

Results of Tests on Vegetated Waterways, and Method of Field Application

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Results of Tests on Vegetated Waterways, and Method of Field Application

By MAURICE B. COX and VERNON J. PALMER*

THIS BULLETIN presents results of four years of research on the use of vegetation as a protective lining of farm waterways, such as pond spillways, terrace outlet channels, and natural watercourses. The protective ability and hydraulic characteristics of linings of alfalfa, Bermuda grass,

blue grama grass, buffalo grass, weeping lovegrass, and a grass mixture native to Oklahoma were determined. The results are analyzed and presented in a manner such that engineers may apply them directly to the design of farm waterways.

The use of vegetation as a lining to protect terrace outlet channels, pond spillways and other types of farm waterways from erosion is now a common practice. Field experience has yielded much information as to suitable vegetal covers, methods of establishment, and maintenance requirements. However, maximum velocities to which vegetal linings may be subjected and remain unharmed and the retardance offered to flow are factors difficult to evaluate in the field. The Oklahoma Agricultural Experiment Station, in cooperation with the Soil Conservation Service, conducted a series of vegetal channel experiments near Stillwater, Oklahoma, from 1940 to 1943 with the primary objective of evaluating these factors for certain vegetal covers adaptable as channel linings in Oklahoma and surrounding states. Contained herein is a final complete report of these studies. It includes the 1940 and 1941 results released as Technical Bulletin No. T-15 in September, 1942 (1).** These studies were conducted under the immediate direction and supervision of Maurice B. Cox.

The first attempt to study the stability and hydraulic behavior of vegetal lined channels was begun in 1935 near Spartanburg, S. C., by the Soil Conservation Service. This project, known as the Spartanburg Outdoor Hydraulic Laboratory, continued until 1941. A comprehensive report of its findings has been prepared by Ree and Palmer (5). In 1941 the site near Spartanburg was abandoned in favor of a much larger site and considerably greater water supply at Lake Carl Blackwell, near Stillwater, Oklahoma. This new location, renamed the Stillwater Outdoor Hydraulic Laboratory, surrounds

the area in which the channel studies reported here were accomplished. Mutual cooperation and assistance benefited both State and Federal projects. Certain results from the studies by the Oklahoma Agricultural Experiment Station have been used by Palmer in technical publications (2, 3, 4).

Seven different covers were tested. They were: Alfalfa (*Medicago sativa*), long and short Bermuda grass (*Cynodon dactylon*), blue grama (*Bouteloua gracilis*), buffalo grass (*Buchloe dactyloides*), weeping lovegrass (*Eragrostis curvula*), and a native grass mixture consisting of little bluestem (*Andropogon scoparius*), Indian grass (*Sorghastrum nutans*), switch grass (*Panicum virgatum*), blue grama, and side-oats grama (*Bouteloua curtipendula*).

Flow retardance results were analyzed and applied to field channels by procedures developed at the Stillwater Outdoor Hydraulic Laboratory on the basis of results obtained at both the Spartanburg and Stillwater laboratories (2, 3, 5).

DESCRIPTION OF LABORATORY

The experimental channels were constructed on a natural land slope, classified as Dougherty silt loam, below the dam of Lake Carl Blackwell, about six miles west of Stillwater, Oklahoma. The general arrangement of channels and facilities is shown in Figure 1. Water was drawn from the lake and pumped into the reservoir, then flowed by gravity through a rate measuring flume and suitable wooden connecting flumes into the channel being tested. The capacity of the system was 30 cubic feet per second.

The test channels were two feet wide and 100 feet long, with sheet iron separators between adjacent channels as shown in Figure 2. The top soil was removed from the slope where the channels were to be located and then the subsoil excavated to grade 12 inches below the finished grade. The sheet iron separators, 18 inches wide, were placed in position and brought to alignment by the use of planks (Figure 3). In channels where the vegetation was to be established from seed the top soil was then replaced and tamped to grade. Where sod was to be used, the channels were back-filled with top

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**Italic numerals in parentheses refer to Literature Cited page 13.

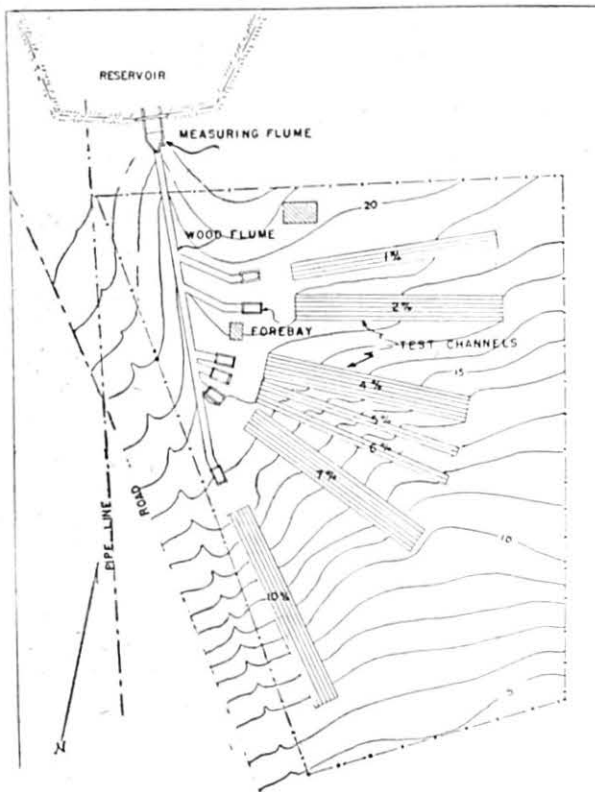


Fig. 1.—Arrangement of experimental area.

soil to within 4 inches of the final grade. Then sod, 4 inches thick, was placed carefully and rolled. The metal sidewall separators extended 6 inches above the finished channel bed. Extension sides 2 feet high were placed on top of the separators so that flows deeper than 6 inches could be obtained (Figure 4).

PROCEDURE

HYDRAULIC MEASUREMENTS

The test flows were measured by a three-foot type H flume (Figure 5). The desired rate of flow was established by adjustment of three control gates in a reservoir outlet structure upstream from the flume. A corrugated sheet metal baffle between the gate structure and flume resulted in satisfactory approach conditions to the flume.

For each run (discharge held constant or nearly so) the flow was allowed to become steady through the channel before water surface observations were begun. The duration of test flows ranged from 8 to 60 minutes. At the close of a run the flow was diverted from the test channel so that the effect of flow on the channel could be observed.

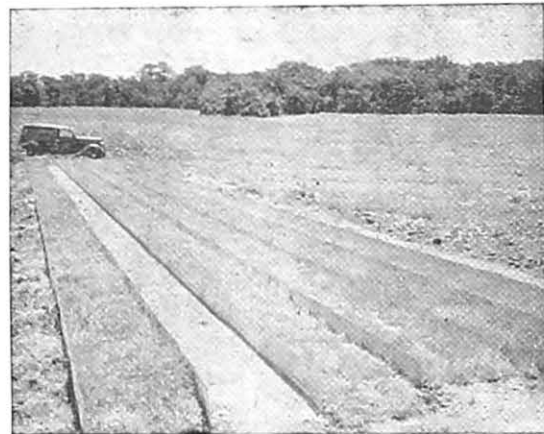


Fig. 2.—Completed test channels shortly after installation. The sheet iron separators extend six inches above the surface of the ground.



Fig. 3.—Installing sheet iron separators between channels. Strips of sheet iron 18 inches wide were placed 12 inches below finished grade and 6 inches above. Note 2" x 12" boards used for maintaining alignment while soil is placed in channel.

McIntyre point gages held in riders operating on horizontal angle-iron supports (Figure 6) were used in making both bed and water surface measurements. Observations at 0.2 foot intervals across the channel were taken at four stations at 20-foot intervals along the channel, with the first station 20 feet from the channel entrance. Water surface measurements were taken simultaneously at the four stations. Two traverses of water surface were taken during each test run, using sharp points in the gages. For bed measurements, blunt points were used.

VEGETATIVE MEASUREMENTS.

During the first two seasons of testing (1940 and 1941) the vegetation was measured by a system yielding a volume of vegetation which was termed "forage cover." The grass was separated into small bunches or clumps and twisted to form a compact, round section. The diameter of this section and average length of stem were recorded. All the vegetation in an area 2 feet square was measured in this manner and the final results expressed in cubic inches of forage per square foot. For each channel, measurements were made at five selected locations. The air-dry weight of forage measured in this manner was found from actual clippings to be 32.9 pounds per cubic foot. The variation in weight was very small for the different grasses studied. The advantage of this method was that the quantity of vegetation, incorporating number, size, and length of stems, was contained in a single figure.

During 1942 and 1943, a stand count method was used. This consisted of counting the number and determining the average length of

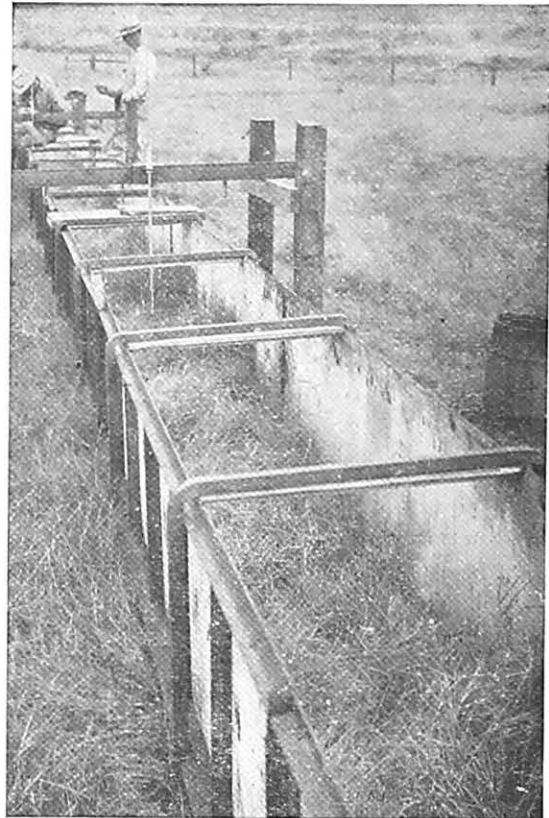


Fig. 4.—Channel with extension walls in place in readiness for testing. Point gage for making bed and water surface measurements is held in a rider operating on a horizontal steel angle. Photograph also shows a heavy growth of long Bermuda grass in Channel 7A, Experiment 1.

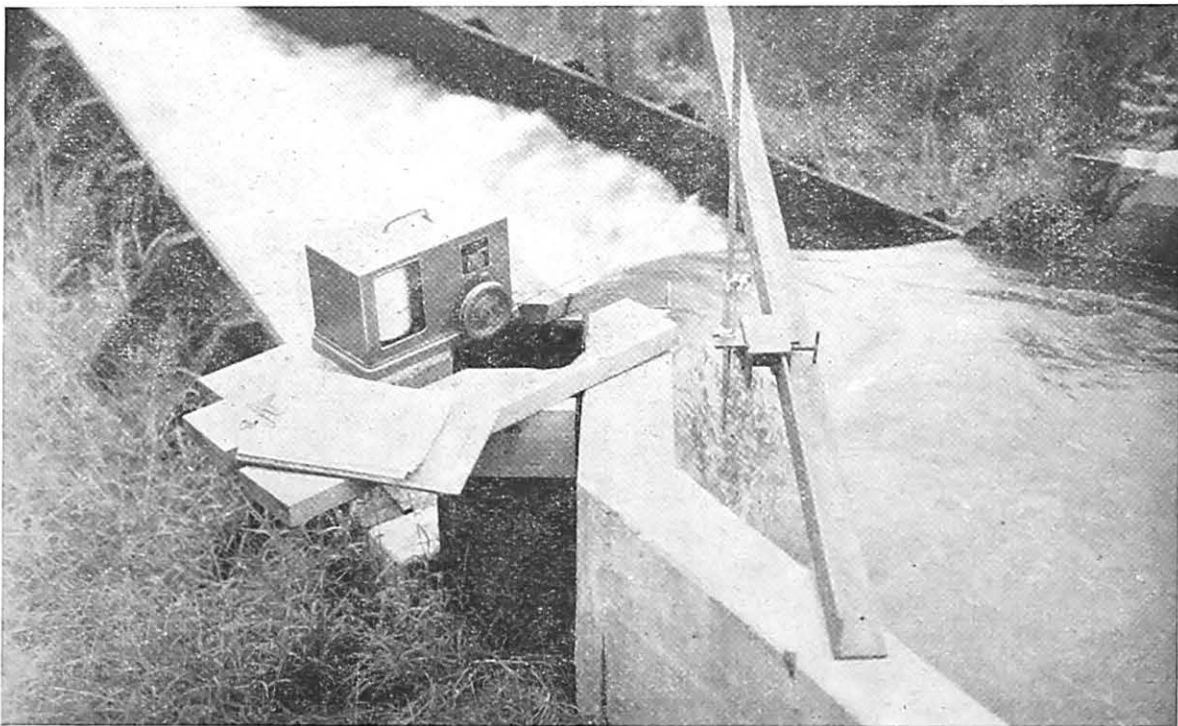


Fig. 5.—Three-foot, type H, rate measuring flume equipped with point gage and recorder.



Fig. 6.—Equipment and procedure used in making bed and water surface observations. Bermuda grass Channel 7A, Experiment 1, with vegetation about 80 percent submerged.

stems in a small area. The five areas counted in each channel were 6 inches square for the sod grasses and 24 inches square for alfalfa and the taller covers. The results are expressed in stems per square foot and average length of cover.

SCOUR MEASUREMENTS.

The rate of scour, expressed as surface inches of soil removed per hour of testing, was determined from the duration of flow and the difference between point gage readings taken across the channel bottom before and after each test run. With point gage measurements taken at only four stations, the computed scour rate is usually not an accurate evaluation of the erosion and damage to the channel. Visual observations of changes in the vegetation and channel bed are generally more significant. Scour rates as given in the included data should be considered as indications only, rather than absolute measurements.

VEGETATION SUBMERGENCE.

A visual observation of vegetation submergence was recorded for each test flow. Submergence was considered to occur only when plants were completely inundated, either by the flow being deep enough to overtop upright plants or by the velocity being great enough to bend the plants down into the flow. It is expressed as the percentage of the vegetation in a channel that was completely inundated. Figure 6 shows

long, green Bermuda grass partially submerged. Submergence is an important action because the retardance to flow begins to decrease sharply after the vegetative cover is submerged.

HYDRAULIC COMPUTATIONS.

The value of the coefficient n in the widely used Manning formula was evaluated for the various vegetal covers tested. The Manning formula to estimate velocity is

$$\text{Where } V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

or to determine capacity directly

$$Q = \frac{1.486}{n} A R^{2/3} S^{1/2}$$

Where V = mean velocity in feet per second

Q = discharge in cubic feet per second

A = cross-sectional area of flow in square feet

R = hydraulic radius in feet (the cross-sectional area divided by the wetted perimeter)

S = slope of the energy line in feet per foot (slope of bed or water surface for uniform flow)

n = a coefficient depending upon all the characteristics of a channel which produce retardation of the flow, such as roughness and irregularities of bed and sides, and irregularities in grade and cross-sectional shape. In vegetal channels the effect of the area blocked out by the vegetation is included.

All the hydraulic elements except n in these expressions were determined from field measurements. The discharge, Q , was measured by the 3-foot H flume. The cross-sectional area was determined from the depth and width at the measuring stations. The mean velocity, V , at each station was computed from Q/A . The depth of flow, D , was used in place of the hydraulic radius, R , since tests on 3 percent slope channels at the Spartanburg Outdoor Hydraulic Laboratory (5) indicated the smooth sidewalls may have little effect when the bottom roughness is as great as it is in grass channels. Using depth of flow as the hydraulic radius has the effect of considering only the bed as the wetted perimeter. The slope of the energy line, S , was determined by slightly correcting the water surface slope to account for differences in velocity-heads at the ends of the reach (since the flow was not always uniform). After these individual hydraulic elements were evaluated, the coefficient n was determined.



Fig. 7.—A very dense and uniform cover of short Bermuda grass with 939 stems per square foot and average length of 2.63 inches. Lower end of pencil and cigarette are in contact with the soil.

DESCRIPTION OF VEGETAL LININGS

ALFALFA.

The alfalfa channels were seeded during the spring of 1942 but poor stands were obtained. They were reseeded during the early spring of 1943 and good stands developed. The alfalfa made a good growth and the first crop was cut for hay. The tests were made during the late summer on new plants ten to thirteen inches tall.

BERMUDA GRASS (long).

The Bermuda grass channels were installed during the spring of 1940 by solid sodding. The grass was allowed to grow without clipping during the spring and most of the summer. A very vigorous top growth developed, with considerable dead material along the ground surface and most of the green leaves on the upper portion of the plants. This condition, Figure 4, prevailed when the tests were conducted in the fall of 1940. In the spring of 1941 the top growth of grass was removed completely and the channel beds given a light dressing of soil to replace that removed during the previous season's testing. For the second experiment (1941) the grass had attained a growth similar to that of the previous fall.

BERMUDA GRASS (short).

During the spring of 1942 the top growth of Bermuda grass on the channels installed in 1940 was again removed and the channel beds repaired. At this time additional channels were installed on 5 and 6 percent slopes. All the



Fig. 8.—Blue grama lined Channel 10D after Experiment 1.



Fig. 9.—Buffalo grass lined Channel 10F before Experiment 1. The cover is 95 percent buffalo grass and 5 percent crabgrass.

Bermuda grass channels were mowed regularly during the 1942 growing season with a lawn mower set to cut as high as possible. A very dense, uniform cover of short grass developed in all channels (Figure 7). This condition was tested in the fall of 1942.

BLUE GRAMA GRASS.

The blue grama grass linings were installed by solid sodding in the spring of 1940. When tested in the fall, the channels were covered with a very good stand of unmowed grass which included a small amount of crabgrass (Figure 8).

BUFFALO GRASS.

Buffalo grass was established in channels on 1, 2, 4, 7 and 10 percent slopes in the spring of 1940 by solid sodding. Covers on the 5 and 6 percent slopes were placed in the spring of 1942. This naturally short vegetation developed a fairly uniform cover (Figure 9) not quite as dense as that for the short Bermuda grass.

WEEPING LOVEGRASS.

The weeping lovegrass channels were seeded early in 1941. Although a generally good stand developed (Figure 10), the plants along the sides received more light and as a result grew more vigorously and tended to shade out plants in the center. This is believed to have caused the development of a narrow bare strip that existed along the centerline of the channel.

NATIVE GRASS MIXTURE.

The native grass channels were seeded in the spring of 1942 to a mixture of tall and short grasses consisting of little bluestem, Indian, switch, blue grama, and side-oats grama. Little bluestem was the most predominant (Figure 11). The tall grasses were clipped the next spring and the channels tested late in the summer.

PROTECTIVE ABILITY OF VEGETATIONS

The following paragraphs present observations on the ability of vegetal linings to reduce scour. These observations, of course, apply to the conditions of these experiments. The soil, Dougherty silt loam, is considered an erosion-resistant soil. The covers were generally quite uniform and with densities considered good to excellent for field conditions. The channels were uniform in grade and had good alignment. The channel beds would be considered very smooth relative to field channels. As field conditions become more conducive to erosion, permissible velocities stated below should be decreased.

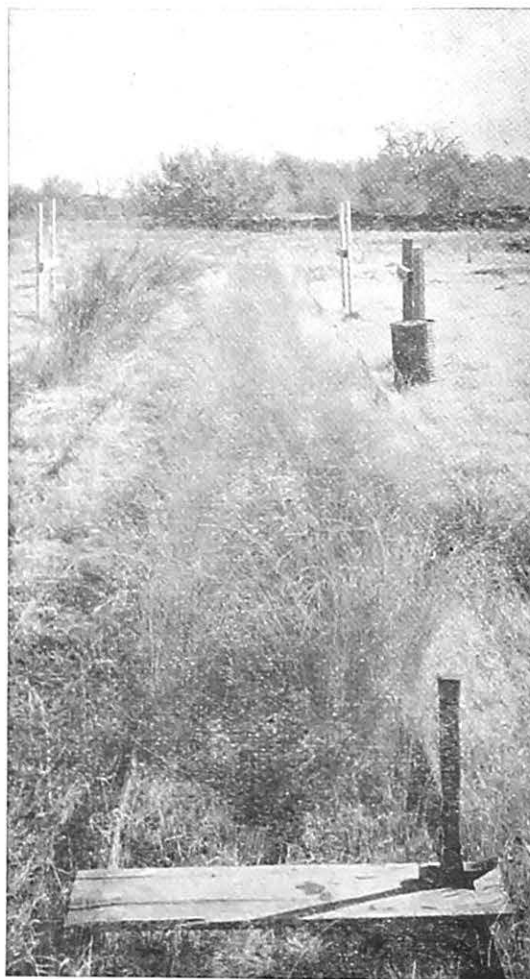


Fig. 10.—Weeping lovegrass in Channel 1B, Experiment 2. Maximum height approached 36 inches.

