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Chena River Lakes Project revegetation study

Three-year summary

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L.A. Johnson, S.D. Rindge, D.A. Gaskin

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During the growing seasons of 1977, 1978 and 1979, revegetation techniques were studied on the Chena River Lakes Project, a flood control dam and levee near Fairbanks, Alaska, to find an optimal treatment for establishing permanent vegetation cover on the gravel structures. The treatments tested on plots at the dam and/or levee involved three main variables: 1) vegetation (grass and clover seed and/or willow cuttings), 2) mulch, mulch blanket, and/or sludge, and 3) substrate (gravel or fine-grained soil over the gravel base). The mulches were hay, wood-cellulose-fiber, peat moss, and Conwed Hydro Mulch 2000, which is a wood-cellulose-fiber mulch with a polysaccharide tackifier. A constant rate of fertilizer was applied to all plots except the control. A section of each plot was refertilized again in their third growing season to compare annual and biannual fertilization. The high fertilization rate produced above-average growth.

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20. Abstract (cont'd).

Fescue, brome, and foxtail were the most productive species on the dam, while alsike clover was the most productive on the wetter levee site. When grass seed and willow cuttings were planted at the same time, willow survival and growth were reduced. Fertilization is required for at least two years to produce an acceptable permanent vegetation cover, although fine-grained soil or sludge reduces the amount of fertilizer needed in the second year. Third-year fertilization may not be necessary since the benefits of the second fertilization continue for at least two years. A sludge treatment refertilized during its second growing season produces the highest biomass recorded in this study. Sludge from the Fairbanks treatment plant poses little, if any, danger of contamination from heavy metals or pathogens. Four-year-old seedlings of willow and native woody species growing on the dam do not have deeply penetrating root systems and therefore don't appear to pose an early threat of leakage through the dam.

PREFACE

This report was prepared by Lawrence A. Johnson, Biologist, of the Alaskan Projects Office (Fairbanks), and Susan D. Rindge, Physical Scientist, and David A. Gaskin, Geologist, of the Geotechnical Research Branch (Hanover), U.S. Army Cold Regions Research and Engineering Laboratory.

The work was jointly funded under a reimbursable order from the Alaskan District, Corps of Engineers, Civil Works Project CWIS 31013, *Environmental Effects and Criteria for Engineering Works in Cold Regions,* and DA Project 4A762720A896, *Environmental Quality for Construction and Operation of Military Facilities,* Task 04, *Land Use Planning,* Work Unit 003, *Revegetation of Terrain After Construction in Cold Regions.*

The authors thank Major Leo Laska and Frank Erie of the Alaska District for their assistance and equipment support. James O'Neil and James Winslade of the Department of Sanitation for the City of Fairbanks, Alaska, provided the sewage sludge used in the study. James Aldrich, from the Institute of Water Resources, University of Alaska, collected sediment data from the sediment tanks in 1977 and 1978.

A number of CRREL personnel have contributed to this multi-year study. In 1977, Robert Bigl, Arthur Gidney and Gary Prokosch helped install the treatments and Mr. Prokosch also assisted in vegetation sampling. In 1978, William Burch, Robert Demars and Sharon Frost applied the treatments; Nancy Robertson and Ms. Frost helped with data collection. In 1979, Mr. Burch, Mr. Demars and Lisa Line helped with the refertilizing and resludging; Linda Donaldson and Ms. Line collected moisture and vegetation data. Richard Haugen designed and supervised installation of the temperature instrument shelters and was responsible for data collection and analysis. Deborah Roach performed the moisture stress study.

We assessed the weather conditions at our study sites using meteorological data collected by the U.S. Army Atmospheric Science Laboratory Meteorological Support Team, Fort Wainwright detachment.

Dr. Brent McCown of the University of Wisconsin and Dr. Jerry Brown, Roy Bates and Antonio Palazzo of CRREL reviewed this report.

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ABBREVIATIONS

Vegetation		Mulches	
W	1977 willow cuttings	CHM 2000	Conwed Hydro Mulch 2000
S	1977 basic seed mixture	EX	excelsior mesh
S+B	1977 seed mix with bluejoint	H	hay
V1,V2,V3	1977 seed mix with varying amounts of annual ryegrass	M	mulch, undifferentiated
		P	peat moss
S1,S2	1978 seed mixtures	WCF	wood-cellulose-fiber
S3	1979 Conwed blanket mixture		
3S	Triple rate 1977 basic seed mix		

Miscellaneous		Fertilizer	
C1,C2	Conwed blanket plots	F	fertilizer (10-20-10)
L	lime	N	not fertilized
SG	sludge	R	refertilized
TS	fine-grained soil	F1	fertilized once during initial treatment
DW	downstream slope of dam	F2	refertilized during second growing season
UP	upstream slope of dam	F3	refertilized during second and third growing seasons

CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
meters	3.281	feet
millimeters	0.040	inches
hectare	2.47	acre
kilogram/hectare	0.8921	pound/acre
metric ton/hectare	0.446	ton/acre
cubic meter/hectare	0.529	cubic yard/acre
number/hectare	0.405	number/acre
°Celsius	°F = 1.8(°C) + 32	°Fahrenheit

SUMMARY

Revegetation techniques were studied on the Chena River Lakes flood control dam near Fairbanks, Alaska, for three growing seasons in cooperation with the Corps of Engineers, Alaska District. The purpose of the study was to determine the optimal treatment for establishing a permanent vegetative cover on the gravel dam.

In May 1977, 70 plots were established with various revegetation treatments: 37 on the upstream side and 33 on the downstream side of the dam. Treatments included three main variables: mulch, substrate (gravel or a fine-soil cover consisting primarily of silts and fine sand over the gravel base), and vegetation (grass seed mix and/or unrooted willow cuttings). The mulches tested were: hay, wood-cellulose-fiber, peat moss, Conwed Hydro Mulch 2000 and a fiberglass blanket. A constant rate of fertilizer was applied to all plots except the control.

To assess the amount of sediment eroded from the treatments (erosion hazard), specially designed tanks were placed at the base of 35 of the upstream plots.

The first season's results indicated that six treatments performed acceptably in terms of growth, erosion hazard and cost effectiveness. These included the seed and fertilizer treatment and seed and fertilizer with any of the following mulches: Conwed Hydro Mulch 2000, hay, peat moss, wood-cellulose-fiber and combined peat moss and wood-cellulose-fiber. Soil loss results for the six were within the limit of 2200 kg/ha recommended by the U.S. General Accounting Office. These treatments were also cost effective ($3710/ha to $6340/ha).

During June 1978, half of each of the existing 1977 plots was refertilized and three sets of additional plots were established on the dam. Ten of the new plots on the downstream side received sludge (thickened wastewater) and fertilizer with or without mulch, grass seed and/or lime. Two other new downstream plots tested experimental erosion-control blankets made of wood-cellulose-fiber in two thicknesses. The blankets were oversprayed with a mixture of seed, fertilizer and additional wood-cellulose-fiber. On the upstream side, a third new set of six plots included fine soil, seed, and fertilizer with or without hay.

A 1978 revegetation site on the Tanana River Levee allowed comparison of the north- and south-facing slopes of the levee with the predominantly east- and west-facing slopes of the dam. The main treatments used at this site were the six most successful ones from 1977 over a fine-soil base.

The two 1978 grass seed mixtures on the dam and levee differed from that of the previous year. One included several additional cold-adapted species while the other had only two perennial species.

A dramatic result of the 1978 season was the favorable effect of refertilization on grass growth. This contrasted greatly with the poor response of non-refertilized grasses. Of the treatments applied in 1978, the two most successful were: fine soil, seed, fertilizer and hay; and seed, fertilizer and sludge without lime. The sludge treatments were also cost-effective, with a range from $3710 to $5770/ha.

In 1979, parts of existing plots were treated with fertilizer and sludge. This involved refertilizing a few 1977 plots again, refertilizing sections of the 1978 fine-soil and sludge plots, and adding more sludge to a section of the sludge plots. The plots with wood-cellulose-fiber blankets received an entirely new treatment of seed, fertilizer, and mulch because they had poor growth the first year.

Several observations are apparent from this three-year study:

1) A vegetative cover can be established on the gravel face of the dam and

levee. The vegetation will help to reduce erosion and will improve the aesthetics of the structures.

2) Fertilization is required for at least two years to produce an acceptable permanent vegetation cover, although fine-grained soil or sludge added to the site reduces the amounts of fertilizer needed in the second year. Fertilization during the third year increases vegetation growth but probably is not required, since the benefits of the second fertilization continue for at least two years.

3) Willow cuttings offer a viable means of revegetating the dam. On the basis of a root penetration study, initial growth of willows and growth of four- to five-year-old native seedlings appear to pose little or no root penetration problem on the gravel dam.

4) Grasses reduce willow growth and survival; therefore, they should not be seeded if willow cuttings are planted. If additional vegetation cover is desired, straw mulch may be used at the time of willow planting, or grasses may be seeded one year later to avoid competition with the first-year establishment of the willows.

5) The Chena River Lakes Project is an ideal location to use the potential of sludge for improving the moisture and nutrient regime of the soil since there appear to be minimal problems with contamination.

6) Sludge offers a viable alternative to annual fertilization or placement of the more expensive fine-soil cover. Two-year-old treatments with sludge plus fertilizer produced the highest biomasses of the study period, exceeding responses of treatments receiving three annual fertilizer applications.

7) Growth on the upstream (SE) side of the dam is less than on the downstream (NW) side due to a combination of higher soil temperature and reduced soil moisture.

8) The levee provides more favorable soil temperatures and moisture than the dam, as evidenced by higher biomass and cover values for comparable treatments.

9) Species that produce adequate biomass on well-drained sites, such as the dam, are fescue, brome, and foxtail grasses. At wetter sites, such as the levee, alsike clover seems to be the most promising species. Alsike clover should be included with the grasses in the seed mixture whenever possible since it will help to increase soil nitrogen.

10) Moisture appears to limit growth principally in treatments receiving high fertilizer applications. Hence, differences in growth between north and south aspects (levee), east and west aspects (dam), and top and bottom of slopes (dam) will be accentuated under high fertility levels.

11) Denser covers of herbaceous vegetation appear to slow the invasion by woody species onto the dam. However, it is not known how long this effect will last.

12) Erosion is a recurring problem on the bare gravel slopes of the dam. Both saturated flows initiated by spring snowmelt and erosion gullies due to above-normal summer rains occurred during the study period. Although the studies do not show that vegetation will prevent slumps and erosion, they suggest that the frequency and severity of erosion can be reduced.

CHENA RIVER LAKES PROJECT REVEGETATION STUDY
Three-year summary

L.A. Johnson, S.D. Rindge, D.A. Gaskin

INTRODUCTION

Background

The Alaska District, U.S. Army Corps of Engineers, designed and constructed the Chena River Lakes Flood Control Project at a site 27 km east of Fairbanks, Alaska. The project consists of the Moose Creek Dam (12.3 km long, 15–21 m high), a gravel dam that extends from the Chena River to the Tanana River; and the Tanana River Levee (33.1 km long, 3–5 m high) that runs along the Tanana River past Fairbanks to the confluence of the Chena River (Fig. 1) (U.S. Army Engineer District, Alaska 1972, 1979).

These structures are designed to divert water from the Chena River that would otherwise inundate Fairbanks during flood periods as occurred in August 1967. Flood waters move along a cleared slow-release channel, or floodway, on the "upstream" side of the dam and overflow into the larger floodplain of the Tanana River.

In cooperation with the Alaska District, we have tested various types of revegetation techniques on the two structures to see which methods would establish an acceptable permanent vegetation cover.

Site characterization

The project is located on the Tanana Lowland, a part of the interior basin of central Alaska. The Tanana Lowland is a wide floodplain composed of thick beds of stratified gravels; it lies between the Yukon-Tanana Upland to the north and the Alaska Range to the south.

In the vicinity of the project, the topography of the Chena River valley ranges from mildly undulating hills to flat, low-lying peat bogs and muskegs. Varying thicknesses of silts and silty sands (0–3 m) overlie sand and gravel deposits. Two prominent highlands interrupt the otherwise broad, flat valley: Moose Creek Bluff on the south side of the Chena River and an unnamed, irregularly shaped ridge about 10.1 km NNE of Moose Creek Bluff on the north side (Fig. 1).

Climate

The Alaska Range to the south and the Brooks Range to the north, which shelter the basin from maritime air masses, strongly influence the climate of the Tanana valley. Consequently, the area has a continental climate characterized by cold, dry winters and warm, dry summers (Bilello 1974, U.S. Army Electronics Command 1966).

Total precipitation averages 285 mm/year, with the normal maximum monthly amount (55.6 mm) usually occurring in August (National Oceanic and Atmospheric Administration 1979).

The mean annual temperature is −3.5°C, with recorded temperature extremes of −54°C and 37°C (NOAA 1979). The frost-free season extends from mid-April to mid-September. The 30-year normal for yearly total growing-season degree-days above 5°C is 1063 (Richard Haugen 1980, pers. comm.). Growing-season degree-days are calculated by totaling the daily amount of temperature deviation from 5°C throughout the season after a daily average of 5°C has been reached.

Purpose

During the period from May 1977 to August 1979, we investigated revegetation and erosion control techniques at the Chena River Lakes Flood Control Project. The purpose of our study

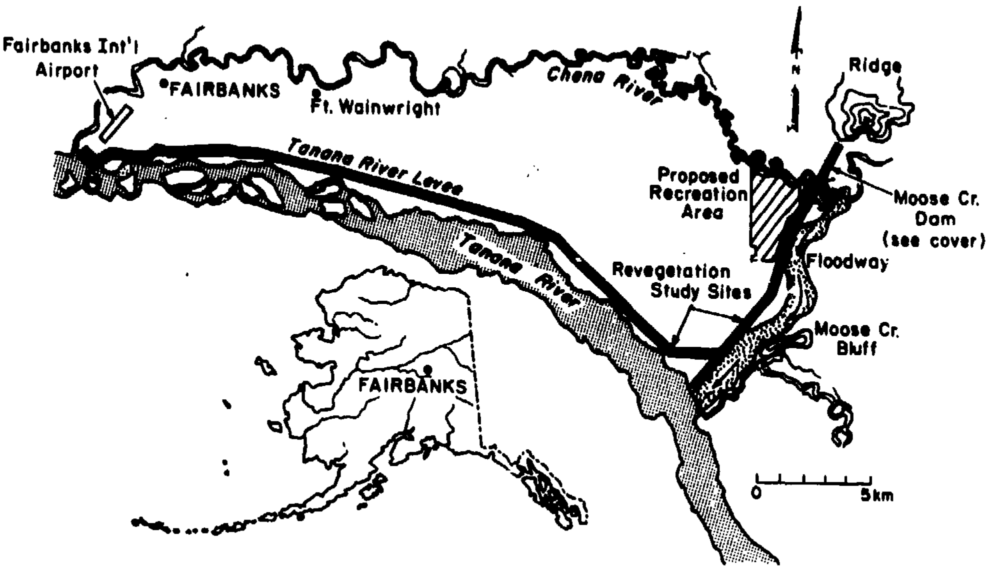


Figure 1. Chena River Lakes Flood Control Project.

was to determine the optimum revegetation treatment or set of treatments which would enable the Corps of Engineers to establish and maintain a permanent vegetation cover on both the upstream and downstream sides of the dam and levee.

Revegetation of these two structures is especially difficult because of unfavorable growing conditions. The coarse gravel surfaces have poor water-holding capacities and provide low levels of plant nutrients. Soil water-holding capacities are further reduced by the dam's steep, high slopes (2:1 to 2.5:1). Compounding the problem is the subarctic climate, with a short growing season (May-August) and low annual precipitation (285 mm/year).

Specific objectives of the study were to determine:

1. The biological success of various treatments, particularly the most successful species and the most beneficial mulches for extremely cold regions.
2. The erosion potential of the treatments.
3. The optimum rate and frequency of fertilization on both gravel and fine-grained soils.
4. The estimated costs of establishing vegetative covers.

Vegetation on the dam improves aesthetics and provides more effective control of erosion. A vegetation cover helps reduce the visual impact of the structure and blends it into its natural setting. This is especially important since visitors will travel along the dam when using the recreation area downstream of the dam.

Erosion control on the dam appears to be necessary. Both gullying and slumping have occurred on the surface of the downstream slope of the dam since its completion in 1978.

MATERIALS AND METHODS

General

Our experimental design was based on results of previous studies which established optimal fertilizing rates, seeding rates, and materials for revegetation and erosion control in cold regions (Johnson and Specht 1975, Gaskin et al. 1977, 1979, Johnson 1978, Rindge et al. 1979, and Palazzo et al. 1980).

Revegetation plots were established at two sites within the project. One site is on the southwest portion of Moose Creek Dam on slopes facing northwest and southeast, and the other is along the north-south-facing Tanana River Levee (Fig.2). This placement permitted us to compare responses on slopes with different aspects.

Treatments applied to the plots included various combinations of the following variables:

1. Vegetation (seed mixes and/or willow cuttings).
2. Fertilizer.
3. Mulch, mulch blanket, or sludge.
4. Substrate (gravel or fine-grained soil* over the gravel base).

*The fine-grained soil consisted primarily of silt and fine sand with a low organic content (30-50 metric tons/ha).

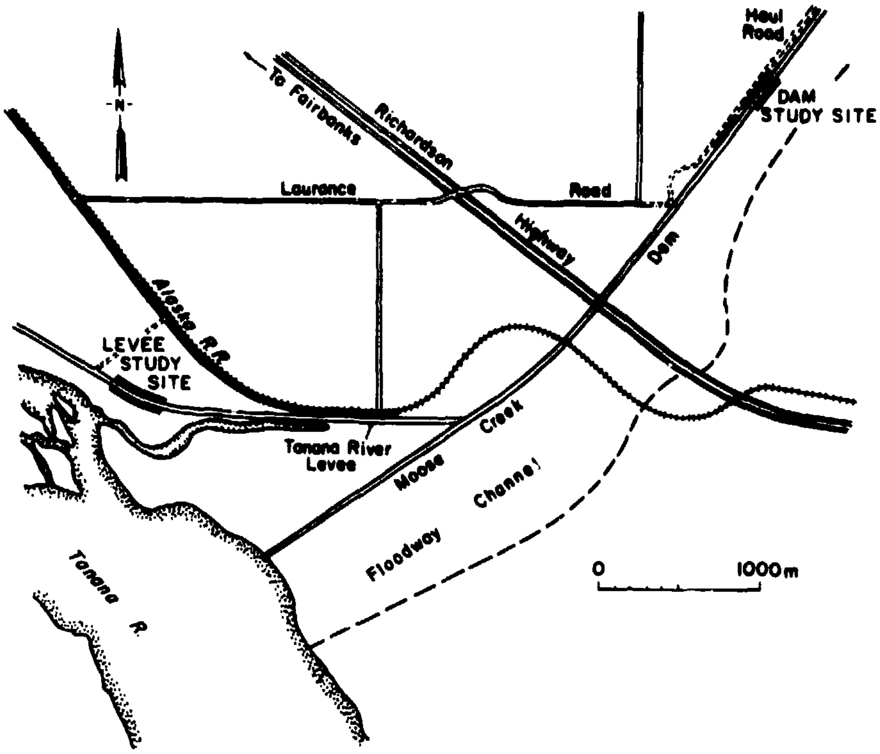


Figure 2. Revegetation site locations.

additional mulch. The final set (six plots measuring 3×15 m) was treated with seed and fertilizer with or without hay mulch over a base of fine-grained soil.

Plots that were installed in 1977 on both sides of the dam were studied for three years. Other plots, installed in 1978 on both the dam and the levee, were studied for two years.

To test the need for refertilization, a section of each plot was treated with additional fertilizer at the beginning of the second growing season. Selected plots were again refertilized during the third growing season to permit a comparison between annual and biannual refertilization.

Sludge was also added as a nutrient source to established sludge plots during the second growing season.

Moose Creek Dam site

There are four sets of plots at the Moose Creek Dam site (Fig. 3, Table 1). The initial set, installed in May 1977, consisted of 70 plots (each 3×15 m) involving a constant fertilizer rate and variations in substrate, vegetation, and mulch. The other three sets of plots were installed in June 1978. Ten plots (each 24×15 m) were treated with sewage sludge and combinations of seed, fertilizer, mulch and lime. Two plots (38×15 m and 32×15 m) used an experimental wood-cellulose-fiber blanket developed by the Conwed Corporation. After installation, the blankets were treated with seed, fertilizer and

1977 plots

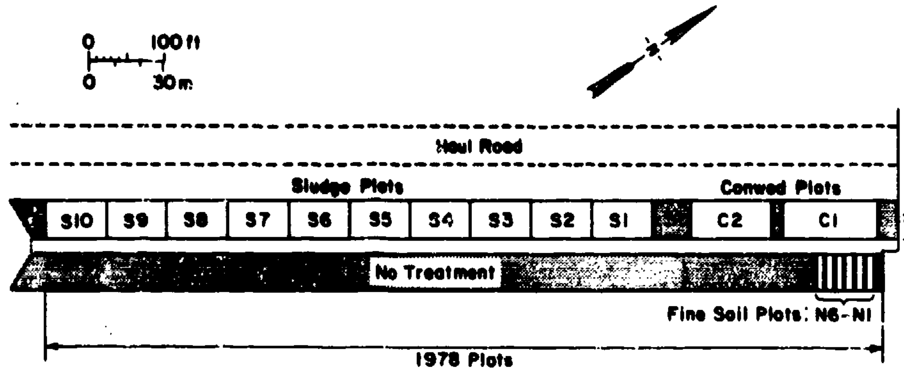
The treatments installed in 1977 included various combinations of mulch, fertilizer, substrate and vegetation. Most treatments had three replicates on both the upstream and downstream slopes of the dam (Table 1).

The five mulches tested were:

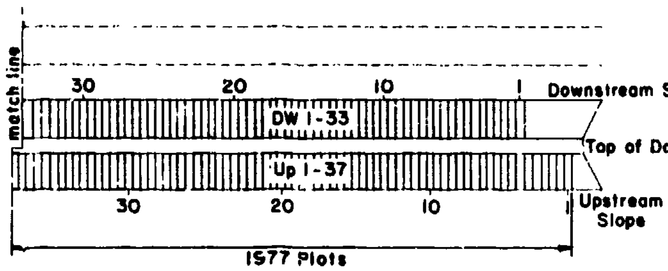
1. Hay (coarse bedding straw).
2. Wood-cellulose-fiber (WCF).
3. Conwed Hydro Mulch 2000 (CHM2000), wood-cellulose-fiber with a colloidal polysaccharide tackifier (glue).
4. Peat moss.
5. Peat moss oversprayed with WCF.

Application rates of the mulches were 4785 kg/ha, except for the peat moss-WCF combination, which had 4785 kg/ha of each for a total 9570 kg/ha. This was double the manufacturer's suggested rate for WCF and CHM 2000 and was based upon the results of studies conducted by Palazzo et al. (1980) on gravel pads in Hanover, New Hampshire, and Fairbanks, Alaska.

Non-mulch and hay-mulch treatments were



a. End view.



b. Side view.

Figure 3. Plan of the Moose Creek Dam site.

applied by hand-broadcasting the hay, seed and fertilizer evenly over the plot surface. All other treatments were applied by spraying a slurry of mulch and water (with or without seed and fertilizer) from a hydromulcher (Fig. 4). In the case of peat moss plus WCF, we sprayed the peat moss first and then oversprayed the WCF along with the rest of the treatment.

An experimental fiberglass erosion control blanket under development by the Owens/Corning Fiberglass Corporation was tested on one upstream plot (Table 1). Erosion control blankets are normally anchored or pinned with U-shaped steel pins on a 1-1.5-m spacing. In this case, however, we applied the fiberglass blanket without pins so that the grass could lift it and be shaded by it.

The fertilizer used on all plots was 10-20-10 grade applied at 880 kg/ha, or a total application of 88 kg of nitrogen (N)/ha, 176 kg phosphorus pentoxide (P_2O_5)/ha, and 88 kg potassium oxide (K_2O)/ha.

