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Flow of Water in Channels Protected by Vegetative Linings

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CONTENTS

[1] The research reported here was begun under the supervision of F. B. Campbell, then in charge of the outdoor hydraulic laboratory of the Soil Conservation Service. In 1938 Mr. Campbell was succeeded by W. O. Ree. Technicians who assisted in the work were C. A. Abrams, R. L. Burt, W. P. Law, Jr., S. H. Anderson, and V. J. Palmer. Valuable cooperation was received from the Operations Branch of the Soil Conservation Service, particularly from the regional office in Spartanburg, S. C., of which T. S. Buie has charge as regional conservator.

INTRODUCTION

Correct distribution and disposal of water on farm lands are the key to successful conservation farming. An earth channel for disposal of excess surface water is much more stable if it has a lining of vegetation (*5*).[2] The roots of the vegetation bind the soil mass, and the plant cover protects the channel surface from the erosive action of flowing water and hinders movement of soil particles from the channel bed. This protective action varies with kind of vegetation and with uniformity of cover. For any individual kind of vegetation it varies according to age and condition of the plants, whether the vegetation is cut short or left long, and season of the year.

Wherever natural sodded drainageways are available on agricultural land, they should be used and should be carefully maintained. They are the best type of channels for collecting and conveying surplus surface water. Where terrace systems are installed, new drainage channels must sometimes be made. New channels should be lined with vegetation, and whenever plant covers protecting drainageways are seriously damaged, as they often are by weather factors, rodents, sediment deposits, or farm implements, they should be reestablished. A field engineer undertaking to establish a vegetation-lined channel needs to know the characteristics of different kinds of vegetation with reference to channel capacity and stability.

This publication presents the results of a study made at an outdoor hydraulic laboratory near Spartanburg, S. C., concerned principally with the effects of vegetal linings on the capacity and stability of small channels.[3] The study dealt with plant species adapted primarily to the Southeastern and South Central States. Extensive experimentation was carried out with Bermuda grass (*Cynodon dactylon*), common lespedeza (*Lespedeza striata*), sericea lespedeza (*Lespedeza cuneata*), and a mixture of orchard grass (*Dactylis glomerata*), redtop (*Agrostis alba*), Italian ryegrass (*Lolium multiflorum*) and common lespedeza. Tests were made also on centipede grass (*Eremochloa ophiuroides*), Sudan grass (*Sorghum vulgare sudanense*), and Dallis grass (*Paspalum dilatatum*) and crabgrass (*Digitaria sanguinalis*). A channel lined with kudzu (*Pueraria thunbergiana*) was subjected to experiments pertaining to seasonal conditions and growth and to one designed to determine the effect of plowing in channel banks covered with kudzu in a dormant condition.

Agronomic variables involved were growth, season, and channel-maintenance conditions. Slope of channel bed ranged from 1 to 24 percent, but in most instances was either 3 or 6 percent. Two general types of channel were used, the trapezoidal and the rectangular.

The protective capacity of each channel lining was measured by

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[2] Italic numbers in parentheses refer to Literature Cited, p. 115.

[3] This study and its results have been the subject of several brief preliminary reports (*2*, *3*, *4*, *9*). Also see Ree, W. O. SOME EXPERIMENTS ON SHALLOW FLOWS OVER A GRASSED SLOPE. Natl. Res. Council, Geophys. Union Trans. 1939: 653–656, illus. [Processed.]

determining the maximum mean velocity of flow to which the lining could be subjected for a reasonable length of time without ceasing to protect the channel from severe erosion. This velocity, sometimes called "safe," "allowable," or "noneroding," is referred to in this bulletin as "permissible."

For vegetation-lined channels that are subjected to intermittent flows only, duration of flow has a bearing on permissible velocity. If the flows are of short duration, some surface scour can be permitted. Under those conditions surfaces from which small quantities of soil have been eroded usually heal over. Accordingly, velocities that may cause slight scour are classed in this bulletin as permissible.

The results of the experiments demonstrate that the degree to which channel vegetation retards flow of water depends largely upon the degree to which the vegetation is bent and flattened by the flow, and that this depends mainly upon physical characteristics of the vegetation, its manner of growth, and the velocity and depth of the flow.

Findings from the study have immediate practical value for application not only in the Southeastern and South Central States but also in other areas where the same or similar types of vegetation may be used as channel linings. Data obtained have served as a basis for (1) establishing permissible velocities of intermittent flow and (2) developing a graphic method of determining a cross section that will permit a channel to carry the expected flow at a velocity not exceeding the permissible. The design graphs were constructed specifically for long green, short green, and short dormant Bermuda grass and long green sericea lespedeza, and the channel-section curves apply to either trapezoidal, triangular, or parabolic channels.

This publication presents a complete, detailed record of the studies conducted and the results obtained.

EXPERIMENTAL CONDITIONS AND PROCEDURE

The outdoor hydraulic laboratory of the Soil Conservation Service near Spartanburg, S. C., in the Piedmont plateau, which was used in making the study reported here, was located on a relatively steep hillside along a small stream. Slopes as steep as 30 percent were available for experimental purposes.

A masonry dam across the stream impounded the water supply. Water for the tests was drawn through an opening controlled by a hand-operated screw-hoist gate (fig. 1). Flows as great as 35 cubic feet per second were obtainable. That rate of flow could be maintained for an hour with a draw-down of less than a foot. After passing through the gate opening the water flowed over a sharp-crested weir into a 900-foot supply canal, of which the first 300-foot portion was lined with masonry (fig. 1) and the remaining 600 feet with Bermuda grass sod.

The general procedure was to construct test channels on the laboratory site, establish vegetal linings in the channels and maintain them, subject the channels to controlled flows of water from the supply canal, and measure the hydraulic elements. For comparative purposes, three channels were tested when they had no vegetal linings. The water passed into the test channels through cut-off gates and side openings. Testing equipment included rate-measuring flumes, current meter, water-level recorders, point gages, and the necessary auxiliary devices. As the work progressed new techniques were developed and new equipment was designed, and these improvements were put to use.

Constructing and Preparing Channels

The trapezoidal channels used in the study resembled those commonly used on agricultural land in the Southeast, except that they were somewhat smaller. It was necessary to make them small in order to obtain appreciable depths and velocities of flow with the maximum discharge available. They had bottom widths of 1 to 4 feet, side slopes of 1.5:1 down to 4:1, and depths of from 1 to 2.5 feet. The rectangular channels had sheet-metal side walls (fig. 2). They were 2 feet wide, with the exception that those having a lining of Bermuda grass sod ranged in width from 1 to 6 feet. The hydraulic behavior of channels of this smooth-sided type was found to be practically the same regardless of whether they were narrow or very wide. In other words, this kind of channel construction in effect eliminated width as a variable. It also simplified the study of channel scour and the assignment of permissible velocities. Bed slope for the trapezoidal channels ranged from 1 to 24 percent, but in most cases was either 3 or 6 percent. All the rectangular channels were constructed with a 3-percent bed slope.

In constructing the channels, most of the excavating was done by hand; occasionally a mule team and a slip scraper were used.

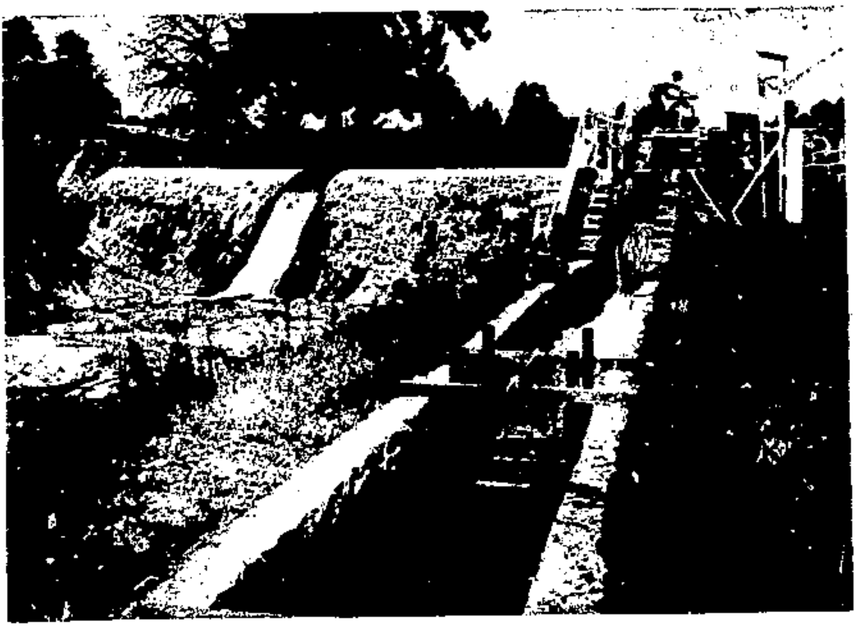

Figure 1.—Dam, headgate, weir, and masonry-lined portion of canal conveying water to experimental channels.