ALFALFA.

Permissible velocities for alfalfa should not exceed 3 feet per second and this cover should not be used as a channel lining on slopes steeper than 3 percent.

Visual observations of channels planted to alfalfa on the Wheatland Conservation Experiment Station near Cherokee, Oklahoma, show that good protection is offered to a channel with a 2 percent slope and that a protective cover developed more rapidly than for native grasses.

BERMUDA GRASS (long).

A permissible velocity of 7 ft. per sec. is a reasonable design value for slopes up to 10 percent where the soil is a silt or clay loam and a good, uniform cover will develop.

A tall, luxuriant growth of Bermuda grass does not necessarily provide the best channel protection. Extensive leaf growth may result in a thin stand of stems and inhibit the development of a dense growth near or on the ground surface. Runners will become very long without being rooted at the joints. The cover consists of a layer of live grass supported by bare stems and an accumulation of dead material. This condition existed for the Bermuda grass experiments conducted on long grass in 1940 and 1941. When subjected to deep, swift flows, the dead material lodged in drifts, forming a very irregular vegetal mat. Under this condition the flow became violently turbulent and excessive bed erosion was evident.

BERMUDA GRASS (short).

When Bermuda grass is mowed regularly or grazed reasonably, a dense stand tends to develop. The dense surface mat formed under such treatment provides excellent protection. In the experimental channels tested with short Bermuda grass only slight erosion was observed even after subjecting the linings to velocities as high as 12 ft. per sec. for 40-minute periods. A permissible velocity of 8 ft. per sec. for slopes up to 10 percent is recommended.

BLUE GRAMA GRASS.

The experiments show that with an excellent stand of blue grama grass a maximum design velocity of 7 ft. per sec. could be used on slopes up to 10 percent. Figure 8 shows the dense, tufted cover that developed in the experimental channels. Since blue grama is essentially a bunch grass and does not have stolons like Bermuda or buffalo grass, it generally will not develop as good a sod cover as these latter grasses. It is believed that permissible velocities under field conditions should be less for blue grama than for sod covers.

BUFFALO GRASS.

Buffalo grass is capable of forming a good, naturally short, sod cover. Only under favorable conditions, however, will it produce a cover providing the protection of clipped Bermuda grass. A permissible velocity of 7 ft. per sec. is recommended for good uniform covers on slopes not exceeding 10 percent.



Fig. 11.—Native grass mixture in Channel 1D, Experiment 1. Little bluestem is the predominant grass, with growth as high as 48 inches.

WEeping LOVEGRASS.

These experiments indicate that with good to excellent stands of weeping lovegrass the velocity should not exceed 3.5 ft. per sec. Use on slopes steeper than 5 percent is not desirable. Dense large bunches, high crowns, and much bare area characterizes a cover of weeping lovegrass. Deep, swift flows become very rough with this type of lining. The excessive turbulence and bare areas are factors very conducive to scour. When lovegrass is used as a lining the channel should be broadcast seeded to insure random location of plants.

NATIVE GRASS MIXTURE.

A native grass mixture consisting of little bluestem, Indian, switch, blue grama, and side-oats grama provides no more channel protection than weeping lovegrass. The bunch grasses, varying naturally in height, density, and size of clump, form a very irregular lining. As with weeping lovegrass, deep, swift flows become very rough and erosive. Velocities and slopes should be limited to 3.5 ft. per sec. and 5 percent respectively.

CAPACITY OF VEGETAL-LINED CHANNELS LABORATORY RESULTS.

Appendix Tables 2 to 8 give a description of the cover, the hydraulic and scour results for each test flow, and observations of the hydraulic behavior. The hydraulic results are average values of three 20-foot reaches, whereas the scour rates are the averages of those determined at four cross-section stations. (See pages 6 and 8).

The capacity, Q , varies inversely as n in the Manning formula:

$$V=Q/A=\frac{1.486}{n} R^{2/3} S^{1/2}.$$

An important consideration of the field technician in designing vegetal lined waterways is the estimation of the value of n . The hydraulic results of the experiments reported here will be presented in such a manner as to aid the technician in selecting a value for n . However, in the actual application, the design is accomplished through graphical means considering but not actually evaluating n .

The analysis of the results obtained will be confined to a presentation of the variation of the retardance coefficient, Manning's n , with depth and velocity of flow for the different covers studied, and to a method of field application. The method of analysis and application was developed at the Stillwater Outdoor Hydraulic Laboratory (3, 5). The product of mean velocity and hydraulic radius (approximately average depth) has been determined at this laboratory to be a satisfactory criterion for estimating n , and a graphical method of solving the Manning formula (considering an n variable with VR) has been developed to facilitate design. The presentation here will be on this basis with the exception that VD rather than VR will be used since side-wall friction has been considered negligible. Plots of n versus VD for the different covers tested are recorded in Figures 12 to 18, pages 14 to 20.

ALFALFA.—A single n — VD relationship applicable to a good uniform stand of green, uncut alfalfa is developed in Figure 12.

BERMUDA GRASS (long).—Figure 13 presents results from a great number of channels varying in bed slope from 1 to 10 percent and with considerable variation in length and density of Bermuda grass cover. The single curve indicated is considered to be an average relationship applicable to good uniform covers of tall Bermuda grass.

BERMUDA GRASS (short).—Figure 14 presents the n — VD results for a number of channels varying in bed slope from 1 to 10 percent. The covers of short Bermuda grass were fairly similar between channels, therefore Figure 14 shows only a single, average n — VD relationship that applies to good, uniform covers.

BLUE GRAMA GRASS.—The length of cover in one channel of blue grama grass (channel 2-D) was considerably greater than that in any other channel. A division of the n — VD results into two classes, tall, and very tall, seems justifiable. These relationships are presented in Figure 15.

BUFFALO GRASS.—The n — VD results for fourteen experiments on unmowed buffalo grass are given in Figure 16. A single average n — VD relationship is shown that may be applied to good, uniform covers of this grass.

WEeping LOVEGRASS.—The weeping lovegrass covers are divided into three groups dependent upon the length and age of cover. These are self-explanatory in Figure 17 for the three groups of plottings.

NATIVE GRASS MIXTURE.—Results from the three grass mixture channels are plotted in Figure 18. A single, average n — VD relationship is shown that is applicable to many channels with mixtures of tall and short grasses native to Oklahoma and surrounding region.

FIELD APPLICATION.

The average or selected n — VD relationships for all vegetal covers tested are presented in Figure 19 (page 21). This figure includes dashed lines indicating four basic n — VR relationships which will serve in applying the results of these experiments to field channels. These four basic relationships, designated as A, B, C, and D and shown separately in Figure 20, were developed from a review of all vegetal channel data prior to 1946. They were presented in the Handbook of Channel Design (2) prepared recently by the Stillwater Outdoor Hydraulic Laboratory for use of Soil Conservation Service Operations, and form the basis of the vegetal channel design method presented in that handbook.

Graphic solutions of the Manning formula for these four degrees of vegetal retardance are presented in Figures 21 to 24. The design procedure is to judge the degree of retardance (whether A, B, C, or D), select a value for V , and then determine the required R from one of the retardance diagrams A, B, C, or D, Figures 21 to 24. After R is determined, enter a diagram like Figure 25 and determine the dimensions of a suitable channel.

EXAMPLE

Given: $Q=100$ cubic feet per second
 $S=3$ percent
 Cover—weeping lovegrass

Find: Dimensions of a trapezoidal channel with 4:1 side slopes that will carry this flow.

Solution: Permissible velocity of weeping lovegrass is 3.5 ft. per second. Retardance B, Figure 19, applies to a good stand of weeping lovegrass at the end of the first growing season.

Enter diagram 22 with $V=3.5$, proceed right to the 3 percent slope line, then downward to the R scale and read $R=0.99$ ft. It is not necessary to determine n .

Compute the area, A, required from Q/V which is $100/3.5=28.6$ sq. ft. Then enter diagram 25 with $R=0.99$ and $A=28.6$ and determine b to be 18 feet. Proceed right at $R=0.00$ and determine depth of flow to be 1.25 feet.

The problem is solved unless b and d are not satisfactory. If so, change V slightly and proceed again through the two design diagrams.

The Handbook of Channel Design (2) contains a rather complete set of diagrams similar to Figure 25 for determining the dimensions of trapezoidal and triangular channels with many different side slopes, and for solving parabolic channels.

SUMMARY AND CONCLUSIONS

Results of rather extensive testing of the usefulness of a number of common vegetations in protecting waterways from erosion have been presented. Covers included alfalfa, Bermuda grass, blue grama grass, buffalo grass, weeping lovegrass, and a mixture of tall and short grasses native to Oklahoma. Channel slopes varied from 1 to 10 percent. The results are analyzed from the standpoint of (1) the protection offered, and (2) channel capacity.

1. Protection.

- a. Short Bermuda grass was superior over all other covers.
- b. Alfalfa, weeping lovegrass and the native grass mixture were the least effective in preventing bed erosion.
- c. Bermuda grass, both long and short, withstood more soil loss from around the roots than any of the other vegetations without serious damage to the channel.
- d. Under sustained high velocities, Bermuda grass was superior to all other grasses.
- e. Buffalo and blue grama grasses provided better channel protection than long Bermuda grass under light to moderate velocity tests but was unable to withstand prolonged high velocity flows as well as Bermuda grass.
- f. Bermuda grass provided more protection when clipped and maintained short than when allowed to grow tall and rank. Mowing produced a very dense, uniform cover that did not develop with the long cover.
- g. The permissible velocities to use in the design of field channels with good cover, good alignment, uniform slope, smooth beds, and with an erosion-resistant soil are suggested from these experiments to be:

Cover	Permissible velocity (feet per second)	Slope limit* (percent)
Bermuda grass; short	8	10
Bermuda grass; long	7	10
Blue grama grass; long	7	10
Buffalo grass	7	10
Native grass mixture; unmowed	3.5	5
Weeping lovegrass; long	3.5	5
Alfalfa; unmowed	3	3

* For slopes steeper than these, permissible velocity is lower for the sod-type covers. For the bunch grasses and alfalfa these slopes are the maximum on which these covers should be used as a channel lining.

2. Channel capacity.

- a. The retardance or resistance coefficient, n, in the Manning formula, widely used to estimate velocity or channel capacity, has been evaluated for a number of vegetal linings.
- b. Manning's n, related to the depth and velocity of flow, is presented graphically in plottings of n versus VD.
- c. The results of these experiments are made directly applicable to the design of field channels by the inclusion of the four general n-VR design curves used in the Handbook of Channel Design (2). The graphical solution of the Manning formula for each of these general relationships as presented in this handbook is included here also. An example of the method of application is given.
- d. The complete hydraulic results including description of channels and notes on hydraulic behavior are tabulated in the appendix.

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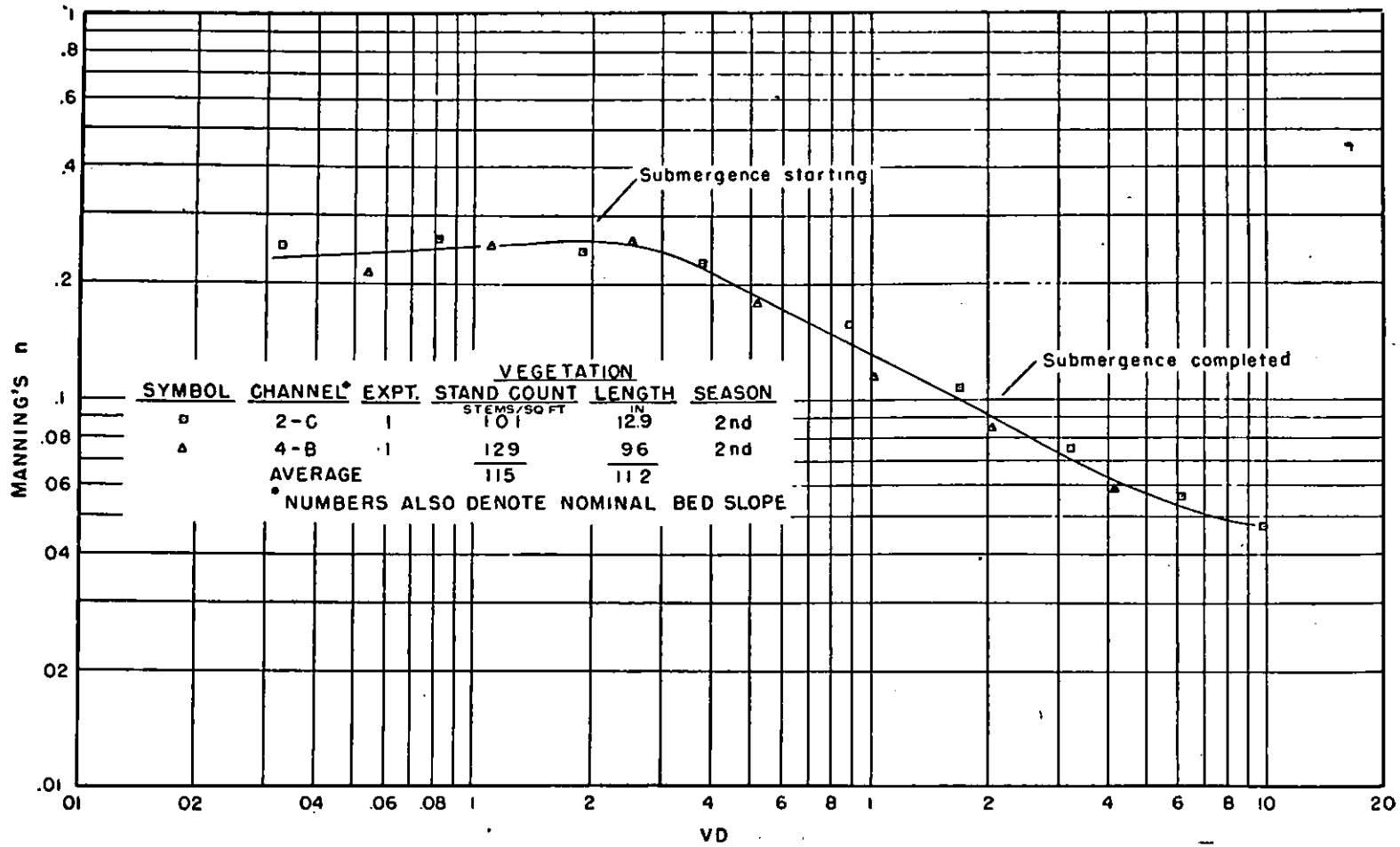


Fig. 12.—Relationship of Manning's n to VD for green, uncut alfalfa in good, uniform stands.

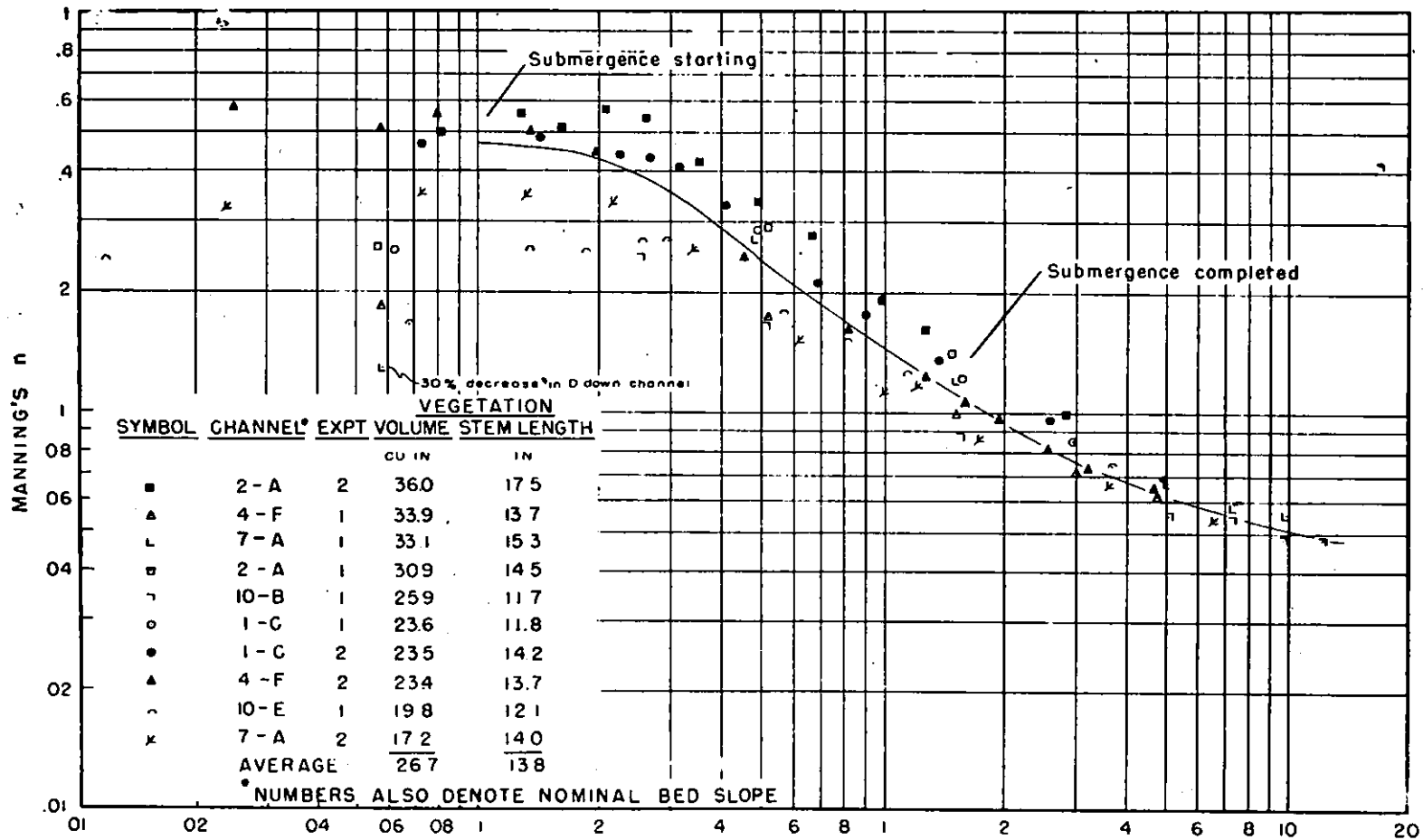


Fig. 13.—Relationship of Manning's n to VD for long, green Bermuda grass

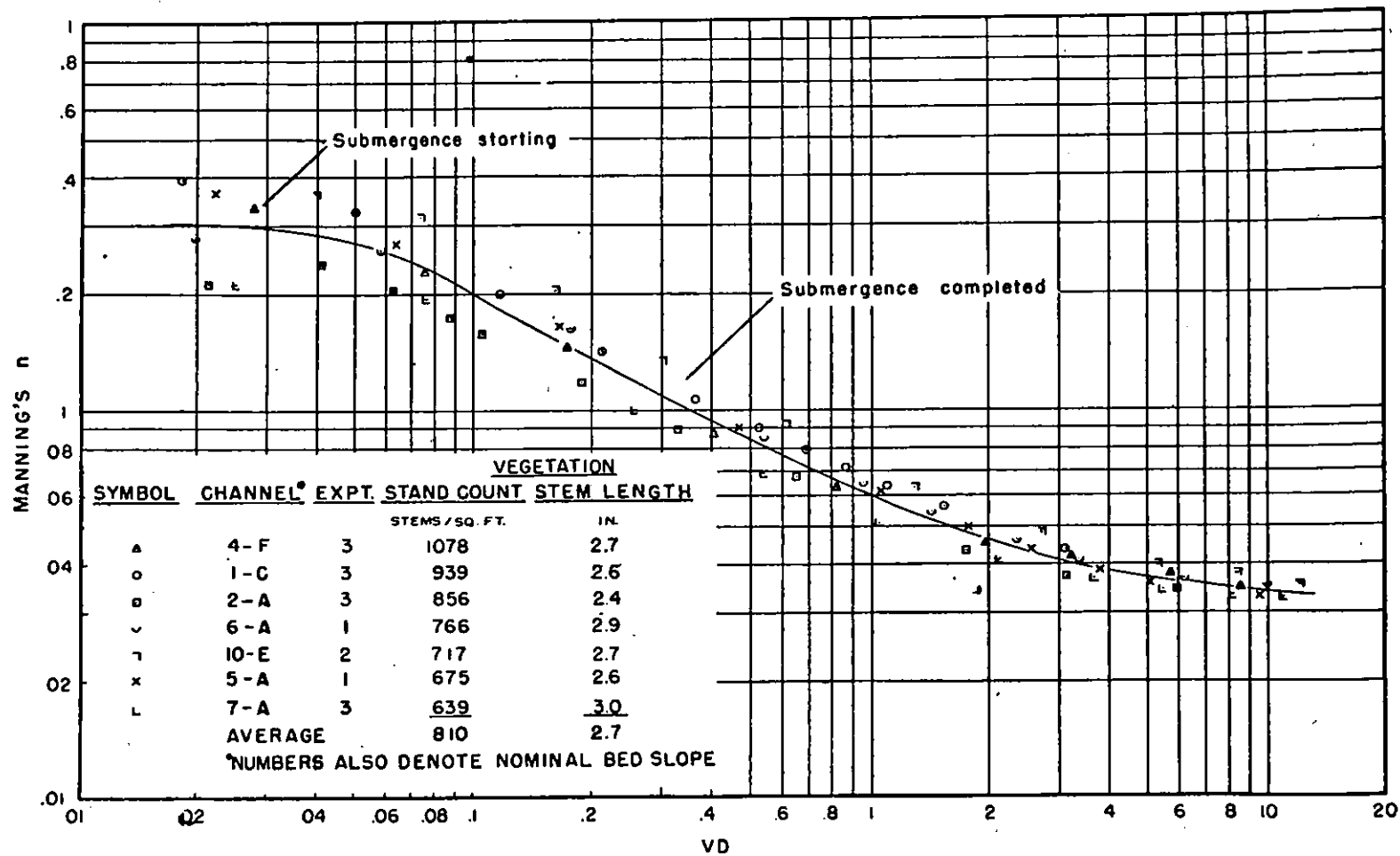


Fig. 14.—Relationship of Manning's n to VD for short, green Bermuda grass.