Fourteen plots received a 23-cm-thick (2300-m^3/ha) cover of fine-grained soil. Ten of these plots were on the upstream side and four were on the downstream side (Table 1). The Alaska District provided the soil from stockpiles originally obtained from the area cleared for the dam. Aldrich and Johnson (1979), who studied the sediment loss on these plots, found that the soil consisted primarily of silt and fine sand (Fig. 5). The soil also had a low organic content ranging from 30 to 40 metric tons/ha.

The vegetation types used in the treatments were either a grass seed mix, unrooted willow cuttings, or a combination of the two. The basic 1977 grass seed mixture was annual ryegrass at a rate of 11 kg/ha, red fescue at 24 kg/ha and Nugget Kentucky bluegrass at 8 kg/ha for a total of 43 kg/ha (S, Table 2). Two upstream plots were seeded with an additional 11 kg/ha of bluejoint reedgrass (a species native to Alaska) in the basic mixture (S+B, Table 2). On three downstream plots annual ryegrass at three rates—6, 8 and 14 kg/ha—was substituted in the seed mixture (V1, V2, V3, Table 2). Finally, on the fiberglass blanket plot an application rate three times that of the basic mixture was used (129 kg/ha) (3S, Table 2). This seeding rate was determined from previous studies using the fiberglass blanket in Han-

Table 1. Moose Creek Dam revegetation treatments.

Plot type	Plot numbers: Upstream	Plot numbers: Downstream	Fine soil (m³/ha)	Sludge (MT/ha)	Willows (no./ha)	Seed mix: Type*	Seed mix: Rate (kg/ha)	Fertilizer 10-20-10 (kg/ha)	Mulch: Type†	Mulch: Rate (kg/ha)	Lime (kg/ha)	Blanket rate (kg/ha)	Plot width (length 15 m) (m)	Method**
1) 1977 plots	1,2,3	—	—	—	—	—	—	—	—	—	—	—	3	
	4,5,6	1,2,3	—	—	—	S	43	880	—	—	—	—	3	Hand
	7,8,9	4,5,6	—	—	—	S	43	880	WCF	4785	—	—	3	Hydro
	10,11,12	7,8,9	—	—	—	S	43	880	H	4785	—	—	3	Hydro
	13,14,15	10,11,12	—	—	—	S	43	880	CHM2000	4785	—	—	3	Hydro
	16,17,18	13,14,15	—	—	—	S	43	880	P	4785	—	—	3	Hydro
	19,20,21	16,17,18	—	—	—	S	42	880	P+WCF	9570	—	—	3	Hydro
	22,24	—	2300	—	—	S+B	54	880	—	—	—	—	3	Hand
	23	—	2300	—	—	3S	129	880	Fiberglass	—	—	—	3	Hand
	—	19	—	—	—	V1	46	880	—	—	—	—	3	Hand
	—	20	—	—	—	V2	40	880	—	—	—	—	3	Hand
	—	21	—	—	—	V3	37	880	—	—	—	—	3	Hand
	—	22,23	—	—	10,745	—	—	880	H	4785	—	—	3	Hand
	25,26,27	24	2300	—	10,745	—	—	880	H	4785	—	—	3	Hand
	28,29,30	25,26,27	2300	—	10,745	S	43	880	H	4785	—	—	3	Hand
	31,32,33	28,29,30	—	—	10,745	—	—	880	CHM2000	4785	—	—	3	Hydro
	34,35,36	31,32,33	—	—	10,745	—	—	880	—	—	—	—	3	Hand
	37	—	2300	—	—	S	43	880	—	—	—	—	3	Hand
2) Sludge plots (1978)††	—	1,2,3	—	25	—	S1	41	660	CHM2000	1830	610	—	24	Unmixed
	—	4,5,6	—	25	—	S2	110	660	CHM2000	1830	610	—	24	Mixed
	—	7,8,9	—	25	—	S2	110	660	WCF	1830	—	—	24	Mixed
	—	10	—	25	—	S1	41	660	—	—	—	—	24	Mixed
3) Conwed blanket plots (1978)††	—	C1	—	—	—	S2	77	473	CHM2000	1177	—	9,585	28	Hydro
	—	C2	—	—	—	S2	77	473	CHM2000	1177	—	14,370	32	Hydro
4) Fine soil plots (1978)	N1,2,3	—	1500	—	—	S1	41	880	—	—	—	—	3	Hand
	N4,5,6	—	1500	—	—	S1	41	880	H	9570	—	—	3	Hand

* Seed mixes: S—1977 basic mix; 3S—triple rate basic mix; S+B—basic mix with bluejoint; V1, V2, V3—variable annual ryegrass mixes; S1, S2—1978 seed mixes; see Table 2.

† Mulches: CHM2000—Conwed Hydro Mulch 2000; H—hay; P—peat moss; WCF—wood-cellulose-fiber mulch.

** Methods: Hand—hand broadcast; Hydro—hydromulched; Mixed—other ingredients mixed with sludge; Unmixed—other ingredients sprayed over sludge.

†† These plots were retreated in 1979—see details in text.

a. End view.

b. Side view.

Figure 4. Hydromulching procedure.

over, New Hampshire (Rindge and Gaskin 1977).

Willow (*Salix alaxensis*) cuttings approximately ½ m long were collected from shrubs near the dam. Soon after cutting, the pieces were inserted in the gravel or soil cover, leaving approximately 10 cm above the surface. They were spaced at 1-m intervals (10,745 cuttings/ha) on 12 upstream and 12 downstream plots (Table 1).

Portions of these plots were refertilized in the second and third years of the study. The fertilizer grade and application rate were the same as the first year, 10-20-10 at 880 kg/ha. It was broadcast by hand over only one half the surface area of the original plots (1.5×15.2 m). In the second year (June 1978), all 70 plots received fertilizer; and in the third year (May 1979), only 14 of the

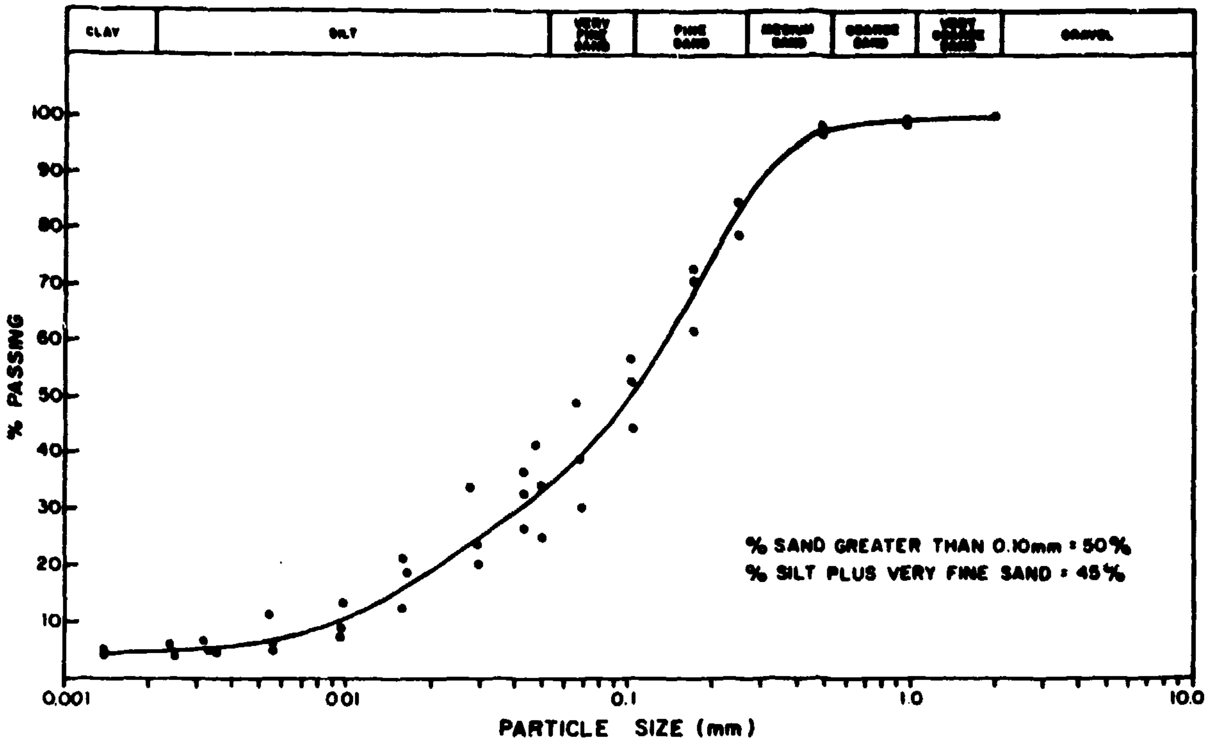


Figure 5. Fine-grained soil size analysis (after Aldrich and Johnson 1979).

Table 2. Seed mixtures.

Seed type	*Rate (kg/ha)* S	3S	S+B	V1	V2	V3	S1	S2*	S2†	S3**
Alsike clover (*Trifolium hybridum* L.)							3.3			
Annual ryegrass (*Lolium multiflorum* Lam.)	11	33	11	14	8	6	5.5			3.5
Arctared fescue (*Festuca rubra* L.)										5.5
Bluejoint reedgrass (*Calamagrostis canadensis*)			11							
Boreal red fescue (*Festuca rubra* L.)							5.5			
Creeping red fescue (*Festuca rubra* L.)	24	72	24	24	24	24		55.0	38.5	
Durar hard tescue (*Festuca ovina* L.)							4.4			4.4
Manchar brome (*Bromus inermis* Leyss.)							5.5			5.5
Meadow foxtail (*Alopecurus pratensis* L.)							13.2			13.2
Nugget Kentucky bluegrass (*Poa pratensis* L.)	8	23	8	8	8	8				
Perennial ryegrass (*Lolium perenne* L.)								55.0	38.5	
Sydport Kentucky bluegrass (*Poa pratensis* L.)							3.3			3.3
Total	43	128	54	46	40	38	40.7	110.0	77.0	35.4

* S2–sludge.
† S2–Conwed (1978).
** S3–Conwed (1979).

plots received fertilizer (Table 3). Plots had the same half refertilized in both 1978 and 1979 to compare refertilization effects.

Sludge plots

In June 1978, ten downstream plots received sewage sludge (thickened wastewater, 3.6% total solids) applied at a rate of 25 metric tons/ha. We applied the sludge with fertilizer and combinations of seed, mulch, and lime (Fig. 3, Table 1). Three treatments had three replicate plots each and one treatment had only a single plot (Table 1).

The Fairbanks Sanitation Department sup-

Table 3. 1977 plots that were refertilized in May 1979.

Plot no. Upstream	Downstream	Treatment*
6	3	S,F
9	6	S,F,WCF
12	9	S,F,H
15	12	S,F,CHM2000
15	15	S,F,P
21	18	S,F,P+WCF
30	27	TS,W,S,F,H

* See list of abbreviations on p.

plied the sludge, which was pumped from the thickening machine at the treatment plant directly into the hydromulcher. In the case of Plots 4–10, we added seed, fertilizer, mulch and lime (Plots 4–6) to the sludge in the hydromulcher and applied the entire treatment in a one-step operation. On Plots 1–3, the sludge was applied first and then oversprayed with the rest of the treatment.

Two new seed mixtures were tested on the sludge plots (Table 2). One of them (S1) included several cold-adapted perennial grass species: Manchar brome, meadow foxtail, boreal red fescue, Durar hard fescue and Sydport Kentucky bluegrass. Including seed of annual ryegrass and alsike clover, the total applied rate was 40.7 kg/ha. This mix was used on Plots 1–3 and 10. The other new seed mixture (S2) had equal amounts of perennial ryegrass and creeping red fescue and was applied to Plots 4–9 at a rate of 110 kg/ha.

The other components of the sludge treatments were fertilizer (10-20-10) applied at 660 kg/ha, mulch (WCF or CHM 2000) applied at 1830 kg/ha, and on two treatments, lime applied at 610 kg/ha. The fertilizer included a crushed limestone filler that was sufficient to neutralize the sludge mixture on those plots not receiving additional lime. The pH was raised on the average from 6.2 to 7.2. It was discovered that the additional lime was excessive, raising the pH to 9.7.

The sludge plots were treated again in May 1979. One-third of each plot (8×15 m) was refertilized with 10-20-10 fertilizer at 880 kg/ha; a second third received an additional 25 metric tons/ha of lime-neutralized (110 kg/ha) sludge (1250 kg solids/ha) sprayed from the hydromulcher; and the final third did not receive any new treatment.

Conwed blanket plots

The Conwed erosion control blanket installed in 1978 consisted of wood-cellulose-fiber mulch held together by a starch tackifier and bonded on one side to a plastic netting (1-cm grid). The 1-m-wide blankets came in two thicknesses (equivalent to 9585 kg/ha and 14,370 kg/ha).

Two plots were established with the blankets—one for each thickness (Table 1). Blankets were rolled down the slope and secured with U-shaped wire staples at 1.2-m intervals (Fig. 6). They were placed netting side up for all except a few rolls.

We then hydromulched seed (S2), 10-20-10 fertilizer and CHM 2000 over the blanket surface (Table 1). The S2 seed mix was applied at a lower rate (77 kg/ha) than on the sludge plots. Fertilizer was applied at 473 kg/ha, and CHM 2000 was applied at 1177 kg/ha.

Because of their poor first-year growth, both blanket plots were retreated with seed, fertilizer and mulch in 1979. This was applied in mid-May so that early season moisture could aid seed germination. The seed mix (S3, Table 2) was similar to the S1 mix, with small amounts of several perennial species; it was applied at a rate of 35 kg/ha. Again the fertilizer was 10-20-10 applied at a rate of 880 kg/ha; the mulch was CHM 2000 at a rate of 1120 kg/ha.

Fine-soil plots

The six fine-soil plots installed in 1978 included three replicates of two successful treatments from 1977 over a 15-cm-thick base of fine-grained soil. These treatments were 1) seed (S1) and fertilizer and 2) seed (S1), fertilizer and hay (Table 1). We applied them by hand broadcasting. The fertilizer was 10-20-10 applied at a rate of 880 kg/ha and the hay (coarse bedding straw) was applied at a rate of 9570 kg/ha. Half of each of these plots was refertilized at the beginning of the second growing season (1979).

Tanana Levee site

The Tanana River Levee site was established in June 1978 and included 20 identical plots (15 ×3 m) on both the north and south sides of the levee (Fig. 2, 7, Table 4). All were treated with S1 seed mix (41 kg/ha) and 10-20-10 fertilizer (880 kg/ha).

Eighteen plots involved six treatments with a 15-cm cover of fine-grained soil over the gravel surface and the six mulch combinations used at the Moose Creek Dam site: hay, peat moss, WCF, peat

Figure 6. Installation of wood-cellulose-fiber blanket.

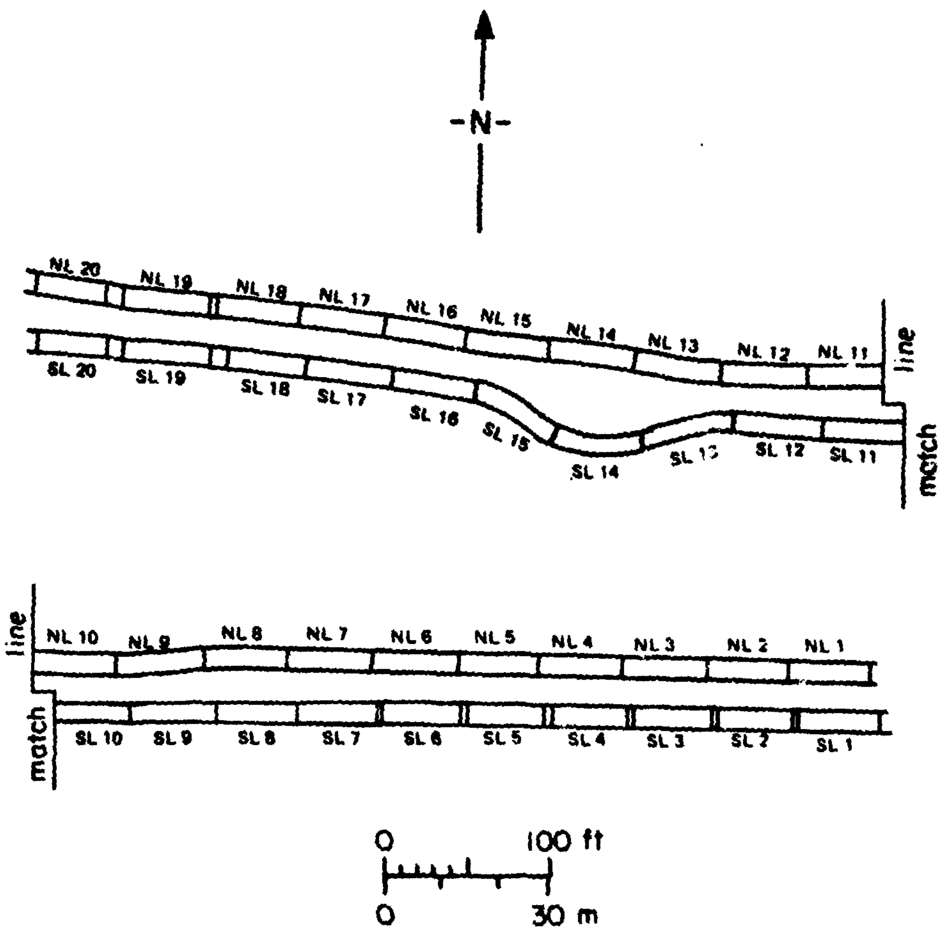


Figure 7. Plan of the Tanana River Levee revegetation site.

Table 4. 1978 Tanana River Levee treatments.*

Plot no.	Fine-grained soil (m^3/ha)	Mulch Type	Mulch Rate (kg/ha)	Blanket rate (kg/ha)
1,7,13	1500	H	9570	–
2,8,14	1500	P	3185	–
3,9,15	1500	WCF	4785	–
4,10,16	1500	CHM2000	4785	–
5,11,17	1500	P+WCF	3185+4785	–
6,12,18	1500	–	–	–
19	–	CHM2000	4785	14,730†
20	–	EX**	4785	–

* All plots received 41 kg/ha of seed mix S1 (Table 2) and 880 kg/ha of 10-20-10 fertilizer.

† Blankets placed mulch side up on south, netting side up on north.

** EX—excelsior mesh.

moss with WCF, CHM 2000 and no mulch. Hay was applied at a rate of 7570 kg/ha, peat moss at 3185 kg/ha, and WCF and CHM 2000 at 4785 kg/ha.

One of the two remaining plots received the Conwed blanket oversprayed with seed mix (S1), fertilizer and CHM 2000 (at 4785 kg/ha). The blanket on the south slope had the mulch side up and the one on the north slope had the netting side up. The final plot on either side of the levee was treated by hand broadcasting the seed mix (S1), fertilizer and excelsior mesh (4785 kg/ha).

In May 1979, half the area of the first replicate of the six main treatments (Plots 1–6) was refertilized with 10-20-10 fertilizer (880 kg/ha).

Sampling and measurement

Herbaceous measurements

In late August of each of the three years of the study, all seeded treatments were sampled for vegetative biomass, total cover, and maximum height. A number of subplots (0.25 m^2) were randomly selected within each treatment. On the dam, two or three subplots were selected from within both the upper and the lower 6 m of each plot or plot section. Because the levee was not as high as the dam, only two or three subplots were selected randomly within the entire plot. Cover percentage was estimated visually, vegetation height was measured to the nearest centimeter, and all aboveground vegetation within the subplots was clipped. Vegetation samples were subsequently oven-dried at 60°C for 48 hours and weighed to determine dry-weight biomass.

To measure the proportion of each species within the total biomass for a certain treatment, dried clippings from six subplots were separated by species; each species was then weighed to determine its dry-weight biomass.

Willow survival

Survival percentage of the willow cuttings was determined in late August 1977, 1978 and 1979 by counting the surviving willows and comparing that number to the number planted per plot. Survival percentage was calculated for the topmost three and bottommost three rows of willows as well as for all willows on the plot. Maximum height of willow growth was measured in 1977 and 1978.

Seedling densities and root excavation

An engineering concern on the dam is the penetration of roots of native woody species and the associated problem of water movement down root channels and through the dam. To assess the potential danger, we surveyed the density of seedlings on the dam and excavated some of their root systems.

Seedling densities were determined by counting the number of seedlings in three or more 1-m^2 plots at different areas and on our treatments on the dam. The average seedling densities were determined for untreated, seeded gravel and both seeded and unseeded fine-soil treatments.

Depth of root penetration by these woody species was investigated during the 1979 field season. The root systems of 13 plants of balsam poplar (*Populus balsamifera*), feltleaf willow (*Salix alaxensis*) and quaking aspen (*Populus tremuloides*) were examined during two sets of excavations. We measured shoot height, lateral root spread, and maximum root penetration. Root systems were excavated, separated according to depth increments, washed, dried at 60°C for 48 hours, and then weighed to determine root biomass, which we compared to depth of penetration.

Sediment loss

The erosion potential of the Moose Creek Dam 1977 treatments was assessed by measuring sediment loss from the plots on the upstream side. A tank placed at the base of each plot (except nos. 22 and 24) trapped any sediment moving down the slope (Fig. 8). The material in the tank was collected and oven dried at 110°C for 48 hours. To convert this dry weight value to

a. Front view.

b. Side view.

Figure 8. Sediment collection tank.

weight/area, we divided the weight of sediment loss by the area of the plot located directly above the tank (1.2 m×15.2 m).

The tanks at the base of the fine-soil plots (nos. 25–30, 37) were covered with specially designed lids to prevent blowing silt from the floodway from entering them. Sediment was collected from these plots after each major storm in both 1977 and 1978 (Aldrich and Johnson 1979). Sediment loss from the gravel base plots was measured during 1977 only.

Limiting soil moisture

To test our hypothesis that soil moisture is limiting to plant growth on the dam, both soil moisture and plant diffusive resistance were measured in 1979. Soil moisture was determined gravimetrically from surface soil samples approximately every two weeks from late May to late July 1979. Three samples were taken from within 6 m of both the top and bottom of the upstream and downstream sides of the dam. The samples were oven dried at 110°C for 48 hours.

A preliminary study of plant diffusive resistance was conducted in August 1979. Diffusive resistance is measured using a diffusive porometer with a lithium-chloride-coated sensor. When placed over a leaf, the sensor absorbs water vapor diffusing from the leaf and the electrical conductivity through the lithium chloride increases. The sensor is responsive over a relative humidity range from 18% to 33%. A change in relative humidity of approximately 1% is timed between two preselected points on the porometer scale. Stomatal resistances are then calculated using the known resistance fields of a calibration plate. Relatively high stomatal resistance values suggest moisture stress conditions.

The diffusive resistances of two species growing on 1977 Plot 9 on either side of the dam were measured during August 1979. The first was a seeded brome and the second was a balsam poplar seedling. Measurements were made on both the upper and lower leaf surfaces. A total of 14 brome plants and 4 balsam poplar plants were examined.

Soil chemical analysis

Samples for soil chemical analysis were collected during July of 1977 and 1978 by taking surface soil samples to a depth of about 10 cm from all plots in 1977 and selected plots in 1978. Samples were analyzed at the University of Wisconsin soil and plant analysis laboratory according to the procedures of Liegel and Schulte (1977). A glass-electrode meter was used to measure pH; organic matter and available P were determined by calorimetric methods; and available K was measured with flame photometry.

Sludge and runoff water analysis

Sludge samples taken in 1978 and 1979 from the Fairbanks treatment plant were analyzed by Environmental Services Ltd. in Fairbanks for heavy metals, pathogens and other chemical parameters.

Runoff water from the sludge plots was collected in tanks similar to our sediment collection tanks. Water samples were taken from the tanks as soon as possible after the first major rainstorm in both the 1978 and 1979 growing seasons. These were analyzed chemically and biologically by Environmental Services Ltd.

