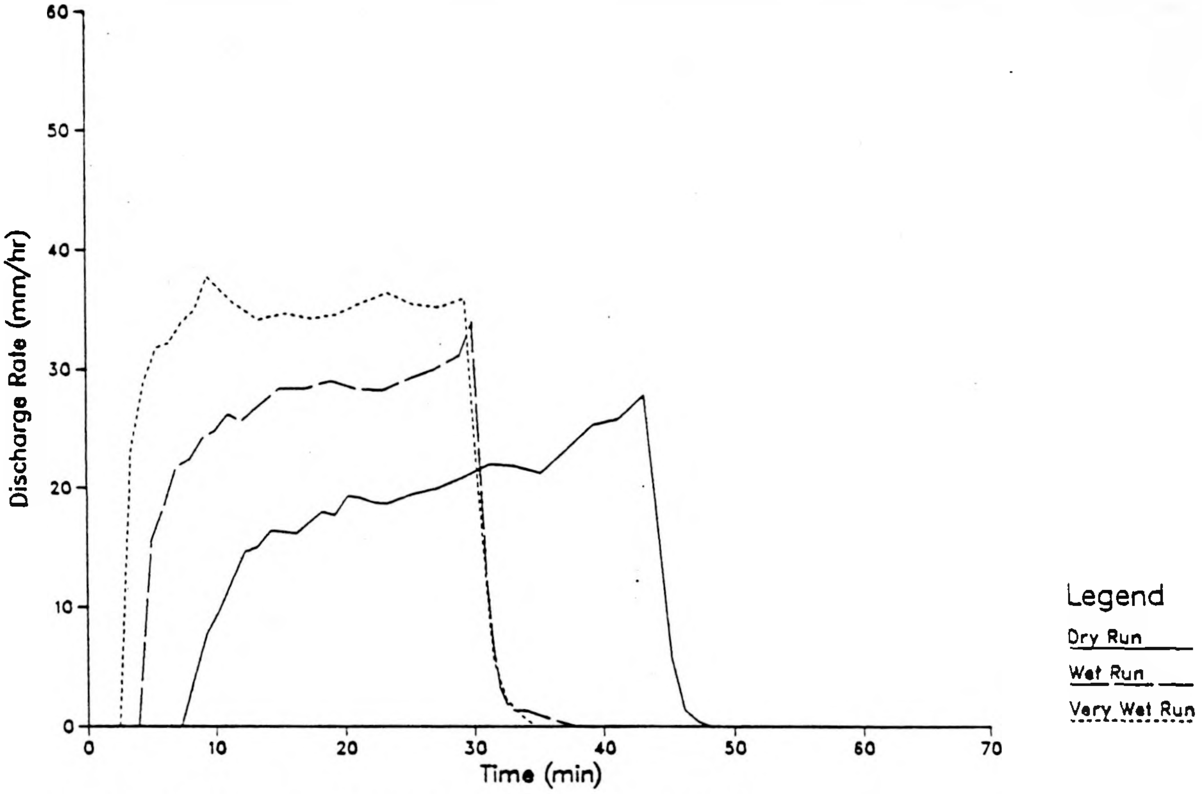
Appendix E. Discharge Rate Curves From 1987:



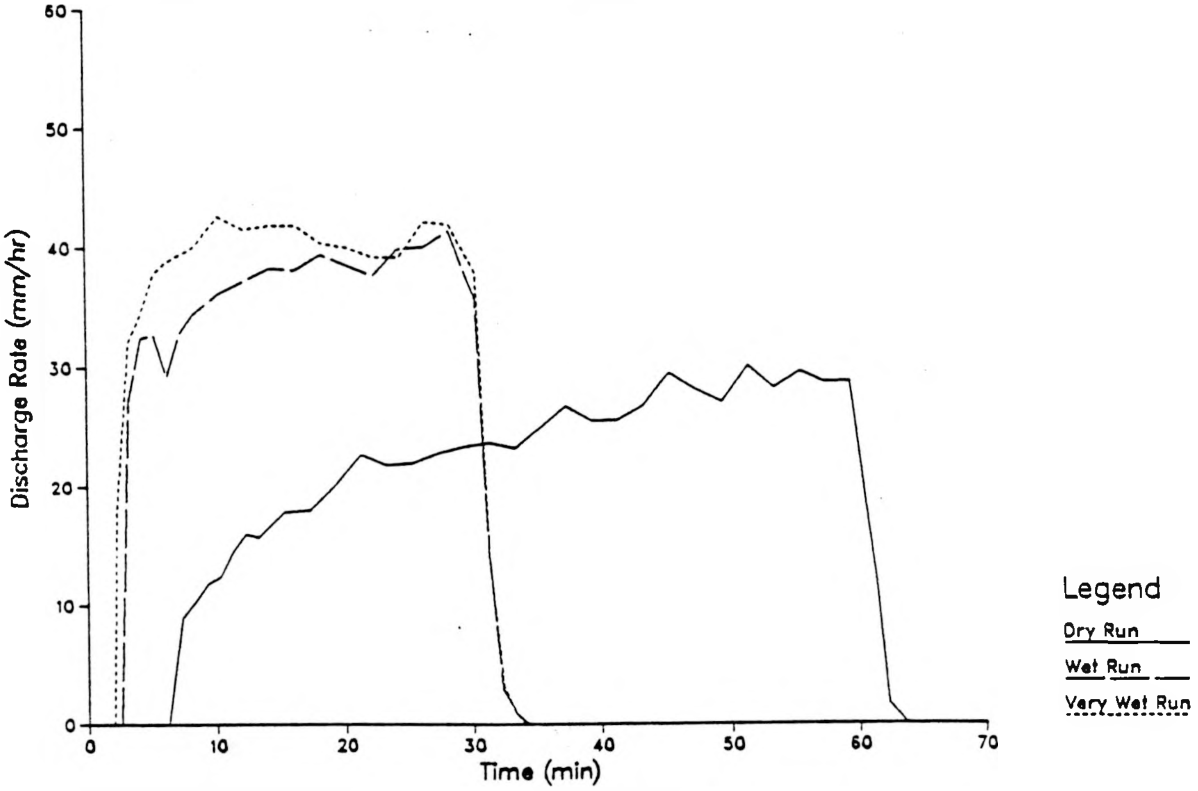
Plot #1 Streambank Wheatgrass June 1987.



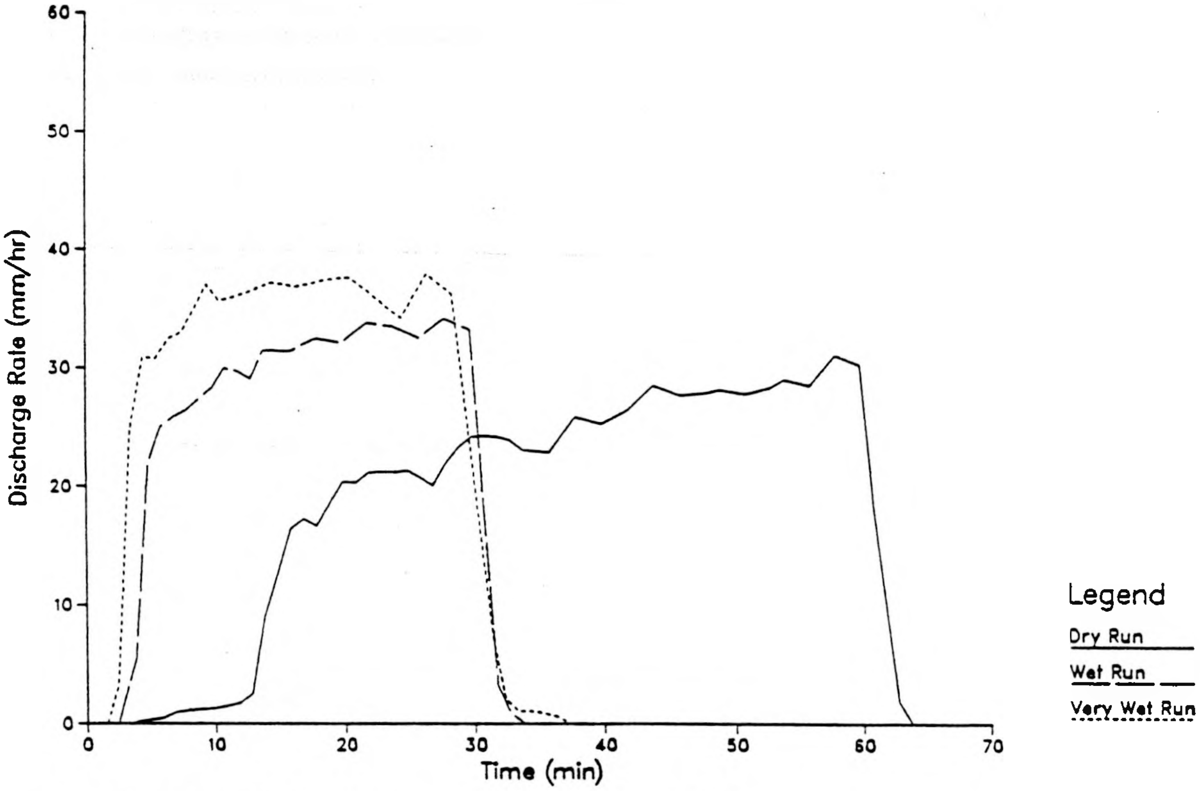
Plot #1 Streambank Wheatgrass September 1987.



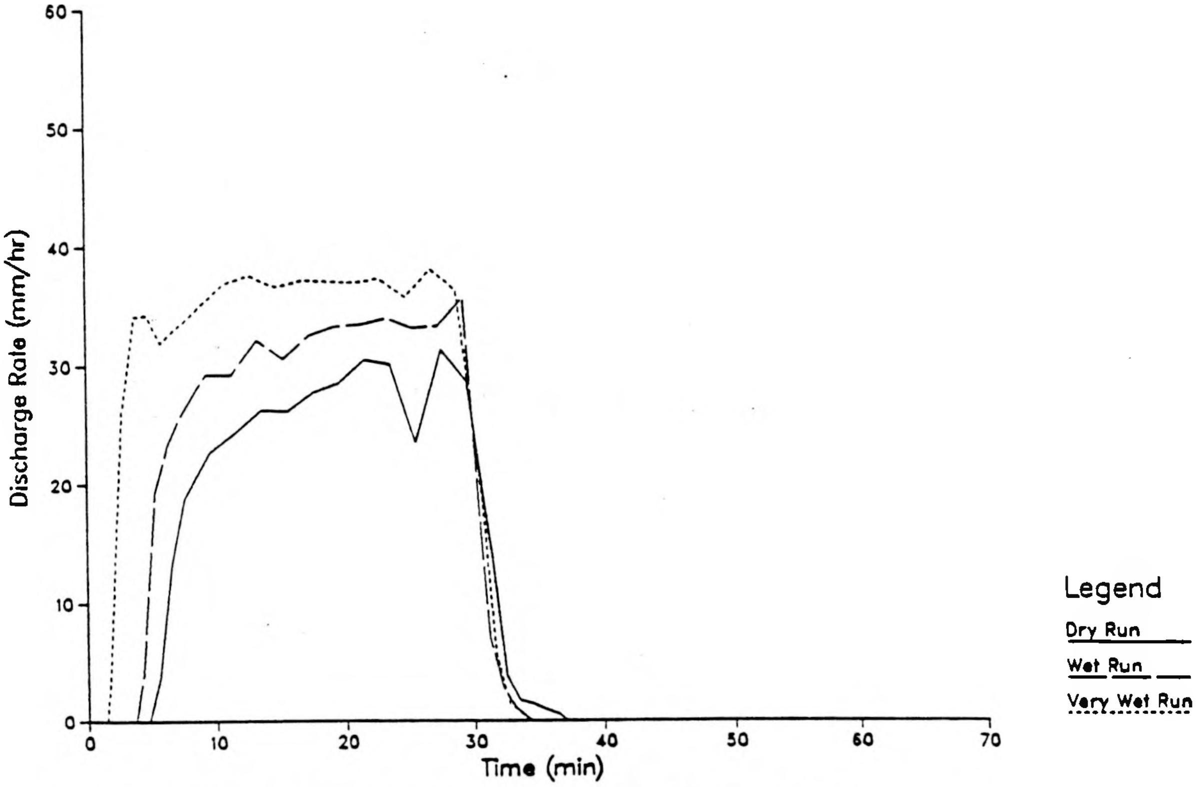
Plot #2 Crested Wheatgrass June 1987.



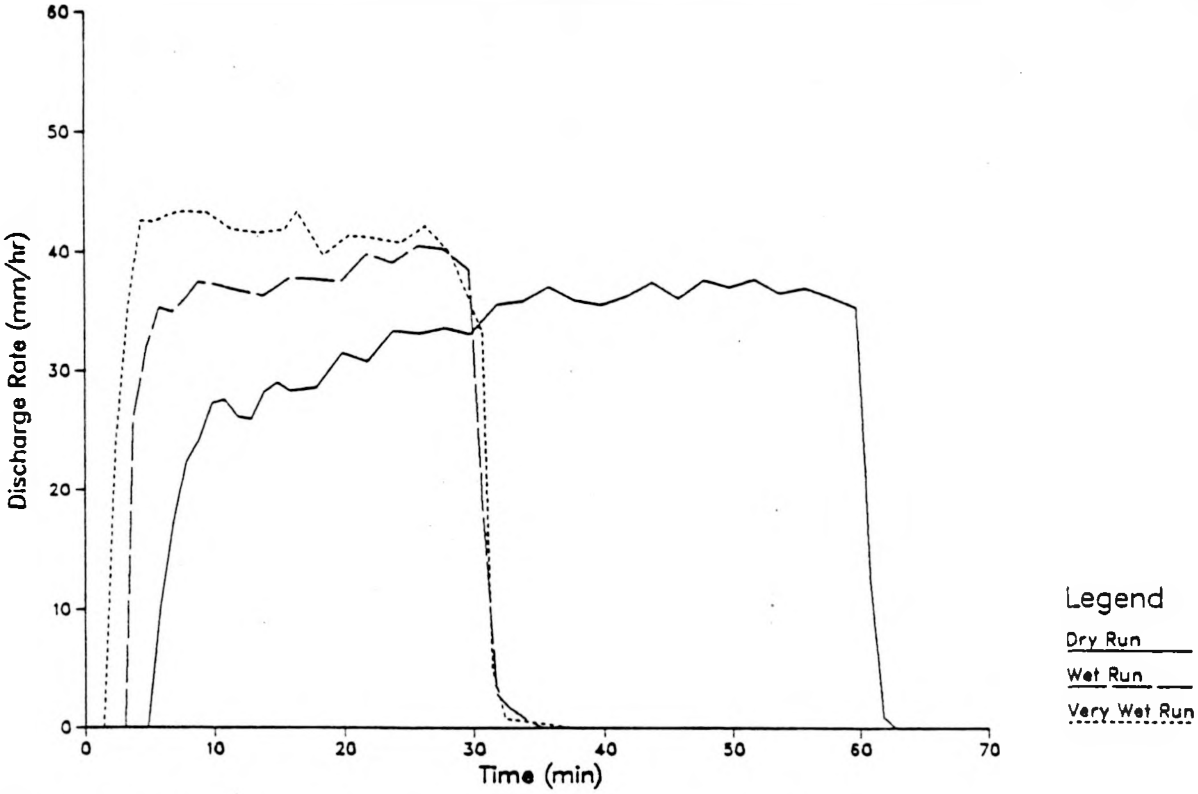
Plot #2 Crested Wheatgrass September 1987.