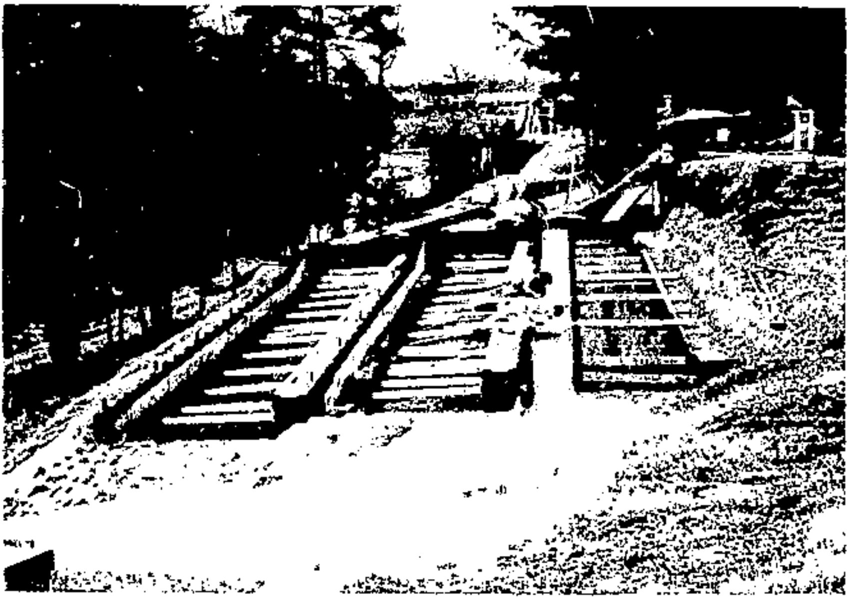

FIGURE 2. Typical arrangement of experimental channels having rectangular cross section and sheet-metal side walls.

During excavation a channel was held to the desired cross section by use of a template.

To eliminate soil type as a variable, the sod to be used for lining channels was produced on Cecil sandy loam and the test channels that were not to be sodded were lined with 4 to 6 inches of the same soil. Cecil sandy loam was considered more typical of the soils of the Southeastern States than the inferior clay found on the steep slopes of the laboratory site. Moreover, since this soil is more subject to scour than the clay material, use of it tended to result in derivation of conservative values for permissible velocity.

Vegetation was established in channels by solid sodding, sprigging, seeding, or setting out plants. The method chosen was commonly the one used with the same plant species in establishing farm drainageways. Sometimes, to assure establishment of a stand, the plants were watered and shaded, and sometimes weeds were removed or cut.

TESTING

The dimensions and vegetal-lining conditions of the supply canal and the 35 channels used in the tests are presented in table 1.

When a channel reached the desired condition it was subjected to a measured flow of water for a definite period, usually 40 minutes. The first flow was usually a low one. If a low first flow caused no damage, a larger flow was discharged down the channel. This procedure was repeated until the channel failed or until the capacity of the channel or of the laboratory water system was

TABLE 1.—*Dimensions and vegetal-lining conditions of experimental channels*

Vegetation and channel No.	Nominal channel dimensions			Experiment number	Condition of vegetation
	Bed slope	Bottom width	Side slope		
	Percent	*Feet*			
Bermuda grass:					
B1-1	23.7	1.5	1:1	1	Green, long.
				2	Dormant, long.
B1-2	20.0	1.5	1.5:1	1	Green, long.
				2	Dormant, long.
B1-6	20.0	1.5	4:1	1	Green, short.[1]
B1-3	10.0	1.5	1.5:1	1	Green, long.
				2	Dormant, long.
B1-5	10.0	1.5	4:1	1	Green, long.
				2	Green, short.[2]
B2-7	3.0	4.0	1.5:1	1	Green, long.
				2	Dormant, long.
				3	Dormant. Long in test 1, short in tests 2 to 10.
B2-8	3.0	1.5	1.5:1	1	Green, long.
				2	Green. Long in test 1, short in tests 2 to 10.
B2-18	3.0	1.5	4:1	1	Green, short.[1]
B2-19	3.0	1.0	Vertical	1	Dormant, short.[2]
		2.0	do	1	Do.
		3.5	do	1	Do.
		6.0	do	1	Do.
B2-17	1.0	1.5	4:1	1	Partially dormant, short.[2]
Supply canal	.2	4.0	1.5:1	4	Green, short.[2]
Centipede grass:					
B1-4	10.0	1.5	1.5:1	1	Green, long.
				2	Dormant, long.
Dallis grass and crabgrass:					
B2-6	6.0	2.0	3:1	1	Green, long.
Kudzu: B2-9	3.0	4.0	1.5:1	1	Green, long, first season.
				2	Green, long, second season.
				3	Dormant, mulch of vines and leaves.
				4	Green, cut.[1]
		(3)	(3)	5	Dead vines (test a). Green (tests b, c, and d).
Lespedeza:					
B2-2	6	2	3:1	1	Dead, uncut.
B2-5	6	2	3:1	1	Green, uncut.
B2-11B	3	2	Vertical	1	Do.
B2-15C	3	2	do	1	Dead, uncut.
B2-15B	3	2	do	1	Green, uncut.
B2-15A	3	2	do	1	Green, short.[1]
Sericea lespedeza:					
B2-1	6	2	3:1	1	Dormant, long.
B2-4	6	2	3:1	1	Green, medium long, woody.[4]
B2-10C	3	2	Vertical	1	Dormant, short.[5]
B2-10B	3	2	do	1	Green, long, not yet woody.
B2-14C	3	2	do	1	Dormant, long.
B2-14B	3	2	do	1	Green, long.
B2-14A	3	2	do	1	Green, short.[1]
Sudan grass:					
B2-3	6	2	3:1	1	Dead, long.
Grass mixture:					
B2-12C	3	2	Vertical	1	Green and dormant, short.
B2-12B	3	2	do	1	Green and dormant, long.
B2-16C	3	2	do	1	Green and dormant, short.
B2-16B	3	2	do	1	Green, long.
B2-16A	3	2	do	1	Green and dormant, short.
No vegetation:					
B2-3	6	2	3:1	1	
B2-13C	3	2	Vertical	1	
B2-13B	3	2	do	1	

[1] Cut shortly before test.
[2] Kept cut.
[3] Changed by plowing.
[4] Cut to 6-inch height 2 months before test.
[5] Cut previous fall.

reached. In some tests the progression was from high to low flows.

As the surface of the pond lowered during a test, the headgate opening was continuously adjusted in order to maintain a steady flow in the channel for a definite period. Wherever possible, a diversion arrangement near the channel entrance was used. The flow would be bypassed at the head of the channel until discharge became steady, then admitted into the channel. At the end of the test period the flow would be turned out abruptly. Where it was impossible to arrange a diversion system, an effort was made to fill the conveying canal and forebays with water to satisfy storage requirements before opening the gate to the test channel. By this method of operation the flow could be kept practically constant during the test.

Measurements and Observations

DISCHARGE

In the earlier experiments, discharge was measured by use of a sharp-crested weir, which had suppressed end contractions. The weir was rated by making head measurements simultaneously on it and a previously calibrated rate-measuring flume. During a test the weir head was measured with a point gage and a water-level recorder. Because of the distance between the test channels and the weir, it was necessary to correct the discharge measurement made at the weir for leakage in the canal conveying the water to the channels. The leakage rates were determined by closing off the conveying canal, the volume of which was known, filling it with water, and determining the rate at which its water surface dropped.

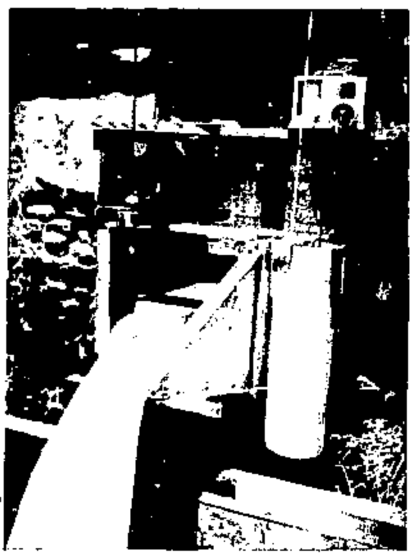

FIGURE 3.—Two-foot H-rate-measuring flume having auxiliary gage for zeroing, point gage for measuring head, and recording gage for recording depth of flow.

This method of determining discharge was not very satisfactory. Whereas the leakage correction was determined for a level water surface, during an experiment the water surface had considerable slope. In addition, the storage effect of the conveying system on the discharge was hard to eliminate. These difficulties were overcome, wherever possible, by making the measurements near the test channel, sometimes with a 2-foot modified Parshall flume and sometimes with an H-flume (fig. 3), which was available in the 1-foot, 2-foot, and 3-foot sizes. All the flumes had been calibrated in advance and were moved about and installed where needed.