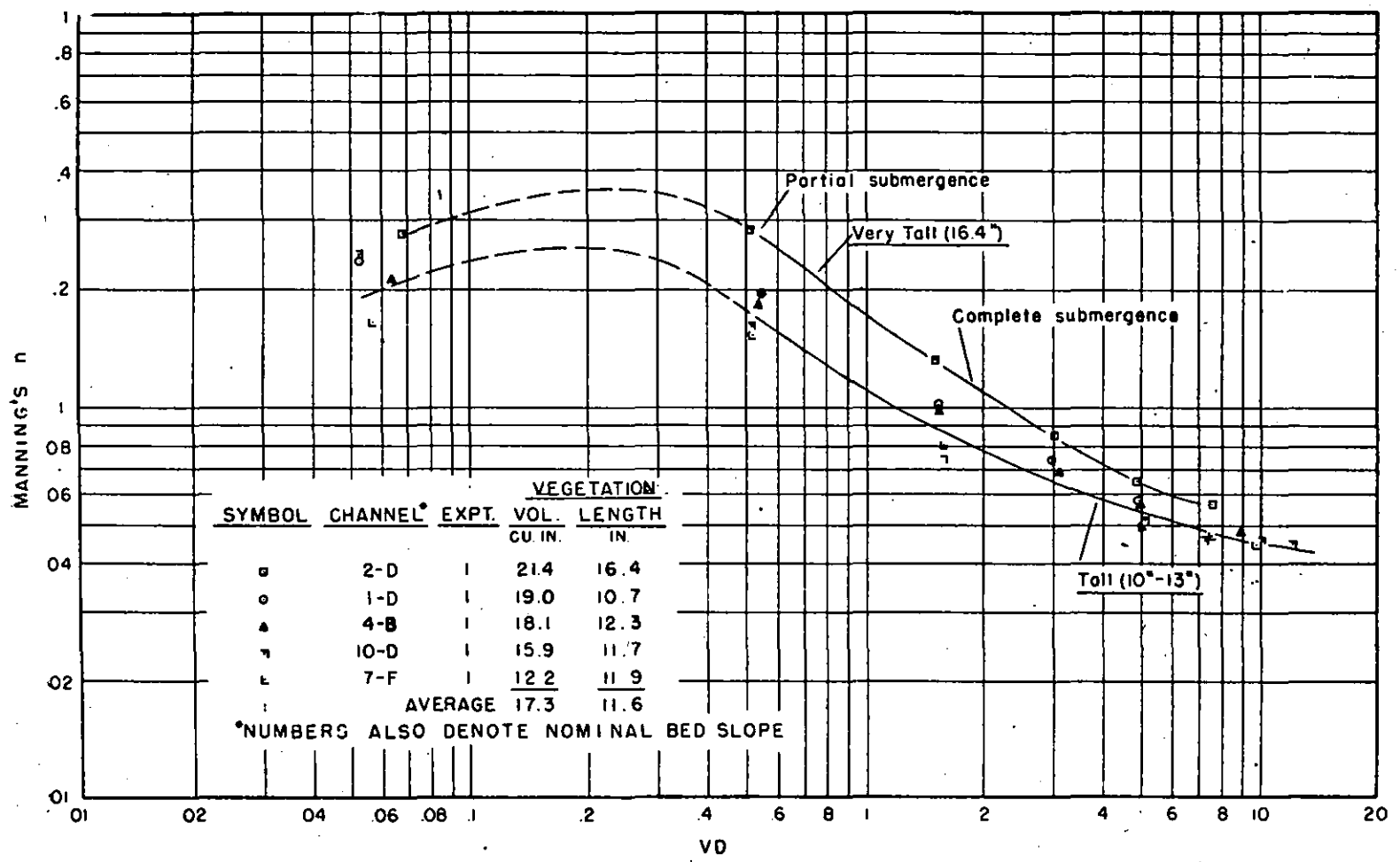


Fig. 15.—Relationship of Manning's n to VD for good, uniform covers of green blue grama grass.

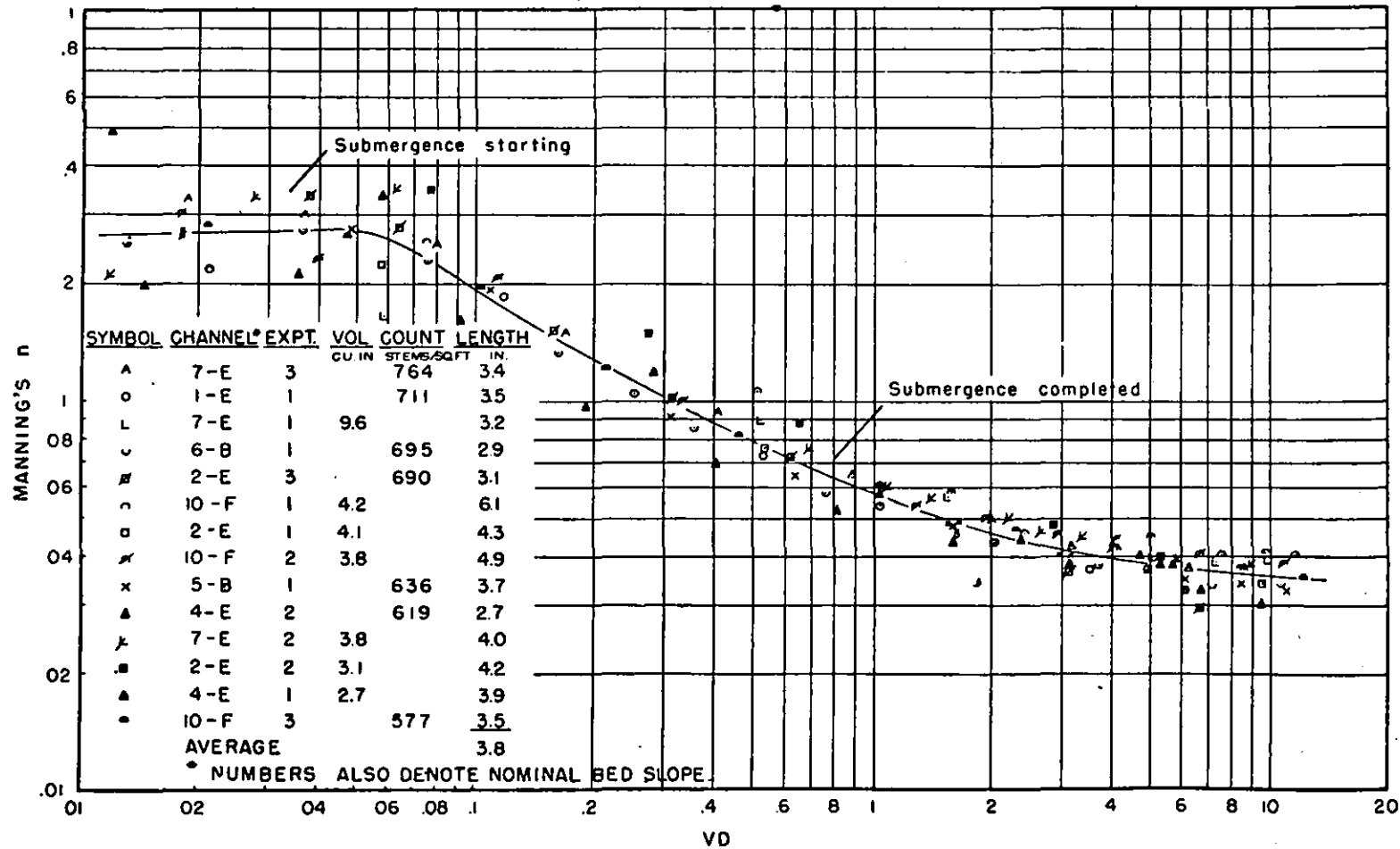


Fig. 16.—Relationship of Manning's n to VD for unmowed buffalo grass.

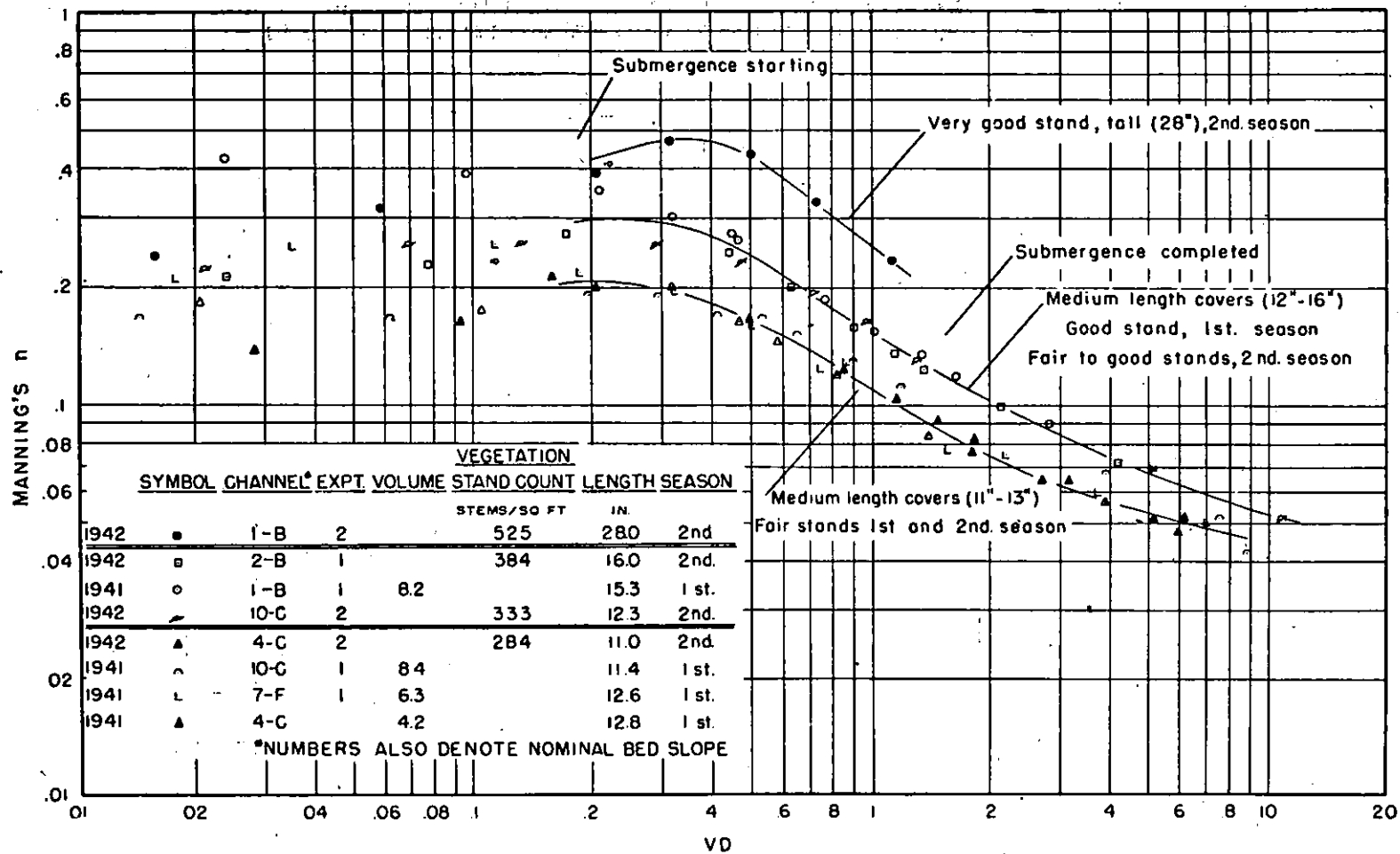


Fig. 17.—Relationship of Manning's n to VD for various conditions of green weeping love-grass.

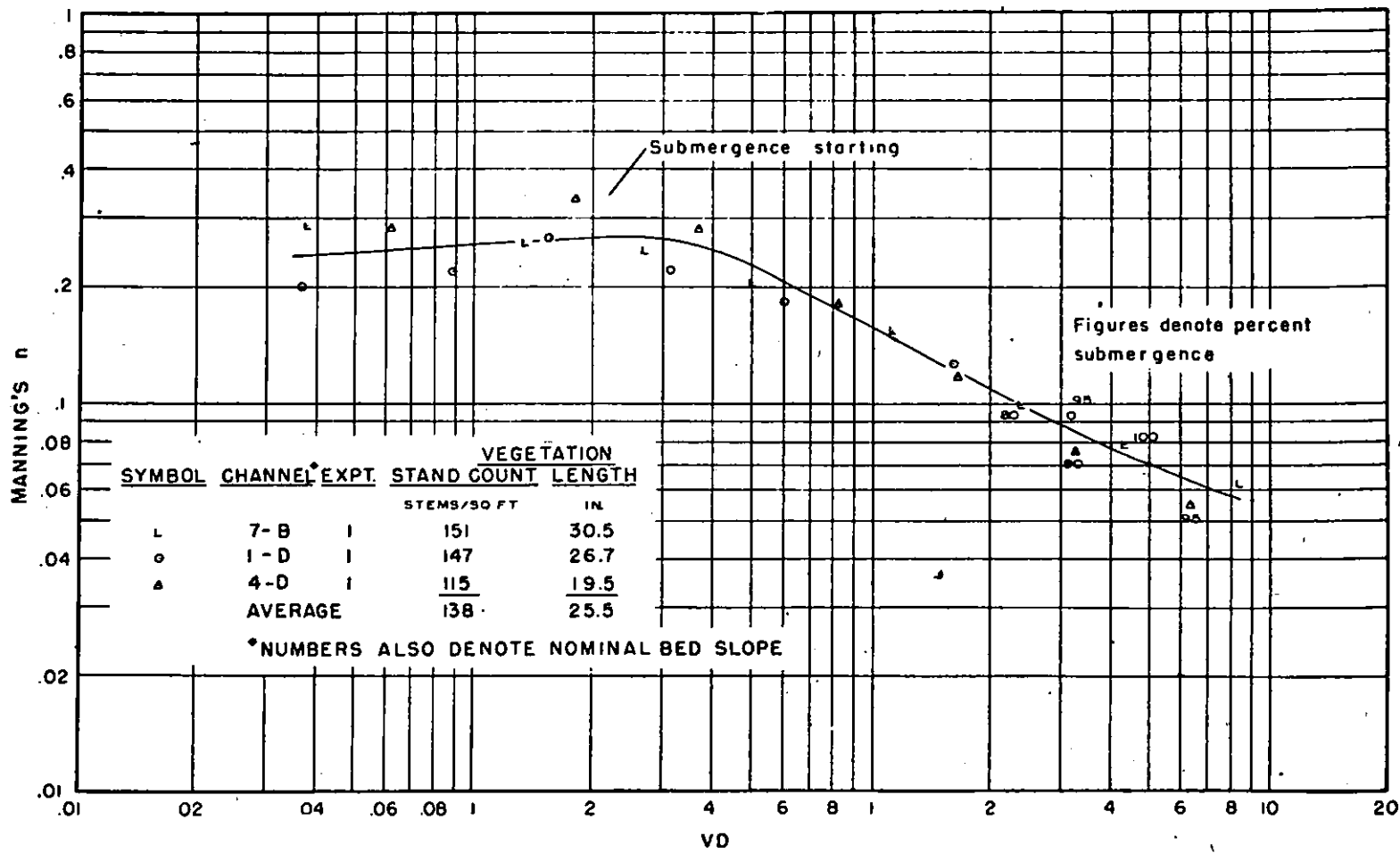


Fig 18.—Relationship of Manning's n to VD for second season uncut native grass mixture (little bluestem, Indian, switchgrass, blue grama, and side-oats grama).