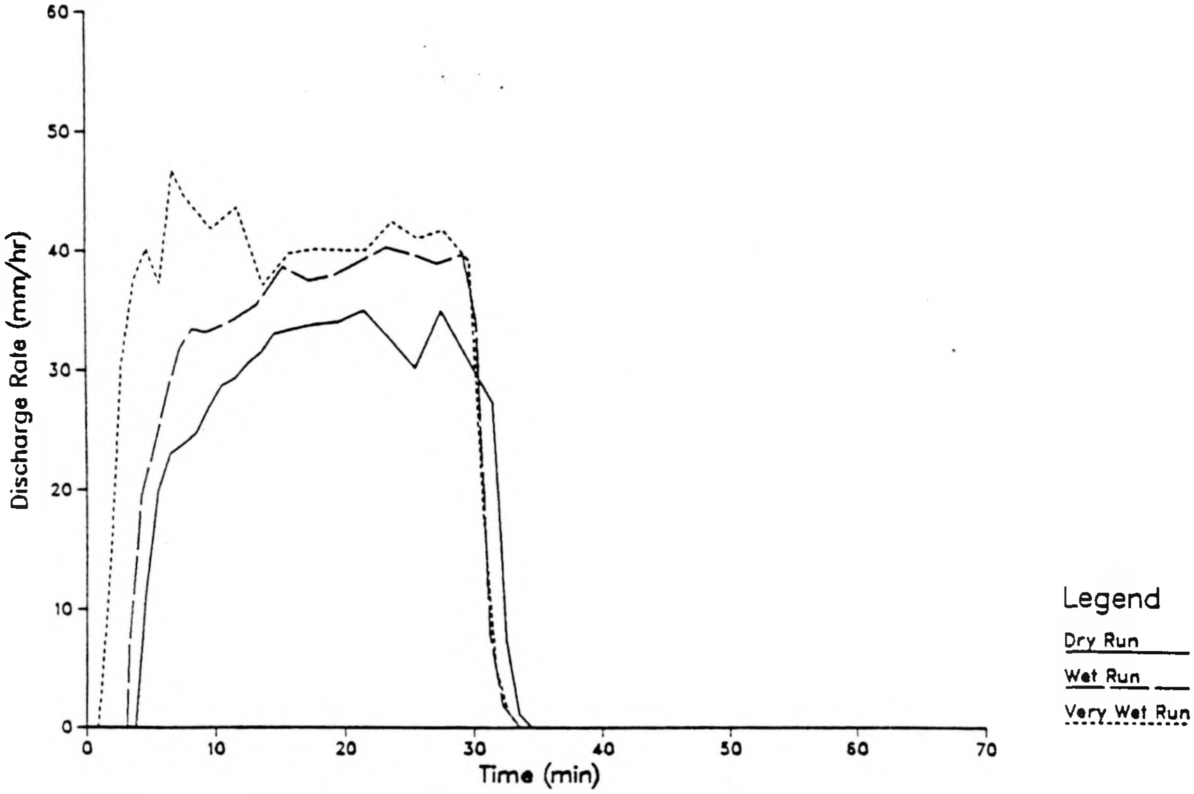
Plot #3 Crested Wheatgrass June 1987.



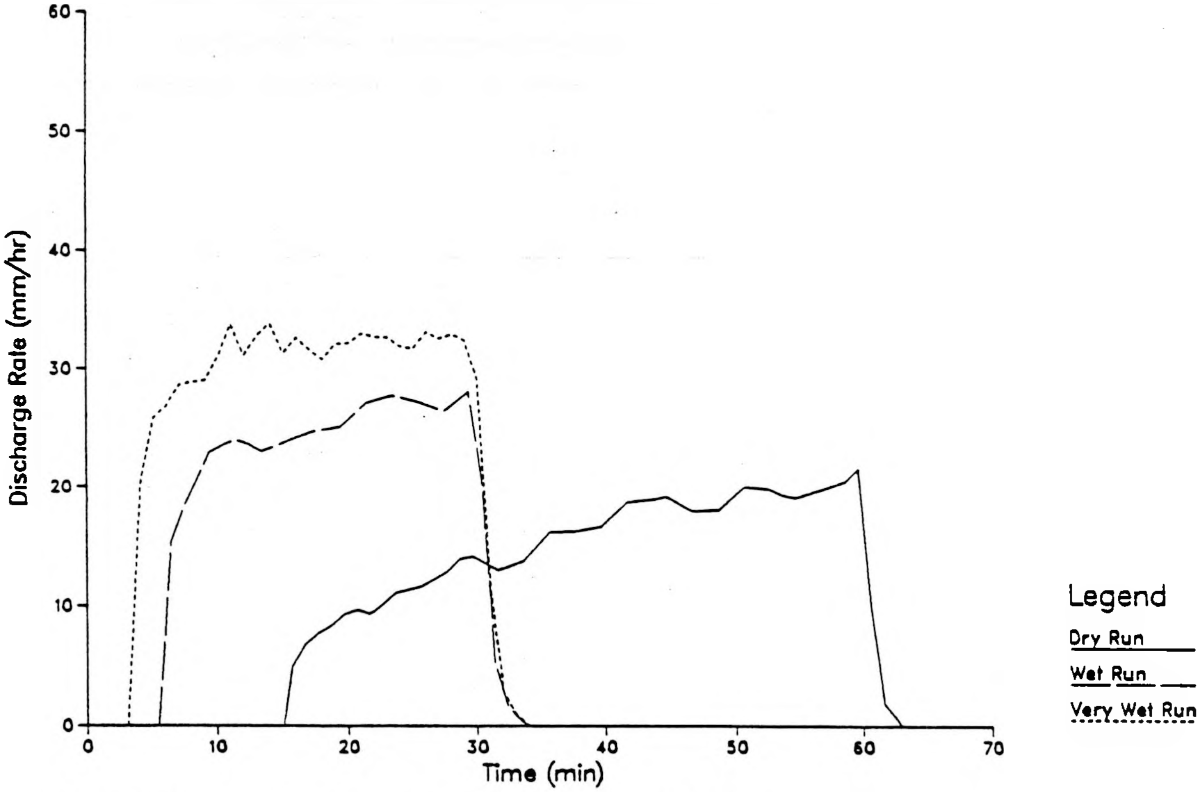
Plot #3 Crested Wheatgrass September 1987.



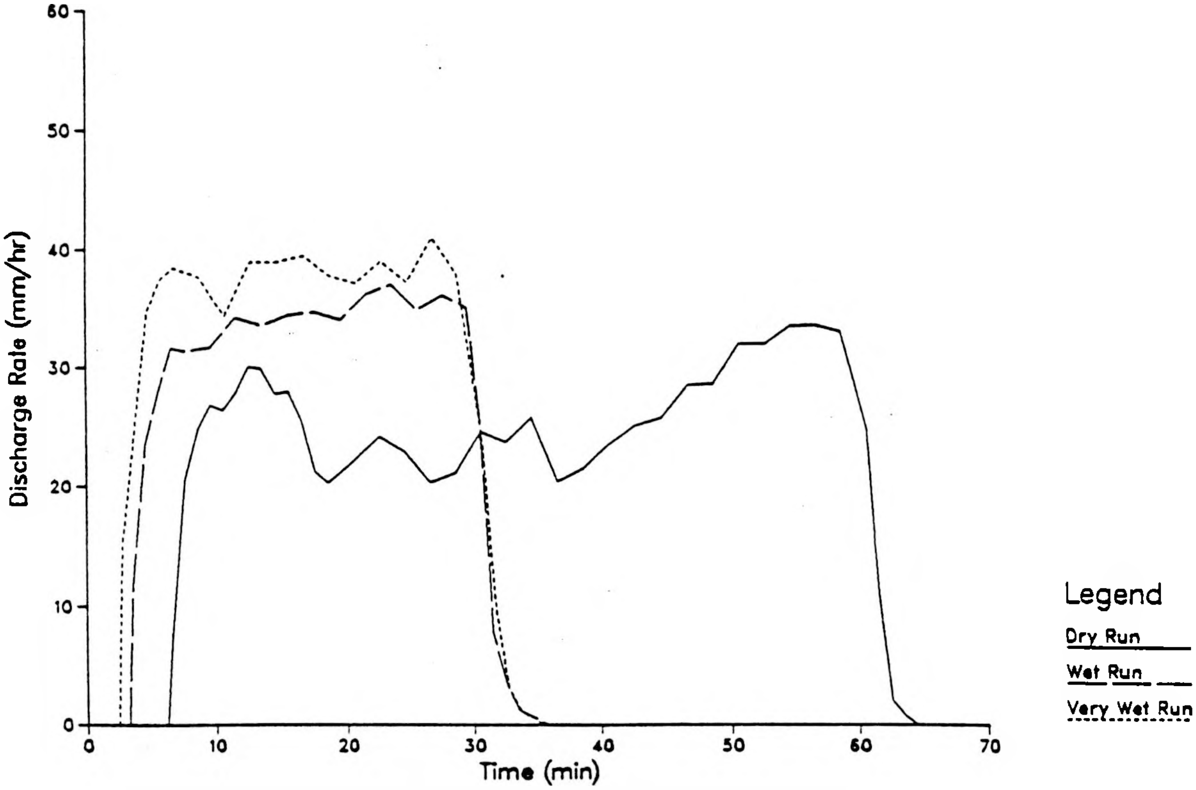
Plot #4 Streambank Wheatgrass June 1987.



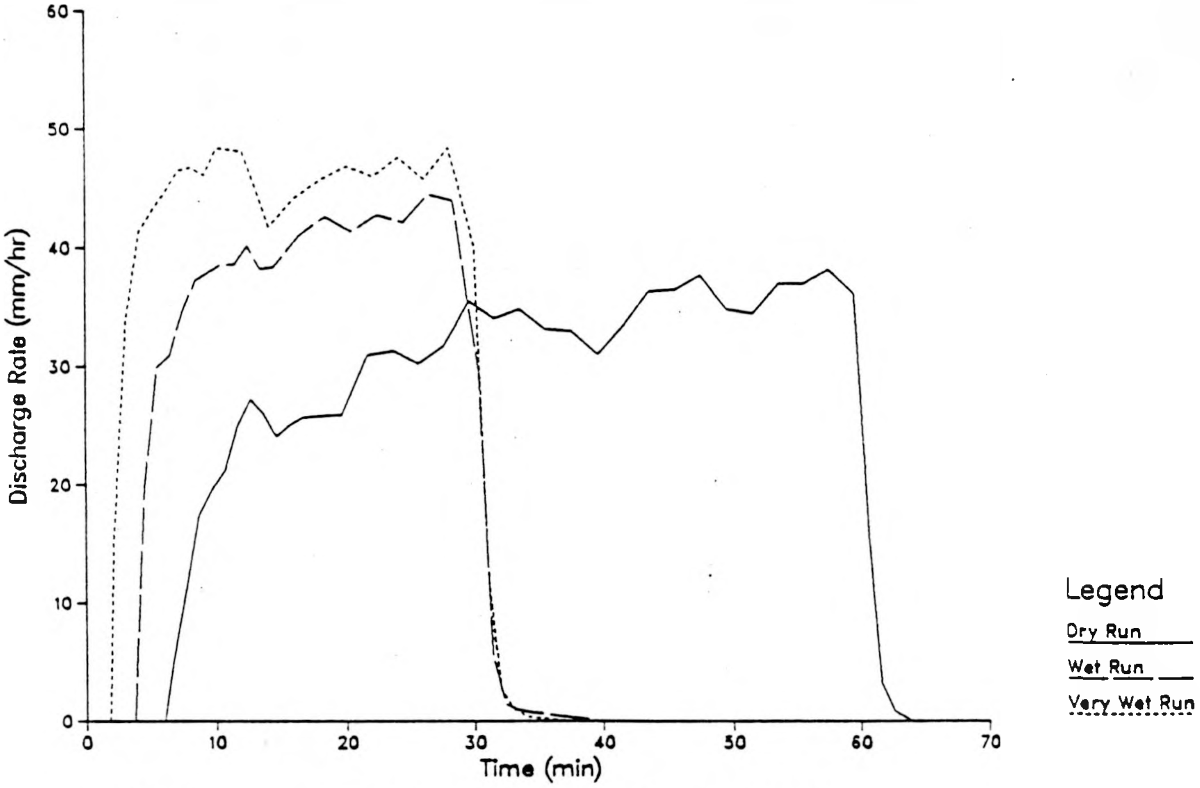
Plot #4 Streambank Wheatgrass September 1987.



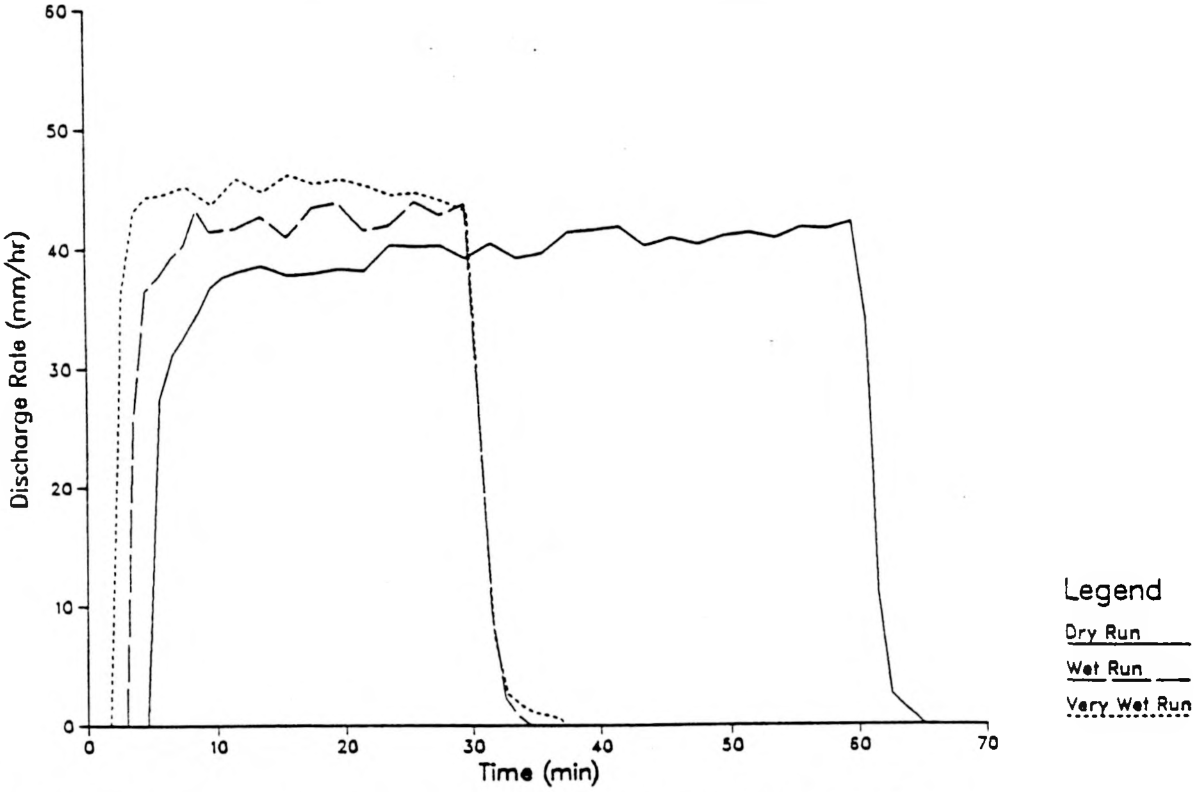
Plot #5 Crested Wheatgrass June 1987.