Air and soil temperature

In 1979 three temperature recorders operated from June to September at a location about 50 m north of our main study site on Moose Creek Dam. The instrument and shelter were placed in a locked metal cage to discourage vandalism (Fig. 9). Two recorders were spaced one-third and two-thirds of the way up from the bottom of the downstream (northwest-facing) slope. The other was located one-third of the way up from the bottom of the upstream (southeast-facing) slope. This set-up was designed to compare temperatures at the top and bottom as well as to compare different aspects. Each recorder had two

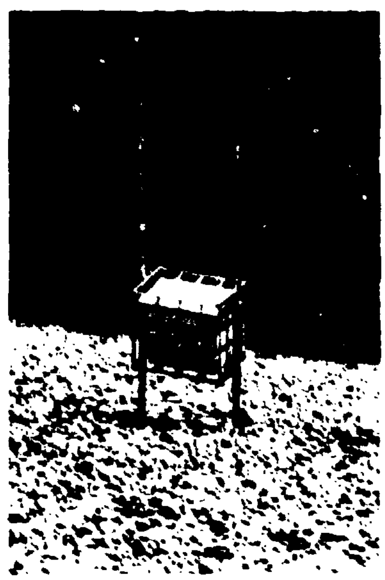


Figure 9. Air and soil temperature recording instrument.

Table 5. Meteorological data summary from mid-1977 to 1979 at Moose Creek Dam met team station.

	Air temperature (°C)			*Precipitation (mm)*		
Month	*Monthly mean**	*Normal mean†*	*Deviation*	*Monthly total**	*Normal total†*	*Deviation*
1977						
May	9	9	0	7	17	−10
June	14	15	−1	94	36	+58
July	15	16	−1	40	48	−8
Aug	17	13	+4	18	56	−38
Sept	9	7	+2	62	27	+35
Oct	−4	−4	0	21	19	+2
Nov	−19	−16	−3	3	17	−14
Dec	−27	−24	−3	18	17	+1
1978						
Jan	(−17)**	−24	+7	(8)**	15	−7
Feb	(−14)	−19	+5	(5)	14	−9
Mar	(−10)	−13	+3	(17)	12	+5
Apr	−1	−2	+1	3	8	−5
May	9	9	0	(10)	17	−7
June	12	15	−3	26	36	−10
July	18	16	+2	21	48	−27
Aug	15	13	+2	39	56	−17
Sept	8	7	+1	(27)	27	0
Oct	−4	−4	0	(12)	19	−7
Nov	(−13)	−16	+3	24	17	+7
Dec	(−16)	−24	+8	(31)	17	+14
1979						
Jan	(−22)	−24	+2	(15)	15	0
Feb	(−31)	−19	−12	(1)	14	−13
Mar	−11	−13	+2	(9)	12	−3
Apr	−2	−2	0	6	8	−2
May	10	9	+1	1	17	−16
June	13	15	−2	27	36	−9
July	16	16	0	82	48	+34
Aug	14	13	+1	5	56	−51
Sept	7	7	0	5	27	−22

* Mean temperatures and accumulated monthly precipitation recorded at Moose Creek Dam site (U.S. Army ASL met team, Ft. Wainwright detachment 1977–1979).

† Normal readings are 30-yr normal (1941–1970) taken at the Fairbanks airport site (NOAA 1979).

** Data missing due to clock stoppages; values shown in parentheses are estimations. See text.

sensors, one for soil temperature at a 15-cm depth and the other for air temperature measured in the shelter 1 m above the ground surface.

ABIOTIC CONTROLS ON VEGETATION

Meteorological data

Throughout our study period, the Ft. Wainwright Meteorological Support Team recorded air temperature and precipitation data at a station near the Moose Creek Dam. Table 5 presents these data along with the 30-year (1941–1970) normals from Fairbanks International Airport (U.S. Army ASL Met Support Team 1977–1979, NOAA 1977–1979). For periods when data from the Met team station were missing due to clock failure, we substituted an average value from nearby stations at Fairbanks International Airport, North Pole and the University of Alaska Experiment Station (NOAA 1977–1979).

Air temperature

In overview, average monthly summer air temperatures during the three years of study were close to normal in most cases (Table 5). The greatest summertime deviation from normal was

4°C in August 1977. The greatest monthly deviations from the Fairbanks normal occurred in the winter (7° to 12°C).

A measure of the overall growing season temperature is the total number of growing-season degree-days. Daily deviations from a selected base temperature (usually 5°C) are totaled for the entire period between the times in the spring and fall when the daily average temperature equals 5°C.

The 30-year average of the total number of growing-season degree-days at the Fairbanks airport is 1063 (NOAA, Richard Haugen 1980, pers. comm.). The comparable values at the Moose Creek Dam for the three years of our study were 1284 growing-season degree-days for 1977, 1218 for 1978, and 1326 for 1979. All three years, then, had above-average normal temperatures. Relatively, 1979 had the highest total, 1977 had the next highest, and 1978 had the lowest (Richard Haugen 1980, pers. comm.).

During the 1977 growing season, temperatures were near normal from May through July and above normal (by 4°C) in August. The winter of 1977–78 started with temperatures slightly above normal (by 2°C) in September, then normal temperatures in October and below normal temperatures in November (by 3°). December was the coldest part of the winter, averaging -27°C (3°C below normal). The remainder of the winter was mild, with temperatures remaining above normal from January through April.

During the summer of 1978, temperatures averaged slightly above normal. They were normal in May, slightly below normal in June (by 3°C), and above normal in July and August (by 2°C). The winter of 1978–79 was, for the most part, mild. Temperatures were normal or above normal between September and April, except for February, which had an exceptionally low average temperature of -31°C (12°C below normal).

Temperatures during the 1979 growing season were close to normal. The greatest deviation from normal was in June when temperatures were 2°C below normal.

Precipitation

Total precipitation during the study period was above the Fairbanks normal in 1977 by 26 mm, below normal in 1978 by 58 mm, and below normal in 1979 by 82 mm between January and September (Table 5). Total growing season (May–August) precipitation was 159 mm (2 mm above normal) in 1977, 96 mm (61 mm below normal) in 1978, and 115 mm (42 mm below normal) in 1979.

Throughout the 1977 growing season, precipitation was highly variable. Amounts were 10 mm below normal in May, 58 mm above normal in June, and 8 and 38 mm below normal in July and August, respectively. September and October were wetter than usual (by 35 and 2 mm, respectively). Between November 1977 and April 1978 there was below-normal precipitation (by 29 mm), although December and March had slightly more precipitation than normal (1 and 5 mm, respectively).

The 1978 growing season was consistently dry, with a total of 96 mm of precipitation for May–August. July was especially dry (27 mm below normal). September returned to normal, but October was dry (7 mm below normal). The winter of 1978–79 began with more precipitation than normal in November and December (7 and 11 mm, respectively). January returned to normal and February–April had less precipitation than normal (by 13, 3 and 2 mm, respectively).

During the 1979 growing season, precipitation was highly variable. May and June had below-normal amounts (by 16 and 9 mm, respectively). July was very wet, with 34 mm above normal. August had very little precipitation (51 mm below normal).

Air and soil temperature on site

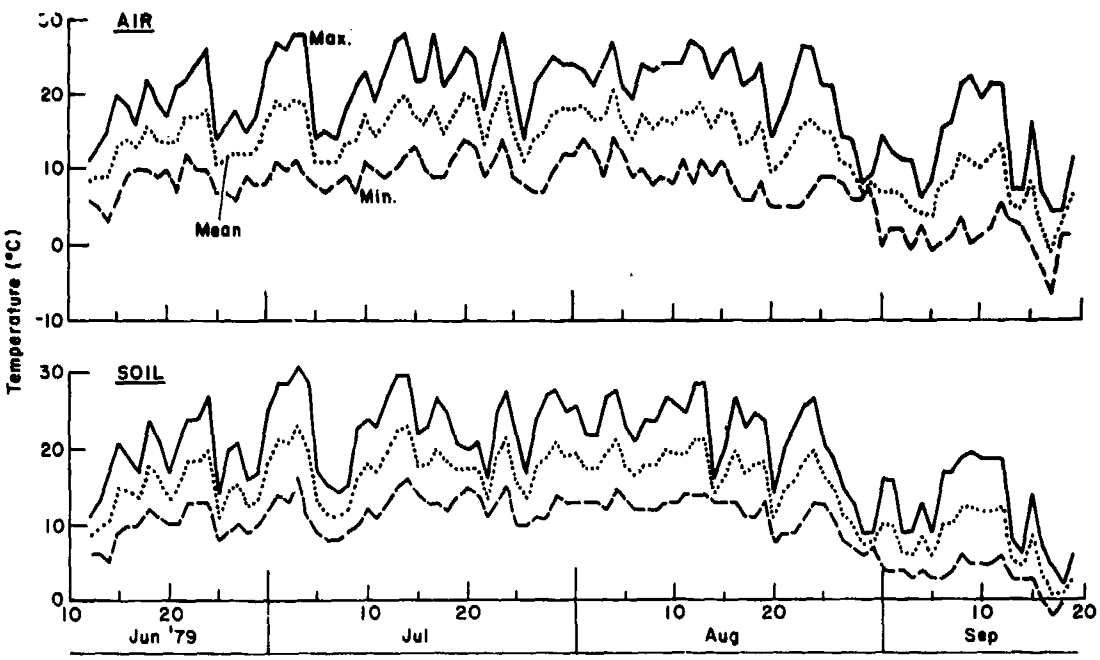
Figure 10 gives the daily maximum, minimum and mean air and soil temperatures during the 1979 growing season at the three recorders near our dam site. Table 6 contains the monthly temperature averages and extremes.

The average air temperature readings (1 m above the soil surface) were close to the 30-year normal at the Fairbanks airport.

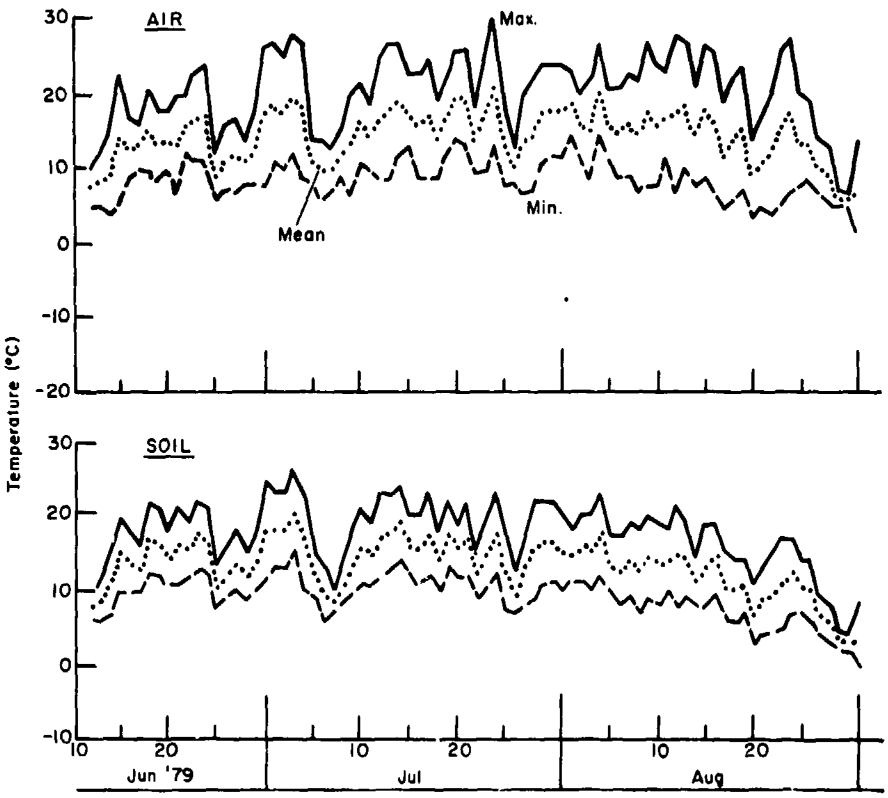
Average air temperatures at the three recorders were quite uniform, all within 0.5°C, and were not significantly different when tested with Wilcoxon's signed rank test. Soil temperatures, on the other hand, were variable. Over the three months of the growing season (June–August), mean soil temperatures averaged 3.2°C higher on the upstream side than on the downstream side. For June and July, soil temperatures at the top of the downstream side averaged 3.0°C higher than farther down the same slope. Both these differences were significant at the 0.001 level with Wilcoxon's signed rank test.

Soil moisture as a limiting factor

To evaluate the importance of soil moisture as a limiting factor for plant growth, both soil moisture and plant moisture stress data were taken in 1979.

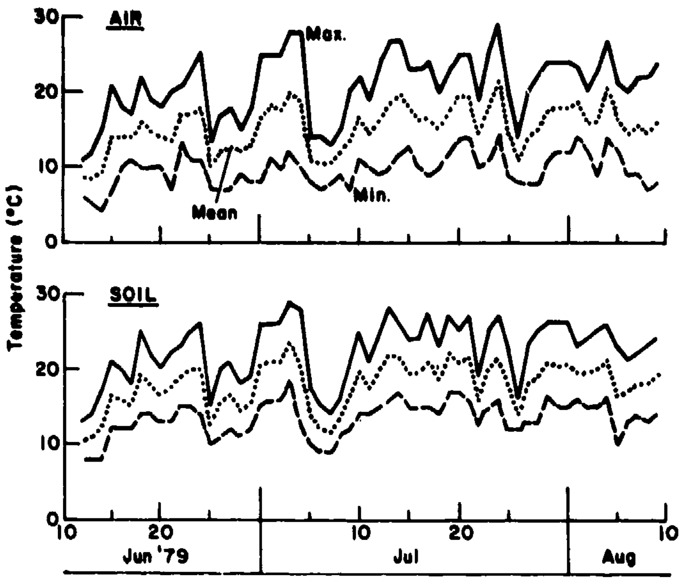


a. Upstream (SE) inside of the dam.



b. Bottom of dowstream (NW) side of the dam.

Figure 10. Daily 1979 air and soil temperatures at the revegetation site.



c. *Top of downstream (NW) side.*

Figure 10. (cont'd) Daily 1979 air and soil temperatures at the revegetation site.

Table 6. Average monthly temperatures (°C) at Moose Creek Dam site (1979).

	June			*July*			*August*		
	Upstream	*Downstream*	*Top*	*Upstream*	*Downstream*	*Top*	*Upstream*	*Downstream*	*Top*
Air									
Average	13.2	12.9	13.4	16.3	16.0	16.2	14.6	14.2	(16.4)*
Absolute max	26.0	26.0	25.0	28.0	30.0	29.0	27.0	28.0	(27.0)
Average max	18.4	17.8	18.3	22.6	22.1	22.1	21.0	20.9	(22.4)
Average min	8.0	8.1	8.5	10.0	9.9	10.3	8.2	7.6	(10.4)
Absolute min	3.0	4.0	4.0	7.0	6.0	7.0	0.0	0.0	(7.0)
Soil									
Average	14.6	14.0	16.2	18.0	15.1	18.9	16.5	11.1	(18.7)
Absolute max	27.0	25.0	26.0	31.0	26.0	29.0	29.0	23.0	(26.0)
Average max	19.4	17.9	20.3	23.6	19.6	23.6	21.7	15.4	(23.4)
Average min	9.8	10.0	12.1	12.3	10.5	14.2	11.3	6.8	(14.0)
Absolute min	5.0	6.0	8.0	8.0	6.0	9.0	4.0	-1.0	(10.0)

* Data for 1-9 Aug only.

Figure 11 presents the soil moisture data for the upstream and downstream sides of the dam from late May through late July 1979. Each point is an average of three samples.

Soil moisture on the bottom of the downstream side was consistently higher than that on the bottom of the upstream side. The soil moisture from the top showed a similar trend 75% of the time.

The relationship of top- to bottom-slope soil moisture was variable on the upstream side of the dam. However, moisture on the bottom of the downstream side exceeded that of the upper part of the same slope 75% of the time, indicating downslope movement of water. This relationship was probably obscured on the upstream side of the dam by the lower total soil moisture.

These results are confirmed with statistical analyses When the moisture data were compared using Wilcoxon's signed rank test, the soil moisture of the samples from the bottom of the downstream side was significantly greater at the 0.01 level than the moisture at the bottom of the upstream side. All other comparisons were not significant.

Table 7 contains measurements of the diffusive resistance of two species growing on Plot 9 on both sides of the dam during August 1979.

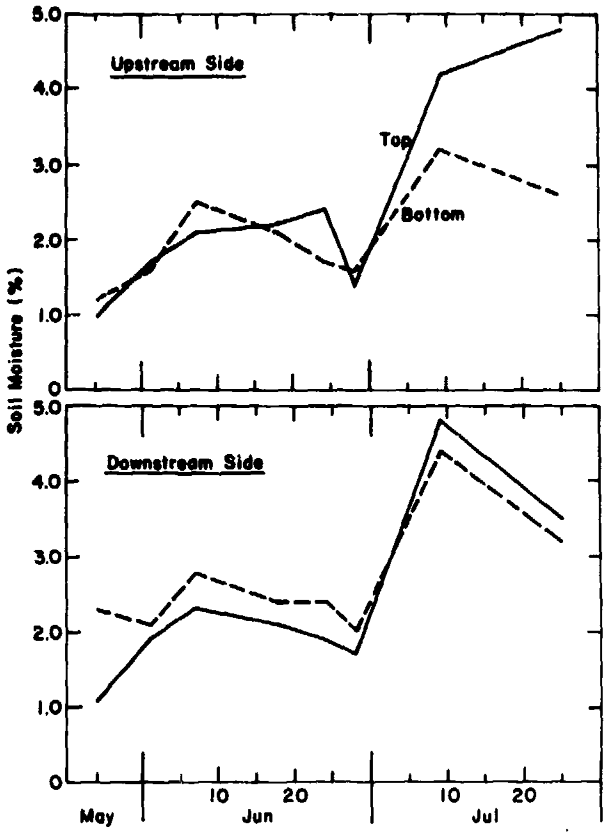


Figure 11. Percent soil moisture at Chena Dam—summer 1979.

Table 7. Stomatal resistances for brome and balsam poplar.

Species	*Location*	*Leaf surface*	*Stomatal resistance (s/cm)*
Brome	Downstream	Lower	27.3±23.4*
		Upper	6.2±1.9
	Upstream	Lower	61.0±32.1
		Upper	12.7±7.9
Balsam poplar	Downstream	Lower	3.65±2.2
		Upper	77.1±30.4
	Upstream	Lower	3.5±0.6
		Upper	80.2±5.3

* $\bar{x}$ ± standard deviation.

Relatively high stomatal resistance values suggest moisture stress conditions. In this preliminary survey, the sample size was not large enough to point out statistically significant differences in the stomatal resistances of the upstream and downstream plants. However, for brome, the mean resistance values were higher in the upstream plot (Table 7). This is consistent with the moisture and temperature data, which show higher soil temperatures and reduced soil moisture on the upstream slope. Hence, vegetation on the upstream slope is probably under greater moisture stress, which reduces growth.

Soil chemical analysis

Soil analyses were performed on samples taken during mid-growing-season in 1977 and 1978 to determine pH, organic matter, available phosphorus (P), and available potassium (K) (Tables 8 and 9).

In 1977 the fine-soil substrate was slightly alkaline, with the pH ranging from 7.5 to 7.9, whereas the gravel substrate pH ranged from 5.9 to 7.5. The more acidic samples were from treatments involving peat moss. In 1978, most of these soils, both refertilized and non-refertilized, were slightly more acidic than they had been the year before.

The fine-soil treatments installed on the dam and levee in 1978 were slightly alkaline, ranging in pH from 7.3 to 7.7. The sludge treatments including additional lime were alkaline (pH 7.5 to 8.6), while the sludge treatments without additional lime were close to neutral (pH 6.8 to 7.0).

The gravel substrate on the dam had 9 metric tons/ha of organic matter. The average organic matter in gravel with applied mulches varied from 11 metric tons/ha for hay-mulched soil to 60 metric tons/ha for peat-moss-mulched soil. The fine-soil cover used in 1977 averaged 32 metric tons/ha organic matter, while the 1978 fine soil averaged 43 metric tons/ha.

Levels of available P and available K in the plots of 1977 were greatly increased from the control, but varied depending on the presence of fine soil and the type of mulch added (Table 8). The fine-soil plots had less available P than other treated plots, while the plots receiving only seed and fertilizer had the highest levels of available P.

In 1978 the levels of available P and available K in the 1977 plots dropped from the previous year on most non-refertilized sections of the plots and were highest on the refertilized sections and on the sludge plots. The levee plots and 1978 fine-soil plots had relatively high levels of K but low levels of P, indicating a fairly rapid immobilization of P by the soil.

No sampling for soil chemical analysis was performed in 1979.

Table 8. Analysis of soil samples from 1977 dam plots (July 1977).*

Plot numbers				Organic matter	Available P	Available K
Upstream	*Downstream*	*Treatment*	*pH*	*(MT/ha)*	*(kg/ha)*	*(kg/ha)*
1,2,3		Control	7.5 (0.03)†	9 (0)	13 (1.6)	110 (0)
4,5,6	1,2,3	S-F	7.1 (0.10)	9 (0.5)	317 (39)	229 (18)
7,8,9	4,5,6	S-F-WCF	7.1 (0.03)	13 (1.0)	147 (11)	177 (5.7)
10,11,12	7,8,9	S-F-H	7.0 (0.03)	11 (0.7)	251 (50)	207 (16)
13,14,15	10,11,12	S-F-CHM2000	7.0 (0.04)	18 (1.3)	155 (23)	186 (13)
16,17,18	13,14,15	S-F-P	5.9 (0.10)	60 (7.9)	166 (13)	188 (9.9)
19,20,21	16,17,18	S-F-P+WCF	6.0 (0.13)	63 (12.7)	141 (6.3)	187 (4.7)
25,26,27	24	TS-W-F-H	7.8 (0.05)	36 (1.7)	80 (14)	199 (12)
28,29,30	25,26,27	TS-W-S-F-H	7.9 (0.07)	34 (1.7)	96 (27)	276 (52)
31,32,33	28,29,30	W-F-CHM2000	7.0 (0.03)	20 (2.1)	141 (10)	188 (4.7)
34,35,36	31,32,33	W-F	7.0 (0.13)	11 (0.8)	188 (62)	244 (55)
	22,23	W-F-H	7.1 (0.05)	13 (1.1)	300 (142)	286 (28)
22,24		TS-S+B-F	7.5 (0)	29 (2.2)	29 (5.6)	179 (31)
23		TS-3S-F-Fibgl	7.8	34	47	138
	19	V1-F	7.1	11	231	182
	20	V2-F	6.9	13	248	237
	21	V3-F	7.0	13	149	182
	37	TS-S-F	7.9	29	74	182

* Analyses performed at Soil and Plant Analysis Laboratory, University of Wisconsin, Madison, Wisconsin.

† $\bar{x}$ (standard error); results without adjacent parentheses are from single samples.

Table 9. Analysis of soil samples from selected plots (August 1978).

Plot type	*Plot no.*	*Treatment*	*pH*	*Organic matter (MT/ha)*	*Available P (kg/ha)*	*Available K (kg/ha)*
1977 dam plots*						
DW	14	S-F-P	5.8	88	138	187
	18	S-F-P+WCF	6.3	34	127	165
	26	TS-S-F-W-H	7.4	38	75	248
DW(R)	16	S-F-P	6.0	38	242	352
	19	V1-F	6.4	14	440	523
	31	F-W	6.4	14	440	660
UP	4	S-F	6.7	11	209	176
	8	S-F-WCF	6.8	14	176	182
	11	S-F-H	6.7	11	73	130
UP(R)	9	S-F-WCF	6.2	11	220	200
	11	S-F-H	6.3	11	440	468
	36	TS-S-F	6.3	11	275	259
Sludge	1,2,3	S1-F-CHM2000-L	7.8 (0.20)†	18 (2.2)	249 (82)	234 (21)
	4,5,6	S2-F-CHM2000-L	8.7 (0.07)	20 (2.2)	403 (37)	296 (38)
	7,8,9	S2-F-WCF	6.9 (0.05)	17 (2.0)	323 (65)	274 (26)
	10	S1-F	6.8	11	242	242
78 fine soil	1,2,3	TS-S1-F	7.4 (0)	44 (2.0)	48 (4.8)	235 (12)
	4,5,6	TS-S1-F-H	7.5 (0.03)	42 (1.2)	37 (4.7)	246 (13)
North Levee	1	TS-S1-F-H	7.6	41	35	226
	10	TS-S1-F-CHM2000	7.7	45	36	215
	11	TS-S1-F-P+WCF	7.6	45	63	220
South Levee	3	TS-S1-F-WCF	7.3	52	226	418
	9	TS-S1-F-WCF	7.4	52	33	226
	16	TS-S1-F-CHM2000	7.6	56	33	215

* DW—downstream slope; UP—upstream slope; R—refertilized.