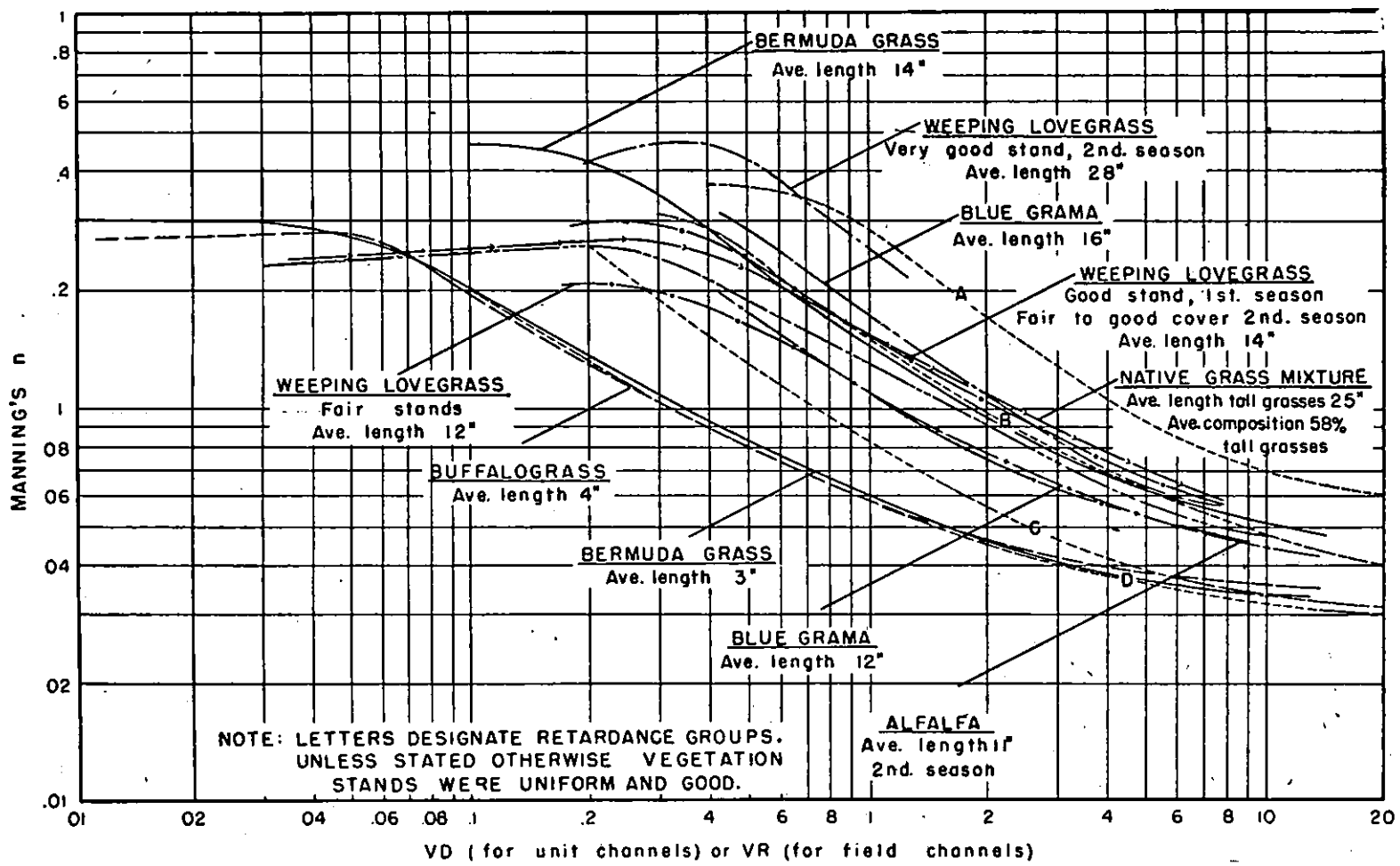


Fig. 19.—Experimental n -VD results as related to the general vegetal retardance curves A, B, C, and D.

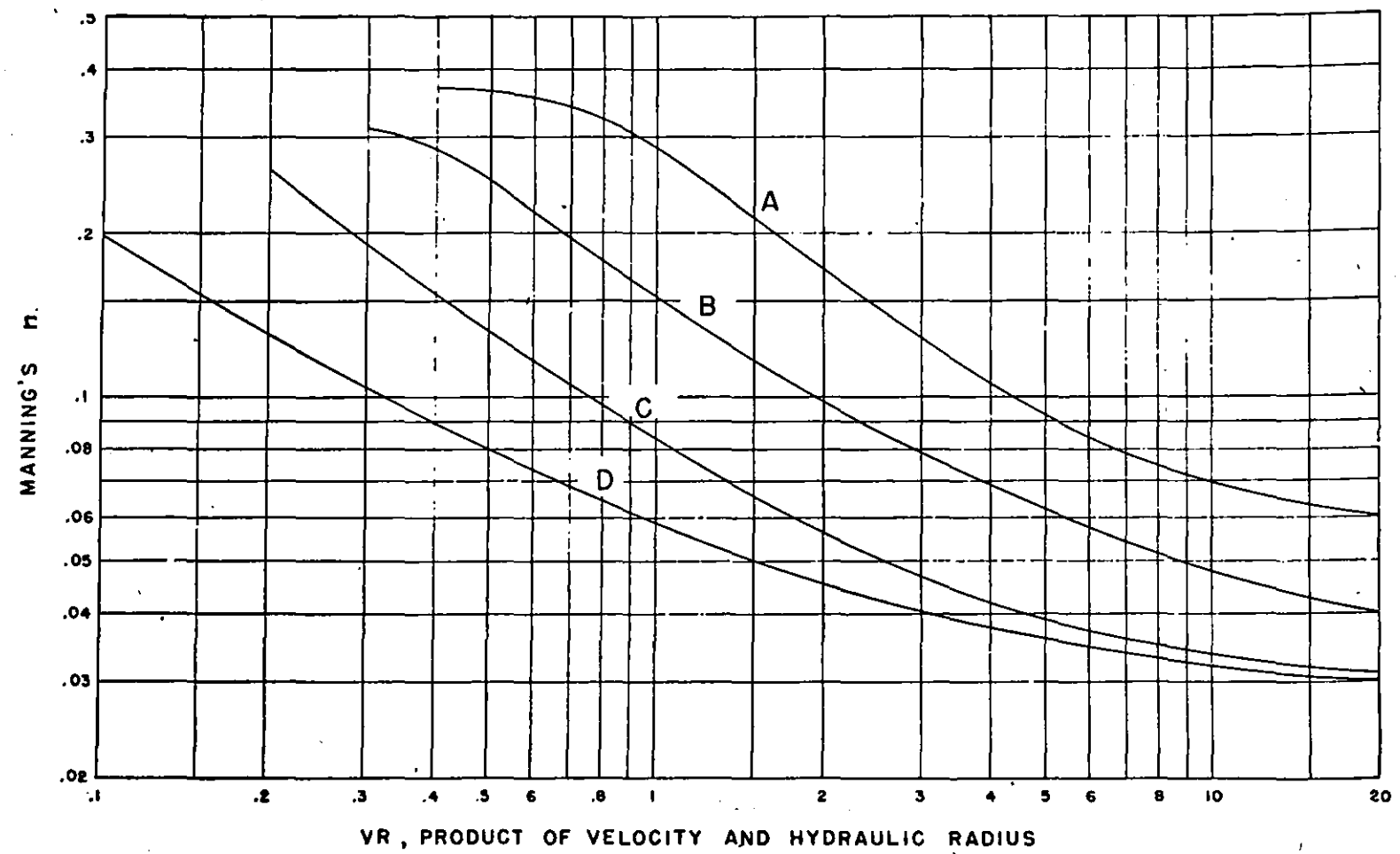


Fig. 20.—Degrees of vegetational retardance for which graphical solutions of the Manning formula have been prepared

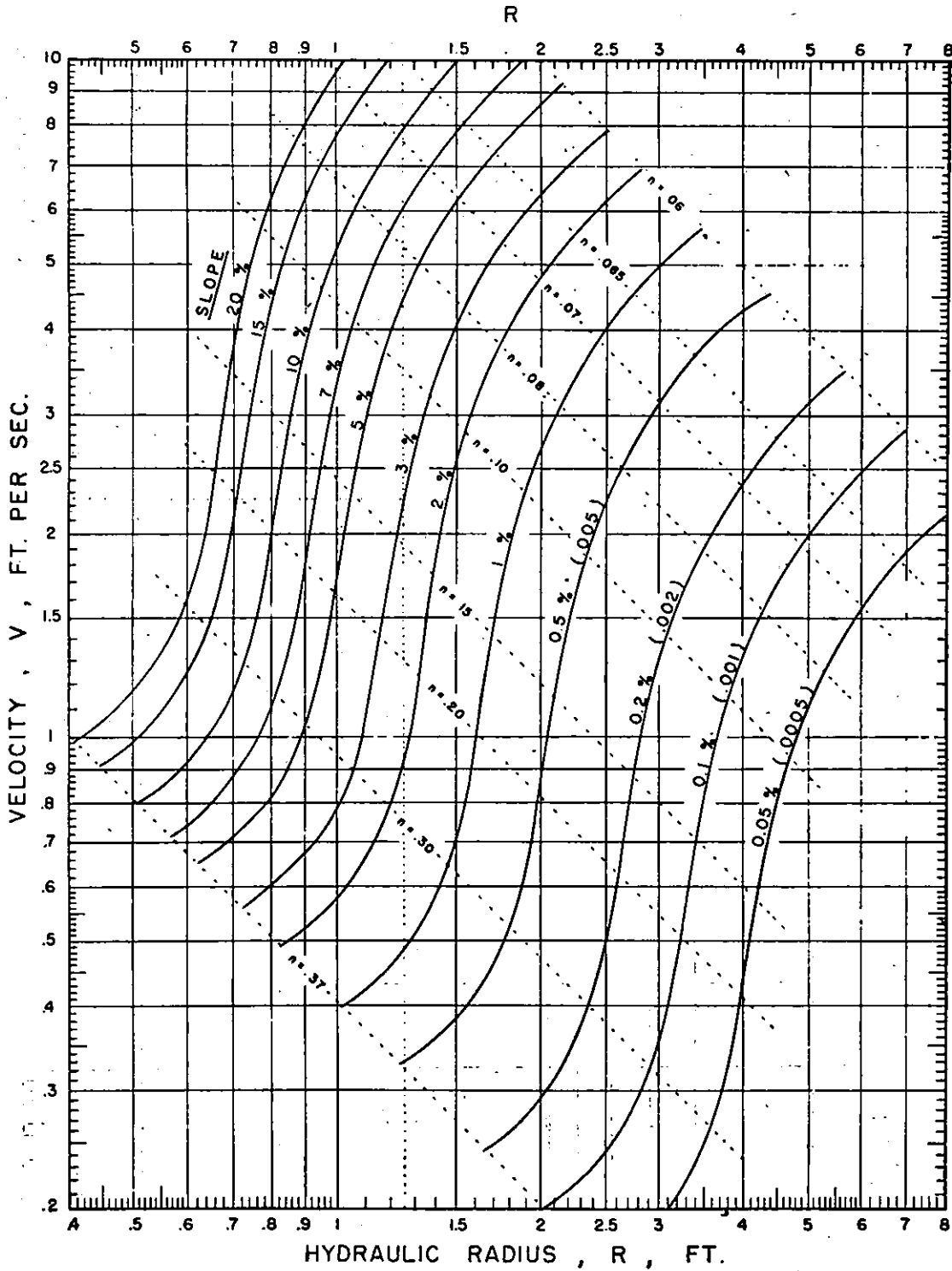


Fig. 21.—Solution of the Manning formula for:
RETARDANCE A
 (very high vegetal retardance).

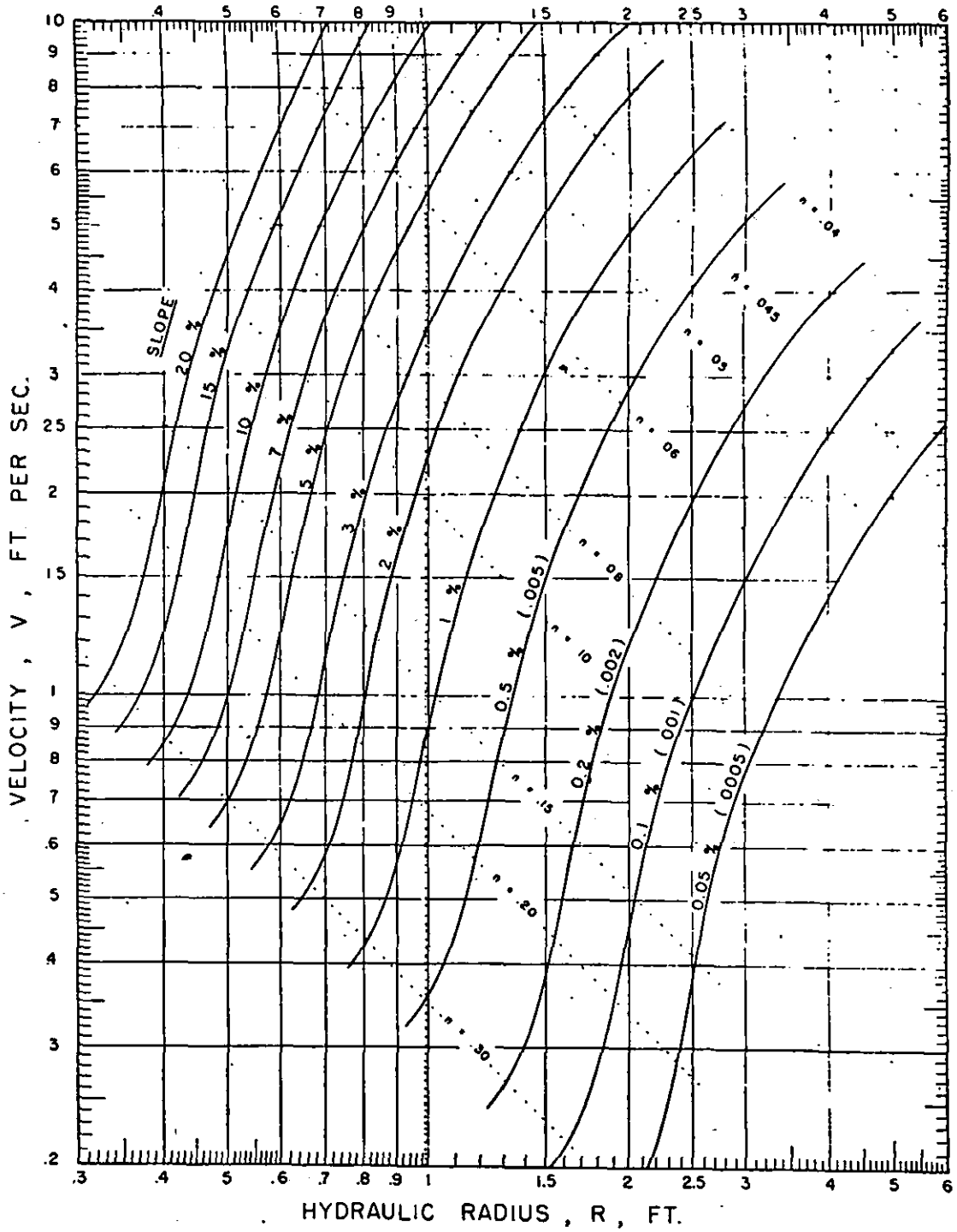


Fig. 22.—Solution of the Manning formula for:
RETARDANCE B
 (high vegetal retardance).

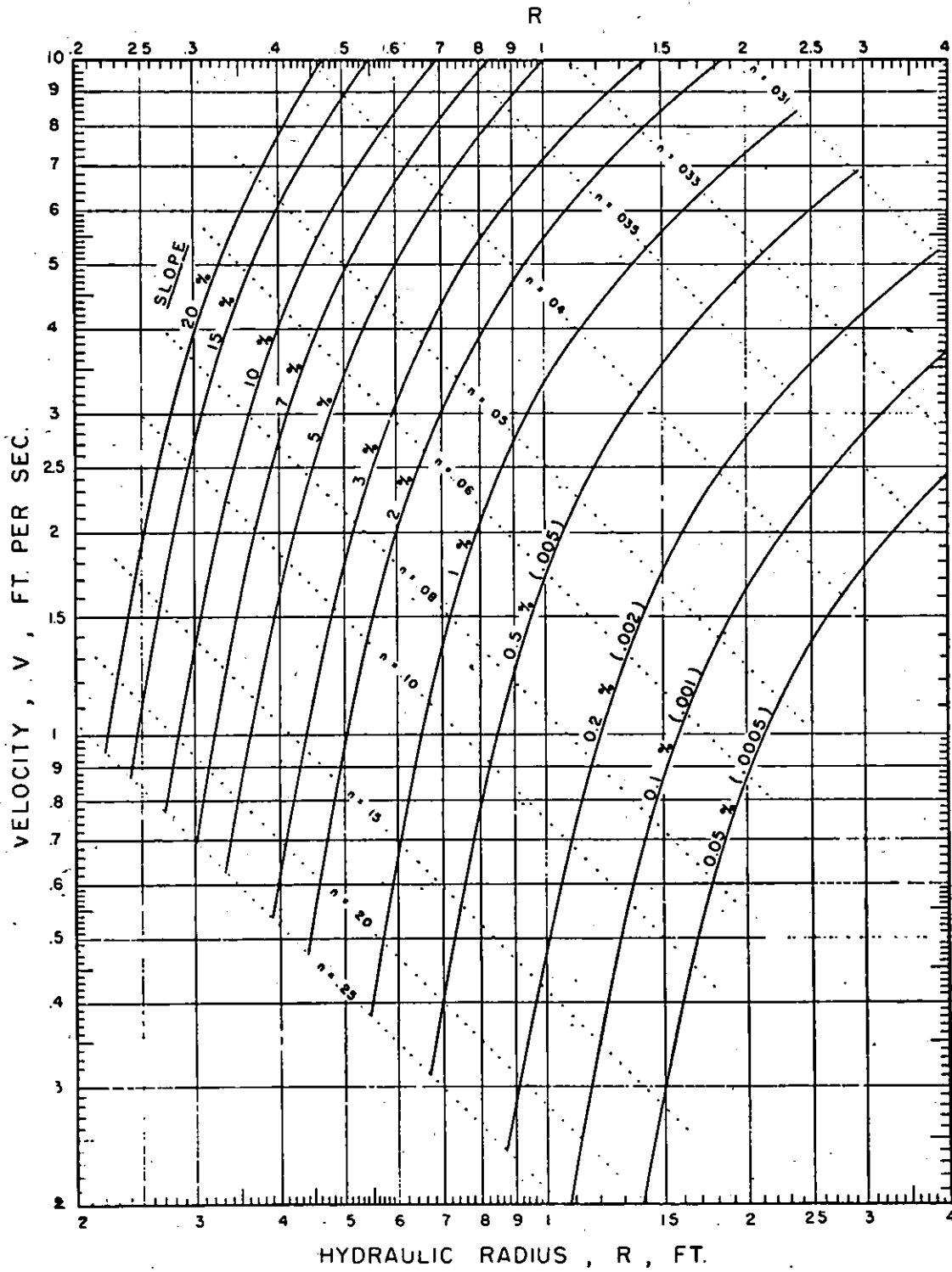


Fig. 23.—Solution of the Manning formula for:
RETARDANCE C
 (moderate vegetal retardance).

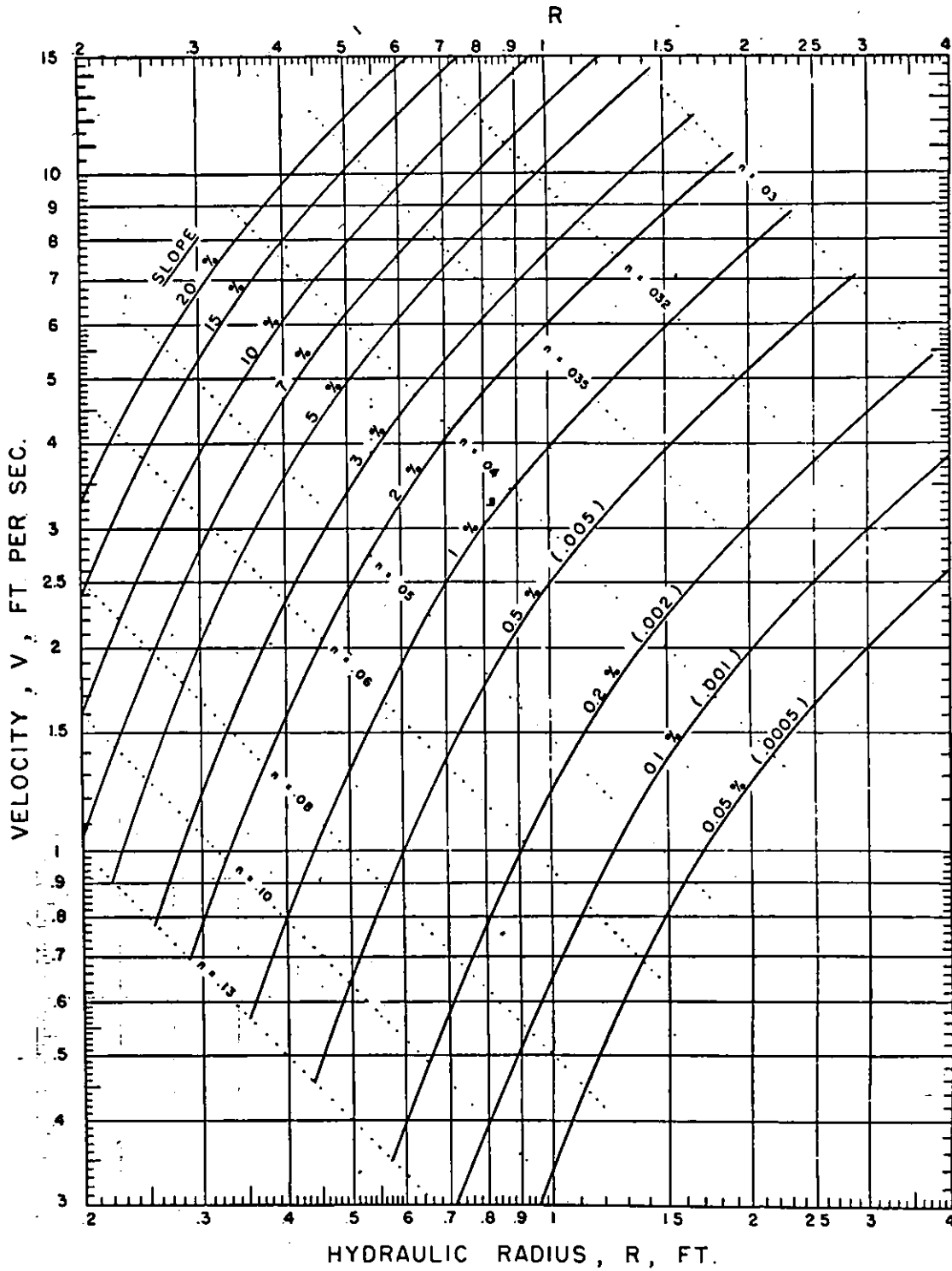


Fig. 24.—Solution of the Manning formula for:
RETARDANCE D
 (low vegetal retardance).