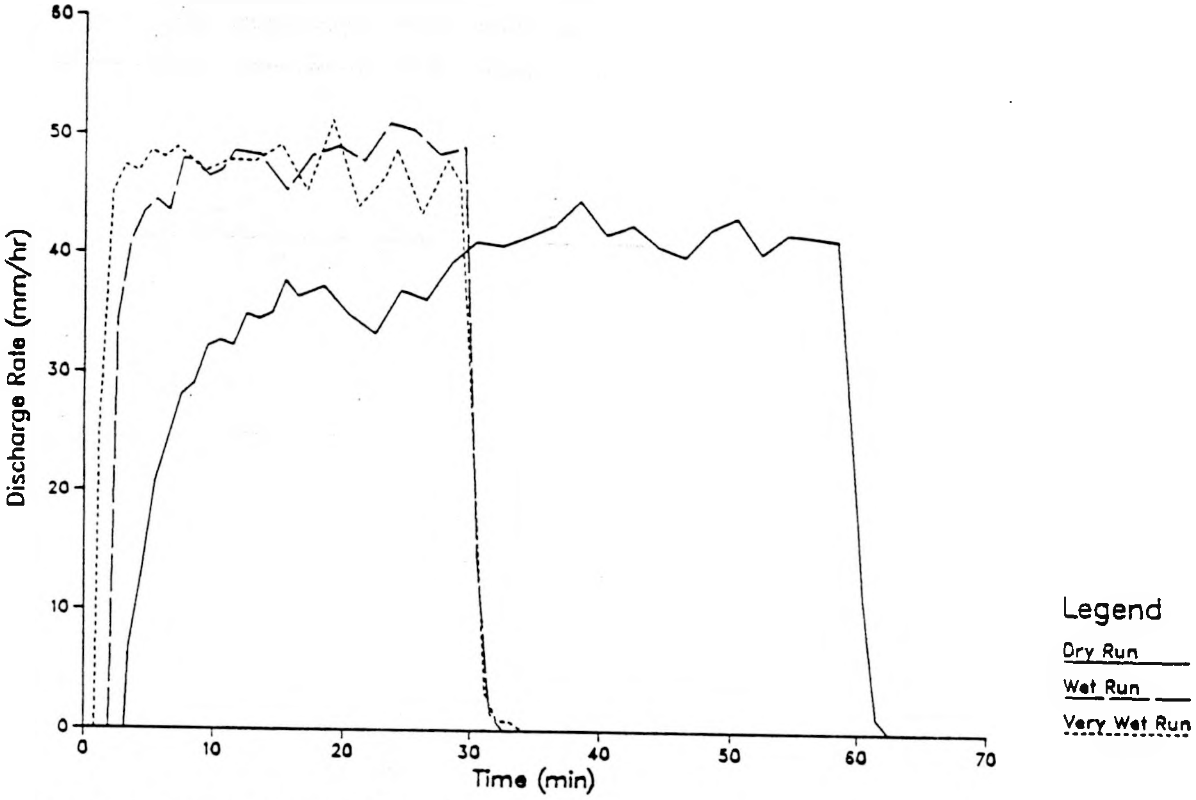
Plot #5 Crested Wheatgrass September 1987.



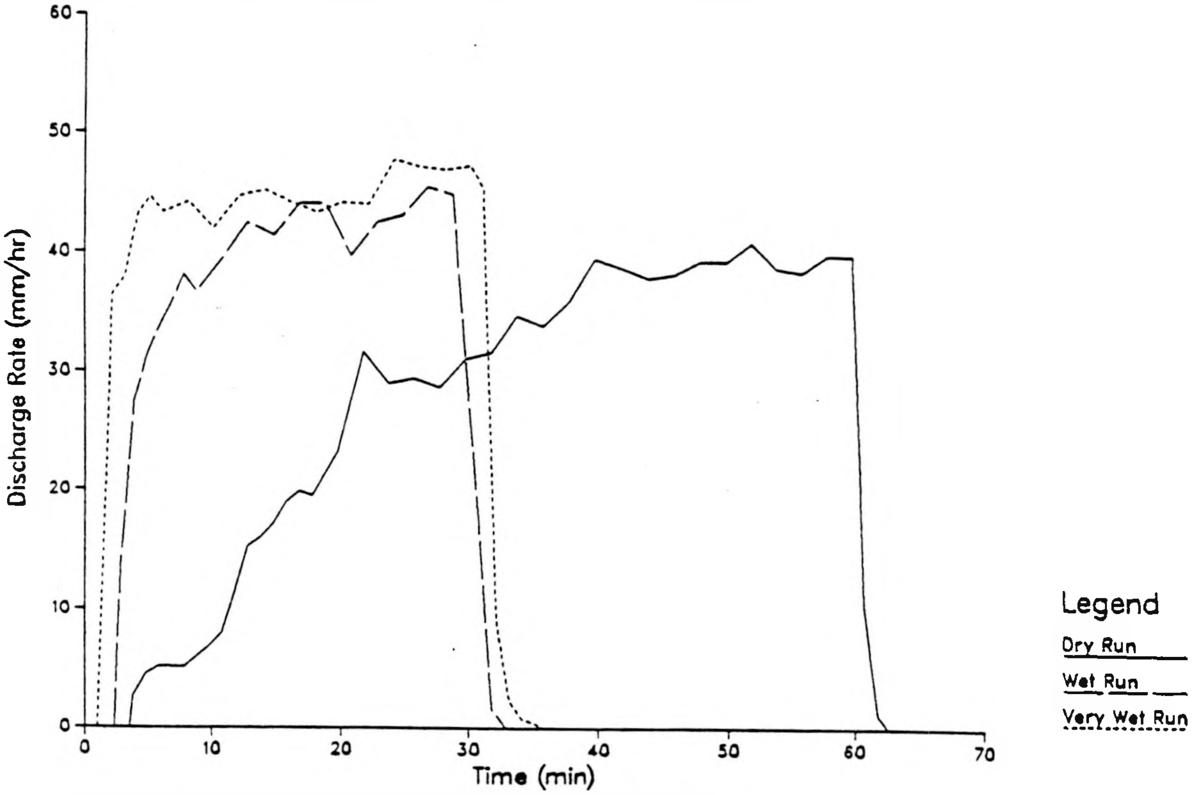
Plot #6 Streambank Wheatgrasss June 1987.



Plot #6 Streambank Wheatgrass September 1987.

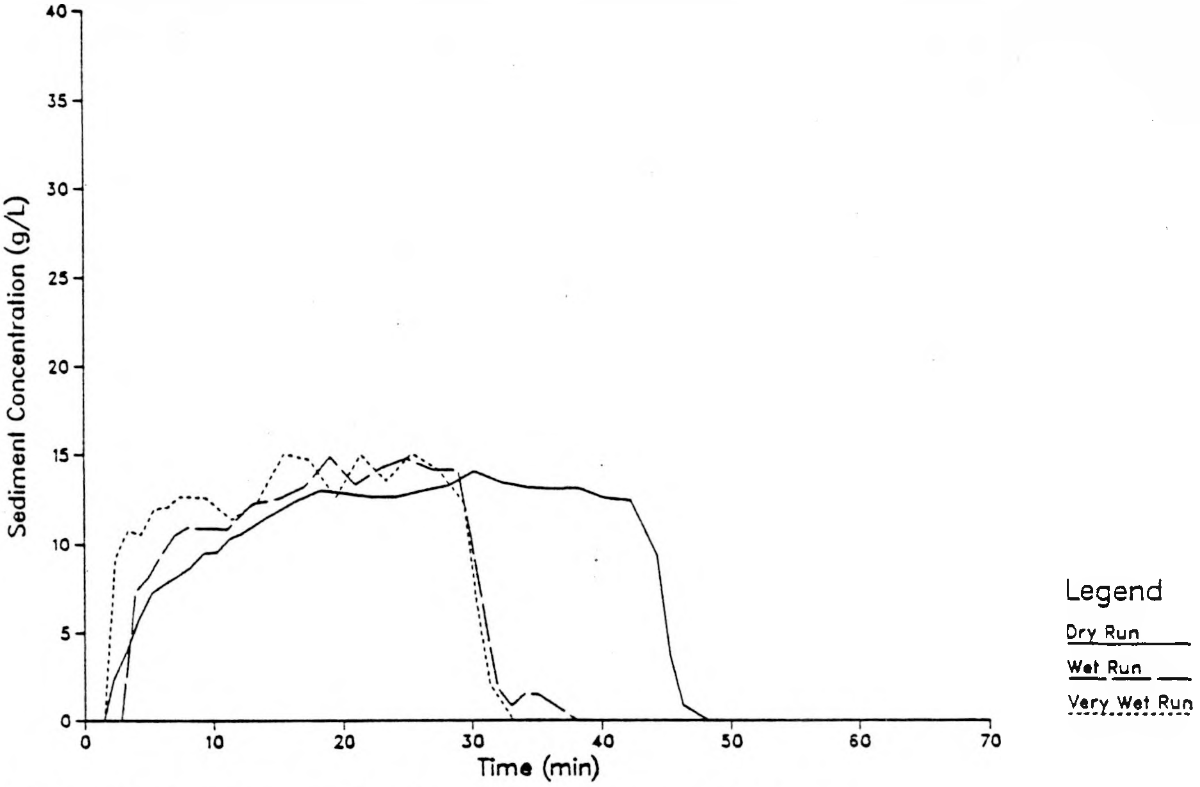


Plot #7 Bare Soil June 1987.

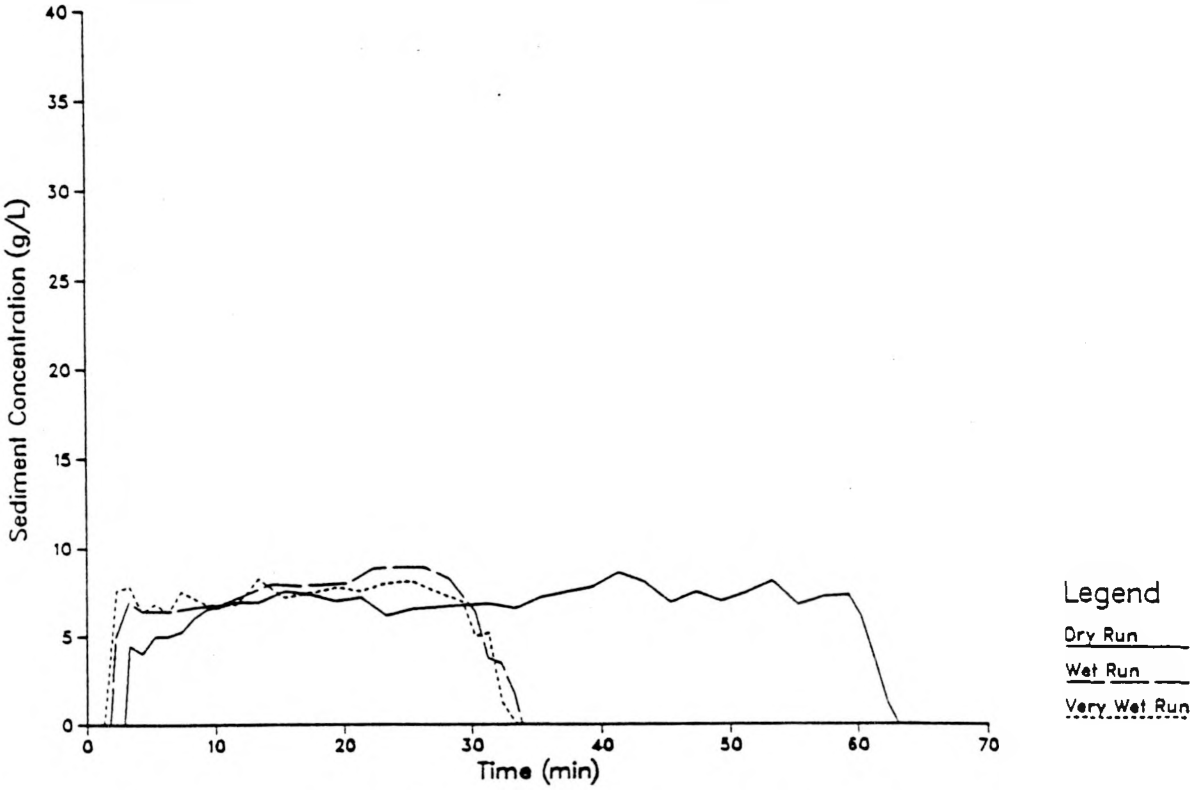


Plot #7 Bare Soil September 1987.

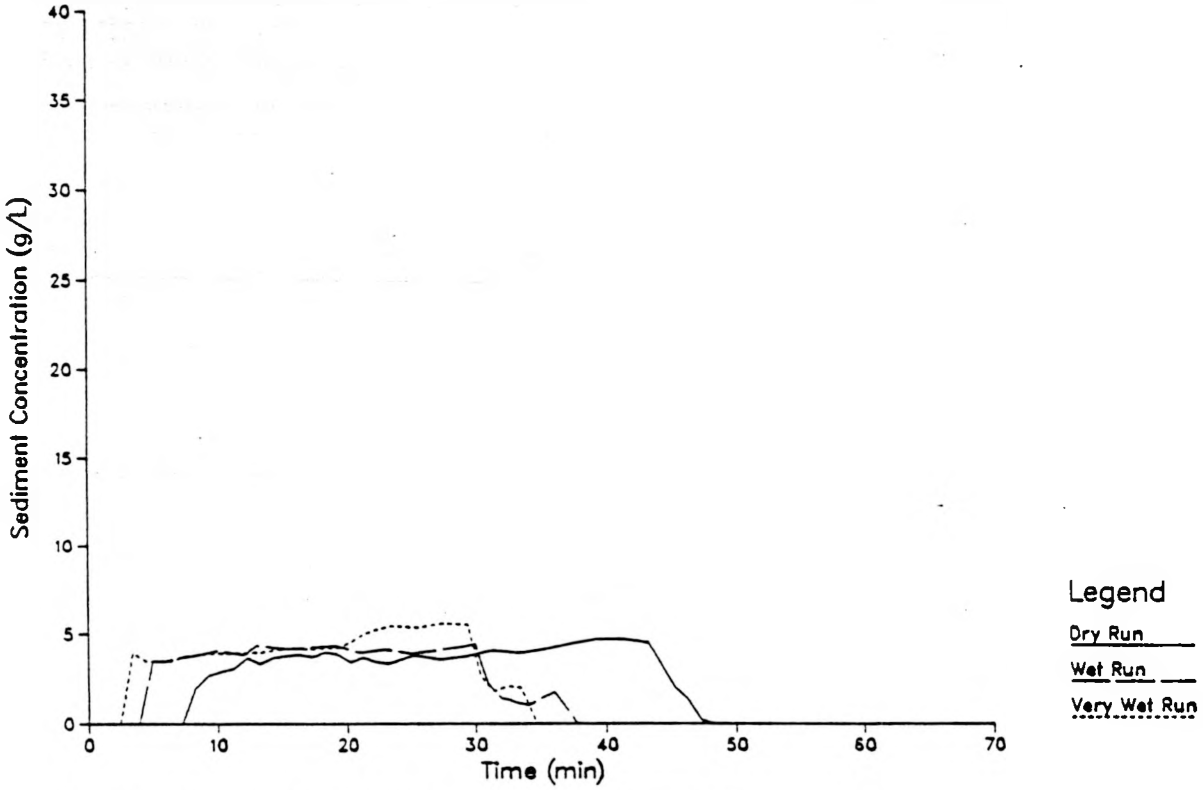
Appendix F. Sediment Concentration Curves From 1987:



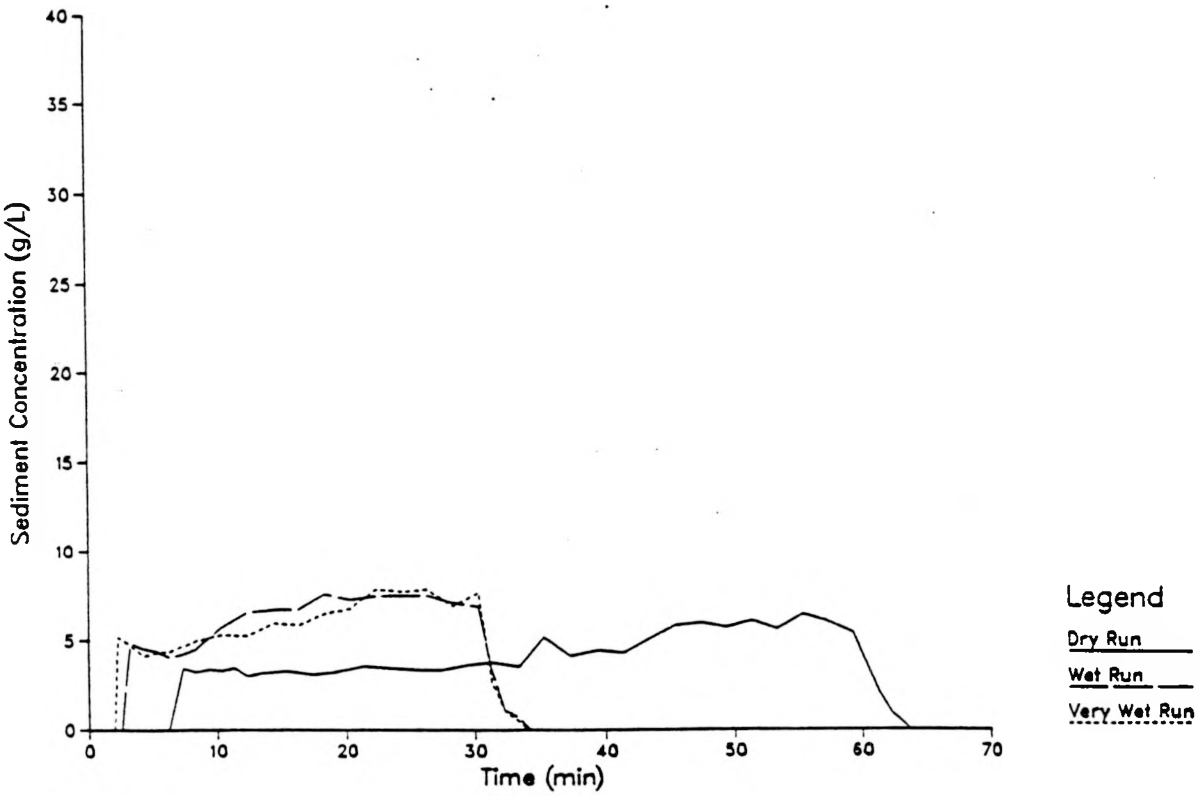
Plot #1 Streambank Wheatgrass June 1987.



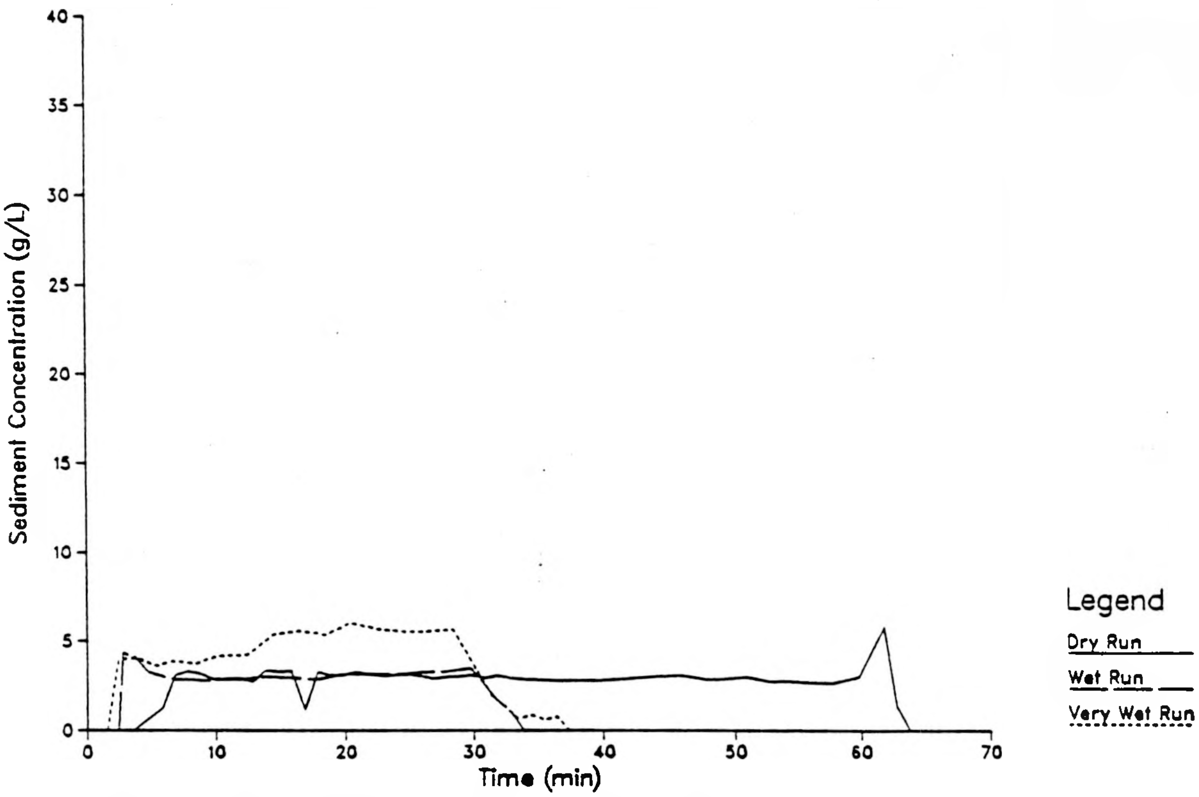
Plot #1 Streambank Wheatgrass September 1987.



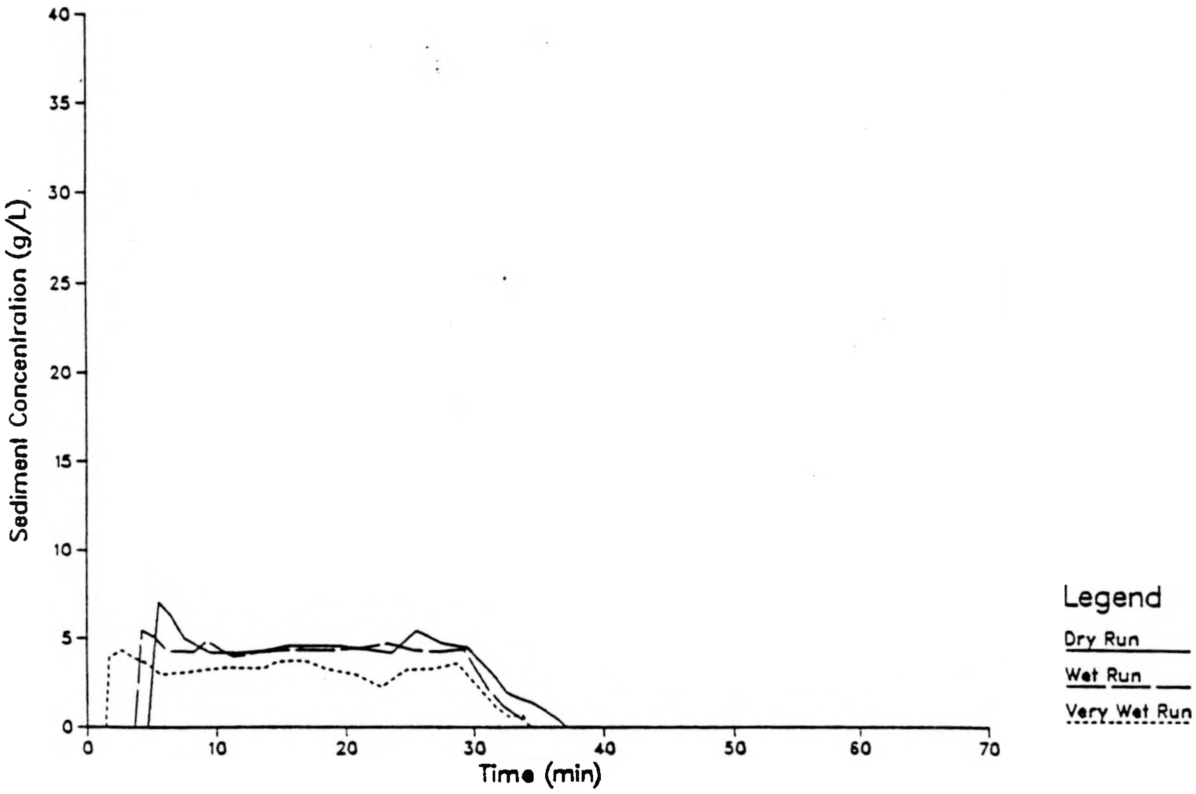
Plot #2 Crested Wheatgrass June 1987.



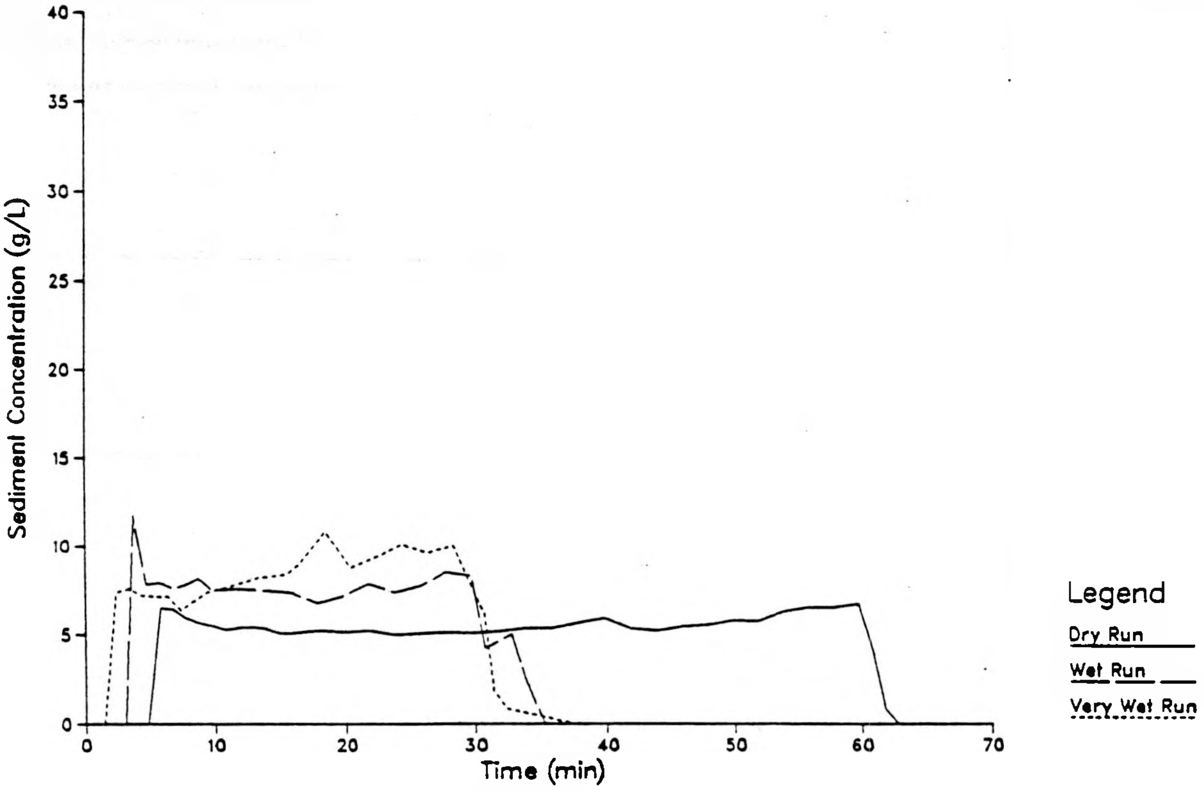
Plot #2 Crested Wheatgrass September 1987.



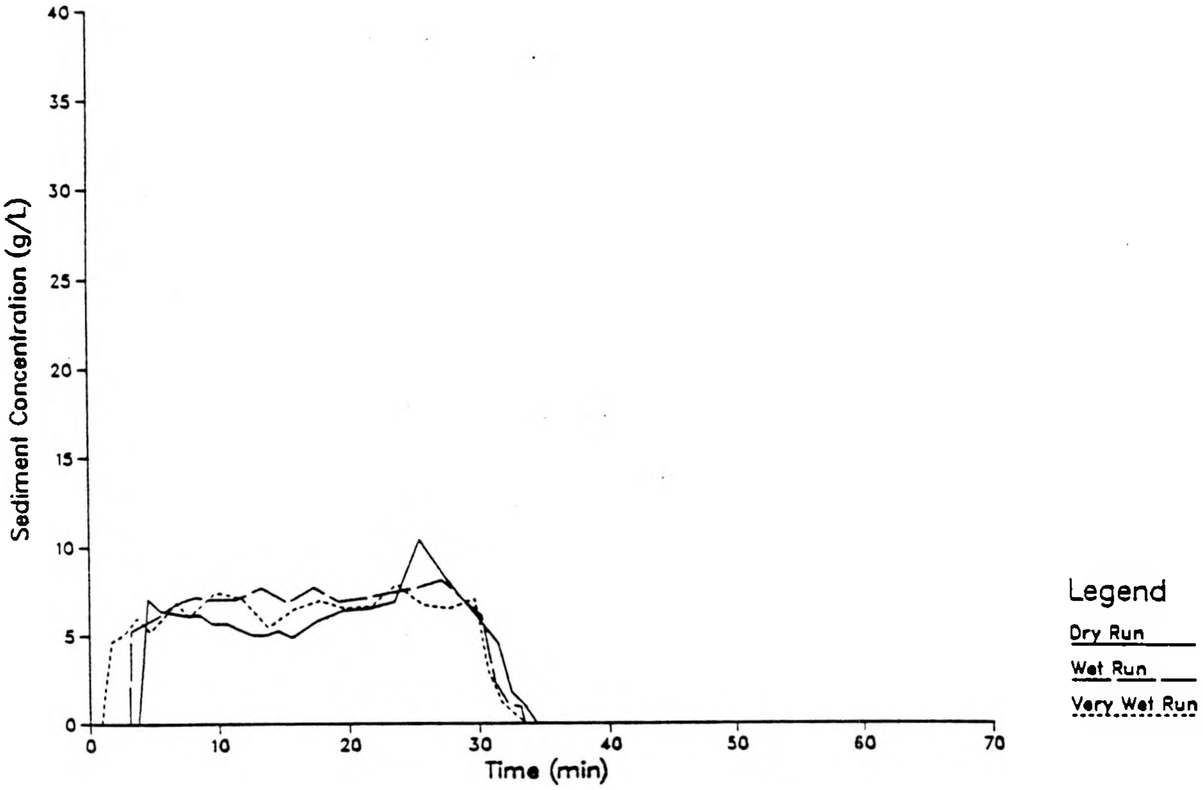
Plot #3 Crested Wheatgrass June 1987.