† $\bar{x}$ (standard error).

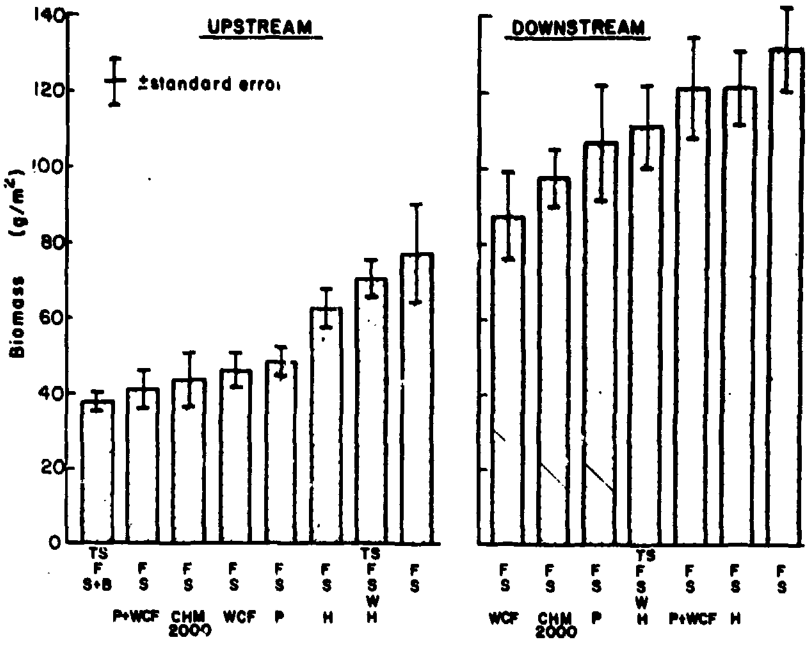


Figure 12. Average dry weight (biomass) of vegetative cover for the 1977 dam treatments in late August 1977.

VEGETATION GROWTH AND SURVIVAL

As previously mentioned, several seed mixes were used in 1977, 1978 and 1979, including both perennial and annual grasses as well as alsike clover. The responses of these seed mixes and of the willow cuttings are first analyzed separately. Discussion of interactions with each other and with the other variables, such as mulch, substrate, plot aspect, frequency of fertilization, soil temperature, and soil moisture, follows.

Data for aboveground biomass, cover, and height are important for several reasons. In addition to providing a quantitative estimate of differences between treatments, vegetative soil cover is an important parameter for erosion control since vegetation reduces the impact of raindrops and slows the movement of water on unprotected soils. This decreases susceptibility to erosion. Dense vegetation provides a protective organic mat, which prevents erosion due to moving floodwaters. Aboveground biomass indirectly measures soil organic matter, which is important for both nutrient- and moisture-holding capacity. Finally, biomass is a good parameter for estimating productivity and, indirectly, vigor of the vegetation.

Moose Creek Dam site

Treatments established in 1977

The average dry weights for the major treatments are presented in Figures 12-14 for the years 1977-1979, respectively. More detailed information on biomass, average cover class, and maximum height for all treatments is presented in the Appendices (Tables A1, A2 for 1977, Tables B1-B4 for 1978, and Tables C1-C5 for 1979). Figure 15 shows some of the changes in biomass during the three years of the study for selected major treatments.

Aboveground biomass ranged from less than 2 g/m^2 to 390 g/m^2 over the three years of study. Generally, downstream plots outproduced upstream plots. Thrice-fertilized plots produced the greatest biomass, followed by twice-fertilized and then once-fertilized plots (Fig. 12-15). Cover values varied between 10 and 90% and maximum heights between 10 and 60 cm (Appendix Tables A1-C5). In most cases both cover values and maximum heights showed the same trends as the biomass data. Therefore, most of the following discussion deals with biomass, since this seems to be the most reliable indicator of growth.

Fertilization had a dramatic effect on biomass

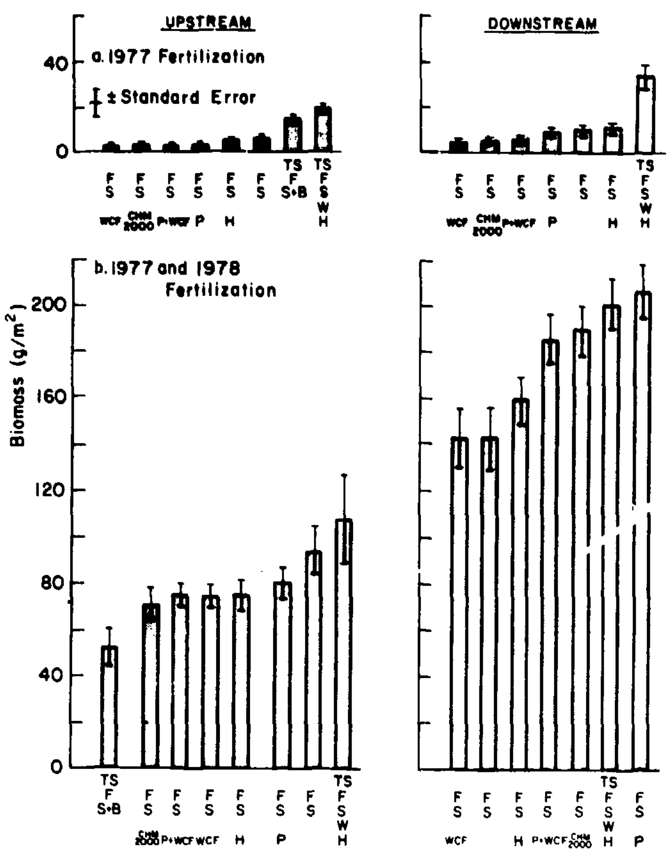


Figure 13. Average dry weight (biomass) of vegetative cover for the 1977 dam treatments taken in late August 1978.

production. This was expected since 1977 soil analyses showed very low levels of P (13 kg/ha), and it is presumed that N levels were also insufficient for good plant growth. Both a second and a third fertilization increased biomass production by the grasses (Fig. 15). During 1978, grass biomass averaged 24 times greater on treatments that received additional fertilizer (Fig. 13; right side of plots shown in Fig. 16, 19 and 21). Soil analyses support these results, since refertilized treatments averaged more than twice as much P and K as single fertilization treatments (Table 9). In 1979 plots that had been fertilized twice averaged 11 times more biomass, while plots that had both the second and third fertilizations averaged 27 times more biomass than their respective plots with only the initial fertilization. In fact, minimum biomass of the twice-fertilized treatments exceeded the maximum biomass of the once-fertilized treatments. Similarly, the minimum biomass of the thrice-fertilized treatments exceeded the maximum biomass of the twice-fertilized treatments (Fig. 14).

Several multiyear trends are evident in Figure 15. Treatments receiving a single fertilization generally had highest biomasses in 1977, with minimum biomasses in 1978 and intermediate ones in 1979 (compare Fig. 20 to left of Fig. 21). This was probably due to two factors. First, the annual ryegrass produced over 95% of the biomass in 1977 but only 31% in 1978 and 3% in 1979. Therefore, some of the decrease in biomass was due to the low rate of reseeding of annual ryegrass. Second, the ryegrass probably inhibited growth of the perennials in both 1977 and 1978, primarily by nutrient competition (Johnson 1978). Weather may also have had some influence; both 1978 and 1979 had below-average precipitation (Table 5) and were slightly cooler than 1977.

Treatments receiving a second fertilization in 1978 generally produced increased yields in 1978 and had their highest yields in 1979, the second year after fertilization (Fig. 15, right side of Fig. 16, right side of Fig. 19). This was due to the higher soil-nutrient levels of refertilized treatments

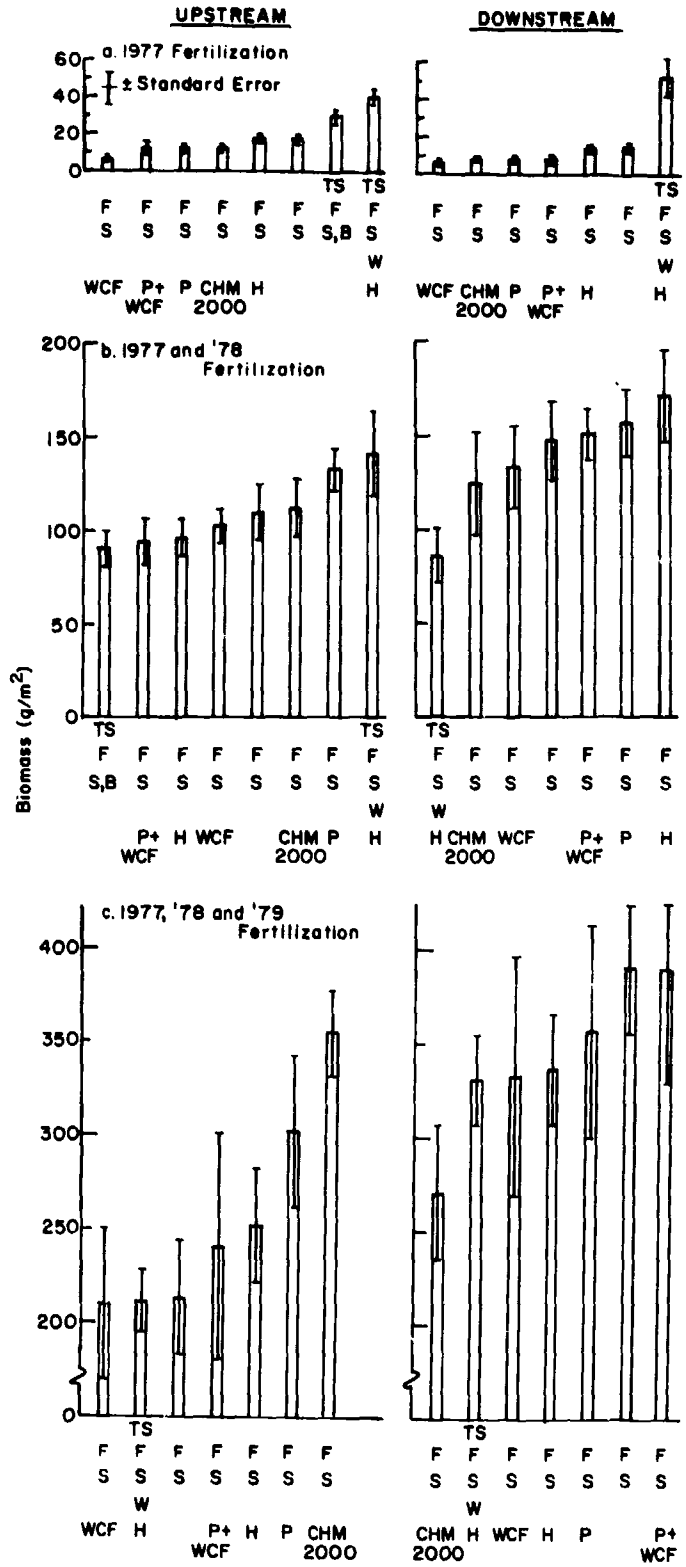


Figure 14. Average dry weight (biomass) of vegetative cover for the 1977 dam treatments taken in late August 1979.

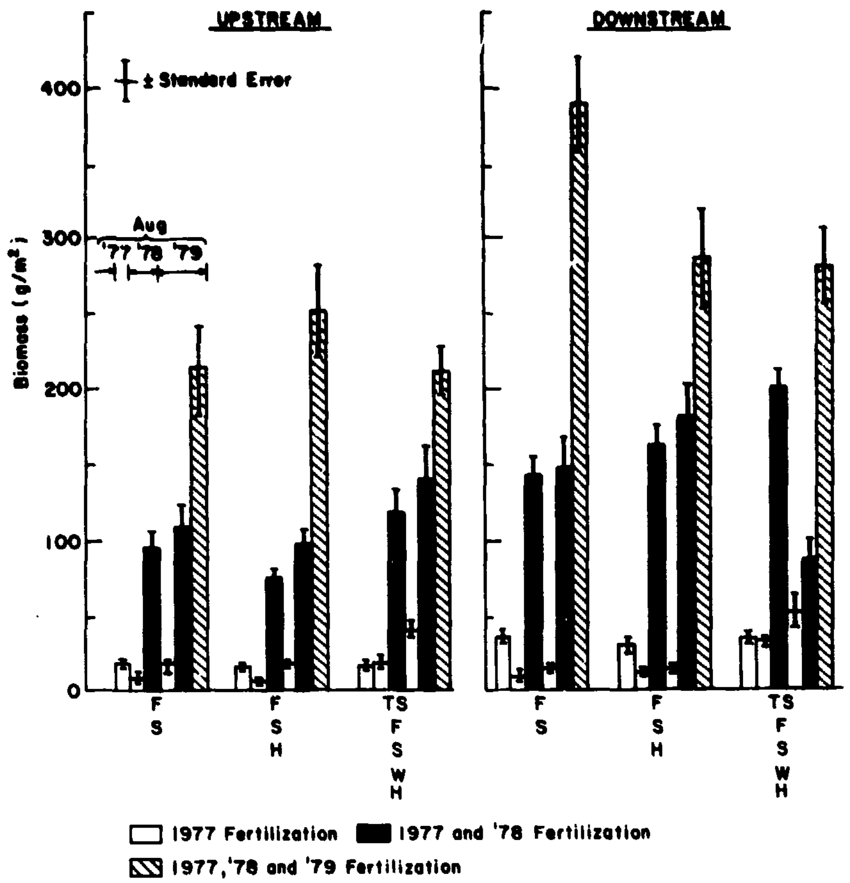


Figure 15. Comparison of biomass means for selected major treatments over three years (1977–1979).

(Table 9) and the reduced ryegrass biomass in 1978; both factors would reduce the influence of nutrient competition by annual ryegrass on the perennial grasses in the seed mix, thereby increasing overall production.

Another observation relating to fertilization concerns interactions between the fine-soil treatments and fertilization. In 1978 and 1979 the fine-soil treatments produced the greatest biomass of all single fertilization treatments. Also, fine-soil treatments receiving a single fertilization did not exhibit the marked decline in biomass in their second year. In fact, some treatments actually produced the lowest biomasses in 1977, followed by increases in both 1978 and 1979. These results indicate the higher nutrient-holding capacity of these soils.

Annual ryegrass competition is influenced by seeding rate as well as fertilization. For the treatments with different annual ryegrass seeding rates, the twice-fertilized plot with 6 kg/ha annual ryegrass (V1 seed mix, Table 2) had the greatest biomass in 1979, whereas in both 1977 and 1978 the plot with 14 kg/ha annual ryegrass (V3) had the highest biomass. This may indicate that a higher proportion of annual ryegrass in the seed mix produces higher short-term biomass production at the expense of longer term reductions. It is not known how long such a reduction may persist.

The aspect of the plots affected the vegetation responses. As previously mentioned, the downstream plots generally outproduced the upstream plots (Fig. 15). In 1977 and especially 1978 the biomass cover and maximum height of the downstream treatments generally exceeded those of the comparable upstream treatments (68% of the time in 1978) (Fig. 17 and 18; Tables A5–A12). Although in 1979 this was true for only 65% of the comparisons, it was true 90% of the time for the triple fertilization treatments and less often for the double and single fertilization treatments.

These results reflect an interaction between soil moisture and fertility levels. Where nutrient levels were adequate (after triple fertilization

Figure 16. Downstream plot 17 (S-F-P + WCF), 22 August 1978, right half refertilized.

Figure 17. Upstream plot 29 (TS-W-S-F-H), 2 August 1977.

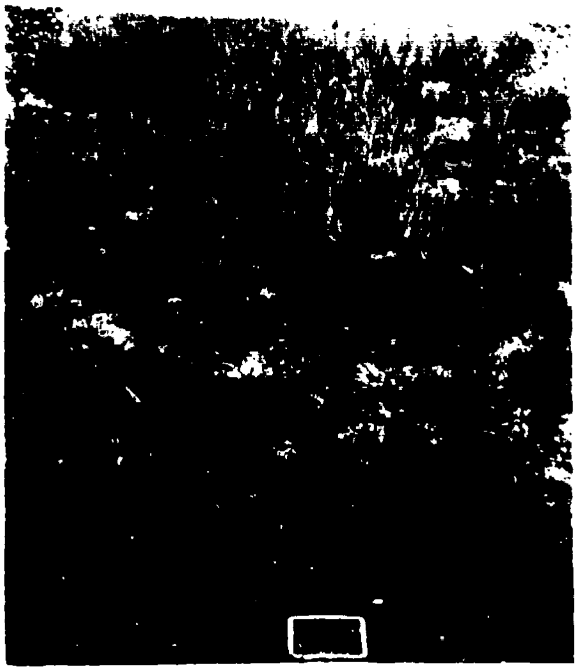


Figure 18. Downstream plot 26 (TS-W-S-F-H), 3 August 1977.

Figure 19. Downstream plot 26 (TS-W-S-F-H), 22 August 1978, right half refertilized.

Figure 20. Upstream plot 14 (S-F-CHM2000), 2 August 1977.

Figure 21. Upstream plot 14 (S-F-CHM2000), 25 August 1978, right half refertilized.

and less so for double fertilization), it is likely that soil moisture limited vegetation growth. Since the upstream side generally had less soil moisture (Fig. 11) and, at least for brome, showed greater moisture stress than the downstream side, it is reasonable that measurements (of biomass, cover and height) should show more growth on the downstream side in the triple-fertilization treatments. However, in both twice-and once-fertilized treatments, the difference between upstream and downstream plots was less dramatic because nutrients, rather than moisture, may have limited growth in at least some cases.

To a lesser extent, growth was also reduced at the top of the slope compared to that at the bottom of the slope. This was particularly true in 1977 and 1978. However, the major treatments did not show any clearly discernible differences in 1979 biomass at the top versus the bottom of the slope. Biomass was greater at the bottom of the slope only slightly more than half (55%) of the time in 1979. In contrast, during 1978 the biomass at the bottom of the slope was greater 77% of the time and averaged 150% of the biomass at the top.

Biomass production of the fiberglass treatment was well below average in both 1978 and 1979 (Tables A8 and A13). This was probably because the fiberglass blanket detrimentally shaded the grass.

Treatments established in 1978

The average dry weights of vegetation for the Moose Creek Dam treatments installed in 1978 are presented in Figure 22, including both 1978 and 1979 results. Tables D1 and D2 present more detailed data for biomass, cover, and maximum height in 1978 and 1979, respectively.

The 1978 and 1979 aboveground biomass from the 1978 sludge and fine-soil treatments ranged from 10 g/m^2 to over 460 g/m^2, the highest values of any treatment on the dam. Cover values ranged from 10 to 70% while maximum heights varied from 16 to 75 cm (Tables D1, D2). (It should be noted that the seed mix on many of these plots included two taller species, brome and meadow foxtail, which were not used on the 1977 plots.)

Although aboveground biomass from the

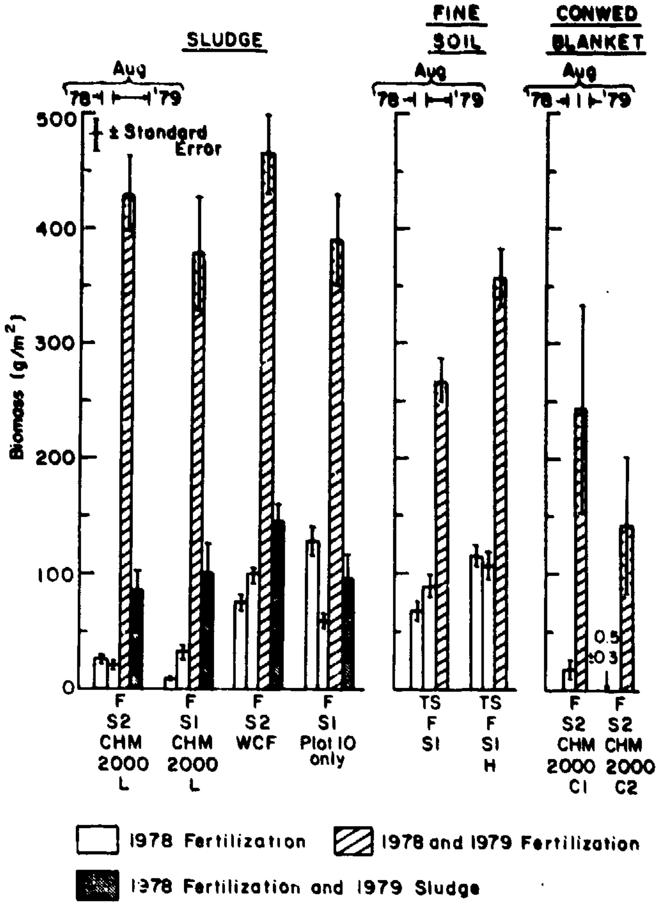


Figure 22. Average dry weight (biomass) of vegetative cover for the 1978 dam treatments in late August 1978 and 1979.

sludge treatments varied widely, the most productive sludge treatments compared favorably with the better 1977 treatments. In 1978 the sludge treatment with fertilizer and the S1 seed mix yielded the greatest average biomass, which was 99% of the maximum first-year biomass of any of the 1977 treatments. In 1979 the twice-fertilized sludge treatment with wood-cellulose-fiber mulch (WCF) produced the greatest biomass of any treatment, including thrice fertilized 1977 treatments that had had an extra year to become established.

Other sludge-treated plots outproduced similar, but unsludged, plots. For example, the once-fertilized sludge treatments with no additional lime produced greater second-year biomass than any of the once-fertilized 1977 treatments except those with fine soil.

Sludge amendments definitely increased growth, although the refertilized sludge plots had the highest yields. The twice-sludged treatments had more biomass in 1979 than the once-sludged treatments (2.8 times) but less than the twice-fertilized sludge treatments (0.29 times). In general, 1979 biomass, cover, and height values increase from once-sludged, to twice-sludged, to once-sludged plus twice-fertilized treatments (Fig. 22).

Sludge aids in vegetation establishment in several ways. On coarse-grained substrates, such as the gravel dam, the organic matter in the sludge increases the moisture- and nutrient-holding capacity of the soil. In addition, the sludge itself is a source of some nutrients for plants. The higher levels of available P and K in sludged treatments (Table 9), compared to those of unsludged treatments (Table 8), reflect these differences in nutrient sources and retention.

Additional lime raised the soil pH (Table 9) and generally reduced plant growth on lime-treated sludge plots. This is shown by the reduced biomass, cover, and maximum height in

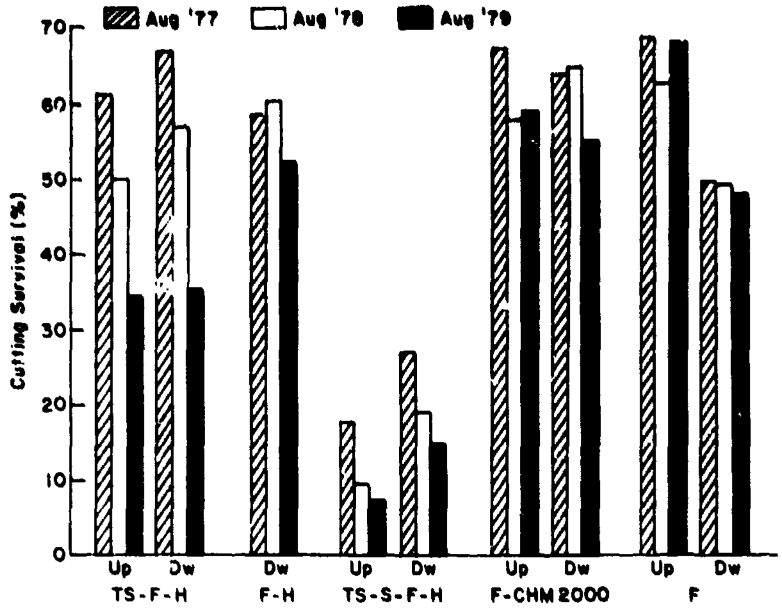


Figure 23. Survival rate of willow cuttings in late August 1977–1979.

the 1978 and 1979 sludge treatments with additional lime, compared to sludge treatments receiving only fertilizer and mulch (Fig. 22, Tables D1 and D2). The high pH may have directly inhibited plant growth or indirectly affected nutrient availability.