In all but a few tests, only the inflow to a channel was measured. Where the test flows were so low that the infiltration loss might become a relatively high percentage of the discharge, the flows were measured also at the outlet end, sometimes volumetrically and sometimes with a 1-foot H-flume.

CROSS SECTION, WETTED PERIMETER, AND SLOPE

Several methods were used to obtain data for determining the cross-sectional area, wetted perimeter, and slope of a test reach. For the earlier tests strings were stretched across each channel, 10 feet apart, between previously leveled stakes on the two sides. The horizontal coordinates of the channel cross section were marked by tying tufts of string, usually 0.5 foot apart, to the strings across the channel. The vertical coordinates were determined by measuring down from these strings with a graduated metal rod. For the first tests the distance between strings was measured horizontally; later, it was measured along the slope. Measuring along the slope was found to be more convenient both for laying out distance and for analyzing the data. For slopes up to 10 percent the difference between measurement on the slope and horizontal measurement is practically negligible. The graduated rod was held in a vertical position except in measuring channels of 10-percent or steeper slope, when it was held normal to the channel grade. A small level was affixed to the rod to serve as a guide to holding it correctly. Readings of the vertical coordinates were taken to the nearest 0.01 foot. This method is referred to later as the string-and-rod method.

To obtain better measurements, a more precise cross-sectioning method was developed. Instead of a string a structural-steel angle, usually a 3- × 3- × 1/4-inch section, was placed across the channel (fig. 4). An adjustable truss was provided to prevent sagging. The ends of the angle rested on carefully leveled supports. Later in the study, screw-adjustable supports were substituted. The upstanding leg of the angle accommodated a rider holding a standard point gage. The angle was so mounted that when the rider was clamped to it the point gage was normal to the channel bottom. A scale was placed on the lower leg of the angle to mark the horizontal coordinates of the cross section. The vertical coordinates were read with the point gage. Where the nature of the surface made it practical to do so, the ordinates were measured to 0.001 foot. The elevation of a channel's bottom surface was measured by use of a blunt point one-quarter inch in diameter, and that of the water surface by use of a sharp point. In order that all elevation measurements on a channel might be referenced to the same datum a stake was placed outside the channel at each of the stations where measurements were to be made, so located that a point-gage reading could be obtained on it. The stakes were carefully leveled with respect to each other, and a nail was set in each to mark the elevation of the point from which measurements were made. This method is referred to later as the point-gage method.

In all experiments, channel-bottom measurements were made before and after each test flow and water-surface measurements during each flow. The methods and equipment used in making

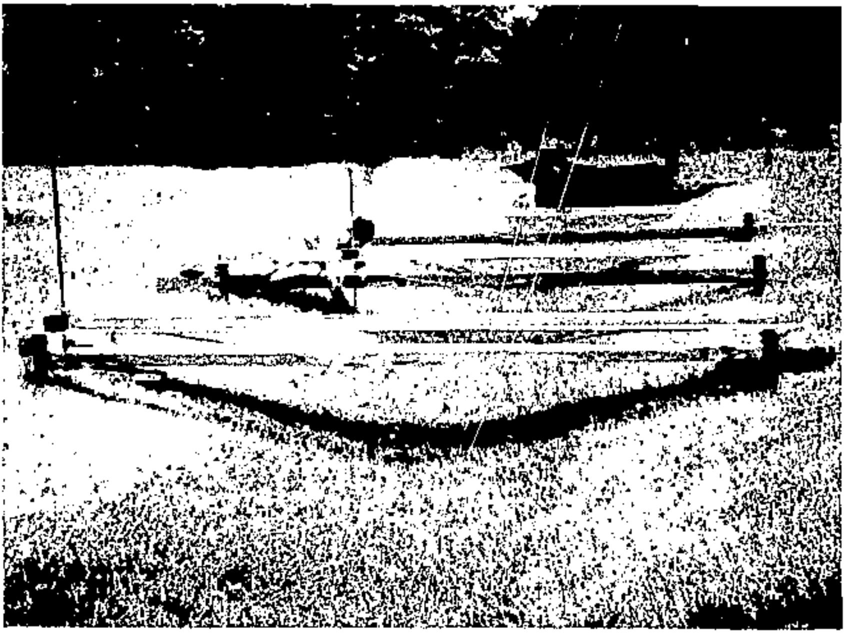

FIGURE 4. Equipment used in cross-section measurements. A scale clamped to the horizontal face of the angle is used to locate the position for measurements.

these measurements were changed and improved as the work progressed. Particularly, the number and order of water-surface measurements were changed. The number of stations where cross sections were taken in a channel varied from three to six.

During each test in the early experiments one observer made water-surface measurements at all stations, beginning at the station farthest upstream and proceeding downstream, making only one traverse at each station. Because of the length of time required for making these measurements, the last was made 40 to 50 minutes later than the first. If considerable erosion had occurred it was difficult to compute the relative water-surface elevations (for slope determination) and the cross-sectional areas. The procedure was improved by providing for simultaneous measurements at all stations. A water-surface traverse was made at each of three stations as soon after the water was turned into the channel as steady flow prevailed, and again just before the flow was shut off. With this procedure the corrections to the cross-sectional areas, necessitated by occurrence of erosion before the first and after the last water-surface measurement of a test, were held to a minimum, and no correction of the water-surface slope was required.

Another change in procedure was made to reduce errors introduced by the personal element. Usually the water surface in the channels was ripply or wavy, and the observer would attempt to estimate its average position. An individual observer would usually read consistently high or low. To reduce the resulting error a third water-surface measurement was made at each station during the test. With three measurements being made at each of three stations, it was possible to rotate the observers so that each man made one measurement at each station. When the results were averaged, errors due to differences in observers would to some extent balance out.

VEGETATION

To identify and describe the vegetation in each channel, careful stand counts were made at locations where, to the eye, channel lining conditions seemed to be typical. A number of 6-inch squares were laid out on the channel surface, the plants or stems of each kind of vegetation within these squares were counted, their length was measured, and the cover was classified as green, dormant, or dead. The slowness and laboriousness of counting the vegetation usually made it impractical to count more than six squares in each channel.

OTHER MEASUREMENTS AND OBSERVATIONS

Other factors noted were temperature of the water and flow characteristics such as waves, aeration, and uniformity.

After each test the channel bottom was carefully inspected. To supplement the scour-rate figures, obtained at selected stations only, notes were made on the condition of the vegetation and the soil surface, and the depth and extent of any eroded areas were estimated.

METHODS OF COMPUTATION AND ESTIMATE

Hydraulic Computations

The capacity of an open channel is usually estimated by one of several empirical formulas, of which the two most commonly used in the United States are Manning's and Kutter's. In each of these a retardance coefficient, n, represents the effect of all factors tending to retard flow of water in the channel. Other factors are symbolized in these formulas as follows:

A = Area of water cross section in square feet.

P = Wetted perimeter in feet.

Q = Discharge in cubic feet per second.

$R = \frac{A}{P}$ = Hydraulic radius in feet.

S_w = Slope of water surface in feet per foot.

S_e = Hydraulic gradient or slope of specific energy line in feet per foot.

n_m = Coefficient of retardance in Manning's formula.

n_k = Coefficient of retardance in Kutter's formula.

The Manning formula is:

$$Q = A \frac{1.486}{n_m} R^{2/3} S_e^{1/2}$$

The Kutter formula is:

$$Q = A \left[\frac{41.65 + \frac{0.00281}{S_e} + \frac{1.811}{n_k}}{1 + \frac{n_k}{\sqrt{R}} \left(41.65 + \frac{0.00281}{S_e} \right)} \right] \sqrt{RS_e}$$

In the study reported in this publication the slope term $\frac{0.00281}{S_0}$ was omitted from the Kutter formula in calculating n_k values. For channels of such slopes as those used in this study the omission of this term has negligible effect.

In using the Manning or the Kutter formula in the field to determine the capacity of a vegetation-lined channel all items except the retardance coefficient n_m or n_k can be determined from the dimensions of the channel. The retardance coefficient, which represents chiefly the retarding effect of the channel lining, is estimated by comparing the appearance of the lining with those of other linings for which n_m or n_k has been determined by experiment. The coefficient represents also the effects of all the other retarding factors in the channel, which include any irregularities in cross section, slope, and alinement of channel and in channel surface, any other flow obstructions, and any blocking out by vegetation of part of the channel's cross section. It has been found that retardance coefficients for vegetation-lined channels vary with shape of channel cross section, slope of bed, and depth of flow.