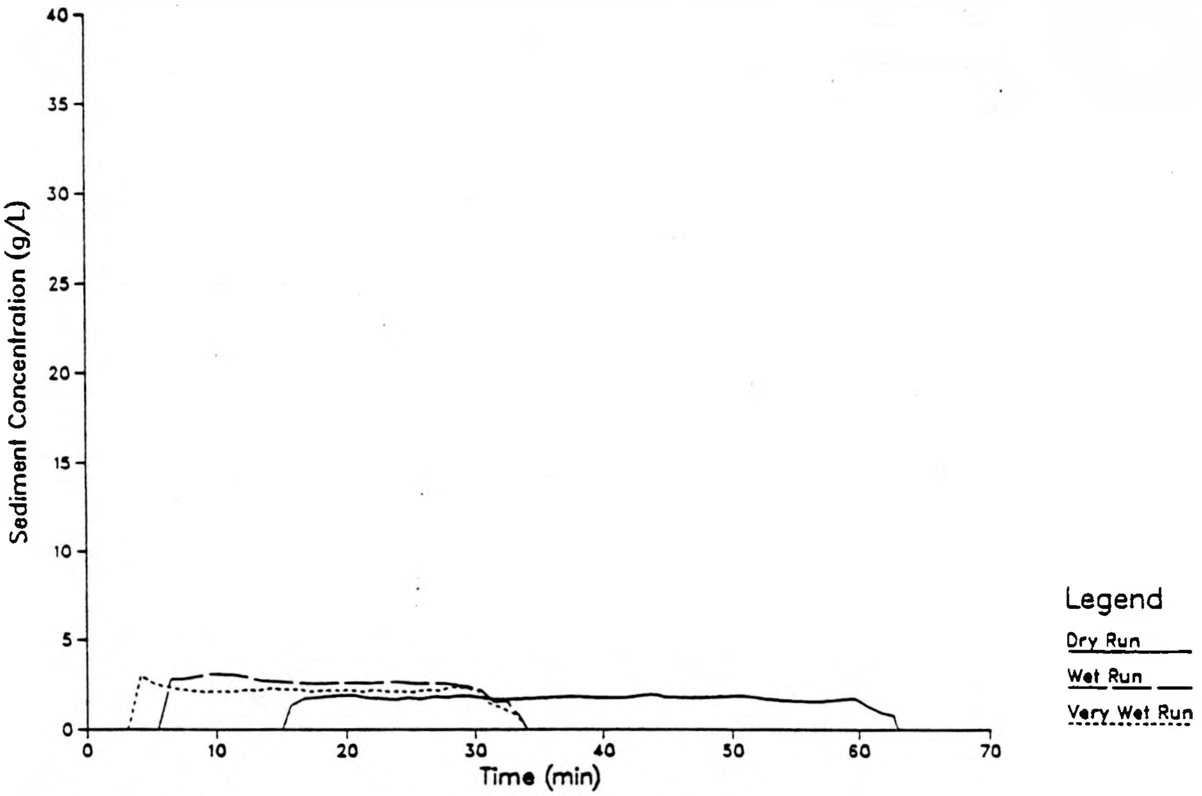
Plot #3 Crested Wheatgrass September 1987.



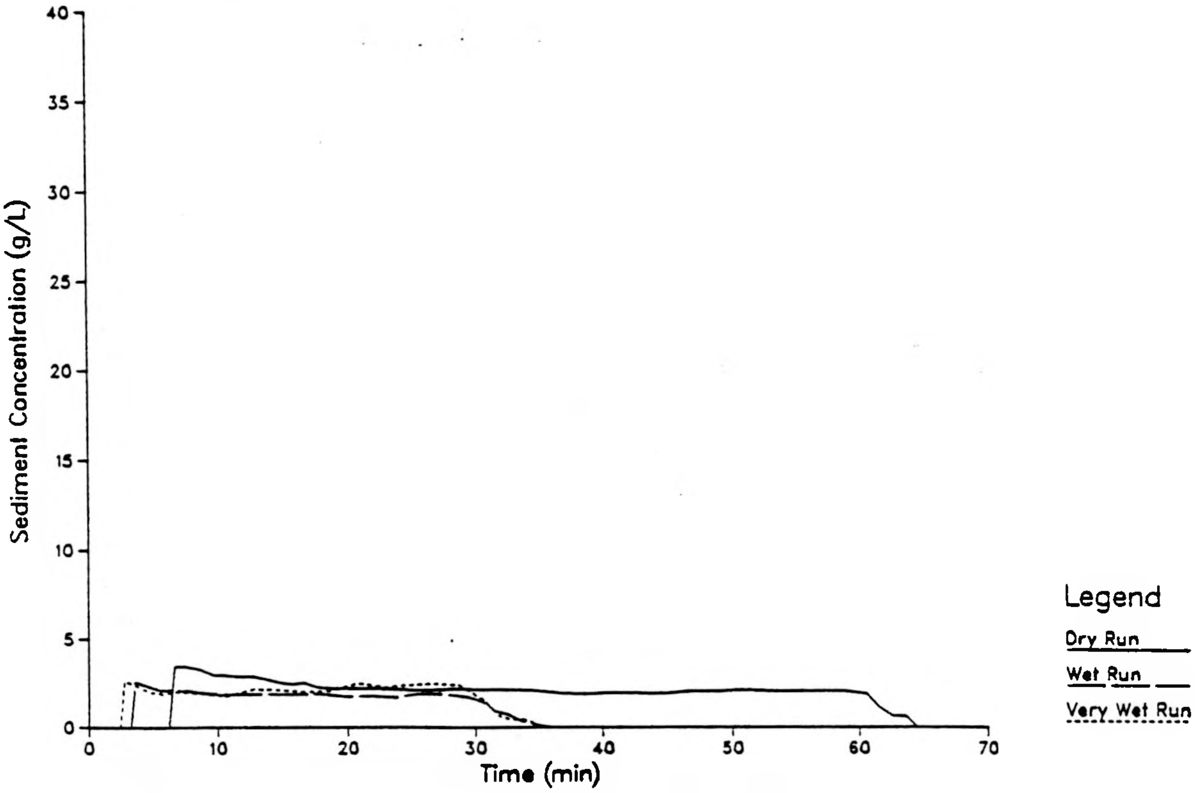
Plot #4 Streambank Wheatgrass June 1987.



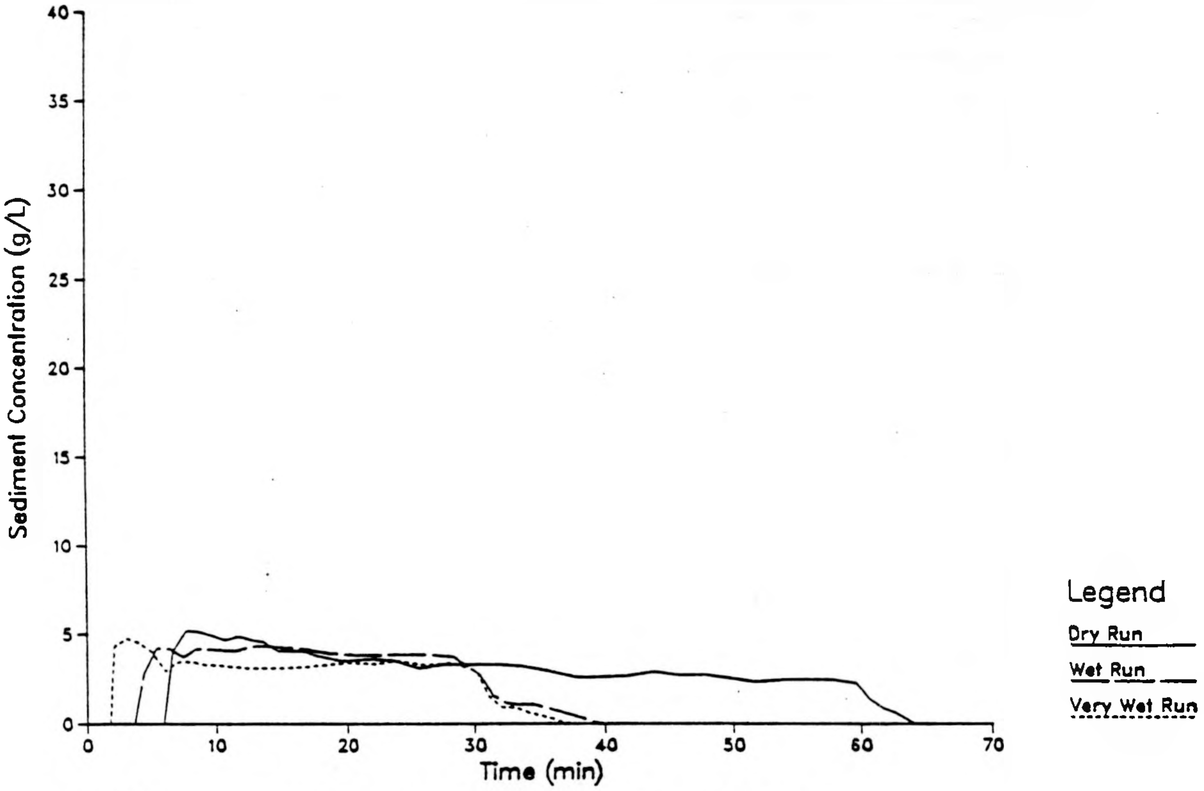
Plot #4 Streambank Wheatgrass September 1987.



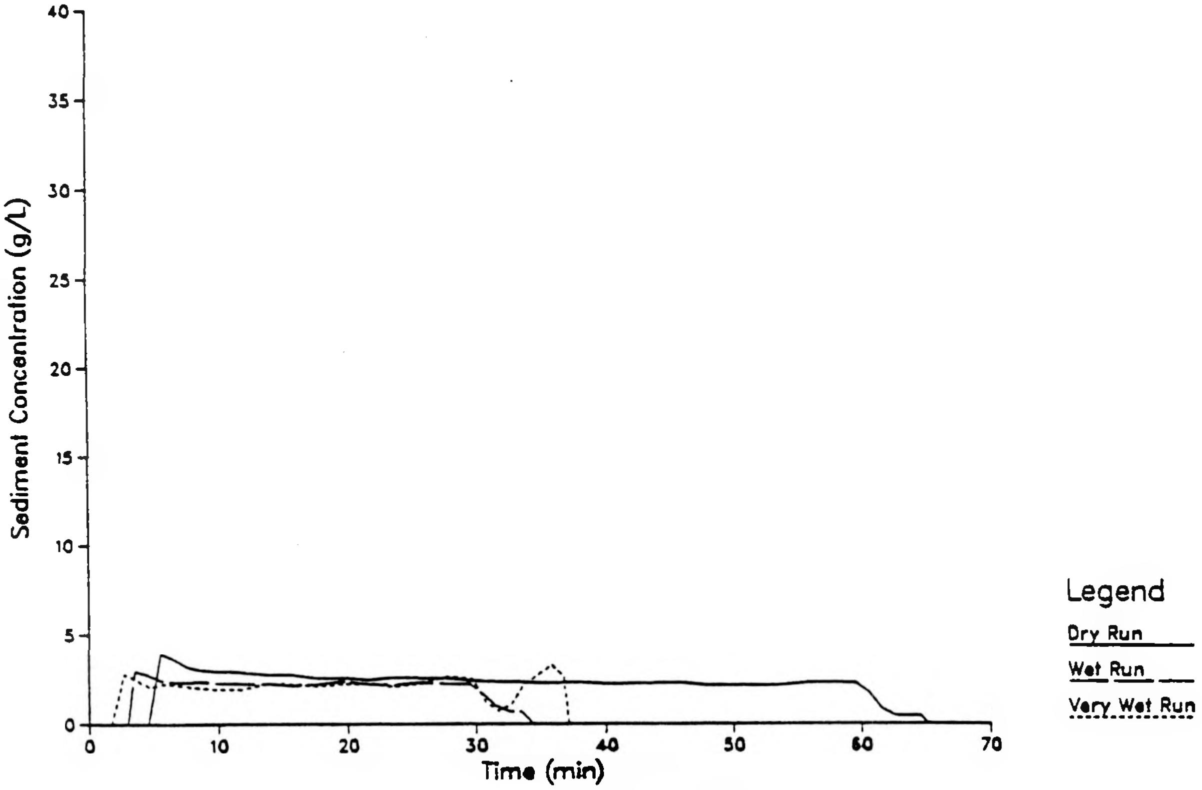
Plot #5 Crested Wheatgrass June 1987.



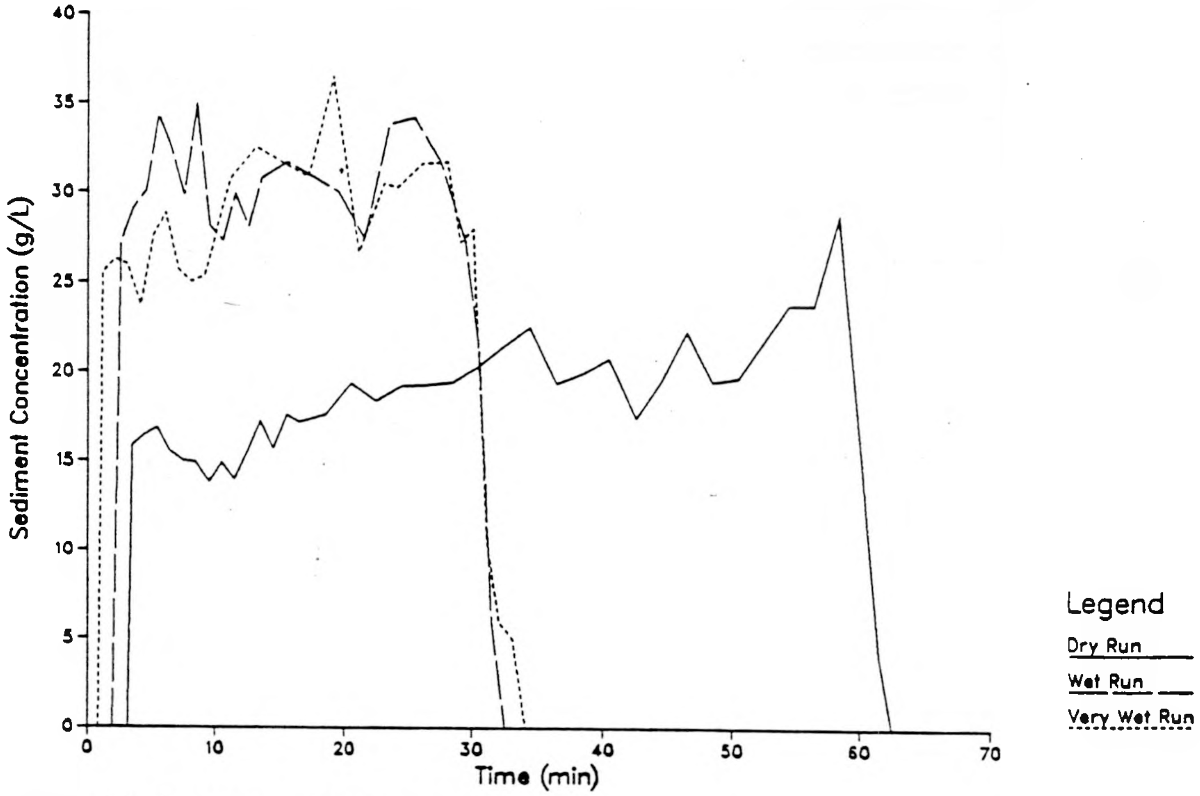
Plot #5 Crested Wheatgrass September 1987.