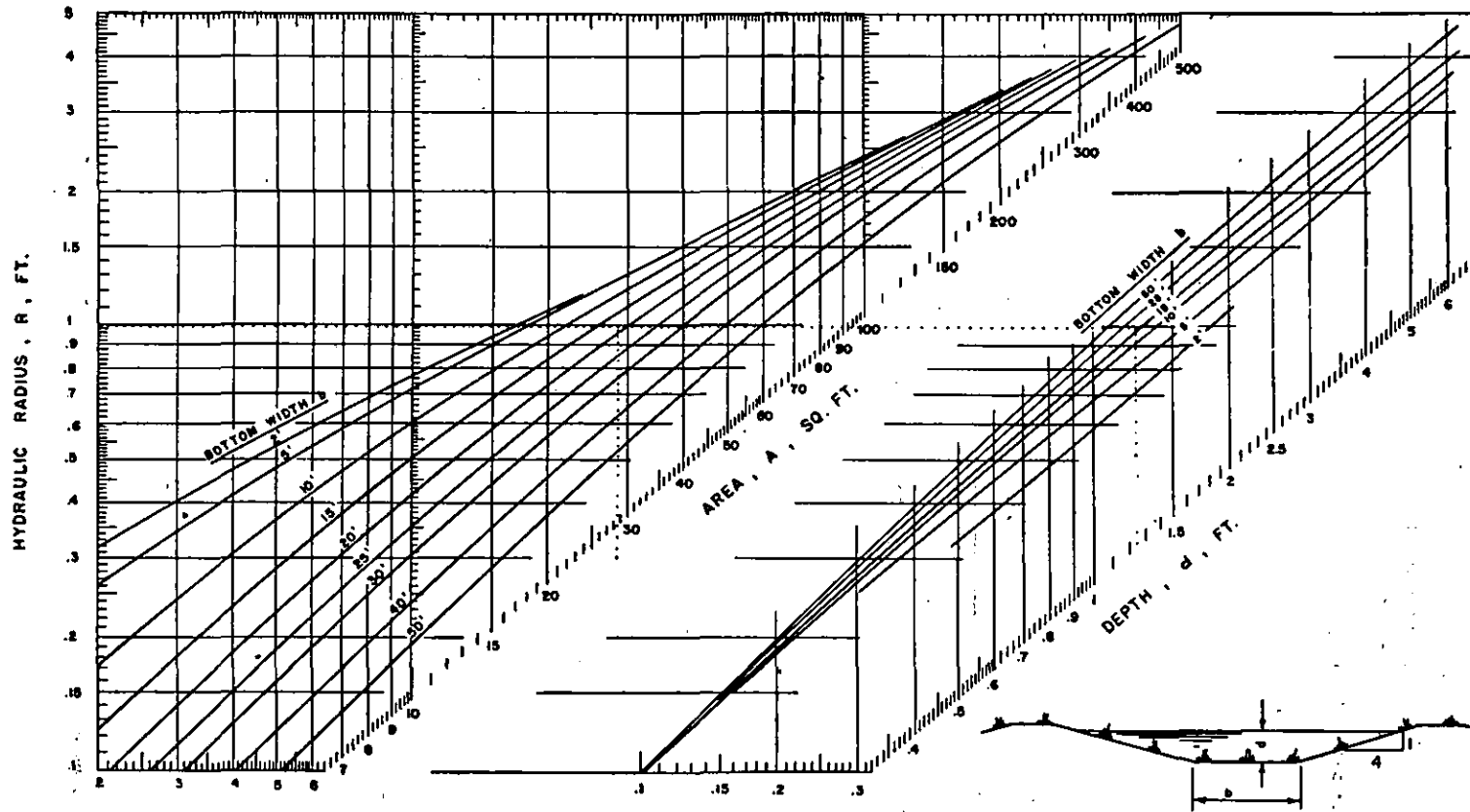


Fig. 25.—Dimensions of trapezoidal channels with 4 to 1 side slopes.

APPENDIX

Table 1.—Experiments Conducted, Bed Slopes of Channels, and Vegetation Measurements.

Vegetal cover and condition	Channel	Experiment		Bed slope	Vegetation measurements		
		No.	Date		Volume	Stand count	Average stem length
				Percent	¹	²	Inches
Alfalfa uncut, green	2C	1	9/43	2.05		101	12.9
	4B	1	9/43	3.86		129	9.6
Bermuda grass long, green	1C	1	9/40	1.20	23.6		11.8
		2	7/41	.89	23.5		14.2
	2A	1	9/40	2.03	30.9		14.5
		2	8/41	1.97	36.0		17.5
	4F	1	9/40	4.06	33.9		13.7
		2	8/41	3.84	23.4		13.7
	7A	1	9/40	7.01	33.1		15.3
		2	8/41	7.01	17.2		14.0
	10E	1	8/40	10.19	25.9		11.7
	1	8/41	10.14	19.8		12.1	
Bermuda grass short, green	1C	3	8/42	.96		939	2.6
	2A	3	8/42	2.00		856	2.4
	4F	3	8/42	3.86		1078	2.7
	5A	1	8/42	5.19		675	2.6
	6A	1	8/42	6.10		766	2.9
	7A	3	8/42	7.06		639	3.0
	10E	2	8/42	10.22		717	2.7
Blue grama grass uncut, green	1D	1	9/40	1.01	19.0		10.7
	2D	1	9/40	1.95	21.4		16.4
	4B	1	9/40	4.11	18.1		12.3
	7F	1	9/40	7.11	12.2		11.9
	10D	1	8/40	10.31	15.9		11.7
Buffalo grass uncut, green	1E	1	9/42	.97		711	3.5
	2E	1	9/40	1.89	4.1		4.3
		2	7/41	2.01	3.1		4.2
		3	9/42	2.05		690	3.1
	4E	1	8/41	3.87	2.7		3.9
		2	8/42	3.83		619	2.7
	5B	1	8/42	5.18		636	3.7
	6B	1	8/42	6.01		695	2.9
	7E	1	9/40	7.14	9.6		3.2
		2	8/41	6.99	3.8		4.0
		3	8/42	6.89		764	3.4
	10F	1	9/40	10.16	4.2		6.1
		2	8/41	10.07	3.8		4.9
	3	8/42	10.12		577	3.5	
Weeping lovegrass long, green	1B	1	7/41	.98	8.2		15.3
		2	9/42	.99		525	28.0
	2B	1	9/42	2.11		384	16.0
	4C	1	8/41	3.91	4.2		12.8
		2	9/42	3.87		284	11.0
	7F	1	8/41	7.04	6.3		12.6
	10C	1	8/41	10.10	8.4		11.4
		2	9/42	9.83		333	12.3
Native grass mixture tall and short, green	1D	1	9/43	.87		147	26.7
	4D	1	9/43	3.85		115	19.5
	7B	1	9/43	7.14		151	30.5

¹ Cubic inches of vegetation per square foot of channel surface (See text for explanation).

² Number of stems per square foot.

ALFALFA

Table 2.—Results of Tests of Channels Lined with Alfalfa.

Run	Date	Discharge per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients		
									Cheney, C	Manning, n	
1	2	3	4	5	6	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.			
Channel 2C		Bed Slope 2.05 Percent						Experiment 1, 1943			
Description of vegetation: Good uniform stand of green, uncut alfalfa with 101 stems per square foot; average length 12.9 inches; composition 95 percent alfalfa; 5 percent crabgrass. Vegetation upright at start of testing. Channel established from seed in spring 1942. Cut for hay fall 1942 and spring 1943.						Hydraulic behavior: Flow uniform through stand for runs 1, 2, 3 and 4, surface smooth. Surface of flow slightly rough for runs 5 and 6 and increased in roughness with each following run. All vegetation submerged for runs 8 and 9.					
1	9-8	.0325	.142	.229	.0200	0	40	.000	4.30	.250	
2	9-8	.0811	.251	.323	.0197	0	23	.016	4.61	.257	
3	9-8	.188	.403	.466	.0191	0	20	.036	5.31	.241	
4	9-8	.372	.583	.639	.0191	10	25	.000	6.07	.225	
5	9-8	.887	.785	1.13	.0200	50	20	.000	9.06	.157	
6	9-8	1.66	.899	1.85	.0204	95	21	.086	13.7	.106	
7	9-8	3.19	1.09	2.93	.0196	100	25	.106	20.2	.0747	
8	9-8	6.06	1.34	4.52	.0202	100	20	.662	27.7	.0566	
9	9-8	9.96	1.63	6.11	.0201	100	18	1.080	34.3	.0474	
Channel 4B		Bed Slope 3.36 Percent						Experiment 1, 1943			
Description of vegetation: Good uniform stand of green, uncut alfalfa with 129 stems per square foot; average length 9.6 inches; composition 97 percent alfalfa; upright at start of testing. Channel established from seed in spring 1942. Cut for hay fall 1942 and spring 1943.						Hydraulic behavior: Flow uniform through stand for runs 1, 2 and 3, surface smooth. Surface of flow slightly rough for runs 4 and 5 and rough for run 6 and very rough for run 7.					
1	9-9	.0533	.143	.373	.0381	0	50	.000	5.07	.214	
2	9-9	.110	.243	.452	.0379	0	15	.000	4.73	.251	
3	9-9	.250	.404	.619	.0372	30	21	.024	5.09	.257	
4	9-9	.521	.508	1.03	.0370	50	30	.012	7.56	.178	
5	9-9	1.02	.583	1.75	.0379	80	39	.022	11.8	.115	
6	9-9	2.04	.728	2.81	.0385	100	25	.071	16.8	.0843	
7	9-9	4.17	.903	4.62	.0385	100	30	.077	24.8	.0590	

BERMUDA GRASS, LONG

Table 3.—Results of Tests of Channels Lined with Long Bermuda Grass.

Channel 1C		Bed Slope 1.20 Percent						Experiment 1, 1940		
Description of vegetation: Heavy uniform stand of long green grass with 23.6 cubic inches of forage per square foot; average length 11.8 inches; composition 98 percent Bermuda; upright at start of testing. Grass established by solid sodding in spring 1940.						Hydraulic behavior: Flow through the grass for run 1 and over about ¼ of the grass down a stream along the center of the channel for run 2. Grass completely submerged for remaining runs but standing up in flow for run 3 causing only slight ripples on the surface. Surface of the flow slightly rough for runs 4 and 5.				
1	9-12	.0622	.251	.248	.0112	0	36	.000	4.69	.253
2	9-12	.498	.915	.544	.0125	25	14	.000	5.10	.287
3	9-12	1.56	1.10	1.42	.0122	100	33	.164	12.3	.123
4	9-12	2.99	1.31	2.28	.0118	100	27	.247	18.3	.0851
5	9-12	4.93	1.56	3.16	.0123	100	33	.098	23.1	.0696
Channel 1C		Bed Slope 0.89 Percent						Experiment 2, 1941		
Description of vegetation: Heavy uniform stand of long green grass with 23.5 cubic inches of forage per square foot; average length 14.2 inches; composition 100 percent Bermuda; upright at beginning of testing. Grass established by solid sodding in the spring of 1940. Maintenance, removed old grass and filled larger holes caused by erosion of previous testing.						Hydraulic behavior: Flow through and over grass for all runs from 1 to 10 with little or no effect on the grass for runs 1, 2 and 3. The surface of the flow remained very smooth throughout all these runs with the grass waving in the flow. Run 11 apparently pressed grass to bottom as velocity appeared to be much higher and the surface of the flow fairly rough.				

Table 3.—Results of Tests of Channels Lined with Long Bermuda Grass—(Continued).

Channel 1C, cont.										
Run	Date	Discharge per foot of width, VD	Depth, D	Mean velocity, V	Effective Slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients	
									Chezy, C	Manning, n
1	2	3	4	5	6	7	8	9	10	11
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.		
2	7-12	.0735	.404	.182	.0110	0	45	.000	2.76	.468
3	7-12	.142	.606	.234	.0117	0	35	.093	2.83	.488
4	7-12	.224	.743	.301	.0122	20	30	.000	3.23	.441
5	7-12	.267	.821	.325	.0124	30	27	.000	3.30	.439
6	7-12	.314	.861	.365	.0126	50	23	.000	3.64	.404
7	7-12	.407	.899	.458	.0127	75	22	.087	4.46	.330
8	7-12	.691	.939	.736	.0124	90	26	.000	7.01	.211
9	7-12	.899	.991	.907	.0124	100	31	.161	8.36	.179
10	7-12	1.36	1.08	1.26	.0123	100	21	.000	11.1	.137
11	7-12	2.56	1.28	2.00	.0124	100	31	.035	16.1	.0964
Channel 2A Bed Slope 2.03 Percent Experiment 1, 1940										
Description of vegetation: Heavy uniform stand of long green grass with 30.9 cubic inches of forage per square foot; average length 14.5 inches; composition 100 percent Bermuda; upright at start of testing. Grass established by solid sodding in spring 1940.						Hydraulic behavior: Flow through grass for run 1 without affecting grass. Run 2, stream formed along sides of channel that covered the grass for about 20 percent of the channel width, and run 3, stream width increased to about 40 percent of channel width, surface of flow was smooth for both last two runs. Wash-out under side of channel during run 4 prevented further testing.				
1	9-10	.0565	.199	.284	.0207	0	40	.000	4.46	.258
2	9-10	.516	.803	.642	.0215	20	18	.000	4.91	.202
3	9-10	1.46	.974	1.50	.0213	40	30	.090	10.5	.141
Channel 2A Bed Slope 1.97 Percent Experiment 2, 1941										
Description of vegetation: Heavy uniform stand of long green grass with 36.0 cubic inches of forage per square foot; average length 17.5 inches; composition 100 percent Bermuda; upright at beginning of testing. Grass established by solid sodding in the spring of 1940. Maintenance, removed old grass and filled larger holes caused by erosion of previous testing.						Hydraulic behavior: Flow through grass for runs 2 through 5 with very little effect on the stems or leaves. Runs 6 to 10 increased in depth with each run and more grass became submerged but remained erect and waving in the flows. All these runs had fairly smooth water surfaces. For runs 11 and 12 the surfaces of the flow were rough.				
2	8-6	.0802	.366	.219	.0209	0	26	.000	2.51	.503
3	8-6	.128	.517	.247	.0211	0	14	.000	2.36	.566
4	8-6	.160	.561	.286	.0211	0	28	.000	2.62	.516
5	8-6	.206	.693	.298	.0215	10	10	.070	2.44	.574
6	8-6	.259	.771	.336	.0214	25	11	.000	2.61	.545
7	8-6	.350	.822	.426	.0190	50	27	.000	3.41	.423
8	8-6	.492	.887	.555	.0187	70	12	.192	4.32	.338
9	8-6	.664	.937	.709	.0191	90	13	.000	5.29	.278
10	8-6	.990	.961	1.03	.0193	100	27	.032	7.59	.195
11	8-6	1.26	.998	1.26	.0194	100	27	.000	9.07	.164
12	8-6	2.80	1.19	2.35	.0199	100	30	.024	15.3	.0998
Channel 4F Bed Slope 4.06 Percent Experiment 1, 1940										
Description of vegetation: Heavy uniform stand of long green grass with 33.9 cubic inches of forage per square foot; average length 13.7 inches; composition 100 percent Bermuda; upright at start of testing; grass established by solid sodding in spring of 1940.						Hydraulic behavior: Flow through grass for run 1 but run 2 submerged the grass along center of channel for about 1/2 of channel width, surface of these flows was smooth. Run 3, all of grass submerged but waving in flow, surface of water smooth. Runs 4 and 5, all of grass submerged, surface of water fairly rough.				
1	9-9	.0572	.133	.430	.0402	0	31	.000	5.94	.182
2	9-9	.516	.487	1.06	.0399	75	10	.000	7.64	.173
3	9-9	1.52	.667	2.28	.0400	100	29	.175	14.0	.0994
4	9-9	3.00	.817	3.67	.0401	100	33	.164	20.0	.0719
5	9-9	4.73	.987	4.79	.0405	100	27	.173	24.0	.0619
Channel 4F Bed Slope 3.84 Percent Experiment 2, 1941										
Description of vegetation: Heavy uniform stand of long green grass with 23.4 cubic inches of forage per square foot; average length 13.7 inches; composition 100 percent Bermuda; upright at beginning of testing. Grass established by solid sodding in the spring of 1940. Maintenance, removed old grass and filled larger holes caused by erosion of previous testing.						Hydraulic behavior: Flow through grass for runs 1 through 4 with little or no effect on the stems. Flow through or over grass for runs 5, 6 and 7 with submerged grass waving in the flow. Runs 8 through 11 pressed submerged grass to bottom of channel and the surface of the flow increased in roughness with each run. Runs 12 and 13, flows fairly rough with some large waves caused by flow over heavy layers of grass.				

Table 3.—Results of Tests of Channels Lined with Long Bermuda Grass—(Continued).