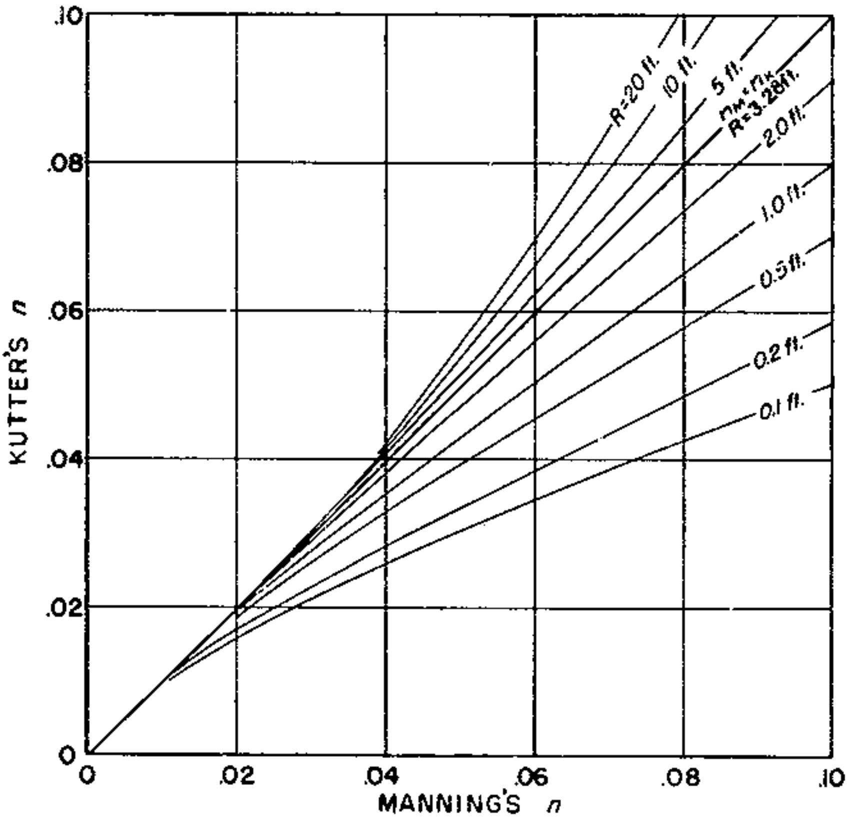

FIGURE 5.—Relation between Kutter's n and Manning's n.

The Manning and Kutter retardance coefficients are equal only for a hydraulic radius of 1 meter (3.28 feet). They differ most for shallow flows in rough channels. Figure 5 illustrates their relation.

In this study the values of Manning's and Kutter's retardance coefficients were computed for individual 10-foot portions of test channels, referred to here as "reaches." In almost every one of the test channels, measurements and computations were made for two or more reaches, which were consecutive. The n values computed for different reaches of a given channel were averaged.

To compute mean velocity (V), discharge was divided by the average of the end cross-sectional areas, including the portions occupied by vegetation, of each test reach. The discharge, as previously explained, was determined by making a head measurement of the flow with a weir or a previously calibrated rate-measuring device and, if necessary, correcting the measurement for leakage or storage effects.

The cross-sectional areas and wetted perimeter were determined either graphically or by a computation method. The average area and average wetted perimeter for a reach were computed for each set of measurements by averaging the values for the stations at the ends of the reach. For trapezoidal channels the hydraulic radius (R) for a reach was computed as the quotient of average area of cross section in square feet (A) and average wetted perimeter in feet (P). For rectangular channels with sheet-metal side walls the depth was used as the hydraulic radius, when it had

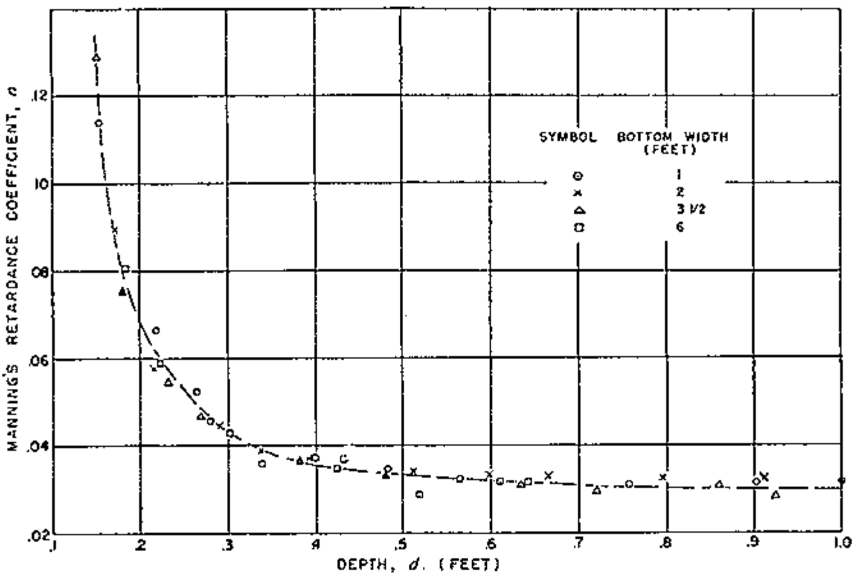

FIGURE 6.—Variation of Manning's n ($n_m = \frac{1.486}{V} d^{2/3} S_e^{1/2}$) with depth of flow for rectangular Bermuda grass-lined channel having sheet-metal side walls. Data from experiment 1 with channel B2–19.

been determined (by experiment 1 with channel B2–19, described herein) that the side walls had negligible retarding effect. Excellent agreement of Manning's n with depth was obtained for rectangular channels of various widths when depth was used as the hydraulic radius (fig. 6).

In cases of nonuniform flow it is necessary to determine the slope of the energy line, S_e, instead of using the channel-bed or water-surface slope. To compute S_e for every test flow, the water-surface slope, computed by dividing the drop in elevation by the slope distance, was corrected for changes in velocity by use of the formula—

$$S_e = S_w - \frac{V}{gl} (V_2 - V_1)$$

in which

S_w = Slope of water surface.
V = Mean velocity in reach.
V_1 = Mean velocity at beginning of reach.
V_2 = Mean velocity at end of reach.
g = Acceleration of gravity (32.14).
l = Slope length of reach.

The values of the retardance coefficients were computed for each reach by substituting in the Manning and Kutter formulas the values of Q, A, R, and S_e that were determined by measurement or computation. Values computed for individual reaches of the same channel were then averaged.

Scour Computations

The effect of each test flow on the channel was determined by computing, for each of several stations, the difference in cross-sectional area of the channel as measured before and after the flow. Because scour was the expected result, scour values were recorded as positive and deposition values as negative quantities.

Average depth of scour or deposition was computed by dividing the cross-sectional area of scour or deposition by the wetted perimeter. Average rates of change in channel depth resulting from scour or deposition were computed, in inches per hour.

Estimating Permissible Velocities

To estimate permissible velocity of flow for a given lining, a study was made of the change in the channel surface as revealed by the cross sections taken before and after each test, by supplementary observations recorded in notes and sketches, and by photographs. Evidences of scour were considered with reference to the mean velocities that had existed in the channel during the tests, and scour rates were plotted against velocities.

RETARDANCE OF FLOW

Influence of a Vegetal Lining

Water flowing at slight depths through vegetation encounters resistance from stalks, stems, and foliage. Often a large proportion of the cross-sectional area of a channel is actually blocked out by vegetation. The presence of numerous obstructions in the path of the flow may result in considerable turbulence. Under these conditions, flow of water is greatly retarded.

As depth of flow increases, the force exerted by the flowing water causes the vegetation to bend. The vegetation is bent over