Although the fine-soil treatments did not produce the highest biomasses in either 1978 or 1979, their growth was quite good. The once-fertilized fine-soil treatments produced the highest biomass of all single fertilization treatments in 1979. However, the twice-fertilized fine-soil treatments had less growth than the twice-fertilized sludge treatments but more than the twice-sludged treatments (Fig. 22). Presumably, the fine soil increased growth by increasing both soil moisture and nutrient retention, in a manner similar to the sludge. When one considers that these 1978 fine-soil treatments were all located on the hotter, drier upstream side of the dam (Fig. 11, Table 7), these results indicate that the 1978 fine-soil treatments may have performed the best of any treatments overall.

Finally, in 1979, reseeded and refertilized Conwed blankets produced below-average yields of vegetation, although they were much greater than in 1978.

Willow cuttings

Figure 23 presents the survival rate (in late August 1977, 1978 and 1979) of the willow cuttings, which were planted in 1977. More detailed data are given in Appendix E. General comments on willow survival are presented below, and interactions between willow cuttings and grasses are discussed in the following section.

Substrate type affected willow survival. Three-year survival was lower on unseeded fine-soil treatments (35.3%) compared to either an identical gravel treatment (52.3%) or the average survival for all gravel treatments (59.0%) (Fig. 23). This may have been indirectly due to competition associated with the higher rate of grass cover on the fine-soil plots (Table C5), as discussed in the subsequent section on interactions between grasses and willows.

Soil moisture was probably a critical factor in determining willow survival. Willows had a higher survival rate on the bottom of the slope, as opposed to the top. Survival at the bottom averaged 12.6% greater in 1977, 9.9% greater in 1978, and 14.8% greater in 1979. Presumably these differences were due to increased soil moisture near the base of the slope, although the soil moisture data are too limited to be conclusive (Fig. 11). Neither refertilization nor aspect had a consistent effect upon survival.

All treatments except fine-soil with fertilizer and hay incurred most of their three-year mortality (32 to 93%) during the initial growing season (32 to 87%). Winter survival for all treatments averaged 85% in both 1977-78 and 1978-79.

Table 10. Maximum height of new growth (cm) of willow cuttings, 1977–78.

Treatment	Side	1977 Top*	1977 Bottom†	1977 Avg.**	1978 Top	1978 Bottom	1978 Avg.	1978 Fert.	1978 Unfert.
TS-F-H	Up	31.1	29.9	30.5	20.6††	46.9	40.0	48.3	29.9
					(6.2)	(7.3)	(5.5)	(6.0)	(8.3)
	Dw	24.3	41.6	35.1	16.2	43.7	32.3	23.8	40.7
	(1 rep only)				(5.0)	(13.4)	(8.8)	(12.6)	(12.4)
F-H	Dw	43.6	43.1	43.4	54.5	53.6	54.1	70.4	37.4
					(5.8)	(11.2)	(6.0)	(9.2)	(6.3)
TS-S-F-H	Up	0	21.6	21.6	6.5	19.5	17.5	22.0	14.6
					(0.5)	(4.2)	(3.8)	(8.1)	(3.7)
	Dw	25.8	31.3	29.8	19.9	25.6	24.2	30.5	17.9
					(4.9)	(4.9)	(3.6)	(5.3)	(4.2)
F-CHM2000	Up	34.5	33.4	34.1	44.6	34.9	39.2	58.2	20.3
					(7.3)	(6.5)	(4.8)	(6.4)	(4.3)
	Dw	42.6	57.9	50.7	52.8	71.8	62.5	82.9	40.4
					(5.6)	(7.5)	(4.8)	(6.5)	(3.6)
F	Up	59.7	47.1	53.1	74.0	56.5	60.2	73.7	46.6
					(7.2)	(5.3)	(4.6)	(5.6)	(6.5)
	Dw	42.0	46.9	44.8	52.8	106.6	77.2	101.1	53.2
					(8.3)	(19.3)	(6.8)	(9.2)	(5.3)

* Top three rows.
† Bottom three rows.
** Average of all cuttings.
†† $\bar{x}$ (standard error).

Winter mortality was highest in the fine-soil treatments, especially during the 1978–79 winter, which was colder than the previous winter (Table 5).

Fertilization, slope position and aspect influenced growth. Willow growth was greater downstream in three out of four treatments during 1977 and 1978 (Table 10). Willow growth was consistently the same or greater at the base of the slope than at the top in both 1977 and 1979 for downstream treatments. Overall, willow growth during 1979 averaged 63% greater at the base of the slope. The greater growth downstream and at the base of the slope was probably due to greater moisture at those locations (Fig. 11). Moisture differences were most pronounced between the top and bottom of the downstream side and between the bottoms of the downstream and the upstream sides. These locations also showed the largest differences in growth.

Interactions of willows and grasses

When grass seed and willow cuttings were planted together, willow survival dramatically decreased. In 1979, as in 1977 and 1978, the survival rate was much higher on unseeded treatments (34.4% versus 7.1% upstream and 35.3% versus 14.7% downstream) (Fig. 23).

Without seeding, good cover and biomass were produced by willows with fertilizer and hay and by willows with fine soil, fertilizer and hay (Tables B4 and C5). In 1978 these treatments produced the highest biomass values for non-refertilized treatments. Presumably, most of this cover was produced by grass and weed species introduced as seed in the hay.

As previously mentioned, soil moisture seems to be a critical factor in willow survival. The seeded grasses probably increased willow mortality by competing for soil moisture. Since the grass roots are generally very shallow, they would be able to absorb moisture from light rains before it reached the deeper roots of the willows. Therefore, willows surrounded by grasses would be primarily dependent on prolonged, soaking rains for moisture. This factor probably accounts for the higher mortality rate of willows in the seeded treatments and, to a lesser extent, in the fine-soil-covered treatments which developed a good grass covering (Table C5).

Tanana Levee site

Figure 24 presents the average biomass values for the levee treatments in 1978 and 1979. Tables F1 and F2 list all biomass, cover and maximum

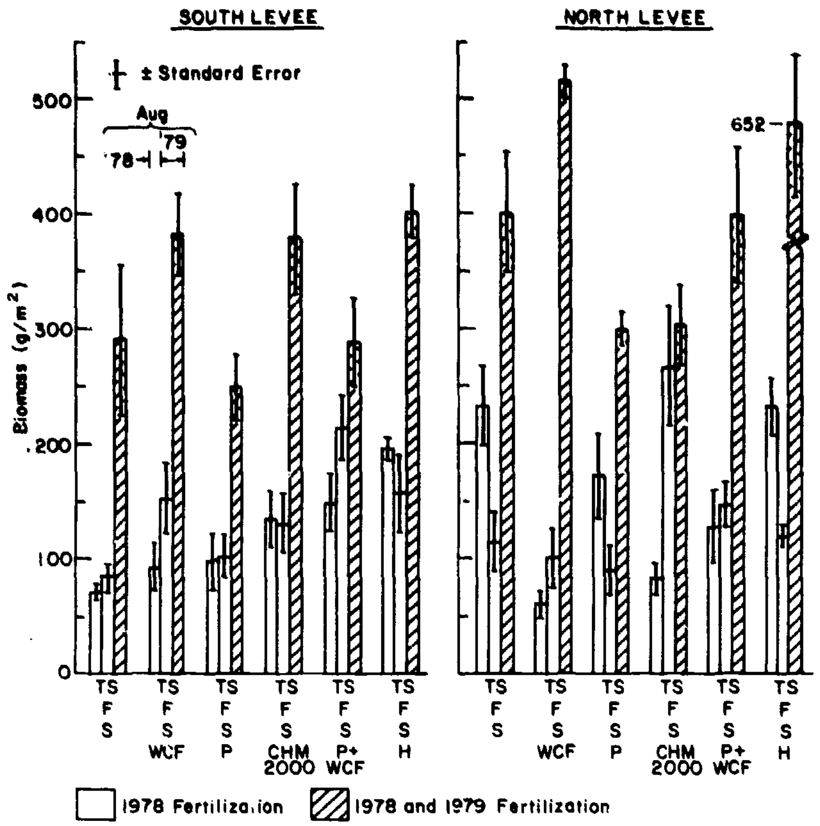


Figure 24. Average dry weight (biomass) of vegetative cover for the Tanana River Levee treatments in late August 1978 and 1979.

heights for the levee treatments in 1978 and 1979, respectively. Aboveground biomass values varied between 60 and 652 g/m² in 1978 and 1979. Vegetative cover ranged from 32 to 70%, while maximum heights varied between 36 and 123 cm. Again, maximum heights on the levee exceeded those of the 1977 dam treatments because both brome and meadow foxtail were added to the seed mix.

The biomass values for the levee treatments consistently exceeded those for comparable once- or twice-fertilized treatments on the dam. Although the data are incomplete, 1978 soil-moisture and temperature measurements from the levee indicate moister, generally cooler conditions on the levee, compared to the slopes of the dam. Furthermore, the organic-matter content of the fine soil on the levee was generally greater than that used on the dam (Table 9). This would tend to increase soil moisture-holding capacity on the levee. Therefore, low soil moisture was probably more limiting on the dam than on the levee.

In both 1978 and 1979, the highest values for biomass, cover and maximum height were greater than those of any of the 1977 dam treatments. The twice-fertilized seed-plus-hay-mulch treatment in 1979 produced greater biomass than any treatment on either the levee or the dam.

Aspect affected differences in growth on the levee itself. In 1978 four of seven treatments on the north side of the levee had greater biomass. In 1979 only two of seven of the once-fertilized treatments and five of seven of the twice-fertilized treatments had greater biomass on the north side. On the levee, the limited data available suggest lower soil temperatures and higher soil moisture on the north side. Therefore, as reported for the 1977 dam treatments, it is likely that soil moisture limited growth on the south-side treatments when soil fertility was high (e.g. 1978 and refertilized treatments in 1979). The lack of consistent differences in north/south growth in 1979 among once-fertilized treatments is probably because soil nutrients are more limiting in these cases than is soil moisture.

The two most productive treatments on the levee were the twice-fertilized seed-plus-hay-mulch and the twice-fertilized seed with wood-cellulose-fiber treatments (Fig. 24).

Table 11. Percentage of biomass by species.

Species	% biomass: 1977 dam plots, 1977	1977 dam plots, 1978	1977 dam plots, 1979	1978 dam plots, 1979	Levee plots, 1979
Perennials	3.7				
Fescue		64	94.3	35.7	9.1
Bluegrass		1	1.6	0.8	0.3
Brome			2.5	22.2	6.7
Annual ryegrass	96.3	31	1.5		0.1
Clover				4.1	76.3
Foxtail				37.2	7.5
Other		4			

Table 12. Measurements of woody species growing on the dam.

Species	Measurement	Length (cm): Max.	Avg.	Std. error
Balsam poplar	Shoot height	5[illegible]	51.3	(2.8)
	Lateral root spread	95	73.0	(11.1)
	Deepest root penetration	70	47.3	(11.4)
Feltleaf willow	Shoot height	151	132.5	(13.5)
	Lateral root spread	132	113.5	(11.4)
	Deepest root penetration	38	22.5	(5.8)

Biomass by species

Table 11 presents the data for the dry weight biomass samples arranged by species. Annual ryegrass dominated all plots in 1977. In 1978 and 1979 fescue became the dominant species by weight on the 1977 plots. In the 1978 plots foxtail produced the greatest biomass, but fescue biomass was almost as large and brome was also a dominant species. Finally, on the levee plots clover produced the greatest biomass by far. Foxtail, fescue, and brome were consistently present, but in much lower amounts than clover. Clover may offer significant advantages in N fixation on wetter, cooler sites such as the levee. However, it should be heavily fertilized with P to enhance this process.

Root penetration

Table 12 presents the data for maximum rooting depths and lateral spread of balsam poplar and feltleaf willow seedlings growing on the dam during the 1979 field season. Table 13 presents data for root biomass of aspen and balsam poplar in relation to depth. Data in the tables are derived from two sets of excavations in which a total of 13 plants were examined.

All excavated roots were less than 1 cm in diameter. Root biomass also decreased rapidly with depth (Table 13). For example, 70% of the balsam poplar and 63% of the aspen root biomass were within the upper 10 cm of soil, while only 12% of the balsam poplar and 5% of the aspen root biomass were deeper than 20 cm.

The maximum depth of rooting was fairly shallow (70 cm) (Table 12). When this is combined with the rapid decrease in root size and biomass with depth, there appears to be little potential for deep root penetration into the dam. Feltleaf willow is especially notable. Although it produced the tallest shoots (151 cm), it had the shallowest maximum rooting depth (35 cm).

Seedling density of invading woody species

Table 14 presents the density of seedlings of invading native woody species on different areas of the gravel dam in 1979. The highest seedling densities were found on the unseeded treatments: the unseeded but fertilized fine-soil treatments and the untreated downstream section.

Weeds

During all three seasons, several weed species as well as several native species of vegetation were present on the site. Species observed, other

Table 13. Biomass of woody species' roots in relation to depth (for roots > 1 mm in diameter).

Species	Shoot ht (cm)		Rooting depth (cm)		Root biomass*		
	Max	*Avg*	*Abs max*	*Avg max*	*0–10 cm*	*10–20 cm*	*20–max depth*
Balsam poplar	92	86.0†	35	35	43.2	10.8	7.6
		(6.1)		(0)	(1.6)	(5.6)	(3.2)
Aspen	93	82.2	52	32.8	40.4	20.4	3.2
		(7.9)		(6.8)	(4.4)	(10.8)	(2.8)

* g/m^2 of rooting zone

† $\bar{x}$ (one standard error)

Table 14. Density of woody seedlings (seedlings/m^2) on the gravel dam.

Side	Untreated	Seeded		Fine-soil cover		
		*F1**	*F2†*	*F1 seeded*	*F2 seeded*	*F1*
Downstream	14.4 (4.7)**	0 (0)	0 (0)	0 (0)	2.6 (1.1)	31.9 (10.7)
Upstream	2.6 (1.1)	0.1 (0.1)	0.3 (0.3)	0 (0)	0.1 (0.1)	25.0 (7.0)

* F1—1977 fertilization.

† F2—1977 + 1978 fertilizations.

** $\bar{x}$ (one standard error).

than those which had been purposely seeded onto the plots, included squirreltail *(Hordeum jubatum)*, yarrow *(Achillea borealis)*, pigweed *(Chenopodium album)*, fireweed *(Epilobium angustifolium)*, aspen *(Populus tremuloides)*, balsam poplar *(Populus balsamifera)*, and brome *(Bromus inermis)*, which was not planted in the 1977 plots. Some of these species were introduced in the mulches, while other species, particularly aspen and balsam poplar, were able to invade from adjacent stands of native vegetation. Squirreltail was the most widespread weedy species, but yarrow achieved the highest densities, primarily on the upstream fine-soil-with-hay treatments. According to our visual estimates, yarrow composed a large part, if not the majority, of the biomass of the vegetation on a few of these plots. It appeared that yarrow seed in the hay germinated and grew well on the hot, droughty upstream fine-soil plots. However, yarrow would probably not provide enough cover to prevent erosion.

SUPPLEMENTAL OBSERVATIONS

Sediment loss

Gravel plots

Table 15 gives the average sediment loss from the gravel plots (no. 1-23, 31-36) collected between their installation (May) and 26 August 1977. The data show that little erosion occurred on any of these plots, including the controls. Individual sediment loss values ranged from 14.5 kg/ha on Plot 10 to 130.8 kg/ha on Plot 1.

These results were expected with the coarse substrate, since less than 4% of the fill on the upstream side would pass through a no. 200 sieve (0.074 mm) and less than 40% would pass through a no. 4 sieve (4.8 mm).

Fine-soil plots

Sediment was collected from the fine-soil plots (no. 25-30 and 37) after each major storm in 1977 and 1978 (Aldrich and Johnson 1979).

Table 15. Sediment loss from upstream gravel plots on the dam (May-26 August 1977).

Plots	*Treatment*	*Sediment loss* (kg/ha)*
31,32,33	W-F-CHM2000	23.6 (9.6)†
13,14,15	S-F-CHM2000	24.4 (6.5)
19,20,21	S-F-P+WCF	24.4 (10.8)
10,11,12	S-F-Ha·	25.6 (29.0)
16,17,18	S-F-P	27.5 (7.8)
34,35,36	W-F	50.5 (33.2)
7,8,9	S-F-WCF	52.6 (44.9)
1,2,3	Control	86.3 (97.0)
4,5,6	S-F	93.1 (62.7)

* Based on plot size 1.2 m×15.2 m; dry weight.
† $x(y)$—average (range).

Table 16. Sediment loss from the 1977 fine-soil plots (kg/ha) during summers of 1977 and 1978.*

	TS-W-F-H			*TS-W-S-F-H*			*TS-S-F*
Date	*Plot 25*	*Plot 26*	*Plot 27*	*Plot 28*	*Plot 29*	*Plot 30*	*Plot 37*
1977							
June	28.8	43.3	121.6	50.6	60.8	56.8	262.6
July	3.7	7.9	5.6	5.7	5.8	6.6	271.8
Aug	68.2	55.8	20.0	96.9	45.1	101.5	14,613.9
Sept	2.2	5.0	2.3	3.1	7.8	7.3	41.7
Oct	1.6	1.2	1.4	1.5	1.3	3.0	101.6
Total	104.5	113.2	150.9	157.7	120.8	175.2	15,291.6
Avg.	122.9 (46.4)†			151.3 (54.4)			
1978							
Apr	13.2	10.7	11.1	71.6	34.4	47.3	348.9
May	12.2	11.7	18.5	17.7	14.9	17.5	41.0
June	2.5	3.1	7.5	7.8	8.0	11.4	32.1
July	983.1	3374.8	869.1	918.1	206.5	8740.8	14,754.0
Aug	87.1	40.2	69.2	244.2	25.0	682.8	1,826 3
Total	1098.2	3802.1	975.4	1259.4	288.8	9499.8	17,002.3
Avg.	1958.6 (2826.7)			3682.7 (9211.0)			

* Based on plot size 1.2 m×15.2 m; dry weight.
† $x(y)$ = average (range).

Table 16 summarizes these data on a monthly basis.

In 1977 the sediment-loss results from most of the fine-soil plots were well below the limit of 2200 kg/ha-year (or 1 ton/acre-year) set by the U.S. General Accounting Office in their report *To Protect Tomorrow's Food Supply, Soil Conservation Needs Priority Attention* (February 1977). The one exception was Plot 37, which lost 15,290 kg/ha of sediment. Poor initial compaction of the soil cover and surface disturbance by motorcycles may have caused this high sediment loss.

Sediment loss collected from April through August 1978 (Table 16) was much higher than that in 1977. Only three of the seven fine-soil plots lost less sediment than the above-mentioned limit. The loss of sediment ranged from 289 kg/ha on Plot 29 to the very high 17,000 kg/ha on Plot 37.

The great increase in sediment loss during 1978 was mainly due to intense July rainstorms. These storms produced sediment loss amounting to 50-90% of the total recorded for both years.

Aldrich and Johnson (1979) also studied the

a. Overall view.

b. Close-up of deeper gully.

Figure 25. Gully erosion on the downstream side of the dam—August 1978.

soil loss from the fine-soil plots. They used the sediment data to solve the universal soil loss equation (USLE) for the cover and management factor for the vegetation types present on the plots. The USLE is used to predict sheet-rill erosion at given locations.

Erosion

The same short, intense storms that produced the erosion on our plots in mid-July 1978 also caused gullies to develop along the dam. Although widespread, they first appeared and were more prominent where the dam curved. The large gullies, averaging 15–45 cm in width and depth, terminated as fans of debris at the toe of the slope (Fig. 25). Smaller rill erosion without the larger washout fans formed during a later storm that summer. Rills were 10–15 cm in width and depth and usually occurred in large numbers covering expanses about 30 m wide.

Slumping occurred in two areas during the 1979 spring thaw period (Fig. 26). These were near Sections 265–270 and Section 310 of the dam. Up to 2 m^3 of material slumped out over the rip-rap at the bottom of the slope.

To determine if vegetation will help prevent slumping during thaws, a plot was established in May 1979 near Section 310 adjacent to the area that experienced slumping. This plot will be examined in future years.

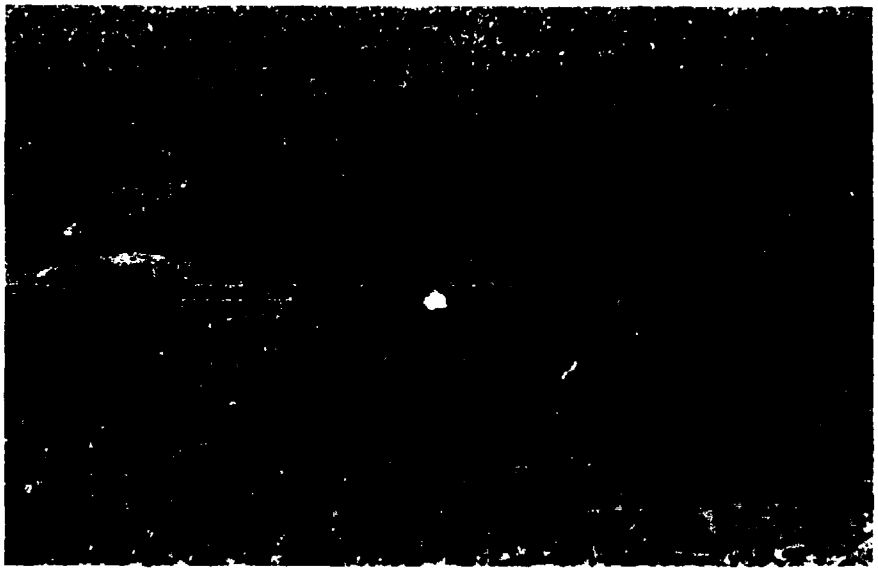
Sludge and runoff-water composition

Sources of public health concern are the presence of heavy metals or other potentially toxic elements in sludge applied to the land and the possible transmission of disease by pathogens, including fecal coliform.

Tables 17 and 18 present partial listings of the analyses performed on the applied sludge and the runoff-water samples collected at the base of our plots in 1978 and 1979, respectively, including heavy metal and coliform contents. The complete results appear in Appendix Tables G1–G4. The data show that runoff water coming directly from the plots conforms to recreational water standards, with minor exceptions, and thus creates minimal contamination problems.

The only high values in the runoff water were

a. Near section 265–270.



b. At section 310.

Figure 26. Slumping that occurred during spring thaw, May 1979.

a generally high chromium content and high counts of total coliform in two 1978 samples, including one from a control plot with no treatment (Table 11). All other samples had coliform contents well below the maximum permitted for recreational use (10,000 total coliform/100 mL and 2,000 fecal coliform/100 mL) (USEPA 1978, Kerri et al. 1976).

Johnson (1979) and Winslade (1979) also studied land application of the Fairbanks sludge for agricultural purposes in 1978 at the University of Alaska Agricultural Experimentation Station. In soil with sludge applied to it they found rapid die-off of pathogens at a rate of about 1/3 of the pathogens per day. Nutrient levels of those soils also increased.

Table 17. Contents of sludge and runoff water, 1978.