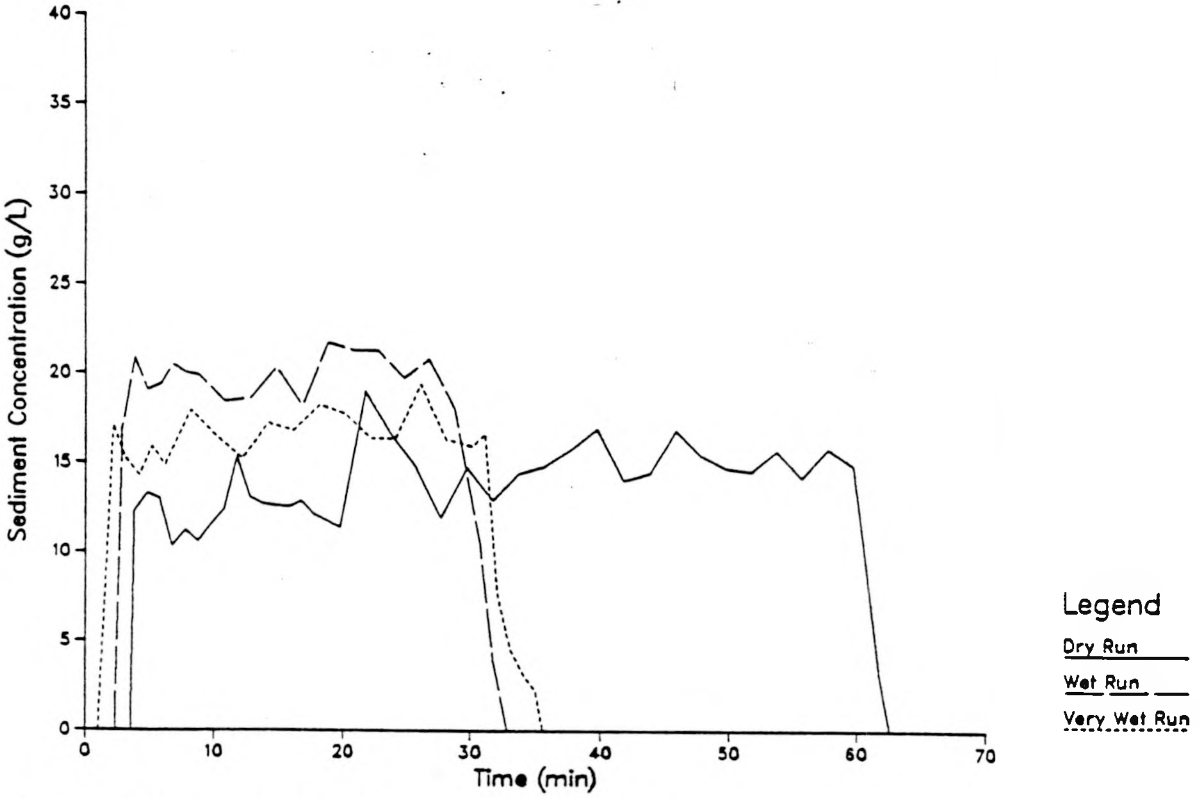
Plot #6 Streambank Wheatgrass June 1987.



Plot #6 Streambank Wheatgrass September 1987.

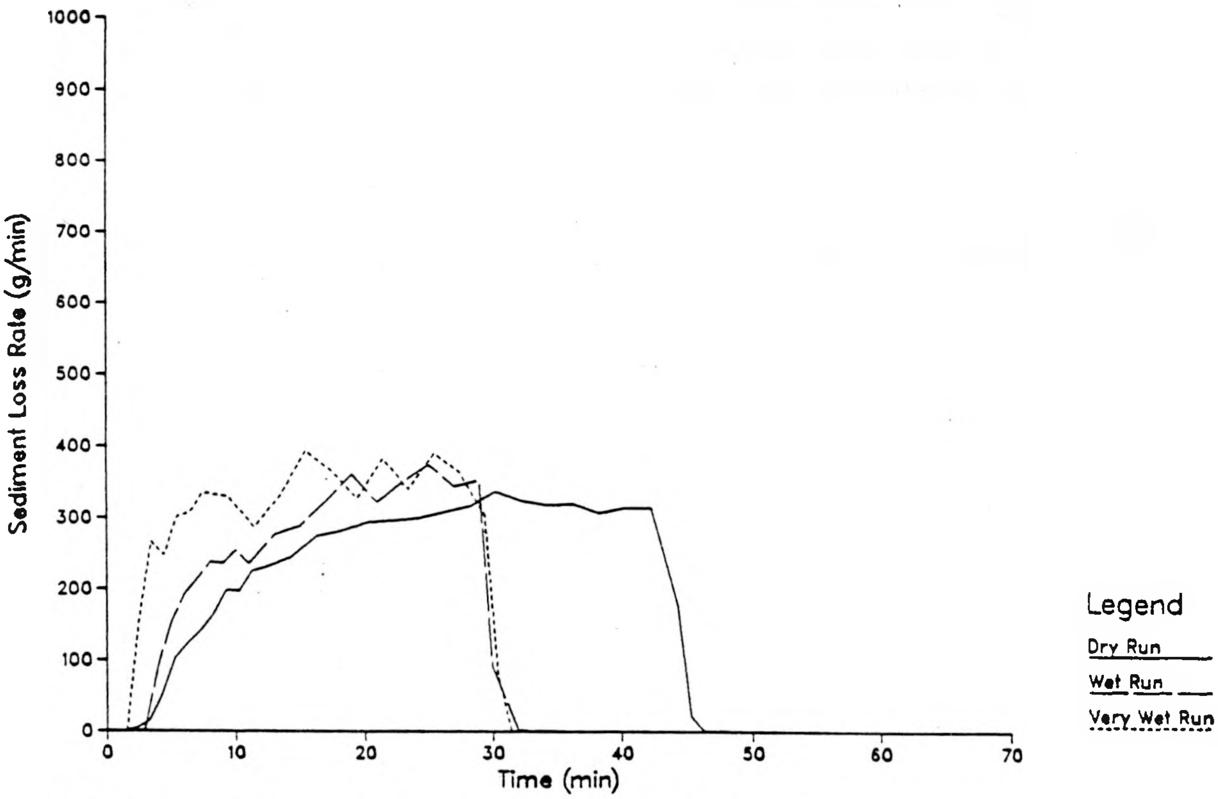


Plot #7 Bare Soil June 1987.

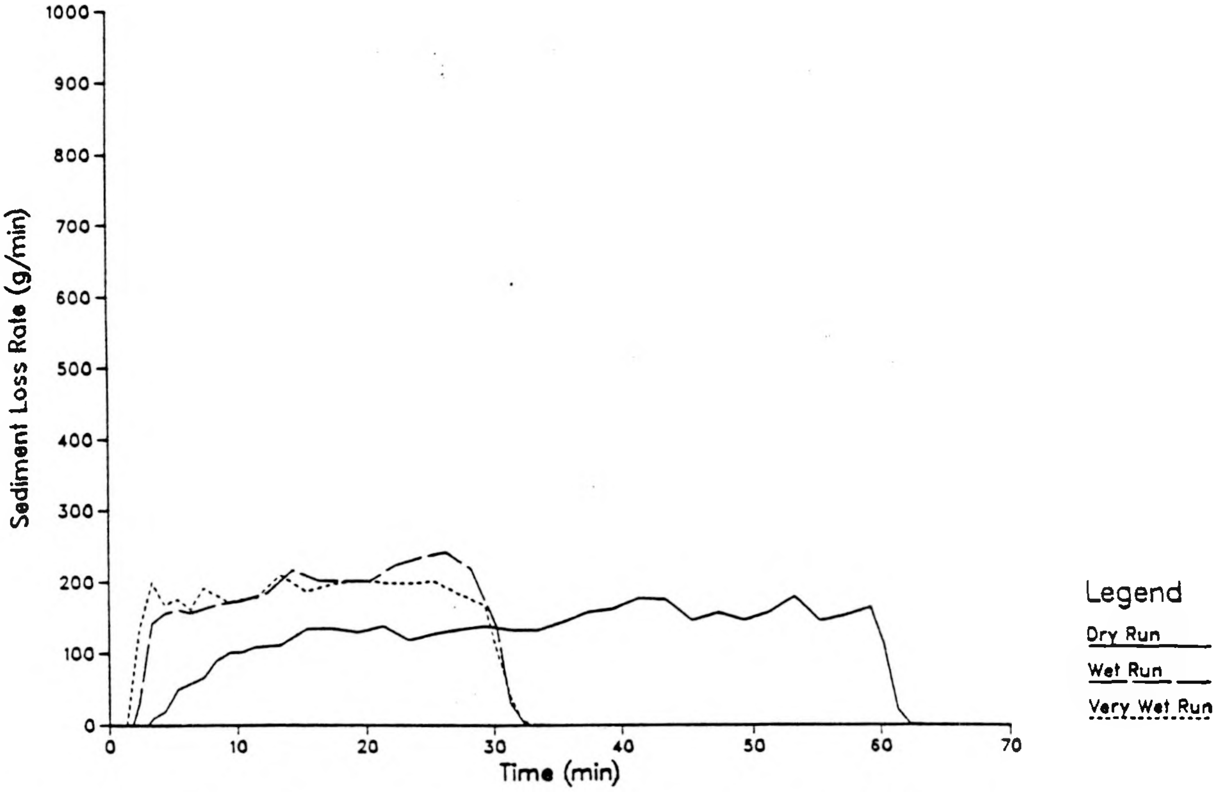


Plot #7 Bare Soil September 1987.

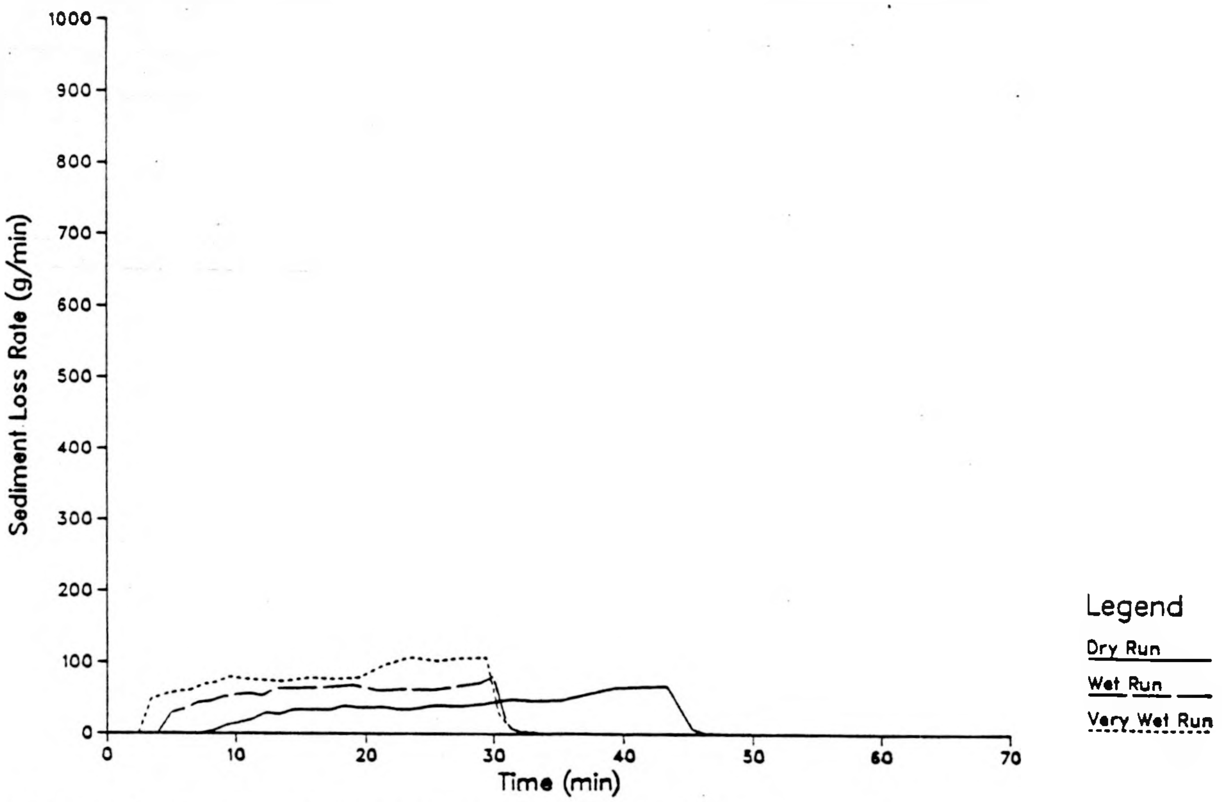
Appendix G. Sediment Loss Rate Curves From 1987:



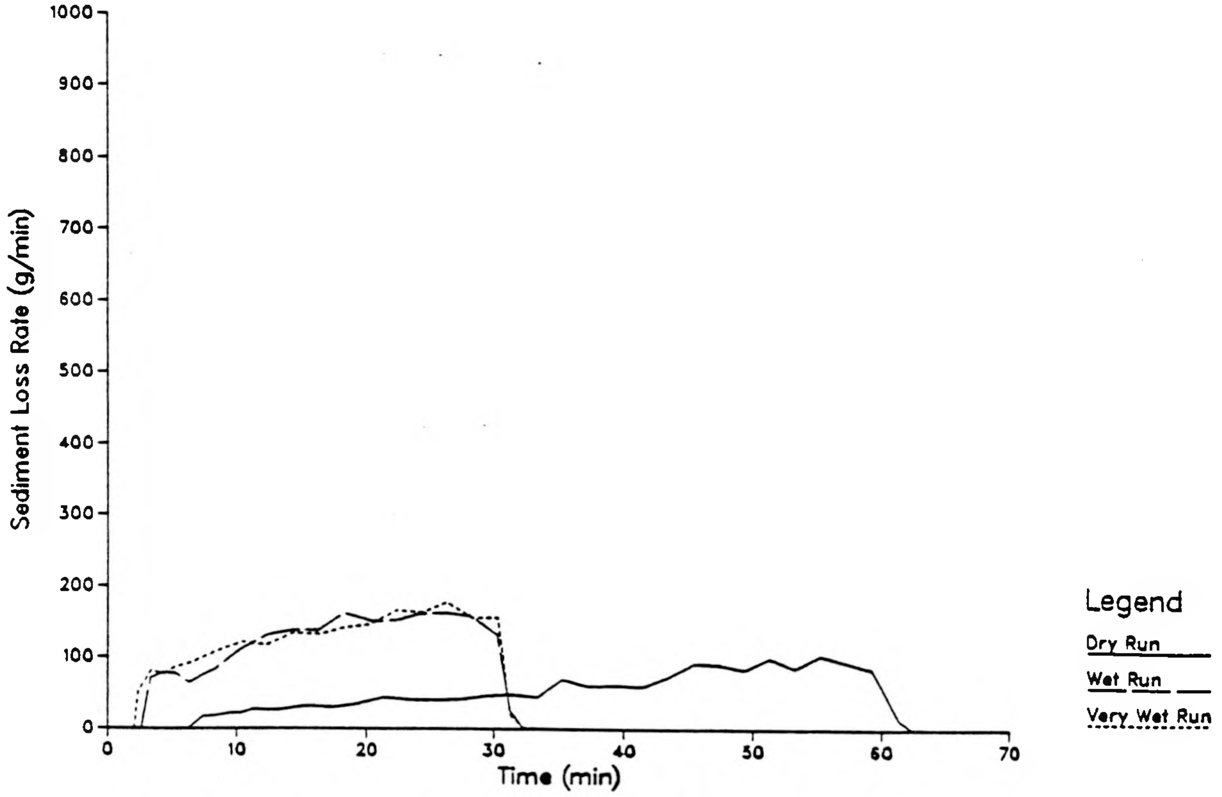
Plot #1 Streambank Wheatgrass June 1987.