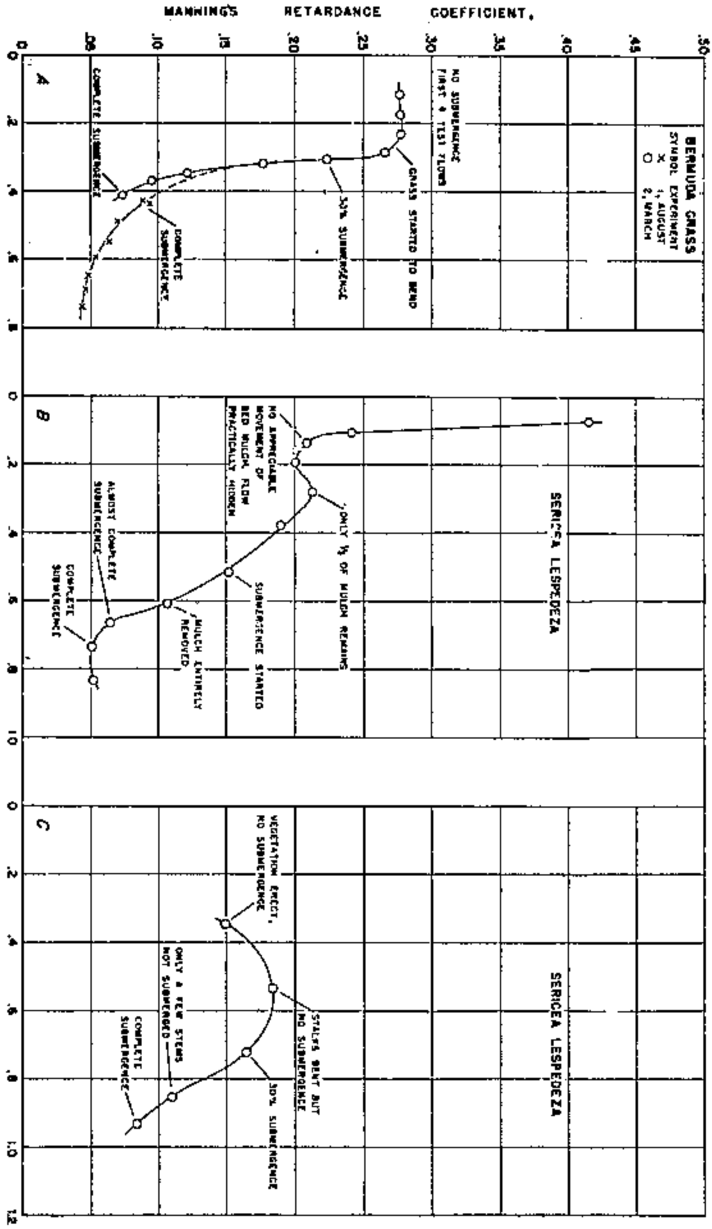

FIGURE 7.—Hydraulic behavior of vegetation-lined channels, having a bed slope of 3 percent, subjected to low and then to high flows. *A*, Bermuda grass channel B2–7. Bottom width 4 feet; side slope 1.5:1; good cover, 8 inches long at time of first experiment (in August) and 12 inches long at time of second (in March). *B*, Sericea lespedeza channel B2–14C. Bottom width 2 feet; vertical metal walls; good cover, 17 inches long and dormant at time of experiment (in March); channel bottom covered with leaf mulch. *C*, Sericea lespedeza channel B2–10B. Bottom width 2 feet; vertical metal walls; good cover, 22 inches long and green at time of experiment (in June).

toward the bed of the channel when the bending moment, which is a function of depth and velocity of flow, becomes greater than the resisting moment. With highly flexible vegetation such as Bermuda grass, bending occurs rapidly. When a portion of the cross section of the channel is freed of vegetal obstructions by bending of the vegetation, resistance to flow is greatly lessened with the result that retardance decreases sharply (fig. 7).

Often a high retardance coefficient holds practically constant through a considerable range of depths before a stage is reached at which the flowing water exerts sufficient force to bend the vegetation. This is illustrated by the graph for the Bermuda grass channel in figure 7.

The presence of dead, loose plant material in the channel bed may give an odd shape to the first part of the resistance-depth curve. This is illustrated by the results, shown in figure 7, of an experiment on a channel (B2–14C) lined with sericea lespedeza in dormant condition. The lining consisted of almost bare stems and a blanket of dead leaves covering the soil surface. The initial retardance coefficient was very high (n_m greater than 0.40). After decreasing sharply for the second flow the resistance remained practically constant for a range of depth, then again decreased, but at a much slower rate than for Bermuda grass. The shape of the resistance-depth curve was influenced by the presence of the bed mulch, the rate at which the mulch was removed, and the stiffness of the dead, bare stems.

A good stand of tall green lespedeza sericea produced another type of resistance-depth relation, shown by the graph for channel B2–10B in figure 7. The sericea plants, averaging 22 inches in height, were flexible, not having attained a woody condition. During the first test the vegetation remained entirely erect. In the second test, when depth of flow was greater, the retardance coefficient was higher. As submergence increased further the resistance decreased, at a much slower rate than for either Bermuda grass or dormant sericea. The same phenomenon was noted by C. E. Ramser in his study of resistance to flow in drainage channels (*8*).

The structure of sericea lespedeza offers an explanation of its performance. Short stems and leaves did not occur in abundance on the stalks for a distance of about 0.15 foot above the ground line; water flow to this depth was obstructed only by almost bare stems. With an increase in the depth of water a greater portion of the cross-sectional area of the flow was filled with foliage. Unlike Bermuda grass, green sericea lespedeza offers considerable resistance to bending and does not readily become flattened when submerged. Even though the submerged plants are bent severely, large portions of them remain within the flow area, waving back and forth. It is because of this and of their mass of foliage that the plants have a marked retarding influence on deep flows.

Influence of Bed Slope

For flows of sufficient depth to bend over and submerge the channel vegetation, greater velocity due to greater slope of channel bed results in lower resistance to flow, apparently because it results in greater flattening of the vegetation. The correlation of lesser retardance coefficients with steeper slopes is illustrated in figure 8. It is more pronounced where flows are shallow, and tends to become insignificant where flows are deep.

The variation of retardance with kind of vegetation is due largely to differences in structure, number, and distribution of plants. The taller the plants, the more widely are *n* values for different kinds of vegetation likely to differ. For short plants *n* values tend not to vary significantly unless flow is very shallow. This is indicated by the fact that in figure 9 the plotted values for cut Bermuda grass, cut sericea lespedeza (both green and dormant), and cut common lespedeza are all included within a relatively narrow band.

Except for the common lespedeza channels B2-11B and B2-15A, the *n* values for short and medium-tall vegetation appear to reach a nearly constant value, as depth of flow increases, of about 0.035. Channel B2-11B had a thin stand that offered very little resistance, and channel B2-15A had only short bare stems. Sericea lespedeza channel B2-10C also had only short stems when tested, yet its *n* values were significantly higher than those of channel B2-15A. Perhaps the difference resulted from a difference in scour and increased roughness of the bed, which were appreciable with sericea and insignificant with common lespedeza.

The effect of density of cover is illustrated by the graphs in figure 9 for channels lined with common lespedeza. Channel B2-15B had a very good stand with an average height of 4½ inches and an average density of 290 plants per square foot.

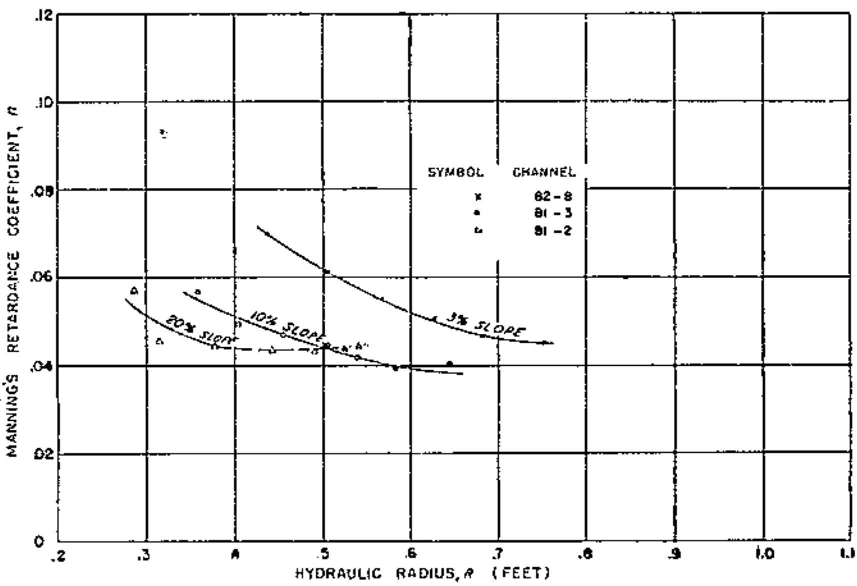

FIGURE 8.—Variation of Manning's *n* with hydraulic radius and bed slope for channels (B1-2, B1-3, and B2-8) lined with long green Bermuda grass, having bed slopes of 20, 10, and 3 percent, respectively, and having a bottom width of 1.5 feet and a side slope of 1.5:1.

Channel B2-11B had a sparse stand of about the same height, averaging only 17 plants per square foot. For a depth of 0.4 foot the thick cover offered twice as much resistance to flow.

Influence of Type and Condition of Vegetation

Data presented in figure 9, representing channels identical in cross-sectional shape and bed slope, indicate variation of retardance with type and condition of vegetal lining. Extremely wide variation of *n* values is shown to occur not only according to species of vegetation but according to seasonal condition, height, and density of stand of an individual species.

Retardance varies with season because season affects physical features of vegetation such as stiffness of stem and quantity and condition of foliage. Vegetation's resistance to bending, the cross-sectional area it occupies, and its behavior when bent over and submerged change as these factors change. Seasonal variation, particularly of foliage effect, is illustrated by the graphs in figure 9 for channels lined with long sericea lespedeza. For channel B2-14C, tested when the sericea was dormant and its stems were bare of foliage, the retardance coefficient is appreciably lower, at flows of 0.45 foot and more, than for channel B2-10B, tested when the sericea was green and retained its foliage.