		Sludge					Runoff water						
Treatment	Plot no.	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Potassium (mg/L)	Total solids (%)	Total coliform (no./100 mL)	Fecal coliform (no./100 mL)	Arsenic (mg/L)	Barium (mg/L)	Cadmium (mg/L)	Chromium (+6) (mg/L)	Fluoride (mg/L)	Iron (mg/L)
Control						TNTC*	0	0.013	<0.1	0.002	0.09	0.03	6.2
SG-S1-F-L-	1	202	130	56.7	4.5	0	0	0.038	<0.1	0.005	0.09	0.05	2.1
CHM2000	2	89	120	55.8	4.1	33	0	0.024	<0.1	0.002	0.10	0.04	3.3
	3	136	140	49.2	4.0	0	0	0.007	<0.1	0.002	0.09	0.05	3.4
SG-S2-F-L-	4	143	135	59.7	3.3	0	0	0.019	<0.1	0.001	0.15	0.04	6.1
CHM2000	5	56	135	54.0	3.4	0	0	0.014	<0.1	0.003	0.12	0.05	5.6
	6	160	120	58.8	3.9	0	0	0.026	<0.1	0.004	0.19	0.04	10.4
SG-S2-F-	7	106	140	60.6	4.4	TNTC	0	0.022	<0.1	0.004	0.10	0.03	6.9
WCF	8	58	145	52.5	4.0	1	0	0.015	<0.1	0.003	0.09	0.03	5.8
	9	199	60	47.1	1.5	68	0	0.015	<0.1	0.002	0.15	0.03	6.9
SG-S1-F	10	193	160	51.0	3.3	0	0	0.012	<0.1	<0.001	0.15	0.03	5.4

* Too numerous to count.

Table 18. Contents of sludge and runoff water, 1979.

		Sludge					Runoff water				
	Fertilization*	Total Kjeldahl N (%)	Total phosphorus (mg/L)	Potassium (mg/L)	Fecal coliform (no./100 mL)	Solids (%)	Total nitrogen (mg/L)	Total phosphorus (mg/L)	Potassium (mg/L)	Total coliform (no./100 mL)	Fecal coliform (no./100 mL)
Control							3.00	0.12	1.898	0	–
							<1	0.06	1.510	0	–
SG-S1-F-L-	F1						1.98	0.18	3.89	0	–
CHM2000	F2						2.44	0.25	4.93	0	–
(plots 1-3)†	SG2	5.35	685	163	2.4×10^7	4.0	3.13	0.24	8.12	3	70
SG-S2-F-L-	F1						1.85	0.12	2.262	0	–
CHM2000	F2						<1	0.21	2.056	0	–
(plots 4–6)†	SG2	4.93	650	186	6.0×10^6	5.5	<1	0.24	2.192	0	–
SG-S2-F-WCF	F1						<1	0.17	7.05	C	–
(plots 7–9)†	F2						<1	0.06	1.603	0	–
	SG2	4.54	678	134	2.4×10^6	5.5	<1	0.21	2.168	0	–
SF-S1-F	F1						<1	0.24	2.337	0	–
(plot 10)	F2						<1	0.25	5.31	1	<10
	SG2						<1	0.21	10.78	0	–

* F1—1978 fertilization; F2—1978 and 1979 fertilizations; SG2—1979 resludging.
† Analyzed samples were composites from all three plots.

COST ANALYSIS

We prepared an analysis of the costs of establishing the treatments tested in this study. The analysis is divided into three main parts. The first is a comparison of various costs based on using hydromulching application methods for all treatments. Second, we compare the cost of aerial seeding and fertilizing with the cost of hydromulching a similar treatment. The third is a discussion of maintenance costs following initial establishment of a vegetative cover.

We computed the treatment application costs by adding all the material and installation costs that would be involved. These costs were chosen from the national averages listed in *Building*

Table 19. Treatments ranked by increasing cost.

Rank	Treatment: Fine soil	Sludge	Vegetation	Fert.	Lime	Mulch	Cost ($/ha): Mat.*	Inst.*	Total	Total $ for dam
1			S	F			2271	1435	3706	140,100
2		SG	S	F			2271	1435	3706	140,100
3			S	F		M	2869	1435	4304	162,700
4		SG	S	F		M	2869	1435	4304	162,700
5		SG	S	F	L	M	2900	1435	4335	163,900
6		SG	S	F	L	M	2900	2870†	5770	218,100
7			S	F		2M	3467	2870	6337	239,500
8	TS		S	F			2271	5858	8129	307,300
9	TS		S+B	F			2821	5858	8679	328,100
10	TS		S	F		M	2869	5858	8727	329,900
11	TS		S	F		M+Blanket	7651	2631	10282	388,700
12			W	F			6366	5733	12098	457,300
13			W	F		M	6963	5733	12696	479,900
14	TS		3S	F		Fibgls	9086	7054	16140	610,100
15	TS		W	F		M	6963	10156	17119	647,100
16	TS		W+S	F		M	8159	10156	18315	629,300

* Cost is divided into material (Mat.) and installation (Inst.) factors—see text and Table 20.
† Includes added cost of spraying mulch, seed, fertilizer and lime over sludge.

Construction Cost Data (Robert Snow Means Co. 1979), a reference designed to aid contractors in calculating their construction expenses. (This reference will hereafter be referred to as "Means.") We also checked with landscaping firms in Anchorage to confirm that the national average would be a good approximation of current Alaska prices.

Table 19 lists treatment cost totals using hydromulching techniques whenever possible. These cost totals were calculated from the individual treatment costs (Table 20), which are divided into material and installation (labor plus equipment) costs. The values given are listed in Means as bare costs, i.e. not including overhead and profit. The reference column in Table 20 shows the exact line number in Means from which the prices were taken.

The installation procedures used for calculating installation costs are: spreading fine soil, stapling the mulch blanket or fiberglass cloth to the ground surface, planting willows, and hydromulching sludge or water with combinations of seed, fertilizer, mulch and lime. Hydromulching installation cost is doubled in two cases. The first is the treatment with both peat moss and wood-cellulose-fiber mulch. Because of the high application rate, these would have to be sprayed in two stages to avoid overloading the hydromulching equipment. The second case is the treatment in which the seed, fertilizer, mulch and lime are sprayed over a previously sprayed layer of sludge.

The prices of materials were taken from Means except in a few case. The combined cost of seed and fertilizer is listed as $2271/ha ($0.19/yd²). However, the addition of a native species, bluejoint, to the seed mixture raised the cost by $550/ha. The high price for bluejoint seed ($50/kg) may be reduced in the future as commercial seed supplies increase.

The same materials cost is used for all the various mulches sprayed by hydromulcher ($598/ha), while costs for the mulch blanket and fiberglass were considered to be equal to that of the stapled plastic netting listed in Means.

No materials cost is included for the fine soil or the sludge, since these do not need to be purchased. Their only cost is the installation charges, which include hauling and spreading by equipment for the fine soil and hydromulching for the sludge.

The cost of willow cuttings and their installation is estimated because an equivalent process is not listed in Means. We used a materials cost of $0.50 per cutting and a planting rate of 400 cuttings/day by a three-person crew. The total cost of the willow treatment could go down if a more mechanized method of planting is developed.

The treatment costs range from about $3706/ha for seed and fertilizer with or without sludge to $18,315/ha for fine soil, willows, seed, fertilizer and mulch (Table 19). Willows and soil cover

Table 20. Individual treatment costs.

	Abbreviation	Cost ($/ha)	Reference*
Material			
Seed	S	1195	2.8 45 100
Triple rate of seed	3S	3585	2.8 45 100
Seed + bluejoint	S+B	1695†	2.8 45 100
Fertilizer	F	1076	2.8 45 100
Mulch	M	598	2.8 45 110
Lime	L	31	Estimated
Sludge	SG	No charge	
Fine soil	TS	No charge	
Willows	W	5290	Estimated**
Blanket	Blanket	4782	2.8 07 010††
Fiberglass	Fibgls	4782	2.8 07 010
Installation			
Fine soil		4423	2.8 25 080
Blanket		1196	2.8 07 010
Fiberglass		1196	2.8 07 010
Willows		4298	Estimated
Hydromulching***		1435	2.8 45 100

* Line reference from *Building Construction Cost Data* (1979).

† Additional bluejoint seed, 11 kg/ha at $50/kg = $550/ha.

** Willows: 2645 cuttings/ha at $0.50 each, installed by a 3-person crew at 50 cuttings/hr.

†† Fiberglass and mulch blanket treated like stapled plastic netting.

*** Hydromulching used spread sludge or water with combinations of seed, fertilizer, mulch or lime.

are the largest cost factors, with a total cost of about $9590/ha and $4420/ha, respectively.

We also calculated the cost of entirely revegetating both sides of Moose Creek Dam with the treatments we have tested (Table 19). This was based on estimated dimensions of the dam of 12,400 m long and 15.2 m high (or 37.8 ha). The total ranges from $140,000 to $692,300.

When we compared the cost of spreading seed and fertilizer aerially to the cost using a hydromulcher, we found that the aerial technique is about half as expensive. Aerial spreading costs $1976/ha (Means 1979, line 2.8-45-220); hydromulching costs $3706. Aerial spreading is not necessarily equally effective, however.

The cost of maintaining vegetation once it becomes established mainly involves annual refertilization for one or two years. This can be done aerially at a cost of about $1500/ha, or $56,700 for the whole dam. No mowing should be necessary.

CONCLUSIONS

The following observations are apparent from this three-year study:

1) A vegetative cover can be established on the gravel face of the dam and levee. The vegetation will help to reduce erosion and will improve the aesthetics of the structures.

2) Fertilization is required for at least two years to produce an adequate biomass, although fine-grained soil or sludge added to the site reduces the amount of fertilizer needed in the second year. Fertilization during the third year increases vegetation growth, but probably is not required since the benefits of the second fertilization continue for at least two years.

3) Willow cuttings offer a viable means of revegetating the dam. On the basis of a root penetration study, they appear to pose little or no threat of deep root growth. The same study shows that four- to five-year-old invading native woody seedlings also do not pose root penetration problems on the gravel dam.

4) Grasses reduce willow growth and survival; therefore, they should not be simultaneously seeded if willow cuttings are planted. If additional vegetation cover is desired, straw mulch may be used at the time of willow planting, or grasses may be seeded one year later (to avoid competition with the willows during establishment).

5) The use of sludge from the Fairbanks treatment plant poses little, if any, danger from heavy metals or pathogens. The Chena River Lakes Project is an ideal place to use this sludge to improve the moisture and nutrient soil regime.

6) Sludge offers a viable alternative to annual fertilization or establishment of a fine-soil cover. The highest biomasses in this study, including those from the three-year treatments receiving three fertilizer applications, were achieved with sludge plus fertilization.

7) Growth on the upstream (SE) side of the dam is less than on the downstream (NW) side due to a combination of higher soil temperatures and reduced soil moisture. Presumably, the higher temperatures compound moisture stress for the plant cover.

8) The levee is a more favorable environment than the dam for growth, as evidenced by higher biomass and cover values for comparable treatments. This is probably due to more favorable moisture conditions.

9) Fescue, brome and foxtail all produce adequate biomass on well-drained sites. Alsike clover seems to be the most promising species at wetter sites such as the levee and should be used whenever possible since it will help to increase soil nitrogen.

10) Lack of moisture appears to limit growth principally in treatments receiving high fertilizer applications. The fertilizer alleviates nutrient limitations that would otherwise commonly be encountered. Hence, differences in growth due to moisture variations between north and south aspects (levee), east and west aspects (dam), and top and bottom of slopes (dam) will be accentuated under high fertility levels (90 kg N/ha, 180 kg P_2O_5/ha).

11) High levels of herbaceous cover appear to slow the invasion by woody species onto the dam. However, it is not known how long this effect will last. More study is needed to verify this preliminary finding and to determine long-term trends.

12) Erosion is a recurring problem on the bare gravel slope of the dam. Both saturated flows initiated by spring snowmelt and erosion gullies due to heavy summer rains occurred during the three years of this study. Although this study does not show that vegetation will prevent slumps and erosion, experience indicates that at least a reduction in the frequency and severity of erosion can be expected.

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APPENDIX A: 1977 GRASS GROWTH ON 1977 DAM TREATMENTS.

Table A1. 1977 grass growth on 1977 replicated treatments.

		Biomass (g/m^2)			Cover class*			Max. height (cm)		
Treatment	Side	Top	Bottom	Avg.	Top	Bottom	Avg.	Top	Bottom	Avg.
S-F	Upstream	73.96†	74.68	74.32	4.78	4.67	4.67	50.33	47.67	49.00
		(10.24)	(24.16)	(13.24)	(0.40)	(0.44)	(0.29)	(1.69)	(1.92)	(1.28)
	Downstream	116.52	145.20	130.84	3.22	3.89	3.56	55.44	72.78	64.11
		(11.52)	(18.44)	(11.08)	(0.32)	(0.72)	(0.39)	(2.85)	(3.03)	(2.91)
S-F-WCF	Upstream	49.40	37.60	45.20	4.11	3.78	3.94	48.11	52.11	50.11
		(4.0)	(6.24)	(3.64)	(0.26)	(0.32)	(0.21)	(1.77)	(2.69)	(1.63)
	Downstream	71.20	102.76	86.96	3.00	4.22	3.61	50.21	65.67	57.94
		(9.20)	(17.96)	(10.52)	(0.41)	(0.52)	(0.35)	(2.11)	(2.89)	(2.55)
S-F-H	Upstream	56.40	68.24	62.32	3.67	3.56	3.61	46.22	56.44	51.33
		(7.24)	(8.48)	(5.60)	(1.12)	(0.29)	(0.98)	(6.87)	(3.21)	(2.28)
	Downstream	105.28	136.24	120.76	3.78	3.89	3.83	55.78	65.78	60.78
		(6.80)	(16.64)	(9.48)	(0.52)	(0.63)	(0.40)	(2.88)	(2.43)	(2.19)
S-F-CHM 2000	Upstream	50.04	36.96	43.52	1.67	1.89	1.78	56.78	54.44	55.61
		(8.24)	(10.24)	(6.56)	(0.24)	(0.61)	(0.32)	(3.05)	(3.09)	(2.12)
	Downstream	96.88	96.52	96.68	4.11	4.67	4.39	52.56	69.4[illegible]	61.00
		(3.60)	(15.36)	(7.64)	(0.34)	(0.73)	(0.39)	(3.14)	(3.44)	(3.05)
S-F-P	Upstream	51.72	44.48	48.08	3.44	8.33	3.39	48.00	47.56	47.78
		(6.76)	(2.88)	(3.68)	(0.24)	(0.37)	(0.22)	(2.06)	(2.69)	(1.65)
	Downstream	62.44	150.60	106.52	4.78	7.00	5.89	54.89	72.67	63.78
		(5.28)	(20.12)	(14.68)	(0.32)	(0.44)	(0.38)	(2.84)	(2.17)	(2.77)
S-F-P-WCF	Upstream	47.12	33.96	40.52	2.11	2.22	2.17	49.00	50.44	49.72
		(7.16)	(4.36)	(4.36)	(1.36)	(0.22)	(1.04)	(2.57)	(2.20)	(1.65)
	Downstream	116.20	130.32	120.76	4.44	5.78	5.11	51.89	66.67	59.28
		(11.52)	(23.20)	(12.76)	(0.41)	(0.40)	(0.32)	(2.05)	(1.58)	(2.19)
TS-S+B-F	Upstream	30.60	43.04	36.80	2.33	2.33	2.33	38.67	51.50	45.08
		(3.72)	(2.56)	(2.84)	(0.33)	(0.21)	(0.18)	(2.30)	(4.86)	(3.21)
TS-W-S-FH	Upstream	69.92	68.96	6[illegible].40	4.33	4.56	4.44	43.89	51.44	51.00
		(7.12)	(7.68)	(5.08)	(1.41)	(0.47)	(1.38)	(5.86)	(1.74)	(1.43)
	Downstream	97.0	125.72	111.36	6.56	4.67	5.61	53.69	65.11	59.50
		(14.28)	(13.6)	(10.20)	(0.29)	(0.73)	(0.44)	(2.28)	(2.35)	(2.09)

* 1 = 1-10%; 2 = 11-20%, . . ., 10 = 91-100%.
† $\bar{x}$ (standard error).

Table A2. 1977 grass growth on treatments with a single plot only.

		Biomass (g/m^2)			Cover class (1-10)			Max. ht. (cm)		
		Top	Bottom	Avg.	Top	Bottom	Avg.	Top	Bottom	Avg.
TS-3S-F-Fiberglass*	Upstream only	39.84†	5.84	22.84	2.00	1.33	1.67	41.67	33.33	37.50
TS-S-F	Upstream only	33.56	58.28	45.92	2.33	2.00	2.17	43.67	42.33	43.00
V1-F	Downstream only	91.72	140.16	115.92	4.33	7.00	5.68	56.33	79.67	68.00
V2-F	Downstream only	137.16	86.64	111.92	5.67	4.33	5.00	49.67	59.67	54.67
V3-F	Downstream only	70.32	202.92	136.6	5.00	5.33	5.17	52.00	75.33	63.67

* Part of vegetation obscured by mat.
† $\bar{x}$.

APPENDIX B: 1978 GRASS GROWTH ON 1977 DAM TREATMENTS.

Table B1. 1978 grass growth on 1977 replicated treatments, non-refertilized.

		Biomass (g/m²)			Cover class*			Max. height (cm)		
		Top	Bottom	Avg.	Top	Bottom	Avg.	Top	Bottom	Avg.
S-F	Upstream	5.6†	10.7	8.1	1.0	2.0	1.5	16.7	17.8	17.2
		(0.7)	(4.3)	(2.2)	(0)	(0.5)	(0.3)	(4.8)	(4.7)	(3.2)
	Downstream	6.1	13.2	9.6	1.3	2.9	2.1	17.1	18.7	17.9
		(1.4)	(1.2)	(1.4)	(0.2)	(0.3)	(0.2)	(2.5)	(1.9)	(2.4)
S-F-WCF	Upstream	2.1	1.4	1.8	1.0	1.0	1.0	11.3	9.3	10.9
		(0.5)	(0.2)	(0.3)	(0)	(0)	(0)	(5.3)	(1.8)	(2.5)
	Downstream	2.1	9.5	3.3	1.1	1.4	1.3	9.5	19.8	16.2
		(0.6)	(0.2)	(0.4)	(0.1)	(0.2)	(0.1)	(2.2)	(2.8)	(1.8)
S-F-H	Upstream	3.9	6.1	5.0	1.0	1.0	1.0	29.0	27.0	28.0
		(0.8)	(1.3)	(0.8)	(0)	(0)	(0)	(6.3)	(4.4)	(3.7)
	Downstream	8.8	14.1	11.4	2.1	2.9	2.5	24.0	45.3	34.7
		(2.0)	(2.2)	(1.6)	(0.3)	(0.3)	(0.2)	(2.9)	(5.1)	(3.9)
S-F-CHM	Upstream	3.0	2.3	2.7	1.0	1.0	1.0	9.7	15.3	12.5
2000		(0.6)	(0.3)	(0.3)	(0)	(0)	(0)	(1.7)	(4.0)	(2.2)
	Downstream	3.4	4.4	3.9	1.2	1.7	1.5	11.2	19.3	15.2
		(0.6)	(0.7)	(0.5)	(0.2)	(0.2)	(0.2)	(1.5)	(2.4)	(1.8)
S-F-P	Upstream	1.4	4.1	2.7	1.0	1.0	1.0	16.0	8.7	12.3
		(0.2)	(1.7)	(0.9)	(0)	(0)	(0)	(4.1)	(1.5)	(2.4)
	Downstream	6.0	10.6	8.3	1.5	3.7	2.6	17.0	20.0	18.5
		(0.8)	(1.3)	(1.0)	(0.2)	(0.4)	(0.4)	(3.6)	(2.1)	(2.2)
S-F-P+WCF	Upstream	1.8	3.6	2.7	1.0	1.0	1.0	15.0	6.8	10.9
		(0.4)	(1.0)	(0.6)	(0)	(0)	(0)	(3.6)	(0.8)	(2.2)
	Downstream	5.6	3.7	4.7	1.7	1.8	1.8	12.3	20.0	16.2
		(1.0)	(1.5)	(0.9)	(0.2)	(0.3)	(0.2)	(1.6)	(2.2)	(1.8)
TS-S+B-F	Upstream	13.4	15.7	14.5	2.0	2.0	2.0	31.5	17.0	24.3
		(2.3)	(2.8)	(2.4)	(0.4)	(0.4)	(0.3)	(1.9)	(3.6)	(3.3)
TS-W-S-F-H	Upstream	16.1	22.0	19.3	2.0	2.7	2.3	41.7	37.2	29.[illegible]
		(2.5)	(3.4)	(2.3)	(0)	(0.3)	(0.2)	(2.3)	(4.3)	(2.4)
	Downstream	35.5	29.1	32.3	6.2	5.2	5.7	34.3	41.5	37.9
		(7.5)	(4.5)	(4.3)	(0.2)	(0.6)	(0.4)	(3.9)	(4.8)	(3.2)
Control	Upstream	—	—	0.2	0.7	0.2	0.4	—	—	3.4
		—	—	(0.1)	(0.2)	(0.2)	(0.2)	—	—	(1.7)
	Downstream	0.4	0.2	0.3	0.7	0.7	0.7	—	—	8.8
		(0.2)	(0.1)	(0.1)	(0.2)	(0.2)	(0.2)	—	—	(3.6)

* 1 = 1–10%; 2 = 11–20%,...,10 = 91–100%.

† $\bar{x}$ (standard error).

Table B2. 1978 grass growth on 1977 replicated treatments, refertilized.

Treatment	Side	*Biomass (g/m²)* Top	Bottom	Avg.	*Cover class** Top	Bottom	Avg.	*Max. height (cm)* Top	Bottom	Avg.
S-F	Upstream	72.4†	114.7	93.6	3.7	4.8	4.2	42.2	37.0	39.6
		(12.5)	(10.0)	(9.9)	(0.5)	(0.6)	(0.4)	(1.6)	(4.2)	(2.3)
	Downstream	148.4	138.2	143.3	7.1	7.0	7.1	48.4	56.4	55.4
		(13.2)	(14.5)	(9.5)	(0.3)	(0.2)	(0.2)	(2.7)	(3.2)	(2.2)
S-F-WCF	Upstream	70.8	78.1	74.5	4.0	5.3	4.7	39.5	37.7	38.6
		(6.0)	(9.6)	(5.6)	(0.4)	(0.5)	(0.4)	(2.3)	(2.7)	(1.7)
	Downstream	110.5	174.8	142.6	6.9	7.3	7.1	48.1	59.7	53.9
		(5.8)	(14.3)	(12.8)	(0.4)	(0.3)	(0.2)	(3.0)	(3.1)	(2.5)
S-F-H	Upstream	69.3	81.6	75.4	4.2	5.2	4.7	41.0	55.5	48.2
		(7.3)	(11.1)	(6.6)	(0.5)	(0.2)	(0.3)	(8.6)	(5.0)	(5.2)
	Downstream	159.3	162.8	161.1	7.0	5.9	6.4	47.6	56.8	52.2
		(13.2)	(20.4)	(11.6)	(0.4)	(0.3)	(0.3)	(2.6)	(1.7)	(1.9)
S-F-CHM 2000	Upstream	85.0	55.0	70.0	4.3	4.0	4.2	37.2	42.0	39.6
		(7.1)	(3.8)	(5.9)	(0.2)	(0.4)	(0.2)	(1.7)	(2.6)	(1.6)
	Downstream	161.1	217.2	189.1	7.7	7.0	7.3	44.0	67.2	55.6
		(8.5)	(11.8)	(10.9)	(0.2)	(0.2)	(0.2)	(1.9)	(3.4)	(3.9)
S-F-P	Upstream	64.8	94.6	79.7	4.7	5.7	5.2	40.5	37.2	38.8
		(5.0)	(11.1)	(7.3)	(0.3)	(0.2)	(0.2)	(3.1)	(2.7)	(2.0)
	Downstream	191.2	222.3	206.7	7.2	8.3	7.8	39.2	51.3	45.2
		(15.7)	(18.1)	(12.4)	(0.6)	(0.3)	(0.4)	(2.9)	(2.2)	(2.9)
S-F-P+WCF	Upstream	68.0	79.9	74.0	4.5	5.3	4.9	32.8	29.0	30.9
		(4.0)	(8.4)	(4.8)	(0.4)	(0.5)	(0.3)	(2.4)	(4.0)	(2.3)
	Downstream	198.1	171.5	184.8	8.0	7.5	7.8	45.7	58.2	51.9
		(22.8)	(9.8)	(12.5)	(0.4)	(0.5)	(0.3)	(4.5)	(4.5)	(3.6)
TS-S+B-F	Upstream	51.6	56.3	53.9	3.0	5.3	4.1	32.5	35.8	39.1
		(8.9)	(8.1)	(8.0)	(0.4)	(0.9)	(0.6)	(3.2)	(3.6)	(2.3)
TS-W-S-F-H	Upstream	88.8	146.3	117.5	4.7	6.0	5.3	50.0	42.7	46.3
		(21.4)	(27.3)	(18.7)	(0.7)	(0.4)	(0.4)	(1.3)	(2.0)	(1.6)
	Downstream	191.6	208.4	200.0	7.2	8.2	7.7	40.7	48.5	44.6
		(17.3)	(15.5)	(11.4)	(0.5)	(0.5)	(0.4)	(3.9)	(4.8)	(3.2)

* 1 = 1–10%; 2 = 11–20%, . . . , 10 = 91–100%.