Channel 4F, cont.										
Run	Date	Discharge per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients	
									Chzy, C	Manning, n
1	2	3	4	5	6	7	8	9	10	11
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In per hr.		
1	8-9	.0245	.161	.152	.0377	0	40	.000	1.98	.574
2	8-9	.0579	.253	.229	.0374	0	32	.000	2.38	.508
3	8-9	.0794	.324	.245	.0382	0	25	.000	2.22	.560
4	8-9	.135	.416	.324	.0384	10	18	.000	2.59	.506
5	8-9	.196	.490	.400	.0374	25	11	.000	2.96	.449
6	8-9	.452	.568	.796	.0366	50	16	.000	5.54	.246
7	8-9	.815	.627	1.30	.0370	80	17	.000	8.54	.162
8	8-9	1.25	.694	1.80	.0364	95	10	.000	11.4	.123
9	8-9	1.59	.733	2.17	.0368	100	10	.000	13.3	.107
10	8-9	1.95	.777	2.51	.0368	100	10	.000	14.9	.0961
11	8-9	2.56	.827	3.09	.0369	100	26	.089	17.8	.0817
12	8-9	3.19	.877	3.64	.0373	100	24	.075	20.2	.0726
13	8-9	4.62	1.02	4.53	.0374	100	24	.051	23.3	.0643
Channel 7A			Bed Slope 7.01 Percent				Experiment 1, 1940			
Description of vegetation: Heavy uniform stand of long green grass with 33.1 cubic inches of forage per square foot; average length 15.3 inches; composition 100 percent Bermuda; upright at start of testing. Grass established by solid sodding in spring 1940.					Hydraulic behavior: Flow through grass for run 1. Run 2, stream down center of channel that had grass submerged for over half of channel width, surface of water smooth. Run 3, grass submerged, surface of flow slightly rough. Runs 4 and 5, surface of flow rough with waves fairly large. Runs 6 and 7, apparently high surface velocity, surface of flow very rough.					
1	9-2	.0578	.091	.635	.0707	0	30	.000	7.99	.128
2	9-2	.480	.513	.936	.0707	50	12	.000	4.93	.271
3	9-2	1.50	.628	2.39	.0700	90	12	.342	11.4	.121
4	9-2	5.02	.897	5.60	.0716	100	31	.208	22.0	.0662
5	9-2	7.22	1.03	7.01	.0715	100	32	.238	25.9	.0577
6	9-2	9.83	1.20	8.19	.0709	100	32	.208	28.1	.0545
Channel 7A			Bed Slope 7.01 Percent				Experiment 2, 1941			
Description of vegetation: Good uniform stand of long green grass with 17.2 cubic inches of forage per square foot; average length 14.0 inches; composition 100 percent Bermuda; upright at beginning of testing. Grass established by solid sodding in spring of 1940. Maintenance, removed old grass and filled larger holes caused by erosion of previous testing.					Hydraulic behavior: Flow entirely through grass for runs 2 through 4. Grass started bending under flow with run 5 and continued being submerged by runs 6 and 7 with stems remaining erect or waving in the flow; flow surfaces fairly smooth. Runs 8 and 9 submerged most of the grass; surfaces of flows fairly rough. Runs 10, 11 and 12, surface of flows rough to very rough.					
2	8-15	.0237	.094	.252	.0700	0	20	.000	3.10	.324
3	8-15	.0737	.197	.374	.0705	0	20	.000	3.19	.358
4	8-15	.134	.278	.482	.0708	10	24	.000	3.45	.352
5	8-15	.216	.360	.601	.0708	25	19	.037	3.78	.335
6	8-15	.345	.408	.846	.0713	50	19	.000	4.99	.260
7	8-16	.623	.427	1.46	.0704	75	18	.000	8.44	.163
8	8-16	1.00	.477	2.10	.0706	90	10	.000	11.5	.115
9	8-16	1.22	.543	2.24	.0706	98	12	.000	11.5	.119
10	8-16	1.74	.561	3.10	.0703	100	23	.038	15.6	.0869
11	8-16	3.61	.746	4.84	.0702	100	22	.039	21.2	.0670
12	8-16	6.49	.936	6.93	.0697	100	26	.112	27.1	.0542
Channel 10B			Bed Slope 10.2 Percent				Experiment 1, 1940			
Description of vegetation: Heavy uniform stand of long green grass with 25.9 cubic inches of forage per square foot; average length 11.7 inches; composition 100 percent Bermuda; upright at beginning of testing. Grass established by solid sodding in spring of 1940.					Hydraulic behavior: Flow through grass for run 1. Run 2, stream down center of channel had grass submerged for over half of channel width, surface of water smooth. Run 3, grass submerged, surface of flow slightly rough. Runs 4 and 5, surface of flow rough with waves fairly large. Runs 6 and 7, apparently high surface velocity, surface of flow very rough.					

Table 3.—Results of Tests of Channels Lined with Long Bermuda Grass—(Continued).

Channel 10B, cont.										Coefficients	
Run	Date	Discharge Per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Chesy, C	Manning, n	
1	2	3	4	5	6	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.			
1	8-30	.253	.295	.858	.101	0	26	.000	4.98	.244	
2	8-30	.517	.359	1.44	.102	60	14	.000	7.54	.166	
3	8-30	1.55	.471	3.30	.102	100	33	.044	15.1	.0870	
4	8-30	5.06	.730	6.93	.102	100	33	.251	25.5	.0553	
5	8-30	7.27	.893	8.14	.102	100	34	.383	27.0	.0540	
6	8-30	9.72	1.09	9.72	.100	100	35	.290	30.7	.0485	
7	8-30	12.2	1.15	10.6	.102	100	27	.280	31.1	.0491	

Channel 10E

Bed Slope 10.1 Percent

Experiment 1, 1941

Description of vegetation: Good uniform stand of long green grass with 19.8 cubic inches of forage per square foot; average length 12.1 inches; composition 100 percent Bermuda; upright at beginning of testing. Grass established by solid sodding in the spring of 1940. Maintenance, removed old grass and filled larger holes caused by erosion of previous preliminary testing.

Hydraulic behavior: Flow through grass for runs 1 through 4 causing very little effect on the grass. Runs 5 and 6, stream flowed along center of channel, submerged part of grass which remained partially erect under the flow. Runs 7, 8 and 9 submerged grass along center line, the surface of the flows was rough. Runs 10 and 11 submerged all grass and surfaces of flows were very rough with some foam riding the surface.

1	8-23	.0118	.046	.256	.101	0	50	.000	3.76	.240
2	8-23	.0683	.106	.644	.102	0	18	.000	6.26	.166
3	8-23	.135	.205	.657	.102	0	12	.162	4.58	.255
4	8-23	.186	.246	.758	.102	10	20	.054	4.81	.250
5	8-23	.247	.306	.807	.102	20	12	.120	4.61	.272
6	8-23	.293	.332	.883	.103	30	14	.000	4.82	.266
7	8-23	.570	.393	1.45	.103	50	10	.085	7.26	.178
8	8-23	.817	.444	1.84	.102	75	9	.120	8.69	.152
9	8-23	1.15	.488	2.35	.102	98	9	.000	10.5	.127
10	8-23	3.65	.713	5.12	.101	100	22	.169	19.1	.0740
11	8-23	7.42	.969	7.66	.0988	100	27	.320	24.8	.0599

BERMUDA GRASS, SHORT

Table 4.—Results of Tests of Channels Lined with Short Bermuda Grass.

Channel 1C										Coefficients	
Bed Slope 0.96 Percent										Experiment 3, 1942	
Run	Date	Discharge Per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Chesy, C	Manning, n	
1	2	3	4	5	6	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.			
1	8-5	.0180	.161	.112	.0099	30	40	.000	2.80	.394	
2	8-5	.0495	.262	.189	.0101	70	8	.046	3.71	.325	
3	8-5	.116	.325	.357	.0102	90	8	.046	6.28	.198	
4	8-5	.208	.374	.555	.0103	95	13	.136	9.01	.141	
5	8-5	.360	.440	.819	.0103	100	10	.120	12.2	.107	
6	8-5	.526	.496	1.06	.0102	100	11	.000	14.8	.0891	
7	8-5	.686	.540	1.27	.0102	100	12	.000	17.2	.0783	
8	8-5	.866	.585	1.48	.0102	100	11	.033	19.1	.0711	
9	8-5	1.10	.633	1.73	.0102	100	11	.080	21.6	.0639	
10	8-5	1.54	.720	2.14	.0102	100	12	.042	25.0	.0563	
11	8-5	3.11	.946	3.29	.0101	100	15	.154	23.8	.0438	

Description of vegetation: Good uniform stand of short green grass with 939 stems per square foot; average length 2.63 inches; composition 100 percent Bermuda; upright at start of testing. Grass established by solid sodding in spring 1940. Old grass removed and channel grade reestablished by filling low places with soil.

Hydraulic behavior: Flow well up on grass for runs 1, 2 and 3 but grass remained erect causing only small ripples on surface. Runs 4, 5, 6 and 7, surface of flow increased in roughness but surface very steady. Surface of flow rough for runs 8, 9, 10 and 11.

Table 4.—Results of Tests of Channels Lined with Short Bermuda Grass—(Continued).

Channel 2A			Bed Slope 2.00 Percent				Experiment 3, 1942				
Run	Date	Discharge per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients		
									Chey, C	Manning, n	
1	2	3	4	5	6	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.			
Description of vegetation: Very good uniform stand of short green grass with 856 stems per square foot; average length 2.42 inches; composition 100 percent Bermuda; upright at start of testing. Grass established by solid sodding in spring of 1940. Old grass removed and channel grade reestablished by filling low places with soil.						Hydraulic behavior: Flow through grass for runs 1, 2 and 3 over all grass for runs 4, 5 and 6 with small ripples on surface, most of grass erect in flow. Runs 7 to 10, grass submerged but surface of flow did not become very rough until run 9.					
1	8-6	.0208	.0948	.219	.0207	50	20	.000	5.08	.212	
2	8-6	.0403	.155	.260	.0204	75	10	.035	4.65	.239	
3	8-6	.0615	.181	.340	.0204	80	10	.070	5.64	.202	
4	8-6	.0873	.202	.432	.0205	95	11	.080	6.77	.171	
5	8-6	.104	.213	.487	.0205	100	10	.035	7.43	.156	
6	8-6	.186	.255	.730	.0204	100	18	.140	10.2	.118	
7	8-6	.326	.302	1.08	.0205	100	10	.035	13.8	.0893	
8	8-6	.645	.384	1.68	.0205	100	11	.067	19.1	.0670	
9	8-6	1.76	.548	3.21	.0198	100	13	.000	31.0	.0437	
10	8-6	3.12	.704	4.44	.0198	100	11	.033	37.8	.0372	
11	8-6	5.94	.986	6.02	.0199	100	12	.000	43.1	.0345	
Channel 4F			Bed Slope 3.86 Percent				Experiment 3, 1942				
Description of vegetation: Very uniform stand of short green grass with 1078 stems per square foot; average length 2.75 inches; composition 100 percent Bermuda; upright at start of testing. Grass established by solid sodding in spring of 1940. Old grass removed and channel grade reestablished by filling low places with soil.						Hydraulic behavior: Flow through and over grass with uniform surface with small ripples for runs 1, 2 and 3. Flow over grass for runs 4 and 5 but grass still erect. Surface of flow increased in roughness with each increase in depth until runs 8 and 9 were very rough.					
1	8-12	.0274	.124	.221	.0382	0	35	.000	3.24	.333	
2	8-12	.0738	.180	.410	.0379	50	16	.000	5.01	.228	
3	8-12	.171	.226	.756	.0377	90	16	.022	8.29	.144	
4	8-12	.403	.282	1.43	.0379	100	32	.034	14.0	.0878	
5	8-12	.821	.354	2.32	.0382	100	29	.012	20.1	.0631	
6	8-12	1.94	.490	3.97	.0387	100	30	.029	28.9	.0458	
7	8-12	3.22	.623	5.17	.0390	100	29	.000	33.2	.0413	
8	8-12	5.73	.826	6.94	.0392	100	35	.056	38.6	.0373	
9	8-12	8.60	1.01	8.52	.0391	100	35	.062	43.0	.0347	
Channel 5A			Bed Slope 5.19 Percent				Experiment 1, 1942				
Description of vegetation: Good uniform stand of short green grass with 675 stems per square foot; average length 2.62 inches; composition 100 percent Bermuda; upright at start of testing. Grass established by solid sodding in the spring of 1942.						Hydraulic behavior: Flow through and over grass for runs 1, 2, 3 and 4 with uniform surface, small ripples. Ripples fairly large for runs 5 and 6. Runs 7 to 10, water surface rough with apparently high surface velocity for runs 9 and 10.					
1	8-17	.0217	.104	.209	.0518	0	35	.000	2.84	.360	
2	8-17	.0625	.165	.379	.0517	75	20	.000	4.10	.269	
3	8-17	.162	.216	.752	.0515	95	18	.020	7.15	.162	
4	8-17	1.06	.372	2.84	.0516	100	30	.017	13.6	.0891	
5	8-17	1.06	.372	2.84	.0519	100	30	.029	20.5	.0619	
6	8-17	1.78	.447	3.99	.0521	100	30	.029	26.1	.0498	
7	8-17	2.56	.512	5.01	.0522	100	32	.016	30.7	.0434	
8	8-17	3.83	.610	6.28	.0521	100	33	.026	35.3	.0388	
9	8-17	5.12	.694	7.38	.0517	100	35	.052	39.0	.0358	
10	8-17	9.71	.975	9.96	.0507	100	39	.166	45.0	.0329	
Channel 6B			Bed Slope 6.10 Percent				Experiment 1, 1942				
Description of vegetation: Good uniform stand of short green grass with 766 stems per square foot; average length 2.92 inches; composition 100 percent Bermuda; upright at start of testing. Grass established by solid sodding in the spring of 1942.						Hydraulic behavior: Flow through and over grass for runs 1, 2 and 3. Grass started to lie down for runs 4 and 5. Surface ripples became more severe for run 6; for remainder of the runs the surface was rough with apparently very high surface velocities for runs 9 and 10.					

Table 4.—Results of Tests of Channels Lined with Short Bermuda Grass—(Continued).

Channel 6B, cont.									Coefficients	
Run	Date	Discharge per foot of width, VD	Depth, D	Avean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Chezy, C	Manning, n
1	2	3	4	5	6	7	8	9	10	11
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.		
1	8-18	.0196	.079	.248	.0613	0	42	.000	3.56	.276
2	8-18	.0577	.146	.395	.0610	50	19	.026	4.20	.258
3	8-18	.173	.212	.815	.0610	80	21	.092	7.16	.160
4	8-18	.536	.285	1.88	.0610	100	30	.041	14.2	.0846
5	8-18	.960	.344	2.79	.0609	100	30	.024	19.3	.0646
6	8-18	1.44	.395	3.64	.0608	100	32	.000	23.5	.0542
7	8-18	2.34	.481	4.87	.0606	100	32	.057	28.5	.0462
8	8-18	3.33	.554	6.01	.0605	100	32	.084	32.9	.0410
9	8-18	6.18	.750	8.24	.0595	100	34	.221	39.0	.0363
10	8-18	10.0	.986	10.2	.0579	100	32	.061	42.6	.0348
Channel 7A			Bed Slope 7.06 Percent				Experiment 3, 1942			
Description of vegetation: Good uniform stand of short green grass with 639 stems per square foot; average length 3.00 inches; composition 100 percent Bermuda; upright at start of testing. Grass established by solid sodding in spring of 1940. Old grass removed and channel grade reestablished by filling low places with soil.						Hydraulic behavior: Flow through and over grass for runs 1 and 2 but grass started bending under flow of run 3. Water surface smooth with small ripples. Grass submerged by flows of run 4 to 10. Surface started getting rough after run 6. High surface velocity indicated by white foam on surface during runs 9 and 10.				
1	8-19	.0246	.074	.332	.0702	0	30	.000	4.63	.211
2	8-19	.0749	.137	.547	.0698	75	19	.000	5.64	.192
3	8-19	.255	.192	1.33	.0699	95	17	.021	11.5	.0991
4	8-19	.535	.240	2.23	.0702	100	37	.010	17.2	.0685
5	8-19	1.03	.298	3.47	.0707	100	34	.025	23.9	.0509
6	8-19	2.10	.396	5.31	.0715	100	33	.054	31.6	.0404
7	8-19	3.68	.524	7.02	.0719	100	36	.060	36.2	.0369
8	8-19	5.50	.636	8.64	.0720	100	31	.058	40.5	.0341
9	8-19	8.23	.799	10.3	.0701	100	33	.146	43.5	.0330
10	8-19	11.0	.957	11.5	.0678	100	40	.116	45.2	.0326
Channel 10E			Bed Slope 10.2 Percent				Experiment 2, 1942			
Description of vegetation: Good uniform stand of short green grass with 717 stems per square foot; average length 2.71 inches; composition 100 percent Bermuda; upright at start of testing. Grass established by solid sodding in spring of 1940. Old grass removed and channel grade reestablished by filling low places with soil.						Hydraulic behavior: Flow through and over grass for runs 1, 2 and 3. Grass mostly submerged and beginning to bend under flow for runs 4 and 5. Water surface fairly smooth. Runs 6 to 10, surface of flow increased in roughness with apparently high velocity for runs 8, 9 and 10.				
1	8-20	.0396	.122	.325	.102	0	40	.000	2.92	.360
2	8-20	.0732	.162	.452	.102	30	18	.000	3.52	.313
3	8-20	.162	.201	.806	.102	75	17	.000	5.63	.203
4	8-20	.300	.227	1.32	.102	95	40	.018	8.68	.134
5	8-20	.610	.276	2.21	.102	100	32	.000	13.2	.0910
6	8-20	1.29	.349	3.70	.102	100	34	.031	19.6	.0638
7	8-20	2.71	.462	5.86	.103	100	31	.035	26.9	.0487
8	8-20	5.32	.617	8.63	.102	100	32	.038	34.4	.0399
9	8-20	8.55	.792	10.8	.0996	100	31	.058	38.4	.0372
10	8-20	12.1	.951	12.7	.0959	100	37	.048	42.3	.0348

BLUE GRAMA GRASS

Table 5.—Results of Tests of Channels Lined with Blue Grama Grass.

Channel 4B									Experiment 1, 1940	
Description of vegetation: Good uniform stand of unclipped green grass with 18.1 cubic inches of forage per square foot; average length 12.3 inches; composition 70 percent blue grama, 30 percent crab and needle grasses; upright at start of testing. Grass established by solid sodding in spring of 1940.						Hydraulic behavior: Flow through grass for run 1 and over part of all of grass for runs 2 and 3 but grass remained erect or waving in the flows. Surface of water smooth for all these runs. Run 4 submerged grass and surface of flow became slightly rough. For runs 5 and 6 surface of flows slightly rough. Very little apparent erosion by test flows.				
Run	Date	Discharge per foot of width, VD	Depth, D	Avean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Chezy, C	Manning, n
1	2	3	4	5	6	7	8	9	10	11
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.		
1	9-5	.0628	.152	.413	.0412	0	15	.000	5.23	.210
2	9-5	.533	.503	1.06	.0415	80	9	.000	7.36	.181
3	9-5	1.53	.661	2.31	.0409	95	32	.249	14.1	.0990
4	9-5	3.10	.812	3.82	.0412	100	29	.135	20.9	.0689
5	9-5	4.95	.958	5.17	.0412	100	31	.178	26.1	.0565
6	9-5	8.94	1.23	7.27	.0414	100	33	.233	32.3	.0478

Table 5.—Results of Tests of Channels Lined with Blue Grama Grass.—(Continued).

Channel 7F			Bed Slope 7.11 Percent						Experiment 1, 1940		
Run	Date	Discharge Per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients		
									Chery, C	Manning, n	
1	2	3	4	5	6	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.			
Description of vegetation: Good uniform stand of unclipped green grass with 12.1 cubic inches of forage per square foot; average length 11.9 inches; composition 80 percent blue grama, 20 percent crab and needle grasses; upright at start of testing. Grass established by solid sodding in spring of 1940.					Hydraulic behavior: Flow through grass for run 1 and over part or all for runs 2 and 3 but grass remained erect or waving in the flows, surface of water smooth. Run 4, surface of flow slightly rough. Runs 5 and 6, surface of flows rough. Very slight apparent erosion by tests.						
1	9-4	.0568	.105	.541	.0713	0	33	.000	6.27	.163	
2	9-4	.516	.377	1.37	.0717	50	11	.033	8.34	.152	
3	9-4	1.57	.500	3.14	.0714	100	29	.030	16.6	.0797	
4	9-5	5.02	.751	6.68	.0720	100	30	.120	28.8	.0494	
5	9-5	7.43	.926	8.02	.0707	100	35	.165	31.5	.0467	
6	9-5	9.83	1.06	9.27	.0704	100	34	.053	34.1	.0441	
Channel 10			Bed Slope 1.01 Percent						Experiment 1, 1940		
Description of vegetation: Good uniform stand of unclipped green grass with 19.0 cubic inches of forage per square foot; average length 10.7 inches; composition 80 percent blue grama, 20 percent crab and needle grasses; upright at start of testing. Grass established by solid sodding in spring 1940.					Hydraulic behavior: Flow through grass for run 1 and over part of grass in run 2, and all for run 3 with grass waving in the flow, surface smooth; runs 4 and 5, the surface of the flows was slightly rough.						
1	9-14	.0523	.218	.240	.0109	0	45	.000	4.95	.235	
2	9-14	.543	.778	.698	.0122	30	20	.218	7.24	.198	
3	9-14	1.53	.982	1.56	.0116	100	29	.192	14.7	.101	
4	9-14	2.96	1.21	2.45	.0114	100	32	.050	21.0	.0734	
5	9-14	4.90	1.43	3.43	.0111	100	31	.011	27.4	.0578	
Channel 2D			Bed Slope 1.95 Percent						Experiment 1, 1940		
Description of vegetation: Good uniform stand of unclipped green grass with 21.4 cubic inches of forage per square foot; average length 16.4 inches; compact; composition 50 per cent blue grama, 170 percent crab and needle grasses; upright at start of testing. Grass established by solid sodding in spring of 1940.					Hydraulic behavior: Flow through grass for run 1 and over grass for run 2 and 3, slight bending of the stems for run 3, surface of flow smooth. Runs 4 and 5 completely submerged, surface of flow slightly rough. Run 6, surface of flow rough. Wash-out under side wall caused run to be very short.						
1	9-11	.0682	.232	.294	.0201	0	27	.000	4.31	.271	
2	9-11	.510	.788	.647	.0214	95	12	.000	5.01	.285	
3	9-11	1.50	.953	1.57	.0213	100	29	.130	11.1	.132	
4	9-11	3.00	1.10	2.73	.0207	100	32	.079	17.9	.0844	
5	9-11	4.86	1.27	3.83	.0202	100	32	.034	24.1	.0643	
6	9-11	7.54	1.53	4.93	.0200	100	10	.106	28.5	.0563	
Channel 10D			Bed Slope 10.3 Percent						Experiment 1, 1940		
Description of vegetation: Good uniform stand of unclipped green grass with 15.9 cubic inches of forage per square foot; average length 11.7 inches; composition 70 percent blue grama, 30 percent crab and needle grasses; upright at start of testing. Grass established by solid sodding in the spring of 1940.					Hydraulic behavior: Flow over part or all grass for runs 1 and 2 but grass remained erect or waving in the flows. Runs 3 and 4, surface of the flow slightly rough. Runs 5 and 6, surface of the flows were rough and run 7 the surface became very rough with apparently high surface velocity. Very little apparent erosion.						
1	8-31	.0523	.198	.264	.103	60	40	.000	4.74	.240	
2	8-31	.516	.349	1.48	.102	100	36	.060	7.84	.159	
3	8-31	1.59	.431	3.70	.102	100	29	.067	17.6	.0733	
4	8-31	5.02	.690	7.28	.101	100	31	.155	27.6	.0507	
5	8-31	7.27	.817	8.90	.101	100	30	.096	31.1	.0462	
6	8-31	10.1	.974	10.4	.104	100	30	.137	32.7	.0454	
7	8-31	12.0	1.08	11.1	.0983	100	32	.102	34.1	.0442	

BUFFALO GRASS

Table 6.—Results of Tests of Channels Lined with Buffalo Grass.