Effect of Cutting Vegetation

If vegetation is cut short instead of being left to grow rank, obviously it occupies less space, presents less vegetal surface, and offers less resistance to flow. Long plants, stems, and leaves tend to vibrate and whip more in the flow and thus to introduce and maintain considerable turbulence. The longer the stem, the greater this tendency. Sericea lespedeza channels B2-10 and B2-14, tested with both long and short growth, demonstrate this contrast in retardance (fig. 9). The effect of cutting is particularly marked in the case of sericea lespedeza because of the stiffness of the plant.

The reduction in flow retardance associated with the mowing of a vegetal lining is illustrated in figure 10. Two channels with the same bed slope and with Bermuda grass linings nearly identical in density and length were tested first when the vegetation was long and then when it had been cut to a length of 4 inches. For a hydraulic radius of 0.4 foot the channel capacities, as reflected by the *n* values, were increased 52 and 92 percent, respectively, by the cutting.

Influence of Shape of Channel

In view of the general behavior of vegetation when subjected to water flow, it is reasonable to expect variation in flow retardance with variation in cross-sectional shape of channel. In a triangular-shaped channel a larger proportion of the channel cross section or of the vegetation is affected by a flow of small volume than in a trapezoidal channel. Other factors being equal, the lesser mean depth of a triangular channel as compared with a trapezoidal channel results in a higher *n* value.

The difference in flow retardance between channels B2-7 and B2-8, shown in figure 10, for test 1, in which their hydraulic radii were approximately equal, might be attributed to channel shape.

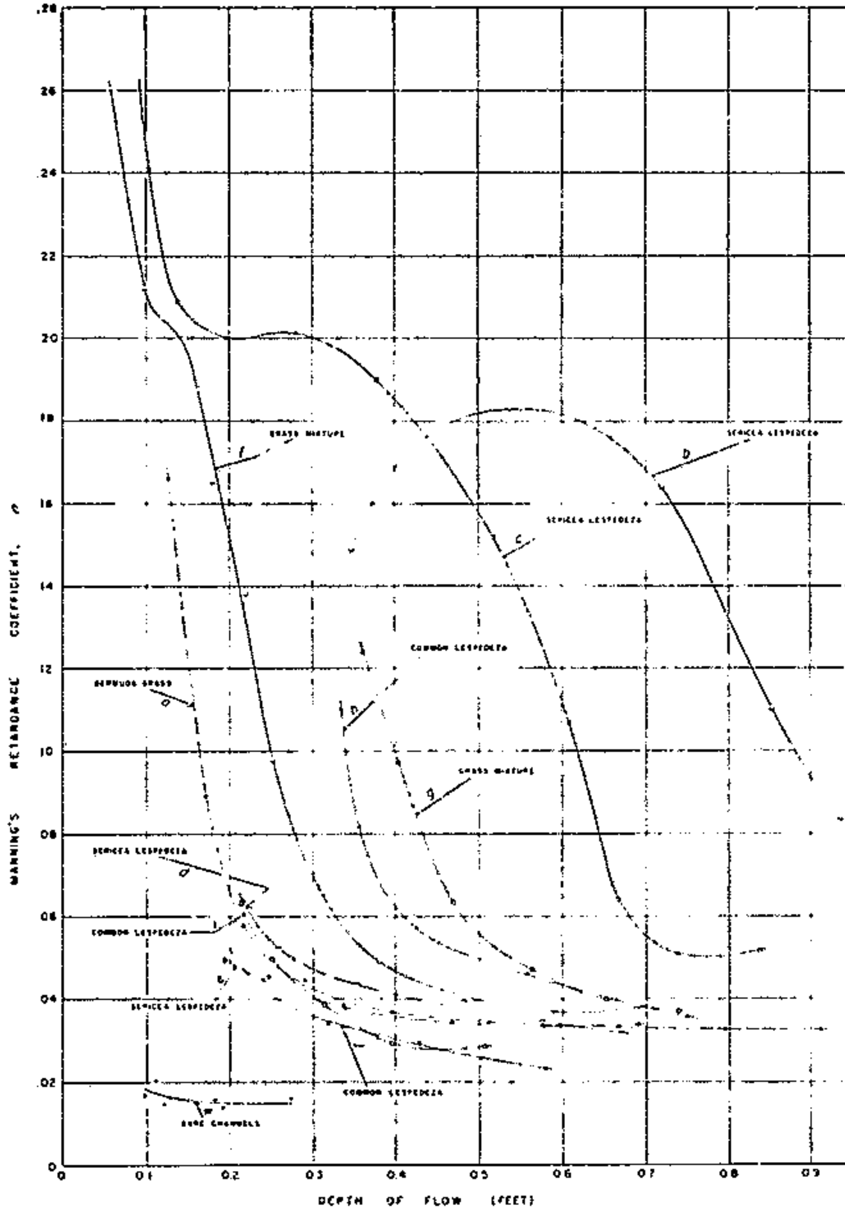

FIGURE 9.—Variation of retardance coefficient with kind and condition of vegetation and with depth of flow, for channels having a bed slope of 3 percent subjected to low and then to high flows: *a*, Short dormant Bermuda grass, good stand kept cut, 2½ inches tall when tested (channel B2–19–2, test in December); *b*, long green sericea lespedeza, good stand 22 inches tall, not yet woody (channel B2–10B, test in June); *c*, long dormant sericea lespedeza, good stand 17 inches tall, stems bare, bed covered with leaves (channel B2–14C, test in March); *d*, short green sericea lespedeza, good stand cut to 2 inches just before test (channel B2–14A, test in October); *e*, short dormant

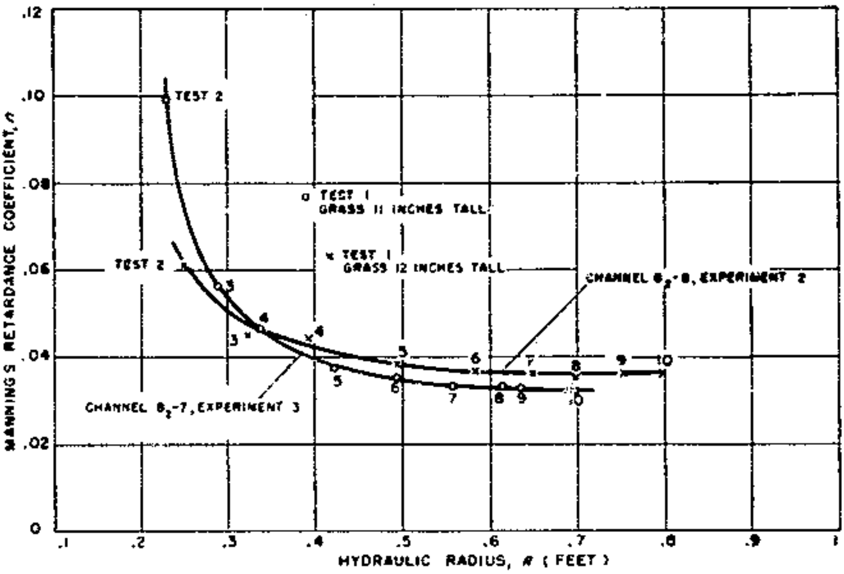

FIGURE 10.—Effect of cutting of a Bermuda grass lining on retardance coefficient. Data from experiment 3 on channel B2–7 and experiment 2 on channel B2–8, conducted in October and November. Bed slope 3 percent, side slope 1.5:1; bottom width 4 feet for channel B2–7, 1.5 feet for channel B2–8. Density of vegetation similar for the two channels. At time of test 1, height of grass 11 and 12 inches for the two channels, respectively; grass then cut to 4 inches. Submergence was complete.

The side slopes of the two channels were similar, but bed width was 4 feet for B2–7 and 1.5 feet for B2–8.

Influence of Order of Test Flows

If the usual practice in these tests had been reversed and the high flows had preceded the low flows instead of following them, somewhat different values of *n* would have been obtained. A moderate flow over vegetation well flattened by a preceding high flow generally encounters less resistance than if it coursed through upright vegetation, particularly if the vegetation is of a flexible, sod-forming plant such as Bermuda grass. Sericea lespedeza, however, may offer greater resistance to shallow flows if it has already been subjected to high flows. Because sericea is stiff and tends to resist flattening, low first flows through a channel lined with it are resisted chiefly by upright stems with little foliage. If the sericea has been compressed toward the bed by a high flow,

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sericea lespedeza, good stand, cut previous fall, stiff stalks 1 inch tall (channel B2–10C, test in April); *f*, green and dormant grass mixture cut previous fall, 4 inches tall (channel B2–16C, test in March); *g*, uncut green and dormant grass mixture, good stand 4 to 7 inches tall (channel B2–16B, test in June); *h*, uncut green common lespedeza, very good stand 4½ inches tall (channel B2–15B, test in June); *i*, uncut green common lespedeza, thin stand 4 inches tall (channel B2–11B, test in June); *j*, short green common lespedeza, good stand, cut to 2 inches of bare stems (channel B2–15A, test in October); *k*, no vegetation (channels B2–13B and B2–13C).

a subsequent low flow encounters resistance not merely from stems but also from a mass of foliage.