† $\bar{x}$ (standard error).

Table B3. 1978 grass growth on 1977 single treatments.

Treatment	Refertilized or non-refertilized	Biomass (g/m²) Top	Bottom	Avg.	Cover class* Top	Bottom	Avg.	Max. height (cm) Top	Bottom	Avg.
TS-3S-F-	N	16.3†	2.3	9.3	2.0	1.0	1.5	41.5	20.5	31.0
Fiberglass		(1.2)	(0.5)	(4.1)	(0)	(0)	(0.3)	5.5	(7.5)	(7.2)
Upstream only	R	84.7	14.9	49.8	3.5	1.0	2.3	53.5	46.5	50.0
		(1.1)	(1.1)	(20.2)	(0.5)	(0)	(0.8)	(7.5)	(0.5)	(3.7)
TS-S-F	N	14.8	19.7	17.2	2.0	2.5	2.2	39.5	18.5	29.0
Upstream only		(3.2)	(2.3)	(2.2)	(0)	(0.5)	(0.2)	(0.5)	(2.5)	(6.2)
	R	48.6	70.2	59.4	2.5	6.0	4.2	37.5	26.5	32.0
		(5.8)	(8.1)	(7.4)	(0.5)	(1.0)	(1.1)	(2.5)	(2.5)	(3.4)
V1-F	N	7.9	14.3	11.1	2.0	2.5	2.3	14.5	32.5	23.5
Downstream only		(0.3)	(2.3)	(2.1)	(0)	(0.5)	(0.2)	(5.5)	(6.5)	(6.3)
	R	233.3	141.7	187.5	8.5	7.0	7.8	39.0	54.0	46.5
		(46.3)	(21.6)	(33.7)	(0.5)	(1.0)	(0.6)	(1.0)	(0)	(4.3)
V2-F	N	3.6	1.6	2.6	2.0	1.5	1.8	11.5	13.0	12.3
Downstream only		(0.4)	(1.0)	(0.7)	(0)	(0.5)	(0.2)	(1.5)	(2.0)	(1.1)
	R	179.9	138.4	209.2	7.5	8.0	7.8	33.5	50.5	42.0
		(25.8)	(26.9)	(22.7)	(1.5)	(1.0)	(0.8)	(8.5)	(5.5)	(6.4)
V3-F	N	11.5	6.4	9.0	2.5	5.0	3.3	17.0	32.0	22.0
Downstream only		(7.3)	(1.9)	(3.4)	(0.5)	–	(0.9)	(1.0)	–	(5.0)
	R	215.3	238.4	226.8	6.0	6.5	6.3	44.5	46.5	45.5
		(30.4)	(26.9)	(17.9)	(1.0)	(1.0)	(1.5)	(2.5)	(5.5)	(5.6)

* 1 = 1-10%; 2 = 11-20%; . . . ; 10 = 91-100%.
† $\bar{x}$ (standard error).

Table B4. 1978 grass growth on 1977 willow plots.

Treatment	Side	Refertilized or non-refertilized	Biomass (g/m²) Top	Bottom	Avg.	Cover class* Top	Bottom	Avg.	Max. height (cm) Top	Bottom	Avg.
W-F-CHM	Upstream	N	5.7†	6.0	5.8	1.0	1.0	1.0	12.5	31.2	21.8
2000			(1.1)	(1.9)	(1.1)	(0)	(0)	(0)	(3.5)	(7.2)	(4.8)
		R	44.6	87.6	64.1	1.8	2.7	2.2	28.2	42.8	35.5
			(9.9)	(18.7)	(12.1)	(0.3)	(0.3)	(0.2)	(7.0)	(4.4)	(4.5)
	Downstream	N	12.2	6.6	9.4	1.2	1.0	1.1	43.7	31.3	37.5
			(2.6)	(1.1)	(1.6)	(0.2)	(0)	(0.1)	(5.6)	(8.2)	(5.1)
		R	88.4	75.0	81.7	3.3	3.0	3.2	48.8	60.0	54.2
			(20.6)	(9.2)	(11.0)	(0.4)	(0.4)	(0.3)	(3.5)	(1.6)	(2.4)
W-F	Upstream	N	3.3	4.4	3.8	1.0	1.0	1.0	18.4	25.8	22.1
			(1.6)	(2.3)	(1.3)	(0)	(0)	(0)	(5.7)	(3.7)	(3.4)
		R	38.9	80.2	59.5	1.83	2.0	1.9	56.8	30.0	44.6
			(7.0)	(25.2)	(14.0)	(0.4)	(0.3)	(0.2)	(15.8)	(4.2)	(9.4)
	Downstream	N	13.3	19.7	16.8	1.0	1.0	1.0	23.5	28.7	25.2
			(4.0)	(4.5)	(3.1)	(0)	(0)	(0)	(6.6)	(8.3)	(4.8)
		R	89.7	72.8	81.2	2.5	3.2	2.8	65.0	75.8	70.4
			(11.7)	(13.9)	(9.0)	(0.6)	(0.3)	(0.3)	(6.5)	(6.6)	(4.7)
TS-W-F-H	Upstream	N	42.3	24.6	33.4	3.2	1.8	2.3	48.2	45.2	46.7
			(6.2)	(2.5)	(4.2)	(0.9)	(0.3)	(0.5)	(1.0)	(4.3)	(2.1)
		R	93.2	60.5	76.8	3.2	3.5	3.8	41.8	48.0	44.9
			(13.1)	(10.9)	(9.5)	(0.3)	(0.4)	(0.3)	(6.2)	(1.7)	(3.2)
	Downstream	N	44.3	76.2	60.3	5.5	3.5	4.5	50.0	58.5	54.2
	(1 rep. only)		(30.1)	(1.9)	(15.4)	(0.5)	(0.5)	(0.6)	(1.0)	(3.5)	(2.5)
		R	187.5	163.6	175.6	5.5	6.0	5.8	58.5	93.0	75.8
			(39.4)	(28.7)	(21.1)	(0.5)	(1.0)	(0.5)	(2.5)	(2.0)	(10.0)
W-F-H	Downstream	N	48.0	36.0	42.0	2.5	1.5	2.0	72.0	62.3	79.9
			(14.8)	(10.6)	(8.7)	(0.5)	(0.3)	(0.3)	(9.3)	(20.8)	(6.1)
		R	197.7	143.7	170.7	4.2	3.8	4.0	83.8	87.5	85.6
			(45.8)	(30.5)	(27.4)	(0.5)	(0.2)	(0.3)	(27.1)	(6.5)	(12.9)

* 1 = 1-10%; 2 = 11-20%; . . . ; 10 = 91-100%.
† $\bar{x}$ (standard error).

APPENDIX C: 1979 GRASS GROWTH ON 1977 DAM TREATMENTS.

Table C1. 1979 grass growth on 1977 replicated treatments; 1977 fertilization only.

Treatment	Side	Biomass (g/0.25 m²) Top	Biomass Bottom	Biomass Avg.	Cover class* Top	Cover class Bottom	Cover class Avg.	Max. height (cm) Top	Max. height Bottom	Max. height Avg.
S-F	Upstream	3.8†	4.8	4.3	1	2	1	13.8	14.5	14.2
		(0.3)	(1.6)	(0.7)	(0)	(0.7)	(0.3)	(2.8)	(2.0)	(1.6)
	Downstream	2.4	4.6	3.5	1	2	2	19.8	22.3	21.1
		(0.9)	(0.7)	(0.6)	(0.3)	(0.4)	(0.3)	(2.5)	(5.4)	(2.8)
S-F-WCF	Upstream	1.7	1.9	1.8	1	1	1	10.8	9.5	10.2
		(0.5)	(0.7)	(0.4)	(0)	(0)	(0)	(1.0)	(0.9)	(0.6)
	Downstream	1.1	1.9	1.5	1	1	1	12.8	18.7	15.8
		(0.4)	(0.4)	(0.3)	(0)	(0)	(0)	(0.9)	(0.9)	(1.0)
S-F-H	Upstream	4.4	4.3	4.3	1	1	1	22.2	22.7	23.4
		(1.0)	(0.5)	(0.5)	(0)	(0)	(0)	(2.2)	(5.5)	(2.7)
	Downstream	3.0	3.7	3.3	1	2	1	18.5	32.5	25.5
		(0.5)	(1.0)	(0.5)	(0.2)	(0.3)	(0.2)	(2.1)	(4.2)	(3.0)
S-F-CHM 2000	Upstream	3.3	2.9	3.1	1	1	1	13.8	13.7	13.8
		(0.7)	(0.6)	(0.5)	(0)	(0)	(0)	(0.7)	(2.0)	(1.0)
	Downstream	1.5	2.2	1.9	1	1	1	12.0	15.0	13.5
		(0.2)	(0.3)	(0.2)	(0)	(0)	(0)	(1.0)	(1.1)	(0.8)
S-F-P	Upstream	3.4	2.8	3.1	1	1	1	12.3	17.7	15.0
		(0.6)	(0.6)	(0.4)	(0)	(0)	(0)	(2.1)	(4.5)	(2.4)
	Downstream	1.4	2.7	2.0	1	1	1	15.3	19.0	17.4
		(0.4)	(0.3)	(0.3)	(0)	(0.7)	(0.1)	(2.5)	(1.3)	(1.4)
S-F-P+ WCF	Upstream	2.0	4.0	3.0	1	1	1	9.7	11.2	10.4
		(0.2)	(1.5)	(0.8)	(0)	(0.2)	(0.1)	(0.5)	(1.4)	(0.7)
	Downstream	1.5	2.8	2.1	1	1	1	13.3	17.0	15.2
		(0.2)	(0.6)	(0.3)	(0)	(0)	(0)	(1.3)	(2.0)	(1.2)
TS-S+B-F	Upstream	6.2	8.7	7.4	2	4	2	39.0	15.3	27.2
		(0.9)	(1.8)	(1.0)	(0.2)	(0.9)	(0.2)	(11.8)	(1.6)	(6.6)
TS-W-S-F-H	Upstream	9.3	10.7	10.0	2	2	2	29.3	34.0	31.7
		(2.1)	(1.1)	(1.1)	(0.3)	(0.2)	(0.1)	(3.6)	(3.7)	(2.5)
	Downstream	13.0	13.1	13.0	3	2	3	24.3	41.7	30.5
		(3.1)	(4.4)	(2.5)	(0.3)	(0.3)	(0.3)	(2.8)	(5.8)	(4.7)

* 1 = 1–10%; 2 = 11-20%; . . . ; 10 = 91–100%.

† $\bar{x}$ (standard error).

Table C2. 1979 grass growth on 1977 replicated treatments with two fertilizations.

Treatment	Side	Biomass (g/0.25 m²)			Cover class*			Max. height (cm)		
		Top	Bottom	Avg.	Top	Bottom	Avg.	Top	Bottom	Avg.
S-F	Upstream	34.3†	20.3	27.3	2.0	5.0	3.0	22.5	35.3	28.9
		(4.1)	(4.3)	(3.8)	(0.5)	(1.5)	(1.2)	(2.2)	(8.4)	(4.7)
	Downstream	40.5	33.4	36.9	8.0	7.0	7.0	27.8	25.8	26.8
		(2.2)	(10.6)	(5.2)	(0.6)	(0.6)	(0.5)	(2.9)	(2.2)	(1.7)
S-F-WCF	Upstream	24.7	26.3	25.5	4.0	4.0	4.0	17.8	22.5	20.1
		(3.2)	(3.8)	(2.3)	(0.9)	(0.5)	(0.5)	(1.1)	(3.5)	(2.0)
	Downstream	28.3	38.5	33.4	6.0	5.0	5.0	23.0	24.8	23.9
		(7.3)	(7.8)	(5.4)	(0.3)	(1.2)	(0.6)	(2.8)	(1.3)	(1.5)
S-F-H	Upstream	22.7	25.3	24.0	3.0	2.0	3.0	44.3	59.3	51.8
		(1.3)	(5.0)	(2.5)	(0.4)	(0.5)	(0.3)	(8.9)	(8.7)	(6.5)
	Downstream	52.7	33.0	42.9	4.0	3.0	4.0	32.0	35.5	33.6
		(9.7)	(0.9)	(5.8)	(0.6)	(0.7)	(0.5)	(3.8)	(4.6)	(2.8)
S-F-CHM 2000	Upstream	31.9	24.1	28.0	4.0	3.0	3.0	20.3	19.5	19.9
		(4.2)	(6.5)	(3.9)	(0.5)	(0.4)	(0.3)	(2.2)	(0.9)	(1.1)
	Downstream	44.3	17.9	31.1	4.0	2.0	3.0	19.3	23.8	21.5
		(8.4)	(5.1)	(6.8)	(1.2)	(0)	(0.6)	(1.0)	(2.1)	(1.4)
S-F-P	Upstream	39.5	27.0	33.2	4.0	5.0	4.0	24.8	24.0	24.4
		(2.7)	(2.2)	(2.9)	(1.0)	(0.6)	(0.6)	(2.5)	(4.1)	(2.3)
	Downstream	39.5	39.0	39.2	5.0	7.0	6.0	26.8	28.0	27.4
		(2.6)	(9.1)	(4.4)	(1.3)	(1.2)	(0.9)	(2.6)	(2.8)	(2.5)
S-F-P+ WCF	Upstream	24.3	22.5	23.4	5.0	4.0	5.0	28.3	19.3	23.8
		(2.1)	(6.2)	(3.1)	(0.4)	(0.4)	(0.3)	(6.3)	(0.5)	(3.4)
	Downstream	40.3	35.0	37.6	5.0	2.0	3.0	22.8	20.3	21.5
		(3.8)	(3.9)	(2.8)	(0.5)	(0.3)	(0.6)	(1.4)	(2.3)	(1.3)
TS-S+B-F	Upstream	21.1	24.0	22.2	4.0	5.0	4.0	34.0	27.7	30.8
		(3.3)	(3.6)	(2.3)	(0.3)	(0.6)	(0.3)	(7.5)	(2.8)	(3.8)
TS-W-S-F-H	Upstream	31.0	39.5	35.2	4.0	5.0	5.0	40.5	37.3	38.9
		(4.8)	(8.5)	(5.7)	(0.9)	(0.5)	(0.5)	(1.6)	(5.8)	(2.9)
	Downstream	27.0	16.0	21.5	7.0	2.0	5.0	39.0	48.0	43.5
		(4.8)	(4.4)	(3.7)	(0.4)	(0.3)	(0.9)	(6.9)	(5.3)	(4.4)

* 1 = 1-10%; 2 = 11-20%; . . . ; 10 = 91-100%.
† $\bar{x}$ (standard error).

Table C3. 1979 grass growth on 1977 replicated treatments with three fertilizations.

Treatment	Side	Biomass (g/0.25 m²) Top	Bottom	Avg.	Cover class* Top	Bottom	Avg.	Max. height (cm) Top	Bottom	Avg.
S-F	Upstream	49.6†	57.3	53.4	5.0	6.0	5.0	31.7	33.7	37.7
		(15.2)	(15.3)	(7.4)	(2.9)	(1.2)	(0.6)	(4.2)	(3.2)	(2.4)
	Downstream	101.4	93.8	97.6	9.0	9.0	9.0	43.0	43.7	43.4
		(17.3)	(7.6)	(8.6)	(0.6)	(0.3)	(0.3)	(3.3)	(1.4)	(1.6)
S-F-WCF	Upstream	71.5	33.2	52.3	6.0	4.0	5.0	39.3	25.3	32.3
		(11.2)	(4.1)	(10.1)	(0)	(0)	(0.5)	(4.5)	(4.0)	(4.2)
	Downstream	88.6	77.7	83.2	8.0	7.0	8.0	56.0	44.0	50.0
		(32.4)	(11.7)	(15.8)	(0.7)	(0.9)	(0.6)	(2.7)	(6.6)	(4.2)
S-F-H	Upstream	79.8	45.8	62.8	4.0	6.0	5.0	52.3	41.0	46.1
		(3.6)	(11.1)	(7.7)	(1.4)	(1.2)	(0.9)	(6.6)	(7.2)	(4.5)
	Downstream	96.7	71.5	84.1	8.0	7.0	8.0	43.0	53.7	48.4
		(10.1)	(3.8)	(7.5)	(0.6)	(0.6)	(0.4)	(4.4)	(11.4)	(6.0)
S-F-CHM 2000	Upstream	90.1	87.1	88.6	6.0	6.0	6.0	33.7	37.0	35.4
		(5.9)	(8.2)	(4.6)	(0)	(0.7)	(0.3)	(1.8)	(5.6)	(2.7)
	Downstream	60.0	75.4	67.7	7.0	6.0	7.0	39.7	51.3	43.5
		(10.1)	(15.0)	(8.8)	(0.6)	(0.6)	(0.4)	(4.3)	(5.9)	(4.2)
S-F-P	Upstream	72.7	78.2	75.5	6.0	7.0	7.0	39.7	36.7	38.2
		(7.5)	(21.1)	(10.1)	(0.9)	(0.6)	(0.5)	(1.4)	(0.9)	(1.0)
	Downstream	63.7	115.1	89.4	9.0	9.0	9.0	46.0	55.7	50.8
		(9.7)	(15.2)	(14.2)	(0.9)	(1.0)	(0.6)	(2.6)	(0.9)	(2.5)
S-F-P+ WCF	Upstream	36.2	84.2	60.2	6.0	7.0	7.0	32.7	40.3	36.5
		(6.3)	(22.2)	(15.1)	(0.6)	(0.7)	(0.5)	(1.4)	(4.6)	(2.8)
	Downstream	72.0	123.2	97.6	6.0	8.0	7.0	51.7	49.0	50.3
		(7.3)	(21.0)	(15.4)	(0.3)	(0.6)	(0.5)	(6.2)	(1.6)	(2.9)
TS-W-S-F-H	Upstream	46.3	59.5	52.9	2.0	2.0	2.0	30.5	37.0	33.8
		(6.1)	(0.9)	(4.1)	(0.5)	(0.5)	(0.3)	(0.5)	(12.1)	(5.3)
	Downstream	86.3	79.0	82.6	7.0	7.0	7.0	60.0	60.0	60.0
		(10.4)	(7.7)	(6.0)	(0.9)	(1.0)	(0.5)	(11.3)	(1.2)	(5.1)

* 1 = 1–10%; 2 = 11–20%; . . . ; 10 = 91–100%.
† $\bar{x}$ (standard error).

Table C4. 1979 grass growth on 1977 single treatments.

Treatment	Fertilization*	Biomass ($g/0.25\ m^2$) Top	Bottom	Avg.	Cover class† Top	Bottom	Avg.	Max. height (cm) Top	Bottom	Avg.
TS-3S-F-	F1	8.4**	2.4	5.4	3.0	2.0	3.0	22.3	17.7	20.0
Fiberglass		(1.6)	(0.9)	(1.6)	(0.9)	(0)	(0.5)	(5.1)	(1.8)	(2.6)
Upstream only	F2	23.2	13.3	18.4	6.0	6.0	6.0	42.0	25.3	33.7
		(0.2)	(5.8)	(2.9)	(0.3)	(1.0)	(0.6)	(12.1)	(1.5)	(7.4)
TS-S-F	F1	11.8	9.9	10.9	2.0	2.0	2.0	19.7	18.0	18.9
Upstream only		(1.0)	(1.8)	(1.2)	(0.6)	(0)	(0.2)	(1.8)	(0.6)	(0.9)
	F2	24.0	32.5	28.3	4.0	6.0	5.0	26.0	24.7	25.4
		(4.2)	(8.3)	(4.6)	(0.9)	(0.9)	(0.6)	(9.2)	(2.4)	(4.3)
V1-F	F1	1.6	2.3	1.9	1.0	6.0	4.0	14.3	27.0	20.7
Downstream only		(0.4)	(0.6)	(0.4)	(0.3)	(0.6)	(1.1)	(2.1)	(1.2)	(3.1)
	F2	78.2	47.7	62.9	1.0	2.0	1	20.3	24.3	22.7
		(36.3)	(12.3)	(18.6)	(0)	(0.3)	(0.2)	(3.3)	(0.7)	(1.8)
V2-F	F1	1.4	3.0	2.2	1.0	1.0	1.0	13.0	14.0	13.5
Downstream only		(0.4)	(1.0)	(0.6)	(0)	(0)	(0)	(2.1)	(1.0)	(1.1)
	F2	22.0	43.9	33.0	4.0	5.0	4.0	30.0	25.3	27.7
		(4.0)	(10.1)	(7.0)	(0.6)	(0.3)	(0.3)	(3.5)	(2.2)	(2.2)
V3-F	F1	1.5	3.9	2.7	1.0	2.0	2.0	11.7	22.3	17.0
Downstream only		(0.7)	(0.6)	(0.6)	(0)	(0.3)	(0.3)	(0.9)	(0.7)	(2.5)
	F2	19.8	21.0	20.9	5.0	4.0	5.0	30.3	33.0	31.7
		(2.2)	(4.5)	(2.3)	(1.6)	(1.0)	(0.9)	(2.2)	(3.1)	(1.8)

* F1—1977 fertilization; F2—1977, 1978 fertilization.

† 1 = 1-10%; 2 = 11-20%; . . . ; 10 = 91-100%.

** $\bar{x}$ (standard error).

Table C5. 1979 grass growth on 1977 unseeded willow plots.