Channel 1E			Bed Slope 0.97 Percent					Experiment 1, 1942			
Run	Date	Discharge per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients		
									Chey, C	Manning, n	
1	2	3	4	5	6	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Mln.	In. per hr.			
Description of vegetation: Good uniform stand of unclipped green grass with 711 stems per square foot; average length 3.5 inches; composition 100 percent buffalo grass; upright at start of testing. Grass established by solid sodding in spring 1940.						Hydraulic behavior: Flow through and over grass for runs 1 and 3. Grass began bending under flow of run 4 and was well submerged by run 5; surface of flow smooth except for small ripples. Surface of flow became rougher with each increase in depth but did not get very rough.					
1	9-2	.0212	.123	.172	.0107	0	50	.000	4.80	.219	
3	9-2	.117	.321	.364	.0093	75	25	.000	6.72	.185	
4	9-2	.251	.361	.695	.0094	95	35	.014	11.9	.105	
5	9-2	.534	.453	1.18	.0096	100	40	.030	18.0	.0728	
6	9-2	1.05	.571	1.84	.0096	100	38	.019	24.8	.0547	
7	9-2	2.03	.747	2.72	.0096	100	24	.036	32.1	.0441	
8	9-2	3.57	.937	3.81	.0101	100	30	.053	39.4	.0376	
9	9-2	6.16	1.21	5.09	.0102	100	35	.000	47.8	.0330	
Channel 2E			Bed Slope 1.89 Percent					Experiment 1, 1940			
Description of vegetation: Good uniform stand of unclipped green grass with 4.1 cubic inches of forage per square foot; average length 4.3 inches; composition 90 percent buffalo, 10 percent crab and other annual grasses; upright at start of testing. Grass established by solid sodding in spring 1940.						Hydraulic behavior: Flow through grass without affecting the stems for run 1. Most of grass submerged by run 2 but waving in the flow. Runs 3 and 4 submerged grass with surface of flow slightly rough. Runs 5 and 6 caused some erosion around grass roots, surface of flow rough.					
1	9-15	.0571	.180	.317	.0197	0	30	.000	5.06	.225	
2	9-15	.532	.377	1.41	.0188	95	12	.000	16.8	.0757	
3	9-15	1.56	.554	2.81	.0186	100	30	.144	28.0	.0490	
4	9-15	3.00	.736	4.08	.0188	100	27	.245	35.0	.0409	
5	9-15	4.99	.946	5.28	.0191	100	31	.166	39.5	.0375	
6	9-15	9.62	1.33	7.23	.0191	100	32	.084	45.4	.0344	
Channel 2E			Bed Slope 2.01 Percent					Experiment 2, 1941			
Description of vegetation: Fair uniform stand of unclipped green grass with 3.1 cubic inches of forage per square foot; average length 4.2 inches; composition 100 percent buffalo; upright at start of testing. Grass established in spring 1940. Maintenance consisted of controlling weeds and filling damaged places caused by previous testing.						Hydraulic behavior: Run 6, grass submerged partially but remaining erect in the flow. Surface of flow smooth. Run 7 apparently indicates a change in flow as surface became fairly rough. Runs 8, 9 and 10 similar in surface condition except slight increase in roughness as depth increased.					
6	7-18	.0763	.290	.263	.0196	80	23	.000	8.50	.348	
7	7-18	.270	.373	.725	.0196	100	12	.000	8.52	.149	
8	7-19	.655	.461	1.42	.0199	100	45	.043	14.8	.0881	
9	7-19	2.85	.780	3.66	.0199	100	50	.082	29.5	.0485	
10	7-19	5.28	.999	5.29	.0202	100	38	.128	37.3	.0399	
Channel 2E			Bed Slope 2.05 Percent					Experiment 3, 1942			
Description of vegetation: Good uniform stand of unclipped green grass with 690 stems per square foot; average length 3.1 inches; composition 100 percent buffalo grass; upright at start of testing. Grass established by solid sodding in spring 1940. Maintenance consisted of cutting weeds and filling damaged places caused by erosion of previous testing.						Hydraulic behavior: Flow through and over grass for runs 1, 2 and 3, very smooth surface. Grass submerged standing in flow for runs 4 and 5; surface smooth; surface of flow fairly rough for runs 6 and 7 and rough for 8 and 9.					
1	9-1	.0180	.103	.175	.0206	0	47	.000	3.81	.267	
2	9-1	.0379	.185	.205	.0203	10	31	.000	3.36	.334	
3	9-1	.0630	.225	.280	.0199	50	20	.025	4.19	.277	
4	9-1	.158	.270	.579	.0200	90	30	.029	7.91	.151	
5	9-1	.311	.320	.971	.0199	100	30	.017	12.2	.101	
6	9-1	.622	.396	1.57	.0200	100	29	.042	17.6	.0723	
7	9-1	1.60	.549	2.92	.0201	100	28	.013	27.8	.0485	
8	9-1	3.11	.697	4.46	.0203	100	30	.096	37.5	.0373	
9	9-1	6.70	.966	6.94	.0198	100	37	.019	50.4	.0294	

Table 6.—Results of Tests of Channels Lined with Buffalo Grass.—(Continued)

Channel 4E			Bed Slope 3.87 Percent					Experiment 1, 1941			
Run	Date	Discharge per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients		
									Chey, C	Manning, n	
1	2	3	4	5	6	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.			
Description of vegetation: Fair uniform stand of unclipped green grass with 2.7 cubic inches of forage per square foot; average length 3.9 inches; composition 100 percent buffalo; upright at start of testing. Grass established in spring 1940.					Hydraulic behavior: Channel wet by rain of night before testing but in good condition. Flow through grass for runs 1 and 2 with smooth surface. Run 3 most of grass submerged but waving in the flow. Surface of flow rough for runs 4, 5, 6 and 7, and very rough for remainder of runs. Erosion was apparent for each of runs 10, 11 and 12 but not enough to make the channel unsuitable for further use.						
1	8-12	.0118	.096	.123	.0386	0	29	.000	2.03	.496	
2	8-12	.0575	.197	.292	.0380	10	22	.000	3.39	.338	
3	8-12	.279	.271	1.03	.0383	80	16	.053	10.2	.118	
4	8-12	1.05	.393	2.67	.0381	100	18	.000	21.8	.0584	
5	8-12	1.67	.467	3.58	.0388	100	10	.000	26.7	.0492	
6	8-12	2.39	.543	4.40	.0391	100	11	.033	30.2	.0446	
7	8-12	3.20	.630	5.08	.0389	100	11	.167	32.4	.0425	
8	8-12	4.06	.722	5.63	.0392	100	10	.000	33.5	.0421	
9	8-12	4.74	.775	6.12	.0392	100	8	.231	35.1	.0406	
10	8-12	5.30	.810	6.54	.0388	100	12	.042	36.9	.0389	
11	8-12	5.74	.840	6.83	.0389	100	24	.126	37.8	.0382	
12	8-12	6.28	.877	7.16	.0389	100	23	.079	38.8	.0375	
Channel 4E			Bed Slope 3.83 Percent					Experiment 2, 1942			
Description of vegetation: Good uniform stand of unclipped green grass with 619 stems per square foot; average length 2.7 inches; composition 100 percent buffalo grass; upright at start of testing. Grass established by solid sodding in spring 1940. Maintenance consisted of cutting weeds and filling damaged places caused by erosion of previous testing.					Hydraulic behavior: Flow through and over grass during runs 1, 2, 3 and 4 with surface of flow smooth. Runs 5 and 6 most or all grass submerged but remaining upright in flow, surface wavy. Surface of flow became rougher with each increase in depth. Runs 9 and 10 surface of flow rough.						
1	8-31	.0144	.062	.233	.0383	0	40	.000	4.79	.198	
2	8-31	.0353	.111	.318	.0384	20	22	.000	4.87	.213	
3	8-31	.0917	.165	.556	.0386	50	20	.036	7.00	.159	
4	8-31	.191	.191	1.00	.0385	75	33	.000	11.7	.0971	
5	8-31	.402	.245	1.64	.0380	95	37	.048	17.1	.0690	
6	8-31	.818	.317	2.58	.0379	100	28	.043	23.6	.0522	
7	8-31	1.60	.424	3.78	.0383	100	35	.035	29.6	.0435	
8	8-31	3.16	.583	5.43	.0388	100	33	.015	36.1	.0376	
9	8-31	6.72	.849	7.92	.0384	100	29	.000	43.9	.0329	
10	8-31	9.60	1.01	9.51	.0373	100	32	.061	49.0	.0304	
Channel 5B			Bed Slope 5.18 Percent					Experiment 1, 1942			
Description of vegetation: Good uniform stand of unclipped green grass with 636 stems per square foot; average length 3.7 inches; composition 100 percent buffalo grass; upright at start of testing. Grass established by solid sodding in spring 1942.					Hydraulic behavior: Flow through and over grass for runs 1, 2 and 3. Grass partially submerged but waving in the flow. Surface of flow regular except for small ripples for runs 4 and 5. Runs 6 to 10, grass submerged and surface of flow increasing in roughness with each increase in depth.						
1	8-28	.0179	.077	.232	.0515	0	60	.000	3.71	.268	
2	8-28	.0478	.143	.334	.0513	10	21	.034	3.91	.277	
3	8-28	.108	.187	.577	.0511	50	18	.100	5.94	.192	
4	8-28	.310	.225	1.38	.0515	75	32	.084	12.9	.0907	
5	8-28	.646	.286	2.26	.0519	90	23	.016	18.6	.0652	
6	8-28	1.64	.414	3.95	.0520	100	20	.073	26.9	.0477	
7	8-28	3.17	.559	5.67	.0524	100	20	.054	33.2	.0407	
8	8-28	6.13	.764	8.03	.0522	100	25	.071	40.3	.0453	
9	8-28	8.57	.921	9.31	.0516	100	24	.171	42.9	.0343	
10	8-28	11.0	1.06	10.4	.0508	100	18	.088	45.1	.0333	

Table 6.—Results of Tests of Channels Lined with Buffalo Grass.—(Continued)

Channel 6B			Bed Slope 6.01 Percent					Experiment 1, 1942			
Run	Date	Discharge Per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients		
									Chezy, C	Manning, n	
1	2	3	4	5	6	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.			
Description of vegetation: Good uniform stand of unclipped green grass with 695 stems per square foot; average length 2.9 inches; composition 100 percent buffalo grass; upright at start of testing. Grass established by solid sodding in spring 1942.						Hydraulic behavior: Flow through grass for runs 1, 2 and 3 and over part of stand for runs 4, 5 and 6 with surface of flow smooth except for small ripples. Runs 7 to 10, grass pressed to the bottom and surface of flow increasing in roughness with each increase in depth. Surface of water smooth. Surface of flow fairly rough.					
1	8-27	.0130	.059	.221	.0604	0	40	.000	3.74	.253	
2	8-27	.0362	.115	.315	.0606	10	13	.054	3.79	.276	
3	8-27	.0750	.159	.472	.0606	30	17	.064	4.82	.228	
4	8-27	.162	.183	.885	.0605	60	29	.050	8.43	.133	
5	8-27	.354	.224	1.58	.0603	90	30	.017	13.6	.0852	
6	8-27	.772	.287	2.69	.0603	100	33	.011	20.5	.0589	
7	8-27	1.64	.387	4.23	.0604	100	31	.074	27.7	.0459	
8	8-27	3.76	.573	6.57	.0604	100	32	.084	35.3	.0384	
9	8-27	7.17	.791	9.06	.0588	100	30	.144	42.1	.0339	
10	8-27	10.9	1.02	10.7	.0576	100	34	.120	44.2	.0338	
Channel 7E			Bed Slope 7.14 Percent					Experiment 1, 1940			
Description of vegetation: Good uniform stand of unclipped green grass with 9.6 cubic inches of forage per square foot; average length 3.2 inches; composition 85 percent buffalo, 15 percent crab and needle grasses; upright at start of testing. Grass established by solid sodding in spring 1940.						Hydraulic behavior: About half of channel width occupied by stream that submerged the grass for run 1. All of grass submerged by run 2 but grass waving in flow. Surface of water smooth. Surface of flow fairly rough for runs 3 and 4 and rough for runs 5 and 6 with apparently very high surface velocities for run 6.					
1	9-5	.0578	.107	.540	.0709	50	30	.000	6.25	.165	
2	9-15	.518	.274	1.89	.0714	100	11	.000	13.5	.0886	
3	9-5	1.53	.403	3.80	.0715	100	32	.231	22.4	.0571	
4	9-6	5.04	.665	7.58	.0718	100	31	.404	34.7	.0400	
5	9-6	7.36	.822	8.96	.0711	100	33	.185	37.1	.0387	
6	9-6	9.96	1.00	9.06	.0596	100	32	.321	37.7	.0394	
Channel 7E			Bed Slope 6.99 Percent					Experiment 2, 1941			
Description of vegetation: Fair uniform stand of unclipped green grass with 3.8 cubic inches of forage per square foot; average length 4.0 inches; composition 100 percent buffalo; upright at start of testing. Grass established in spring 1940. Maintenance consisted of controlling weeds and filling damaged places caused by previous testing.						Hydraulic behavior: Flow through grass for runs 1 and 2 with slight bending of stems for run 2. Part of grass submerged for run 3. Surface of flow smooth. All grass submerged by run 4 and surface of flow starting to get rough. Remainder of runs the flow increased in roughness until runs 10, 11 and 12 were exceedingly rough with foam riding the surface of the flow.					
1	8-14	.0118	.048	.246	.0699	0	25	.000	4.24	.212	
2	8-14	.0274	.106	.259	.0699	10	16	.000	3.01	.339	
3	8-14	.0625	.177	.353	.0700	40	18	.120	3.18	.351	
4	8-14	.696	.300	2.32	.0697	90	23	.000	16.0	.0758	
5	8-14	1.10	.346	.318	.0698	100	12	.324	29.5	.0509	
6	8-14	1.42	.391	3.64	.0698	100	10	.000	22.1	.0575	
7	8-14	2.42	.471	4.73	.0701	100	16	.000	26.1	.0504	
8	8-14	2.71	.511	5.30	.0701	100	9	.416	28.0	.0474	
9	8-14	3.41	.572	5.97	.0698	100	9	.000	29.9	.0453	
10	8-14	4.04	.607	6.66	.0700	100	24	.141	32.3	.0423	
11	8-14	5.92	.735	8.05	.0696	100	24	.162	35.6	.0897	
12	8-14	8.99	.933	9.64	.0673	100	27	.272	38.5	.0382	
Channel 7E			Bed Slope 6.89 Percent					Experiment 3, 1942			
Description of vegetation: Good uniform stand of unclipped green grass with 764 stems per square foot; average length 3.4 inches; composition 100 percent buffalo grass; upright at start of testing. Grass established by solid sodding in spring 1940. Maintenance consisted of cutting weeds and filling damaged places caused by erosion of previous testing.						Hydraulic behavior: Flow through and over grass for runs 1, 2, 3 and 4 with surface of flow smooth. Surface of flow rough for runs 5 to 10 increasing in roughness with each increase in depth. Apparent high surface velocity for runs 8 and 9 with some foam on the surface.					

Table 6.—Results of Tests of Channels Lined with Buffalo Grass.—(Continued)

Channel 7E, cont.										
Run	Date	Discharge per foot of width VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients	
									Chey. C	Mannin. n
1	2	3	4	5	6	7	8	9	10	11
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.		
1	8-26	.0184	.082	.225	.0689	0	35	.000	3.00	.329
2	8-26	.0367	.118	.311	.0688	0	14	.036	3.46	.302
3	8-26	.0790	.167	.473	.0689	30	17	.086	4.43	.251
4	8-26	.166	.191	.872	.0690	50	35	.025	7.62	.149
5	8-26	.408	.246	1.66	.0690	85	30	.065	12.8	.0925
6	8-26	.893	.319	2.80	.0690	100	32	.034	19.0	.0649
7	8-26	2.02	.446	4.54	.0691	100	30	.096	25.9	.0502
8	8-26	4.18	.621	6.74	.0693	100	30	.113	32.5	.0423
9	8-26	8.62	.893	9.65	.0678	100	31	.108	39.3	.0372
Channel 10F			Bed Slope 10.2 Percent				Experiment 1, 1940			
Description of vegetation: Good uniform stand of unclipped green grass with 4.25 cubic inches of forage per square foot; average length 6.1 inches; composition 95 percent buffalo, 5 percent crabgrass; upright at start of testing. Grass established by solid sodding in spring 1940.						Hydraulic behavior: Flow through grass with stems bending slightly by force of the water for run 1. Most of grass submerged by run 2 and all by run 3 but remaining erect and waving in the flows. Runs 4 and 5 surface of flows and some erosion caused around grass roots. Runs 6 and 7, surface of flows very rough and considerable erosion but channel still in fair condition.				
1	9-1	.0745	.146	.510	.101	0	18	.000	4.21	.258
2	9-1	.512	.274	1.87	.102	90	12	.102	11.2	.107
3	9-1	1.58	.379	4.17	.101	100	30	.125	21.3	.0595
4	9-1	5.07	.653	7.77	.0997	100	31	.443	30.5	.0455
5	9-1	7.60	.783	9.70	.0978	100	32	.215	35.1	.0407
6	9-1	9.84	.928	10.6	.0976	100	33	.196	35.6	.0413
7	9-1	11.7	1.02	11.5	.0948	100	27	.259	36.9	.0405
Channel 10F			Bed Slope 10.1 Percent				Experiment 2, 1941			
Description of vegetation: Good uniform stand of unclipped green grass with 3.8 cubic inches of forage per square foot; average length 4.9 inches; composition 100 percent buffalo; upright at start of testing. Grass established in spring 1940. Maintenance consisted of controlling weeds and filling damaged places caused by previous testing.						Hydraulic behavior: Flow through grass for runs 1 and 2 with apparently high velocity for depth. Runs 3 and 4, part of grass submerged with surface of flow slightly rough. Remainder of runs completely over grass with surface of flow increasing in roughness to runs 9, 10, and 11 when surface of flow became exceedingly rough with foam on the surface. Erosion was quite apparent but channel still in fair condition.				
1	8-2	.0178	.068	.262	.101	0	43	.000	3.16	.304
2	8-2	.0395	.094	.420	.101	5	20	.000	4.31	.232
3	8-2	.113	.165	.685	.101	30	12	.000	5.30	.208
4	8-2	.331	.203	1.63	.101	80	15	.000	11.4	.100
5	8-2	1.30	.320	4.06	.101	100	14	.313	22.6	.0547
6	8-2	1.97	.393	5.02	.102	100	12	.000	25.2	.0507
7	8-2	2.44	.425	5.73	.102	100	10	.000	27.6	.0468
8	8-2	2.95	.471	6.25	.102	100	9	.720	28.5	.0462
9	8-2	4.16	.564	7.38	.103	100	9	.000	30.7	.0442
10	8-2	6.77	.726	9.32	.101	100	23	.401	34.5	.0409
11	8-2	10.9	.950	11.5	.0960	100	33	.299	33.1	.0387
Channel 10F			Bed Slope 10.1 Percent				Experiment 3, 1942			
Description of vegetation: Fair uniform stand of unclipped green grass with 577 stems per square foot; average length 3.5 inches; composition 100 percent buffalo grass, upright at start of testing. Grass established by solid sodding in spring 1940. Maintenance consisted of cutting weeds and filling damaged places caused by erosion of previous testing.						Hydraulic behavior: Flow through and over grass for runs 1, 2 and 3, uniform velocity. Flow over most of grass during run 4 and 5 but grass waving in flow. Surface of flow a little rough during run 6. Surface of flow very rough for runs 7 to 10 with foam on surface during 9 and 10.				
1	8-24	.0206	.072	.286	.101	0	30	.000	3.35	.286
2	8-24	.0468	.113	.414	.102	10	20	.000	3.88	.268
3	8-24	.103	.151	.684	.102	40	18	.068	5.52	.197
4	8-24	.211	.173	1.22	.102	60	36	.030	9.26	.122
5	8-24	.456	.217	2.10	.102	90	38	.000	14.1	.0821
6	8-24	1.06	.304	3.50	.101	100	33	.022	20.0	.0610
7	8-24	2.33	.419	5.57	.101	100	38	.061	27.2	.0473
8	8-24	4.16	.561	7.42	.100	100	30	.041	31.3	.0432
9	8-24	8.42	.794	10.6	.0974	100	27	.120	38.0	.0376
10	8-24	12.2	.979	12.5	.0932	100	20	.218	41.4	.0358

WEEPING LOVE GRASS

Table 7.—Results of Tests of Channels Lined with Weeping Lovegrass.