Channel B2–3, lined with Sudan grass, was tested in November, when the cover consisted of dead stems 2 to 4 feet long, first with high and then with low flows. For the first flow the hydraulic radius was 0.42 foot and the mean velocity 4.83 feet per second. The vegetation became submerged during the first test and remained submerged for succeeding lower flows. The data (fig. 11) indicate but slight increase in *n* with decrease in volume of flow. It is probable that the retardance coefficients for tests 4 and 3 would have been appreciably higher had these tests been conducted first. They would not have been higher, however, if velocity and depth were sufficient to bend and submerge the vegetation.

Figure 11 illustrates another influence of order of test flows. Test 3a was a repeat of test 3 conducted on channel B1–6 after the regular series of tests with low to high flows was completed.

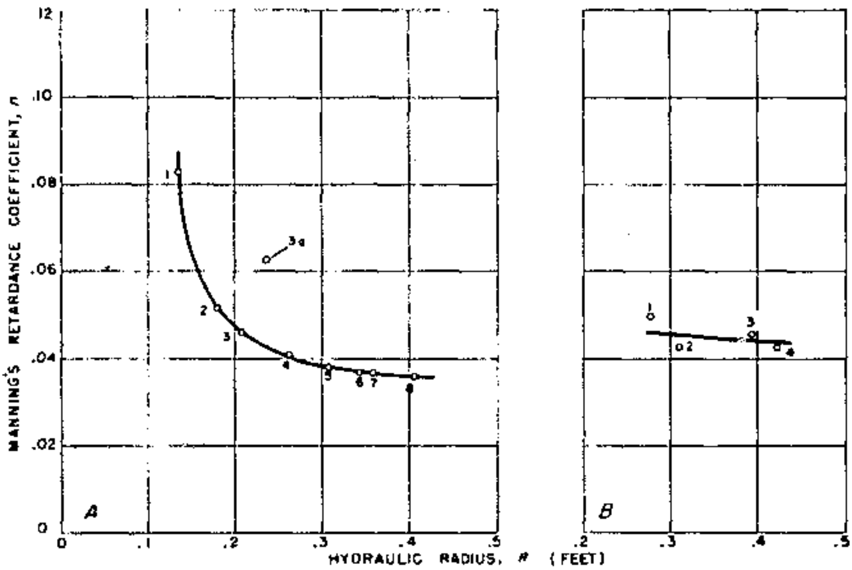

FIGURE 11.—Effect of order of tests on relation of hydraulic radius (depth of flow) and retardance coefficient. Numbers indicate order of tests. (Test 3a followed test 8.) *A*, Channel B1–6, lined with short green Bermuda grass. Bed slope 20 percent, bottom width 1.5 feet, side slope 4:1. *B*, Channel B2–3, lined with long dead Sudan grass. Bed slope 6 percent, bottom width 2 feet, side slope 3:1.

The *n* value obtained in this duplicate test was significantly higher than that obtained for the same hydraulic radius in the initial test. This resulted from actual roughening of the channel bottom by intervening flows. If the high flows had been run first, still higher retardance coefficients might have been obtained for the smaller hydraulic radii because of this increase in bottom roughness.

VR AS AN INDEX OF RETARDANCE

At the present time the product of mean velocity and hydraulic radius, *VR*, suggests itself as a suitable criterion for estimating n, the retardance coefficient, for channels lined with vegetation. The resistance to flow is a function of the degree of flattening of the vegetation, which is influenced by velocity and depth of flow. The product of velocity, which is affected by channel slope, and hydraulic radius, which is determined by channel shape and depth, constitutes a criterion that is relatively easy to apply.

Availability of data for Bermuda grass-lined channels varying widely in slope and cross-sectional shape has made possible a study of the variation and limitations in the usefulness of *VR* as an index of retardance. Figure 12 illustrates the n_m-VR relation for five channels lined with short green Bermuda grass that had bed slopes of from 0.2 to 20 percent, bed widths of 1.5 and 4 feet, and side slopes of 1.5:1 and 4:1; three channels lined with short dormant Bermuda grass that had bed slopes of 3 and 1 percent, bed widths of 1.5 to 4 feet, and side slopes of 1:1 to 4:1; and six channels lined with long green Bermuda grass that had bed slopes of 3 to 24 percent, bed widths of 1.5 and 4 feet, and side slopes of 1:1 to 4:1. Dimensions and data on vegetal covers for these channels are presented in table 2.

TABLE 2.—*Dimensions and vegetal-lining conditions of channels from which the data represented by the n_m-VR curves in figure 12 were obtained*

Channel	Experiment	Nominal dimensions: Bed slope	Nominal dimensions: Bottom width	Nominal dimensions: Side slope	Vegetal-lining conditions: Mowing[1]	Vegetal-lining conditions: Height	Vegetal-lining conditions: Stems per square ft.
CHANNELS LINED WITH SHORT GREEN BERMUDA GRASS (FIG. 12, *A*)							
		Percent	*Feet*			*Inches*	*Number*
B1-6	1	20.0	1.5	4 :1	1	3.5	208
B1-5	2	10.0	1.5	4 :1	2	2	480
B2-18	1	3.0	1.5	4 :1	1	4	320
B2-8	2	3.0	1.5	1.5:1	1	4	220
Supply canal		.2	4.0	1.5:1	1	4	169
CHANNELS LINED WITH SHORT DORMANT BERMUDA GRASS (FIG. 12, *B*)							
B2-7	3	3.0	4.0	1.5:1	1	4	250
B2-19	2	3.0	2.0	Vertical	2	2.5	400
B2-17	1	1.0	1.5	4 :1	2	2	480
CHANNELS LINED WITH LONG GREEN BERMUDA GRASS (FIG. 12, *C*)							
B1-1	1	23.7	1.5	1 :1		9	421
B1-2	1	20.0	1.5	1.5:1		15	148
B1-3	1	10.0	1.5	1.5:1		18	214
B1-5	1	10.0	1.5	4 :1		14	312
B2-7	1	3.0	4.0	1.5:1		8	330
B2-8	1	3.0	1.5	1.5:1		12	345
	2	3.0	1.5	1.5:1		12	220

[1] 1 Mowed shortly before test. 2 Mowed regularly.
[2] Vegetation fairly luxuriant.

The scatter of the points representing values for different channels in each of the curves of figure 12 may be influenced somewhat by differences in length and density of vegetation. In figure 12, *A*, values of n for given values of *VR* are highest for channel B2-18, and the vegetation height-and-density counts for

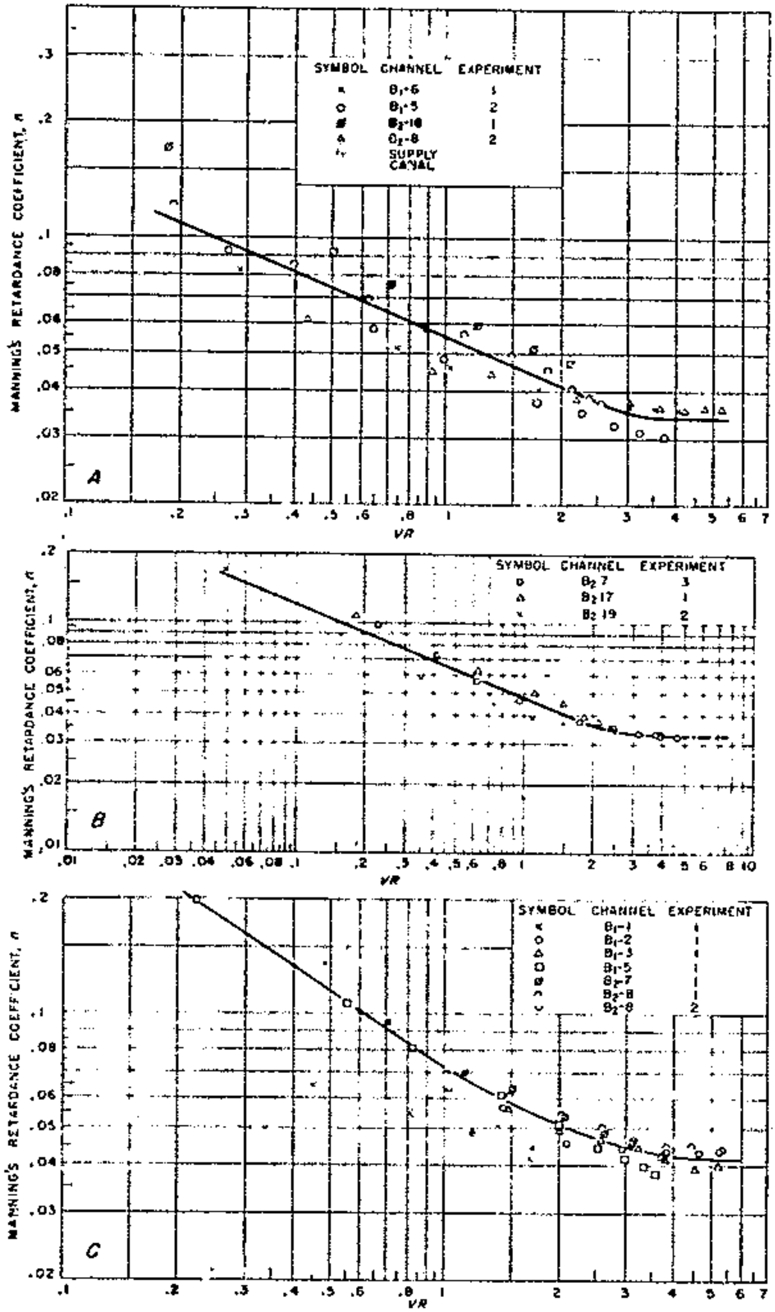

FIGURE 12.—Relation of *VR* and Manning's *n* for channels lined with (*A*) short green, (*B*) short dormant, and (*C*) long green Bermuda grass. Dimensions and vegetal-lining conditions of the channels are presented in table 2. The vegetation was completely submerged by all flows except the first two in channel B2–19 (lined with short dormant grass).