Treatment	Side	Fertilization*	Biomass ($g/0.25\,m^2$) Top	Bottom	Avg.	Cover class† Top	Bottom	Avg.	Max. height (cm) Top	Bottom	Avg.
W-F-CHM	Upstream	F1	1.7**	4.7	3.2	1.0	1.0	1.0	11.7	13.2	12.2
2000			(0.8)	(2.0)	(1.1)	(0)	(0.2)	(0.1)	(4.9)	(1.5)	(1.0)
		F2	21.5	21.0	21.2	2.0	2.0	2.0	18.3	17.7	18.0
			(4.0)	(4.1)	(2.0)	(0.2)	(0.3)	(0.2)	(2.6)	(2.2)	(1.6)
	Downstream	F1	2.1	3.8	2.9	1.0	1	1.0	22.7	18.7	20.6
			(0.7)	(0.8)	(0.6)	(0.2)	(0)	(0.1)	(5.8)	(3.7)	(3.2)
		F2	22.3	18.0	20.2	2.0	2.0	2.0	40.5	38.2	39.3
			(4.7)	(2.9)	(2.6)	(0.4)	(0.4)	(0.3)	(8.5)	(10.9)	(6.4)
W-F	Upstream	F1	0.1	2.1	1.1	1.0	1.0	1.0	14.2	21.2	17.1
			(0.1)	(1.0)	(0.6)	(0.2)	(0)	(0.1)	(3.5)	(6.0)	(3.4)
		F2	11.4	11.4	11.4	1.0	1.0	1.0	39.5	53.5	46.3
			(7.8)	(6.7)	(4.8)	(0.2)	(0.2)	(0.1)	(6.2)	(8.8)	(5.4)
	Downstream	F1	3.3	2.2	2.7	1.0	1.0	1.0	15.5	49.2	32.3
			(3.2)	(1.6)	(1.6)	(0)	(0.2)	(0.1)	(3.3)	(4.7)	(5.7)
		F2	9.6	1.7	5.6	2.0	2.0	2.0	55.8	62.5	59.2
			(4.5)	(1.2)	(2.4)	(0.4)	(0.4)	(0.2)	(6.0)	(17.9)	(8.8)
TS-W-F-H	Upstream	F1	10.2	7.3	8.8	3.0	2.0	2.0	40.2	30.0	35.1
			(2.1)	(2.3)	(1.5)	(0.4)	(0.2)	(0.2)	(6.5)	(5.4)	(4.2)
		F2	38.3	28.5	33.4	3.0	2.0	2.0	48.7	44.2	46.4
			(8.3)	(6.5)	(5.1)	(0.3)	(0.2)	(0.3)	(2.9)	(4.2)	(2.5)
	Downstream	F1	36.8	20.1	28.4	3.0	2.0	2.0	57.3	62.7	60.0
	(1 rep. only)		(10.9)	(7.2)	(7.6)	(0.3)	(0.3)	(0.3)	(4.4)	(11.1)	(5.5)
		F2	54.7	63.7	59.2	4.0	2.0	3.0	56.7	78.3	67.5
			(7.0)	(16.8)	(8.4)	(0.9)	(0.6)	(0.7)	(0.9)	(16.7)	(9.0)
W-F-H	Downstream	F1	3.5	10.5	7.0	1.0	1.0	1.0	44.0	41.0	42.5
			(3.4)	(2.6)	(1.6)	(0.2)	(0)	(0.1)	(6.1)	(3.3)	(3.2)
		F2	38.7	50.0	44.3	3.0	2.0	2.0	80.8	77.2	79.0
			(3.3)	(4.2)	(2.5)	(0.2)	(0.3)	(0.2)	(8.9)	(9.2)	(5.9)

* F1—1977 fertilization; F2—1977, 1978 fertilization.

† 1 = 1-10%; 2 = 11-20%; . . . ; 10 = 91-100%.

** $\bar{x}$ (standard error).

APPENDIX D: GRASS GROWTH ON 1978 DAM TREATMENTS.

Table D1. 1978 grass growth on 1978 dam treatments.

		Biomass (g/m^2)			Cover class*			Max. height (cm)		
Treatment	*Side*	*Top*	*Bottom*	*Avg.*	*Top*	*Bottom*	*Avg.*	*Top*	*Bottom*	*Avg.*
TS-S1-F	Upstream	51.8†	85.3	68.5	3.0	3.2	3.1	53.5	58.7	56.1
		(7.9)	(11.4)	(8.5)	(0.4)	(0.3)	(0.2)	(1.9)	(2.0)	(1.5)
TS-S1-F-H	Upstream	106.8	125.8	116.4	4.0	4.8	4.4	68.2	78.0	73.1
		(12.1)	(14.2)	(9.4)	(0.6)	(0.6)	(0.4)	(3.7)	(3.1)	(2.8)
SG-S2-F-CHM2000-L	Downstream	22.3	31.2	26.8	1.6	2.3	1.8	43.8	51.7	46.4
		(4.8)	(5.1)	(3.6)	(0.2)	(0.4)	(0.2)	(3.0)	(7.9)	(3.3)
SG-S1-F-CHM2000-L	Downstream	7.5	12.0	9.8	2.0	2.5	2.2	10.2	21.8	16.0
		(0.9)	(1.4)	(1.0)	(0.3)	(0.2)	(0.2)	(1.5)	(2.4)	(2.2)
SG-S2-F-WCF	Downstream	71.8	78.6	75.2	5.8	7.2	6.5	34.3	43.8	39.1
		(12.2)	(5.8)	(6.5)	(0.5)	(0.4)	(0.4)	(5.0)	(3.0)	(3.1)
SG-S1-F	Downstream	102.0	153.7	128.2	4.5	5.0	5.0	51.0	70.5	60.8
		(11.3)	(30.1)	(12.7)	(0.5)	(0)	(0.3)	(0)	(11.5)	(7.3)
C1-S2-F-CHM2000	Downstream	–	–	17.0	0.7	1.0	0.8	–	–	14.3
		–	–	(7.4)	(0.3)	(0.6)	(0.3)	–	–	(7.9)
C2-S2-F-CHM2000	Downstream	–	–	0.5	0.7	1.0	0.8	–	–	13.3
		–	–	(0.3)	(0.3)	(0)	(0.2)	–	–	(3.6)

* 1 = 1–10%; 2 = 11–20%; . . . ; 10 = 91–100%.
† $\bar{x}$ (standard error).

Table D2. 1979 grass growth on 1978 dam treatments.

Treatment	Side	Fertilization*	Biomass (g/0.25 m²) Top	Bottom	Avg.	Cover class† Top	Bottom	Avg.	Max. height (cm) Top	Bottom	Avg.
TS-S1-F	Upstream	F1	22.9**	21.7	22.3	3.0	3.0	3.0	40.0	36.5	38.3
			(4.3)	(1.9)	(2.2)	(0.2)	(0.2)	(0.2)	(5.5)	(3.2)	(3.0)
		F2	62.7	71.1	66.9	5.0	5.0	5.0	67.8	56.5	62.2
			(9.1)	(3.4)	(4.7)	(0.3)	(0.5)	(0.3)	(4.2)	(4.9)	(3.4)
TS-S1-F-H	Upstream	F1	28.3	25.4	26.9	4.0	4.0	4.0	64.8	45.3	55.1
			(4.7)	(4.7)	(3.1)	(0.6)	(0.3)	(0.3)	(8.7)	(7.9)	(6.2)
		F2	86.9	92.1	89.5	7.0	7.0	7.0	79.7	69.8	74.8
			(5.9)	(11.4)	(6.0)	(0.6)	(0.4)	(0.3)	(2.8)	(6.0)	(3.4)
SG-S1-F-L-CHM2000	Downstream	F1	4.2	11.9	8.0	1.0	1.0	1.0	32.0	39.3	35.7
			(0.8)	(1.6)	(1.4)	(0.2)	(0.2)	(0.2)	(4.7)	(3.8)	(3.0)
		F2	64.1	124.5	94.3	4.0	6.0	5.0	65.2	75.5	70.3
			(6.0)	(17.3)	(12.4)	(0.6)	(1.1)	(0.6)	(2.1)	(8.6)	(4.4)
		SG2	24.7	25.2	24.9	2.0	3.0	3.0	33.2	62.2	47.7
			(13.7)	(5.7)	(6.8)	(0)	(0.3)	(0.2)	(5.3)	(5.5)	(5.6)
SG-S2-F-L-CHM2000	Downstream	F1	41.0	6.6	5.3	1.0	1.0	1.0	24.5	24.3	24.4
			(0.7)	(1.0)	(0.7)	(0.2)	(0.2)	(0.1)	(5.7)	(6.3)	(3.9)
		F2	90.9	124.6	107.7	6.0	7.0	6.0	60.3	63.3	61.8
			(10.1)	(10.0)	(8.3)	(0.9)	(0.8)	(0.6)	(3.3)	(3.3)	(2.2)
		SG2	14.0	29.3	21.6	2.0	4.0	3.0	38.3	48.8	43.6
			(1.7)	(6.3)	(3.8)	(0.2)	(0.5)	(0.4)	(4.9)	(4.6)	(3.6)
SG-S2-F-WCF	Downstream	F1	23.2	26.2	24.7	3.0	3.0	3.0	32.5	25.7	29.1
			(2.9)	(2.6)	(1.9)	(0.6)	(0.6)	(0.4)	(4.0)	(3.9)	(2.8)
		F2	96.4	136.7	116.6	7.0	7.0	7.0	57.0	63.0	60.0
			(10.1)	(9.5)	(8.8)	(0.6)	(0.8)	(0.5)	(1.8)	(3.6)	(2.1)
		SG2	31.3	40.7	36.0	3.0	5.0	4.0	24.7	51.8	38.3
			(2.8)	(3.7)	(3.8)	(0.5)	(0.7)	(0.6)	(3.4)	(5.1)	(5.0)
SG-1-F	Downstream	F1	14.7	14.9	14.8	2.0	3.0	3.0	27.0	63.3	45.2
			(0.4)	(3.8)	(1.7)	(0.3)	(1.0)	(0.3)	(3.9)	(14.2)	(10.6)
		F2	89.2	105.6	97.6	5.0	6.0	6.0	65.7	74.7	70.2
			(16.9)	(12.2)	(10.0)	(0.7,	(1.0)	(0.4)	(7.6)	(2.8)	(4.2)
		SG2	26.6	21.2	23.9	3.0	4.0	4.0	47.3	84.3	65.8
			(5.5)	(9.4)	(5.0)	(0)	(1.0)	(0.3)	(13.9)	(17.8)	(13.2)
C1-S2-F-CHM2000	Downstream	F2	45.6	76.8	61.2	2.0	4.0	3.0	62.0	63.0	62.5
			(12.7)	(47.0)	(22.9)	(0.3)	(0.6)	(0.5)	(4.7)	(0.6)	(2.1)
C2-S2-F-CHM2000	Downstream	F2	31.4	40.3	35.9	2.0	2.0	2.0	51.3	59.7	55.5
			(23 0)	(23.7)	(14.9)	(0.3)	(0.6)	(0.3)	(6.5)	(1.7)	(3.5)

* F1—1978 fertilization, F2—1978 + 1979 fertilizations; SG2—1978 fertilization and 1979 resludging.

† 1 = 1-10%, 2 = 11-20%,..., 10 = 91-100%.

** $\bar{x}$ (standard error).

APPENDIX E: 1977, 1978, AND 1979 SURVIVAL OF WILLOW TREATMENTS.

Table E1. 1977, 1978 and 1979 survival of willow cuttings.

		Survival (%)										
		Top*			Bottom†			Average**			1977 Fert. only	1977 & 1978 Fert.
Treatment	Side	1977	1978	1979	1977	1978	1979	1977	1978	1979	1979	1979
TS-F-H	Upstream	64.0	33.3	22.2	63.9	68.0	48.1	61.3	50.0	34.4	38.8	30.0
	Downstream (1 rep. only)	50.0	56.6	22.2	83.3	55.6	33.3	66.7	56.9	35.3	35.3	35.2
F-H	Downstream	63.5	50.0	44.4	70.9	55.6	55.6	58.8	60.7	52.3	48.8	55.8
TS-S-F-H	Upstream	0	7.7	3.8	28.0	29.6	23.1	17.3	9.2	7.1	8.2	5.9
	Downstream	11.1	11.1	15.4	44.5	18.5	33.3	26.4	18.8	14.7	15.4	14.0
F-CHM2000	Upstream	66.7	51.8	46.2	55.6	55.6	55.6	67.3	57.8	59.0	59.0	67.1
	Downstream	61.1	70.4	40.7	75.0	74.1	74.1	63.9	65.0	54.9	51.9	58.0
F	Upstream	66.7	62.9	63.0	69.6	74.1	48.1	68.5	62.5	67.9	48.9	87.0
	Downstream	46.2	48.2	25.9	60.1	50.0	46.1	44.5	49.1	47.8	47.0	48.7

* Top three rows.
† Bottom three rows.
** Average of all cuttings.

APPENDIX F: GRASS GROWTH ON TANANA LEVEE TREATMENTS.

Table F1. 1978 grass growth on levee treatments.

Treatment	Side	Biomass (g/m²)	Cover class* (%)	Max. height (cm)
TS-S1-F-H	N	232.0†(34.6)	7 (0.4)	104.1 (2.2)
	S	195.3 (9.5)	6 (0.3)	89.1 (1.7)
TS-S1-F-P	N	171.6 (37.3)	5 (0.5)	88.8 (3.8)
	S	97.5 (24.7)	4 (0.5)	68.9 (4.3)
TS-S1-F-WCF	N	60.6 (11.8)	3 (0.2)	75.2 (2.6)
	S	92.8 (20.7)	4 (0.5)	79.0 (4.3)
TS-S1-F-CHM2000	N	83.4 (13.5)	4 (0.3)	85.3 (2.4)
	S	134.4 (23.8)	5 (0.3)	89.6 (3.9)
TS-S1-F-P+WCF	N	128.2 (31.6)	5 (0.3)	84.6 (2.2)
	S	147.7 (24.6)	5 (0.5)	78.2 (4.4)
TS-S1-F	N	232.9 (35.3)	6 (0.3)	89.1 (4.3)
	S	72.0 (7.2)	3 (0.2)	63.8 (3.6)
C1-S1-F-CHM2000	N	— —	1 (0)	15.7 (8.4)
	S	14.7 (1.0)	1 (0)	36.3 (7.4)
EX-S1-F	N	137.7 (11.6)	5 (1.7)	89.0 (6.4)
	S	55.3 (0.5)	3 (0)	77.2 (3.7)

* 1 = 1-10%; 2 = 11-20%; . . . ; 10 = 91-100%.
† $\bar{x}$ (standard error).

Table F2. 1979 grass growth on levee treatments.

Treatment	Side	Fertilization*	Biomass (g/0.25 m²)	Cover class* (%)	Max. height (cm)
TS-S1-F-H	N	F1	30.2 (2.1)**	5 (0.4)	84.8 (8.9)
		F2	163.1 (16.3)	7 (1.8)	122.7 (10.1)
	S	F1	49.0 (8.3)	4 (0.8)	72.8 (7.9)
		F2	100.5 (5.9)	6 (0.7)	99.0 (8.7)
TS-S1-F-P	N	F1	22.9 (5.5)	5 (0.8)	50.3 (5.9)
		F2	75.4 (3.7)	7 (1.0)	90.0 (7.6)
	S	F1	25.4 (4.4)	4 (0.4)	51.8 (7.6)
		F2	62.3 (7.4)	5 (0.7)	65.0 (7.4)
TS-S1-F-WCF	N	F1	25.2 (6.3)	5 (0.3)	48.3 (4.8)
		F2	128.9 (41.2)	7 (0.3)	92.0 (11.2)
	S	F1	38.1 (7.7)	5 (0.5)	36.5 (4.1)
		F2	95.5 (9.1)	7 (0.3)	50.0 (7.1)
TS-S1-F-CHM2000	N	F1	66.9 (13.4)	5 (0.7)	50.7 (4.8)
		F2	75.9 (8.8)	6 (0.9)	75.3 (3.4)
	S	F1	32.9 (6.3)	6 (0.4)	50.7 (1.9)
		F2	94.9 (12.0)	7 (0.3)	54.3 (6.1)
TS-S1-F-P+WCF	N	F1	36.9 (5.0)	5 (0.6)	45.0 (3.1)
		F2	99.5 (14.9)	7 (0.9)	83.7 (10.3)
	S	F1	53.4 (7.0)	6 (0.2)	42.8 (3.9)
		F2	72.1 (10.0)	7 (0.3)	77.0 (12.4)
TS-S1-F	N	F1	28.9 (6.3)	6 (0.6)	45.8 (6.8)
		F2	100.4 (13.2)	7 (1.0)	112.7 (6.8)
	S	F1	20.9 (2.8)	4 (0.6)	64.3 (5.2)
		F2	72.5 (16.5)	5 (0.9)	73.3 (8.4)
C1-S1-F-CHM2000	N	F1	4.4 (4.4)	1 (0.5)	32.5 (32.8)
	S	F1	6.8 (0.4)	1 (0)	31.5 (15.7)
EX-S1-F	N	F1	10.4 (2.4)	3 (0.5)	29.5 (2.5)
	S	F1	13.5 (3.9)	2 (0.5)	48.5 (9.6)

* F1—1978 fertilization; F2—1978 + 1979 fertilization.
† 1 = 1-10%; 2 = 11-20%; . . . ; 10 = 91-100%.
** $\bar{x}$ (standard error).

APPENDIX G: CHEMICAL ANALYSIS OF SLUDGE AND RUNOFF WATER.

Table G1. Chemical analysis (mg/L) of 1978 sludge samples.

Plot	Arsenic	Barium	Cadmium	Chromium	Cyanide	Fluoride	Iron	Nitrogen: Ammonia	Nitrogen: Kjeldahl	Nitrogen: Total Kjeldahl	Nitrogen: Nitrate	Nitrogen: Nitrite	pH	Total phosphorus	Potassium	Selenium	Silver	Sodium	Turbidity (NTU)	Total solids (%)
1	1.21	70.8	0.51	3.12	494	15	1170	57.4	143	200	2.2	14	7.3	130	56.7	0.99	0.55	130	9,000	4.5
2	1.16	66.0	0.40	2.92	572	12	1099	44.8	40.2	85	4.2	15	7.1	120	55.8	0.93	0.73	167	14,000	4.1
3	1.16	17.4	0.36	2.63	494	14	822	35.0	100	135	0.9	13	7.2	140	49.2	0.79	0.36	137	13,000	4.0
4	1.08	62.1	0.37	2.42	390	10	807	30.8	109	140	3.0	41	7.1	135	59.7	0.75	1.09	143	6,000	3.3
5	1.21	71.4	0.45	2.89	364	10	1019	30.8	24.2	55	0.6	27	7.1	135	54.0	1.00	0.48	133	4,000	3.4
6	1.28	71.1	0.43	2.96	390	11	1034	35.0	68.6	160	0.4	38	7.0	120	58.8	0.91	0.91	151	7,000	3.9
7	1.35	81.3	0.59	3.40	364	14	1291	36.4	68.6	105	0.9	54	7.3	140	60.6	1.08	1.50	169	10,000	4.4
8	1.06	62.7	0.33	2.30	190	12	736	28.0	30	58	0.4	54	7.1	145	52.5	0.70	0.69	139	12,000	4.0
9	0.96	42.0	0.40	2.79	286	5	833	19.6	155	175	24.0	20	7.8	60	47.1	0.74	0.22	129	4,400	1.5
10	0.96	73.2	0.44	3.13	120	14	616	28.0	162	190	2.8	40	7.3	160	51.0	0.66	1.74	199	12,000	3.3

Table G2. Chemical analysis* of runoff water from sludge plots (1978).

Plot	Coliform (no./100 mL) Total	Coliform (no./100 mL) Fecal	Arsenic	Barium	Cadmium	Chromium (+6)	Cyanide	Fluoride	Iron	Nitrogen Ammonia	Nitrogen Kjeldahl	Nitrogen Total Kjeldahl	Nitrogen Nitrate	Nitrogen Nitrite	pH	Total phosphate	Potassium	Selenium	Silver	Sodium	Turbidity (NTU)
SG-S1-F-L-CHM2000																					
1	0	0	0.038	<0.1	0.005	0.09	0.05	0.05	2.12	0.015	0.82	0.84	0.06	<0.01	7.5	0.33	9.02	<0.001	<0.01	14.8	8
2	33	0	0.024	<0.1	0.002	0.10	0.04	0.04	3.29	0.068	0.75	0.82	0.01	<0.01	7.1	0.17	2.48	<0.001	<0.01	4.1	10
3	0	0	0.007	<0.1	0.002	0.09	0.04	0.05	3.36	0.023	0.76	0.78	0.04	<0.01	7.1	0.27	2.58	<0.001	<0.01	5.9	10
SG-S2-F-L-CHM2000																					
4	0	0	0.019	<0.1	0.001	0.15	0.03	0.04	6.1	0.030	1.12	1.15	0.02	<0.01	7.1	0.28	2.64	<0.001	<0.01	8.5	21
5	0	0	0.014	<0.1	0.003	0.12	0.05	0.05	5.6	0.028	1.35	1.38	0.02	<0.01	7.2	0.34	4.18	<0.001	<0.01	6.3	17
6	0	0	0.026	<0.1	0.004	0.19	0.04	0.04	10.4	0.031	0.97	1.00	0.08	<0.01	7.3	0.36	3.41	0.007	<0.01	5.9	12
SG-S2-F-WCF																					
7	†	0	0.022	<0.1	0.004	0.10	0.05	0.03	6.9	0.045	0.88	0.92	0.06	<0.01	7.2	0.32	3.14	0.004	<0.01	5.9	4.6
8	1	0	0.015	<0.1	0.003	0.09	0.04	0.03	5.8	0.038	2.57	2.61	0.04	<0.01	7.1	0.32	1.10	0.004	<0.01	0.4	22
9	68	0	0.015	<0.1	0.002	0.15	0.01	0.03	6.9	0.024	0.91	0.93	0.06	<0.01	7.0	0.27	2.97	<0.001	<0.01	2.8	7.5
SG-S1-F																					
10	0	0	0.012	<0.1	<0.001	0.15	0.01	0.03	5.4	<0.001	0.64	0.64	0.07	<0.01	7.1	0.28	2.09	<0.001	<0.01	0.4	8
Control	†	0	0.013	<0.1	0.002	0.09	0.01	0.03	6.2	0.135	3.46	3.60	0.06	0.02	7.3	0.31	2.92	<0.001	<0.01	8	25

* Units mg/L unless otherwise noted.

† Too numerous to count.

Table G3. Chemical analysis of 1979 sludge samples.

Load*	Nitrogen: Ammonia (mg/L)	Ammonia (mg/kg)	Kjeldahl (%)	Total Kjeldahl (%)	Nitrate (mg/L)	Nitrate (mg/kg)	Nitrite (mg/L)	Nitrite (mg/kg)	Total phosphorus (mg/L)	Total phosphorus (mg/kg)	Potassium (mg/L)	Potassium (mg/kg)	Coliform (no./100 mL) Total	Coliform Fecal	Solids (%)
1	280	7000	4.65	5.35	1.8	45.0	0.170	4.25	685	17,125	163	4075	7.1×10^7	2.4×10^7	4.0
2	340	6182	4.31	4.93	2.3	41.8	0.174	3.16	650	11,818	186	3382	8.4×10^6	6.0×10^6	5.5
3	350	6364	3.90	4.54	2.8	50.9	0.166	3.02	678	12,327	134	2436	2.0×10^7	2.4×10^6	5.5

* Load 1 was sprayed on plots 1–3.
Load 2 was sprayed on plots 4–6.
Load 3 was sprayed on plots 7–9.

Table G4. Chemical analysis of runoff water from sludge plots (1979).

Fertilization*	Nitrogen (mg/L): Ammo	Kjeldahl	Total Kjeldahl	Nitrate	Nitrite	Total phosphorus (mg/L)	Potassium (mg/L)	Total coliform (no./100 mL)	Fecal coliform (no./100 mL)
SG-S1-F-L-CHM2000									
F1	0.62	1.10	1.72	0.26	<0.010	0.18	3.89	0	0
F2	0.68	1.14	1.82	0.62	0.076	0.25	4.93	0	0
SG2	0.79	1.42	2.21	0.92	<0.010	0.24	8.12	3	70
SG-S2-F-L-CHM2000									
F1	0.39	0.95	1.32	0.53	<0.010	0.12	2.262	0	0
F2	0.41	≤0.41	<1	0.48	<0.010	0.21	2.056	0	0
SG2	0.20	≤0.20	<1	0.73	<0.010	0.24	2.193	0	0
SG-S2-F-WCF									
F1	0.84	≤0.84	<1	0.85	0.021	0.17	7.05	0	0
F2	0.30	≤0.30	<1	0.78	<0.010	0.06	1.603	0	0
SG2	0.33	≤0.33	<1	0.18	0.027	0.21	2.168	0	0
SG-S1-F									
F1	0.76	≤0.76	<1	0.44	0.036	0.24	2.337	0	0
F2	0.60	≤0.60	<1	0.23	<0.010	0.25	5.31	1	<10
SG2	0.044	≤0.044	<1	0.16	<0.010	0.21	10.78	0	0
Control	0.30	1.00	1.30	1.7	0.041	0.21	1.898	0	0
	0.49	≤0.49	<1	<0.1	<0.010	0.06	1.510	0	0

* F1—1978 fertilization; F2—1978 and 1979 fertilizations; SG2—1978 fertilization and 1979 resludging.

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