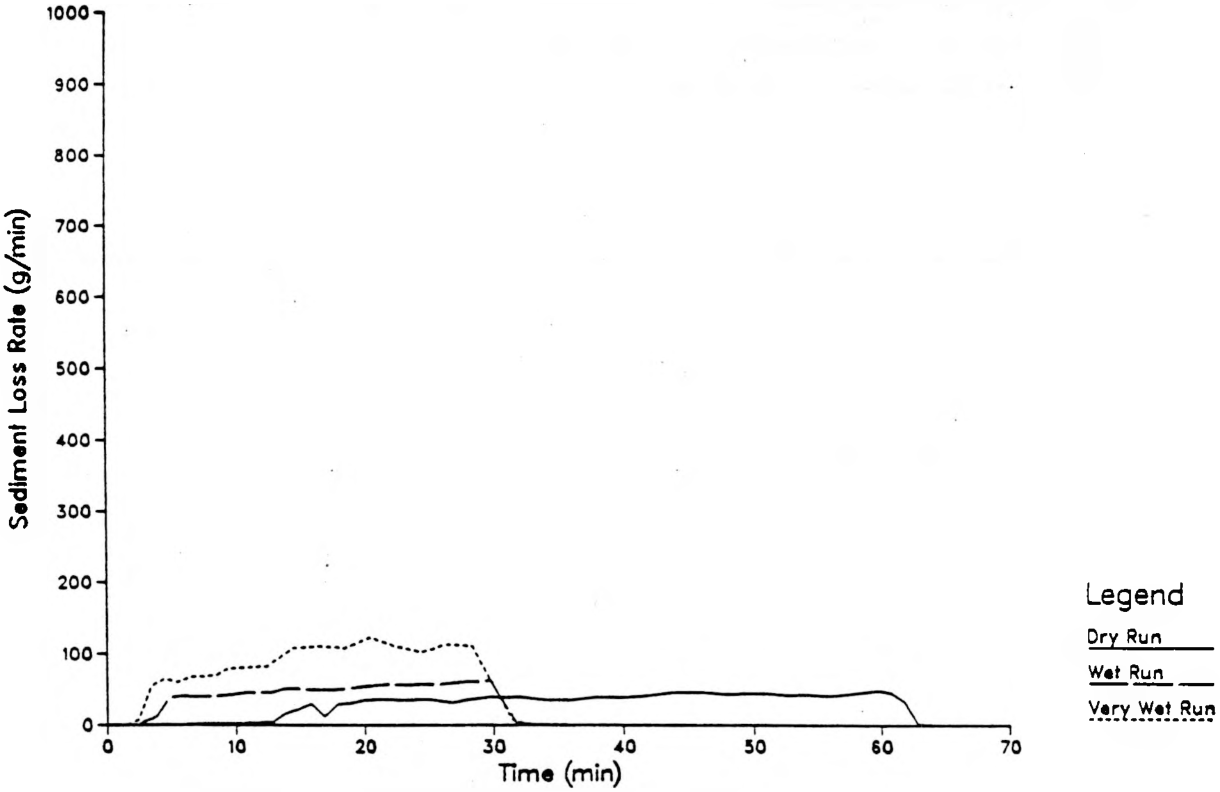
Plot #1 Streambank Wheatgrass September 1987.



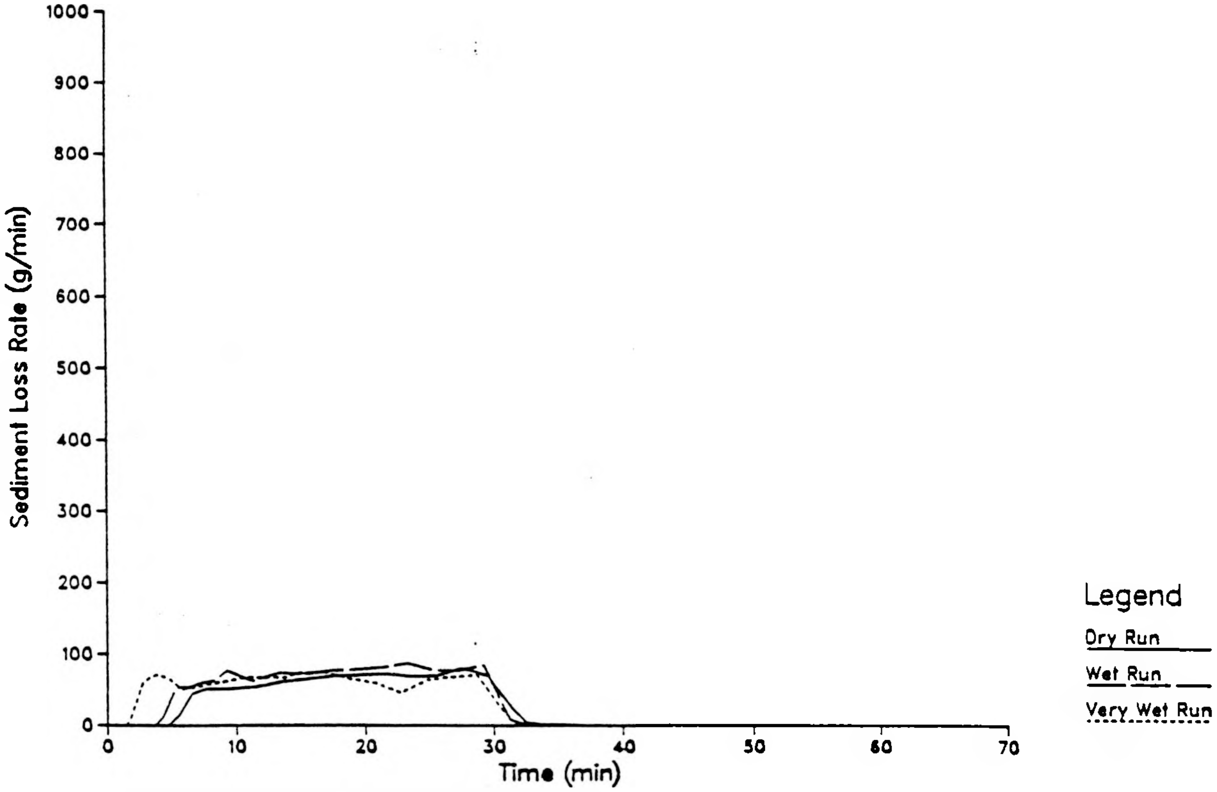
Plot #2 Crested Wheatgrass June 1987.



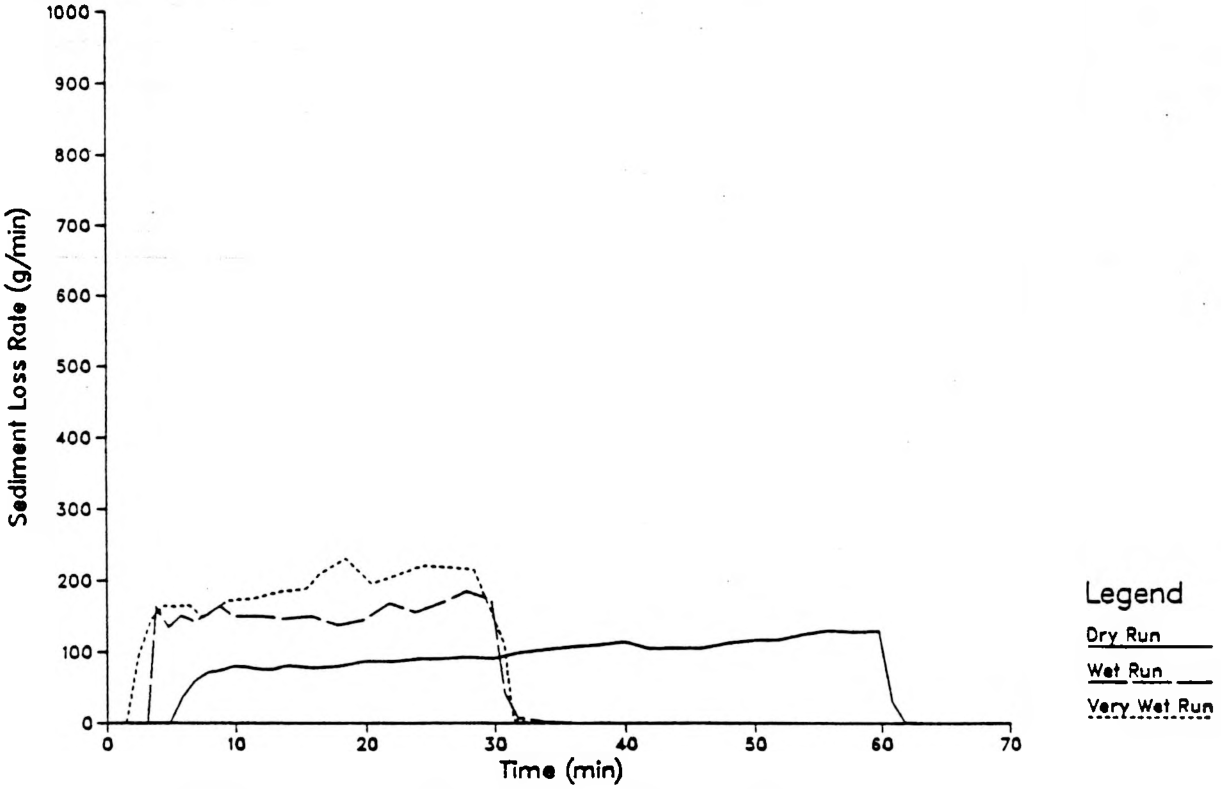
Plot #2 Crested Wheatgrass September 1987.



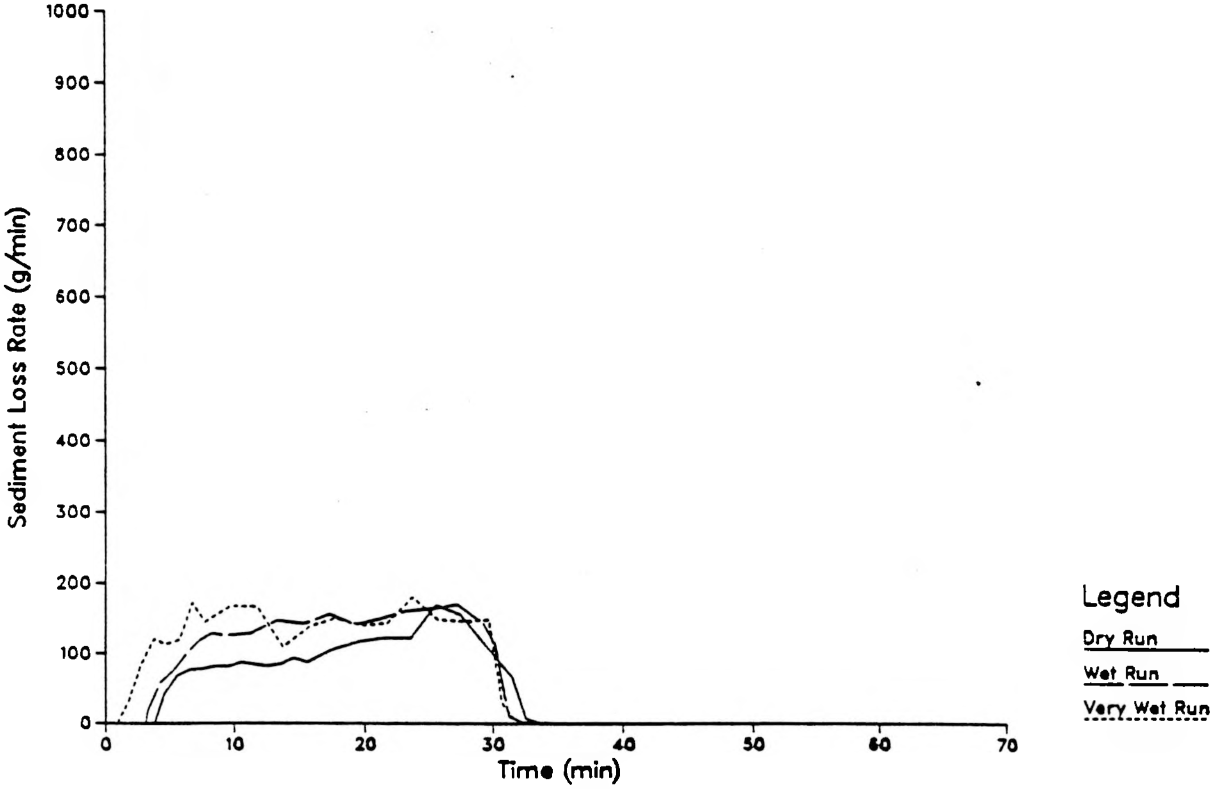
Plot #3 Crested Wheatgrass June 1987.



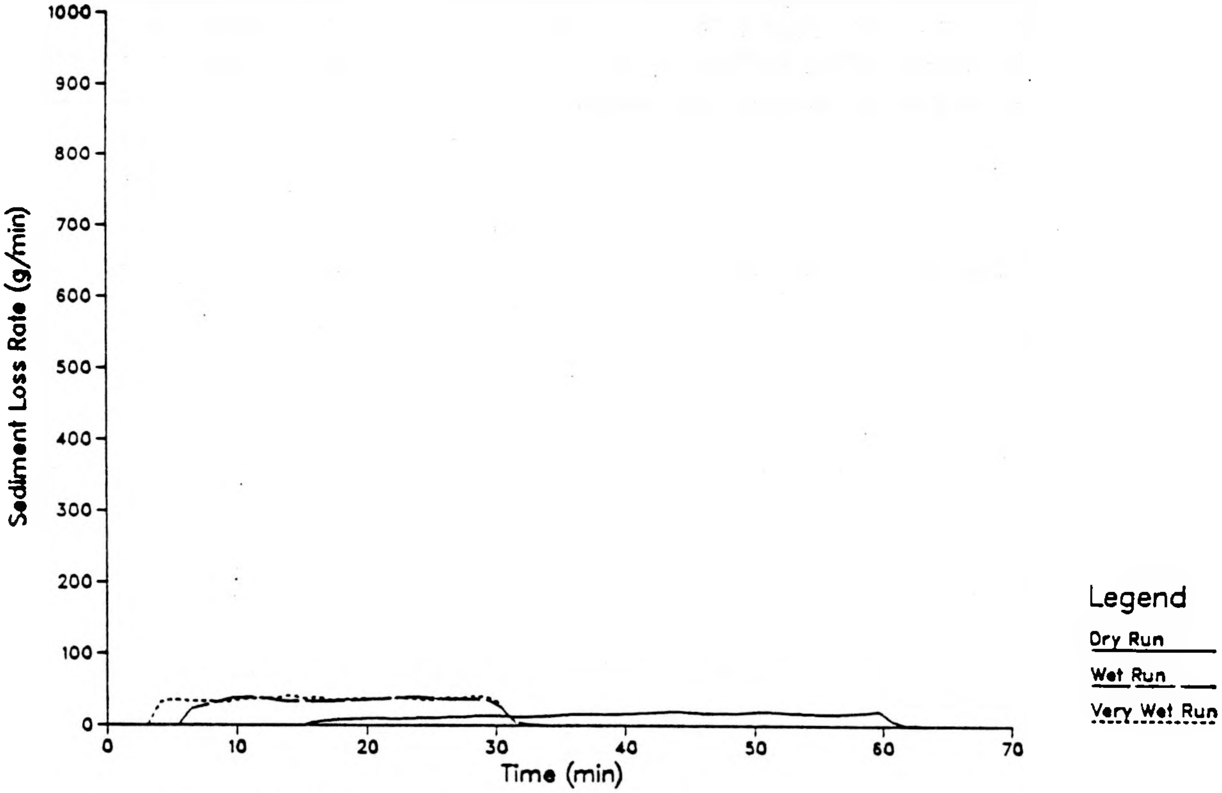
Plot #3 Crested Wheatgrass September 1987.