Channel 1B			Bed Slope 0.98 Percent					Experiment 1, 1941			
Run	Date	Discharge Per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients		
									Chey, C	Manning, n	
1	2	3	4	5	6	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.			
Description of vegetation: Good uniform stand of long green grass with 8.2 cubic inches of forage per square foot; average length 15.3 inches; composition 100 percent love grass, upright at start of testing. Grass established from seed in spring 1941.						Hydraulic behavior: Flow passing through and around grass with no apparent effect on grass for runs 1, 2 and 3. Stream formed down center of channel that had part of grass submerged for runs 4 and 5. Most of grass submerged for run 6 and all for run 7 and 8 with much of submerged grass waving in the flow for all three runs. Surface of the flows fairly smooth. The surface of the flows for runs 9, 10 and 11 were slightly rough but the grass could be seen waving in the flow.					
1	7-15	.0235	.193	.122	.0107	0	30	.000	2.71	.426	
2	7-15	.0961	.418	.230	.0116	0	22	.000	3.32	.391	
3	7-15	.219	.640	.342	.0121	0	16	.187	3.92	.356	
4	7-16	.318	.724	.440	.0124	20	19	.000	4.66	.303	
5	7-16	.448	.829	.540	.0128	50	15	.000	5.28	.274	
6	7-16	.462	.826	.560	.0128	80	9	.056	5.45	.265	
7	7-16	.767	.913	.840	.0126	100	15	.000	7.84	.187	
8	7-16	1.02	.967	1.06	.0127	100	15	.130	9.59	.154	
9	7-16	1.34	1.05	1.28	.0126	100	9	.496	11.1	.135	
10	7-17	1.64	1.10	1.49	.0126	100	35	.010	12.7	.119	
11	7-17	2.81	1.29	2.18	.0126	100	35	.014	17.3	.0899	
Channel 1B			Bed Slope 0.99 Percent					Experiment 2, 1942			
Description of vegetation: Very good uniform stand of long green grass with 525 stems per square foot; average length 28 inches; composition 100 percent weeping love grass; upright at start of testing. Grass established in spring 1941. Grass clipped 4 inches above ground in spring 1942 and soil replaced where erosion had occurred by previous testing.						Hydraulic behavior: Flow through stand for runs 1, 2 and 3 with smooth surface. Runs 4 and 5 submerged part of grass but surface of flow remained fairly smooth. Most of grass was submerged by run 6 with grass waving in the flow. Run 7 submerged all of the grass except a few of the taller stems that remained at or above the surface of the flow.					
1	9-3	.0158	.110	.144	.0107	0	60	.000	4.80	.243	
2	9-3	.0586	.279	.210	.0111	0	24	.021	4.15	.317	
3	9-3	.204	.631	.323	.0131	10	24	.030	3.74	.393	
4	9-3	.311	.889	.350	.0143	20	24	.060	3.25	.476	
5	9-3	.503	1.13	.445	.0146	50	22	.039	3.65	.439	
6	9-3	.733	1.22	.601	.0136	80	20	.036	4.98	.331	
7	9-3	1.13	1.31	.866	.0132	98	18	.128	7.07	.234	
Channel 2B			Bed Slope 2.11 Percent					Experiment 1, 1942			
Description of vegetation: Good uniform stand of long green grass with 384 stems per square foot; average length 16 inches; composition 100 percent weeping love grass; upright at the start of testing. Grass established in spring 1941. Grass clipped 4 inches above ground in spring 1942.						Hydraulic behavior: Flow through stand for runs 1, 2 and 3, water surface smooth. Runs 5 and 6, flow slightly rough with grass waving in flow. Surface of flow became more rough and turbulent as depth increased through runs 7 to 10.					
1	9-4	.0240	.105	.229	.0211	0	32	.000	4.88	.211	
2	9-4	.0764	.219	.349	.0216	0	24	.000	5.11	.228	
3	9-4	.171	.398	.436	.0221	0	22	.000	4.72	.272	
4	9-4	.437	.650	.673	.0222	25	20	.000	5.64	.247	
5	9-4	.632	.715	.884	.0225	50	14	.000	7.00	.202	
6	9-4	.912	.766	1.19	.0226	80	17	.043	9.10	.157	
7	9-4	1.15	.811	1.42	.0226	95	17	.051	10.5	.137	
8	9-4	1.37	.850	1.61	.0226	100	24	.090	11.7	.125	
9	9-4	2.11	.965	2.19	.0225	100	30	.024	14.9	.0993	
10	9-4	4.18	1.20	3.48	.0221	100	28	.089	21.4	.0717	
Channel 4C			Bed Slope 3.91 Percent					Experiment 1, 1941			
Description of vegetation: Fair uniform stand of long green grass with 4.2 cubic inches of forage per square foot; average length 12.8 inches; composition 100 percent love grass; upright at start of testing. Grass established by seed in spring 1941.						Hydraulic behavior: Flow through and around grass for runs 1 through 4. Stream formed down center of channel for runs 5 and 6 and all of grass under flow for runs 8 and 9 but grass waving in the flow. Runs 10 through 13 pressed the grass fairly well down with the surface of the flow increasing in roughness with each run. Runs 12 and 13 caused some erosion between bunches of grass.					

Table 7.—Results of Tests of Channels Lined with Weeping Lovegrass.—(Continued)

Channel 4C, cont.										Coefficients			
Run	Date	Discharge per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Chezy, C	Manning, n			
1	2	3	4	5	6	7	8	9	10	11			
		Cu. ft. per sec.	Feet	Ft. per sec	Ft. per ft.	Percent	Min.	In. per hr.					
1	8-28	.0205	.073	.281	.0390	0	30	.000	5.25	.183			
2	8-28	.105	.190	.553	.0393	0	17	.000	6.40	.176			
3	8-28	.158	.272	.583	.0396	0	10	.049	5.64	.213			
4	8-28	.315	.393	.801	.0402	10	10	.000	6.40	.201			
5	8-28	.467	.441	1.06	.0399	50	10	.000	8.01	.163			
6	8-28	.584	.471	1.24	.0401	75	10	.070	9.07	.146			
7	8-28	.816	.510	1.60	.0401	98	10	.000	11.3	.119			
8	8-29	1.39	.572	2.43	.0394	100	11	.000	16.2	.0838			
9	8-29	1.79	.631	2.84	.0394	100	10	.070	18.1	.0763			
10	8-29	2.72	.733	3.71	.0393	100	10	.070	21.9	.0647			
11	8-29	3.90	.847	4.60	.0388	100	21	.110	25.4	.0570			
12	8-29	5.13	.941	5.45	.0388	100	23	.133	28.5	.0515			
13	8-29	5.92	.981	6.04	.0387	100	120	.048	31.0	.0477			
Channel 4C										Bed Slope 3.87 Percent		Experiment 2, 1942	
Description of vegetation: Fair uniform stand of long green grass with 284 stems per square foot; average length 11 inches; composition 100 percent weeping love grass; upright at the start of testing. Grass established in spring 1941. Grass clipped 4 inches above ground in spring 1942 and soil replaced when erosion had occurred by previous testing.						Hydraulic behavior: Flow through stand for runs 1, 2 and 3, surface of flow smooth. Runs 4, 5, 6 and 7, grass waving in flow, surface fairly rough. Runs 8, 9 and 10, surface of flow increased in roughness with each increase in depth and velocity.							
1	9-5	.0280	.074	.378	.0387	0	22	.000	7.08	.138			
2	9-5	.0924	.167	.553	.0393	0	22	.000	6.83	.163			
3	8-5	.202	.296	.682	.0401	10	20	.018	6.33	.197			
4	9-5	.492	.451	1.09	.0407	30	20	.036	8.16	.164			
5	9-5	.850	.528	1.61	.0405	60	19	.019	11.1	.123			
6	9-5	1.16	.577	2.02	.0402	90	18	.040	13.3	.104			
7	9-5	1.47	.621	2.37	.0398	100	15	.000	15.1	.0915			
8	9-5	1.82	.661	2.75	.0398	100	18	.028	17.0	.0820			
9	9-5	3.14	.794	3.96	.0396	100	14	.000	22.4	.0642			
10	9-5	6.05	1.04	5.82	.0387	100	23	.016	29.0	.0517			
Channel 7F										Bed Slope 7.04 Percent		Experiment 1, 1941	
Description of vegetation: Fair uniform stand of long green grass with 6.3 cubic inches of forage per square foot; average length 12.6 inches; composition 100 percent love grass; upright at start of testing. Grass established by seed in spring 1941.						Hydraulic behavior: Flow through grass stand for runs 1, 2 and 3 but highest velocity appeared to be down center of channel. Stream formed down center of channel for runs 4, 5 and 6 with a few bunches remaining above the flow for run 7, surface of the flow smooth with grass waving in flow. Runs 8 and 9, all grass submerged but still standing in the flow. Runs 10, 11 and 12 pressed grass below surface of flow with apparently high surface velocity for runs 11 and 12.							
1	8-27	.0178	.081	.292	.0705	0	22	.000	4.47	.210			
2	8-27	.0350	.102	.343	.0707	0	16	.000	4.03	.254			
3	8-27	.113	.207	.546	.0713	10	26	.033	4.52	.256			
4	8-27	.186	.254	.734	.0711	40	12	.000	5.46	.217			
5	8-27	.317	.330	.960	.0710	60	9	.120	6.26	.198			
6	8-27	.504	.385	1.31	.0717	75	12	.162	7.92	.161			
7	8-27	.745	.416	1.79	.0715	95	10	.049	10.4	.124			
8	8-27	.870	.465	1.87	.0714	100	9	.096	10.3	.128			
9	8-27	1.56	.492	3.18	.0713	100	9	.256	17.0	.0779			
10	8-27	2.18	.588	3.71	.0708	100	22	.152	18.2	.0750			
11	8-27	3.75	.713	5.26	.0710	100	23	.196	23.4	.0601			
12	8-27	6.96	.939	7.41	.0690	100	26	.265	29.2	.0506			
Channel 10C										Bed Slope 10.1 Percent		Experiment 1, 1941	
Description of vegetation: Fair stand, fairly uniform, long green grass with 8.4 cubic inches of forage per square foot; average length 11.4 inches; composition 100 percent love grass; upright at start of testing. Grass established by seed in spring 1941.						Hydraulic behavior: Flow through grass for runs 1 through 4 with very little effect on grass except along center line where stand is thin. Runs 5 and 6, stream found down center of channel. Runs 7 and 8, most of grass under the surface but waving in the flow. Runs 9, 10 and 11 all grass submerged, apparent high surface velocity for runs 10 and 11.							

Table 7.—Results of Tests of Channels Lined with Weeping Lovegrass.—(Continued)

Channel 10C, cont.										Coefficients	
Run	Date	Discharge per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Chezy, C	Manning, n	
1	2	3	4	5	Ft. per	7	8	9	10	11	
		Cu. ft. per sec.	Feet	Ft. per sec.	ft. 6	Percent	Min.	In. per hr.			
1	8-26	.0144	.042	.344	.101	0	25	.000	5.31	.167	
2	8-26	.0619	.100	.619	.102	0	12	.102	6.16	.167	
3	8-26	.195	.215	.906	.103	0	12	.162	6.16	.191	
4	8-26	.293	.274	1.07	.103	10	11	.067	6.45	.190	
5	8-26	.411	.314	1.31	.103	25	12	.090	7.34	.170	
6	8-26	.534	.366	1.46	.103	75	10	.247	7.58	.168	
7	8-26	.657	.391	1.68	.102	90	10	.070	8.41	.162	
8	8-26	.895	.426	2.10	.102	98	9	.136	10.1	.129	
9	8-26	1.19	.465	2.56	.102	100	11	.233	11.8	.112	
10	8-26	3.90	.704	5.54	.101	100	25	.348	20.8	.0676	
11	8-26	7.48	.895	8.36	.0989	100	30	.269	28.1	.0519	
Channel 10C		--			Bed Slope 9.83 Percent		Experiment 2, 1942				
Description of vegetation: Fair uniform stand of long green grass with 333 stems per square foot; average length 12.3 inches; composition 100 percent weeping love grass; upright at start of testing. Grass established in spring of 1941. Grass clipped 4 inches above ground in spring 1942 and soil replaced where erosion had occurred by previous testing.					Hydraulic behavior: Flow through grass with smooth surface for runs 1, 2 and 3. Grass bending under flow for runs 4, 5, 6 and 7, and waving in current. Run 8 most of grass submerged but waving in flow causing rough surface. Runs 9 and 10 very rough surface.						
1	9-8	.0212	.063	.336	.0987	0	55	.000	4.28	.222	
2	9-8	.0694	.141	.492	.0989	0	23	.032	4.17	.257	
3	9-8	.132	.208	.637	.0990	0	20	.062	4.44	.258	
4	9-8	.289	.331	.874	.0987	20	19	.026	4.84	.256	
5	9-8	.476	.421	1.13	.0985	40	14	.052	5.57	.232	
6	9-18	.720	.483	1.49	.0982	50	18	.020	6.87	.194	
7	9-8	.985	.524	1.88	.0978	70	11	.067	8.32	.162	
8	9-8	1.32	.550	2.40	.0983	90	33	.037	10.4	.131	
9	9-8	5.12	.843	6.08	.0987	98	29	.055	21.1	.0688	
10	9-8	10.8	1.12	9.64	.0978	100	41	.115	29.3	.0519	

NATIVE GRASS MIXTURE

Table 8.—Results of Tests of Channels Lined with a Native Grass Mixture.

Channel 1D										Bed Slope 0.87 Percent		Experiment 1, 1943	
Description of vegetation: Good stand of tall and short grasses, uncut with 147 stems per square foot; the long grasses averaged 26.7 inches in length with 97 stems per square foot. Composition 66 percent tall grasses, 34 percent crab and grama grasses; upright at start of testing. Channel established from seed in spring 1942. Tall grasses cut in spring 1943.					Hydraulic behavior: Flow uniform through stand for runs 1, 2, 3 and 4, surface smooth. Grass was largely submerged but standing up in flow for runs 5 and 6 surface of flow was fairly smooth. Run 7, all grass submerged except very stiff bunches; surface of flow slightly rough.								
1	2	3	4	5	6	7	8	9	10	11			
1	9-7	.0366	.167	.219	.0095	0	80	.000	5.71	.200			
2	9-7	.0876	.293	.299	.0100	0	30	.029	5.71	.218			
3	9-7	.163	.447	.342	.0107	0	30	.060	5.16	.265			
4	9-7	.309	.600	.515	.0112	20	36	.040	6.59	.220			
5	9-7	.597	.765	.780	.0127	50	31	.069	8.21	.183			
6	9-7	1.60	1.05	1.52	.0149	80	35	.000	12.8	.126			
7	9-7	3.15	1.34	2.35	.0144	95	33	.011	17.6	.0933			

Table 8.—Results of Tests of Channels Lined with a Native Grass Mixture.—(Continued)

Channel 4D			Bed Slope 3.85 Percent					Experiment 1, 1943		
Run	Date	Discharge per foot of width, VD	Depth, D	Mean velocity, V	Effective slope	Vegetation submergence	Duration of flow	Av. rate of scour	Coefficients	
									Chezy, C	Manning, n
1	2	3	4	5	6	7	8	9	10	11
		Cu. ft. per sec.	Feet	Ft. per sec.	Ft. per ft.	Percent	Min.	In. per hr.		
Description of vegetation: Fair stand of tall and short grasses, green, uncut with 115 stems per square foot. The tall grasses averaged 19.5 inches in length with 49 stems per square foot. Composition 43 percent tall grasses, 57 percent crab and grama grasses; upright at start of testing. Channel established by seed in spring 1942. Tall grasses cut in spring 1943.					Hydraulic behavior: Flow through stand for runs 1, 2 and 3 with surface fairly smooth. Flow for runs 4 and 5 was rough with stiff grass waving in the flow. Runs 6 and 7 were very rough with practically all grass submerged except for a few very stiff bunches.					
1	9-11	.0609	.183	.333	.0375	0	60	.000	4.05	.281
2	9-11	.179	.391	.457	.0368	0	20	.000	3.83	.337
3	9-11	.365	.542	.674	.0368	10	22	.023	4.79	.281
4	9-11	.815	.668	1.22	.0379	40	21	.017	7.73	.180
5	9-11	1.64	.783	2.09	.0374	60	13	.093	12.2	.117
6	9-11	3.22	.900	3.58	.0376	90	15	.082	19.5	.0750
7	9-11	6.23	1.10	5.66	.0381	95	19	.101	27.6	.0547
Channel 7B			Bed Slope 7.14 Percent					Experiment 1, 1943		
Description of vegetation: Good stand of tall and short grasses, green, uncut with 151 stems per square foot. The tall grasses averaged 30.5 inches in length with 97 stems per square foot. Composition 64 percent tall grasses, 36 percent crab and grama grasses; upright at start of testing. Channel established by seed in spring 1942 and tall grasses cut in spring 1943.					Hydraulic behavior: Flow through stand for runs 1, 2 and 3 with fairly smooth surface. Surface of flow slightly rough for runs 4 and 5, rough for run 6 and very rough for runs 7 and 8.					
1	9-10	.0376	.113	.333	.0717	0	50	.000	3.76	.287
2	9-10	.134	.232	.580	.0716	0	29	.067	4.52	.260
3	9-10	.265	.341	.777	.0713	20	23	.189	5.00	.249
4	9-10	.495	.438	1.13	.0713	30	37	.043	6.40	.203
5	9-10	1.11	.598	1.86	.0721	50	27	.112	8.99	.153
6	9-10	2.34	.721	3.24	.0716	80	31	.058	14.3	.0985
7	9-10	4.22	.891	4.74	.0718	100	24	.156	18.8	.0777
8	9-10	8.41	1.17	7.19	.0719	100	29	.330	24.8	.0617