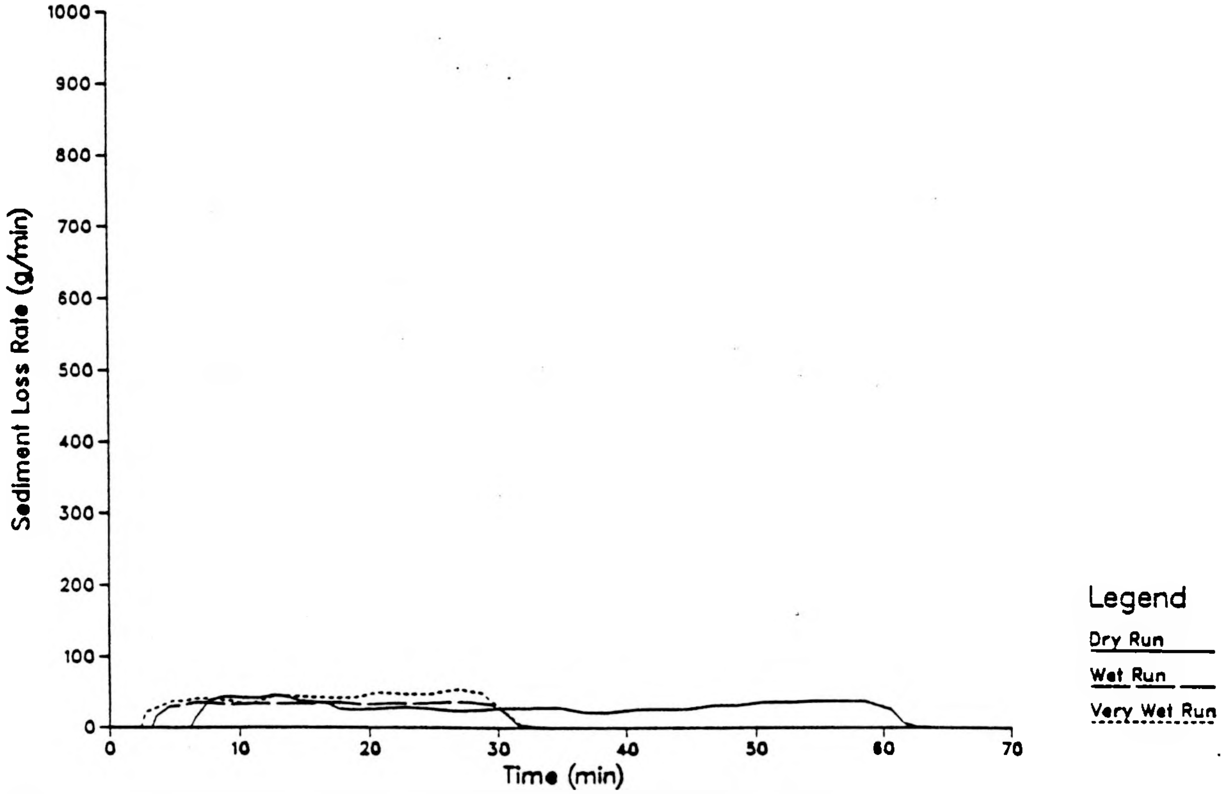
Plot #4 Streambank Wheatgrass June 1987.



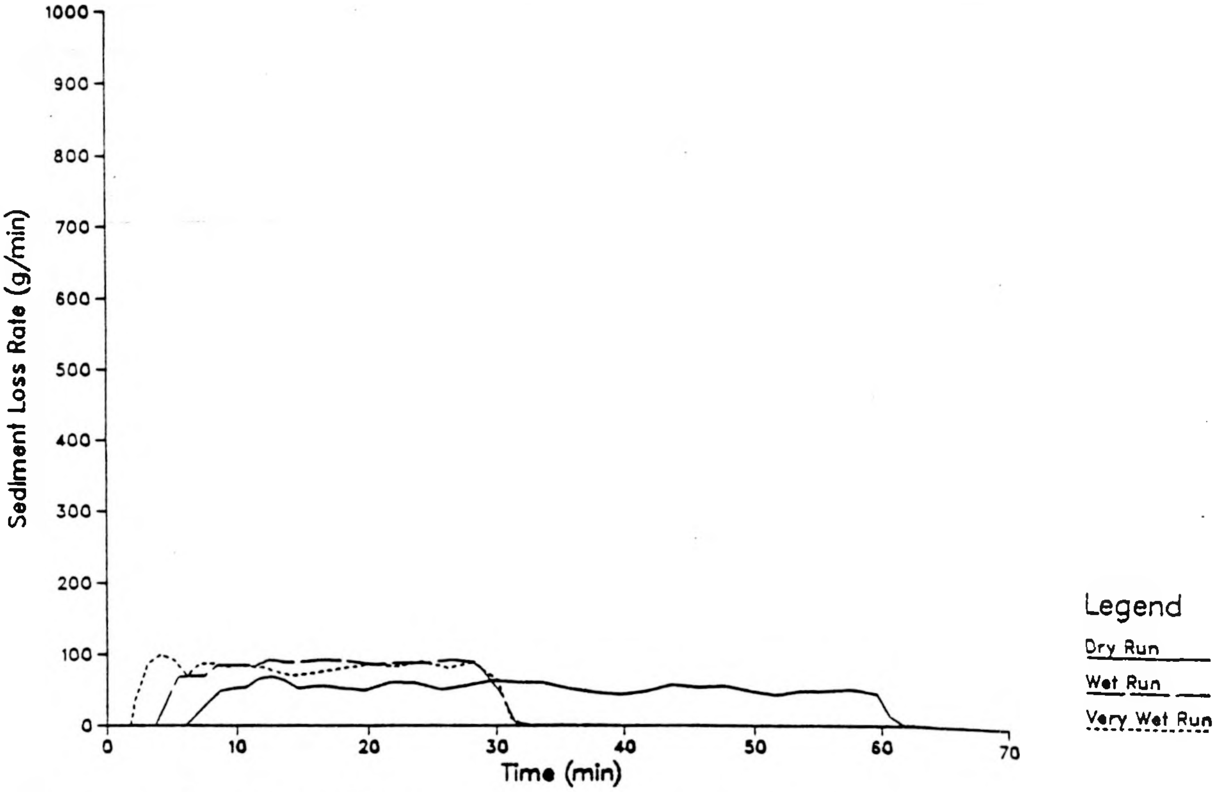
Plot # 4 Streambank Wheatgrass September 1987.



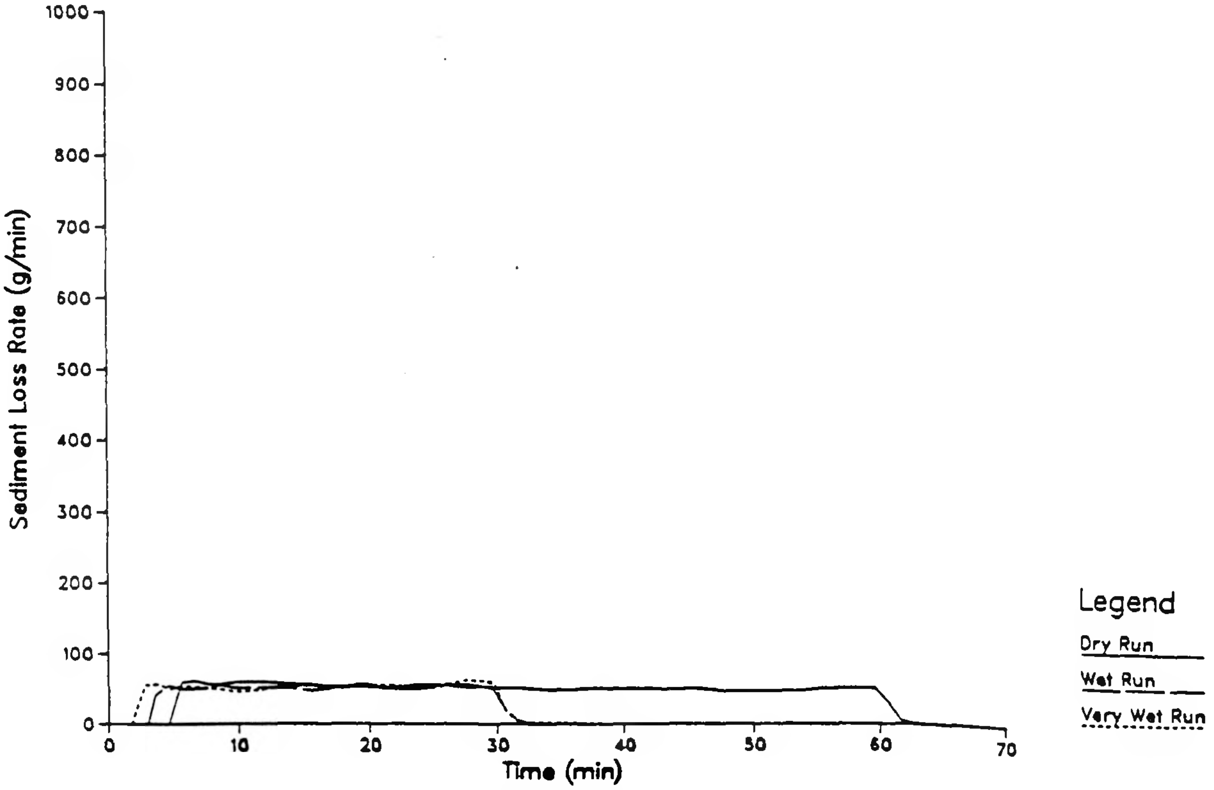
Plot #5 Crested Wheatgrass June 1987.



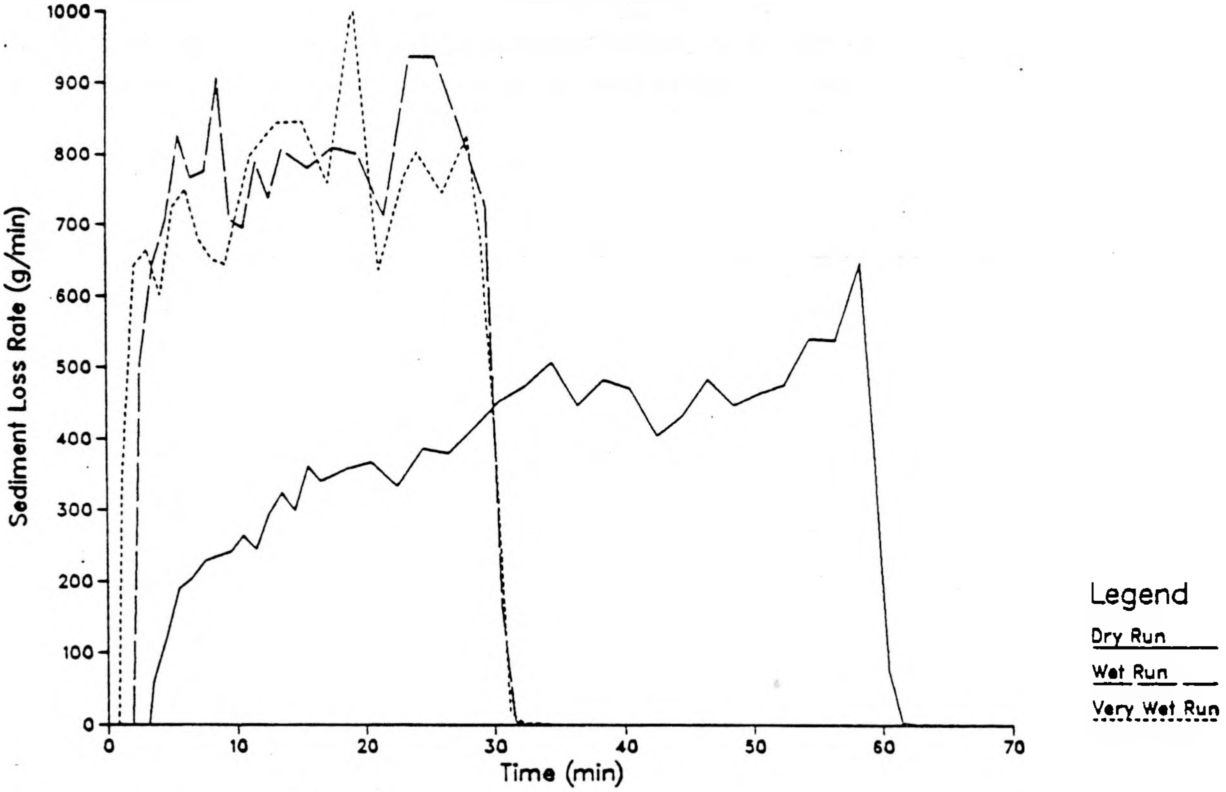
Plot #5 Crested Wheatgrass September 1987.



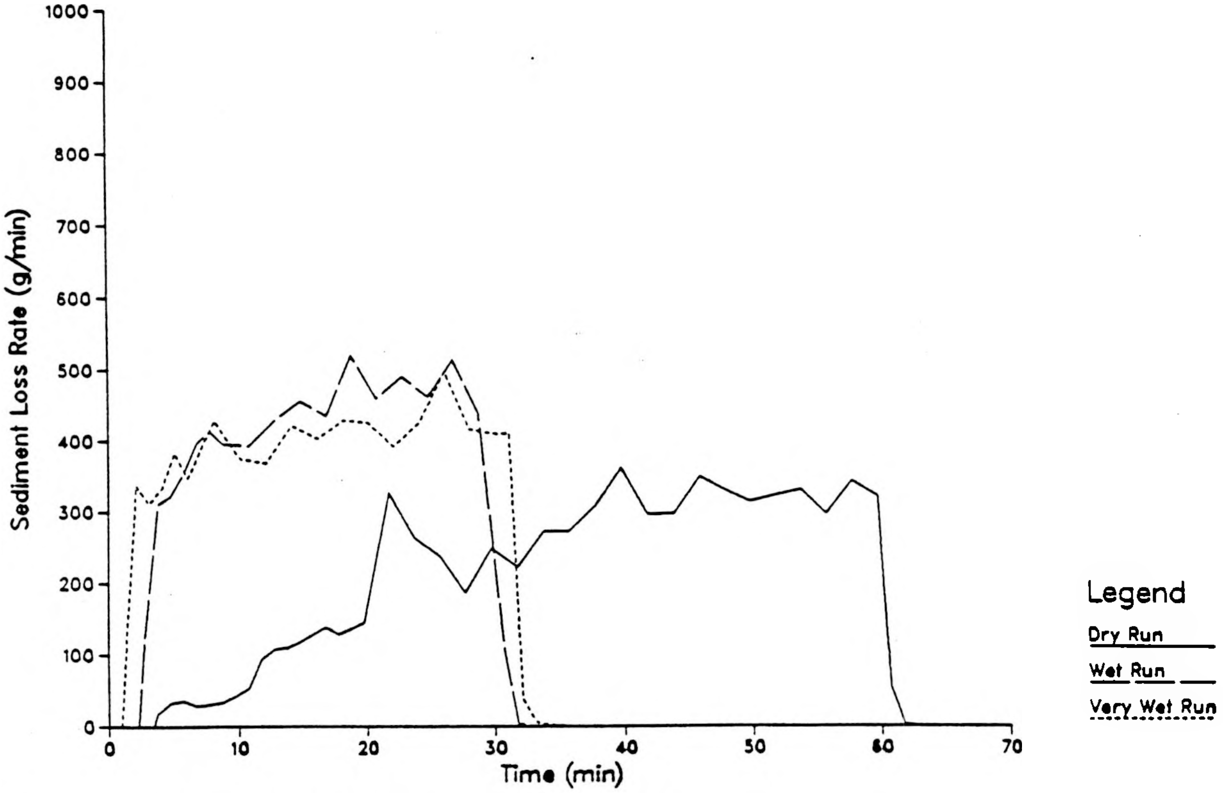
Plot #6 Streambank Wheatgrass June 1987.



Plot #6 Streambank Wheatgrass September 1987.



Plot #7 Bare Soil June 1987.



Plot #7 Bare Soil September 1987.