this channel indicate that it had better cover than any of the four others; but no variation of the n–VR relation with quality of cover is indicated for the other channels. All the channels represented in figure 12, *A*, had dense, uniform covers, and a single curve representing the n–VR relation for these channels is believed to be applicable to other channels having good covers of short green Bermuda grass. The coefficient of linear regression of VR values 0.18 to 2.5 is 0.85. The effect of channel slope and shape is believed to be reasonably well accounted for.

The curve for channels lined with long green Bermuda grass, figure 12, *C* likewise reveals a satisfactory relation of n with VR. Excellent agreement appears here among values for seven channels differing markedly in slope and cross section, with the one exception of channel B1–1. This channel was irregular in slope and cross section and was tested before the technique of testing vegetation-lined channels was well developed. Its 24-percent slope and the roughness of its water surface made measurement difficult. All the other channels were regular in cross section and bed slope. Consequently channel B1–1 has been disregarded as not comparable, and data for it were not used in constructing the curve in figure 12, *C*.

Beyond the VR values of 3 and 3.5 for short and long Bermuda grass, respectively, the retardance coefficient ceases to be associated with VR. Further significant changes in n are due chiefly to roughening of the channel bed by scour.

The evidence that the relation between n and VR is reliable for Bermuda grass channels differing widely in slope and shape suggests that VR may well be used as a general criterion of retardance. This value appears to be the best, most readily applied index of retardance now available for use in designing small channels that are to be lined with vegetation. The presentation and discussion of the hydraulic behavior of the different kinds of vegetation tested are largely in terms of the n–VR relation.

BERMUDA GRASS EXPERIMENTS

Bermuda grass, a perennial that makes vigorous and persistent growth in nearly all the warmer parts of the world, is the most common and most valuable pasture plant in the Southern States, having the same relative importance in that region that Kentucky bluegrass has in the more northern States. In many sections of the South it is one of the best grasses for hay. It spreads by runners, by rootstocks, and by seed. Its erect flower-bearing branches usually grow to a height of 6 to 12 inches. The leaf blades are narrow, flat, and 1 to 4 inches long. Bermuda grass requires warm weather during its growing season, bears intense summer heat without injury, is seriously injured by a moderate degree of cold, and seldom persists where the temperature falls much below zero. East of the 100th meridian the northern limit of its profitable growth is about the same as the southern limit of that of Kentucky bluegrass. It is not common north of the Potomac and Ohio Rivers or north of central Missouri and southeastern Kansas. It is common in irrigated valleys of the Southwest. Bermuda grass is probably more effective than any other grass now used to prevent washing on levee banks, in road cuts, and in gullies.

Because of its importance and widespread use, Bermuda grass was tested extensively. Ten trapezoidal and four rectangular channels were employed in testing it in various conditions—green and dormant, long and short.

Experimental conditions and results for channels lined with Bermuda grass are presented in table 3, and further information regarding the experiments on these channels is summarized in the following material in small type. The relation between n and VR, shown in figure 12 for Bermuda grass-lined channels in which the grass is short and either green or dormant or is long and green, is shown in figure 13 for those in which the grass is long and dormant. Dimensions and data on vegetal covers for the channels represented in figure 13 are given in table 4.

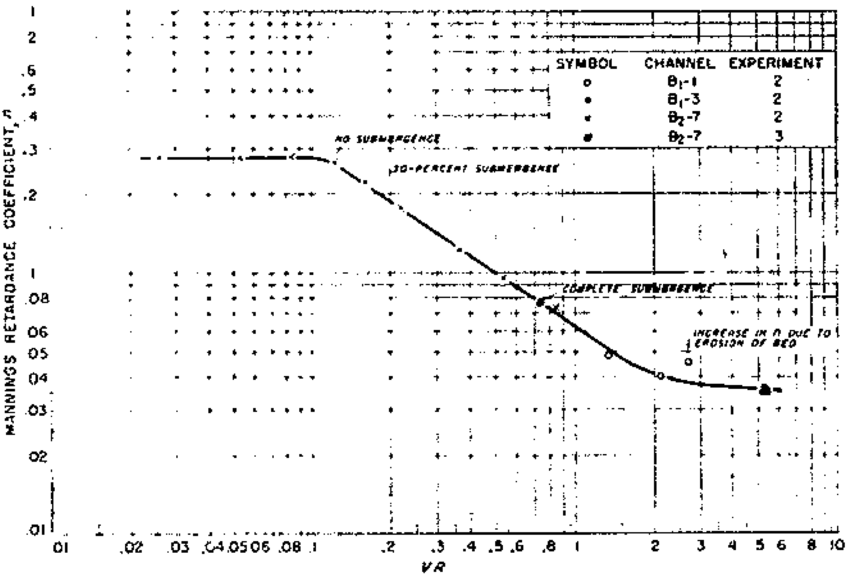

FIGURE 13.—Relation of Manning's n and VR for channels lined with long dormant Bermuda grass. Dimensions and vegetal-lining conditions of the channels are presented in table 4.

RECORD OF EXPERIMENTS

CHANNEL B1–1

Bed slope 23.7 percent, bottom width approximately 1.5 feet, side slope approximately 1:1, length 70 feet, slope and cross section irregular but alinement true, planted September 1935 by solid sodding.

Experiment 1, October 1936, grass green and uncut.—Average length of grass, 9 inches; stand described as "fairly luxuriant" (fig. 14). Soil firm.

Equipment: Sharp-crested weir, rod and string.

During each test a single observer made water-surface measurements at three stations, progressing downstream. There were two 10-foot reaches.

Vegetation was submerged during all tests. Water surface very rough for all flows. Some self-aeration during all tests. Values of n unusually

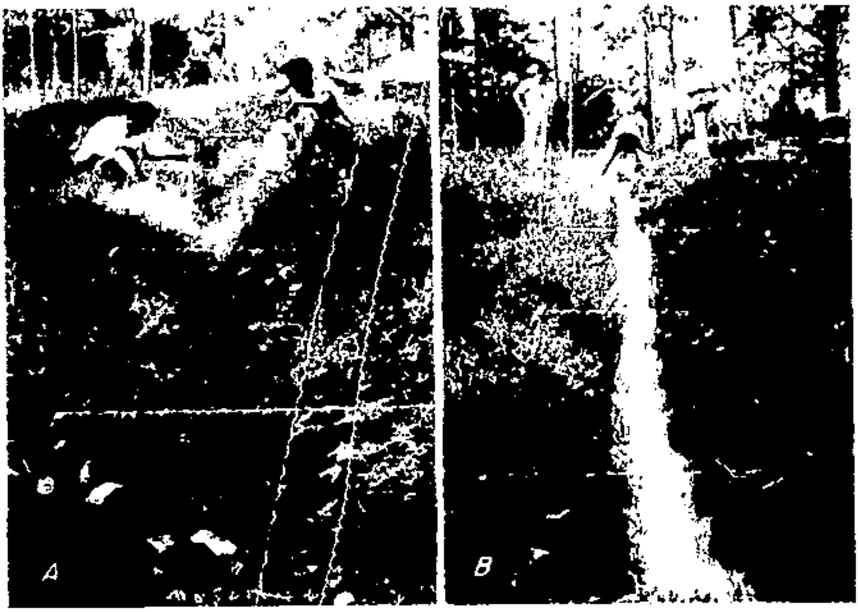

FIGURE 14.—Bermuda grass channel BE-1, experiment 1: *A*, View just before testing; *B*, [illegible] 1.

low, possibly because of defect in testing technique (this was the first channel tested). Roughness of water surface made measurements difficult.

Tests caused some erosion in channel. About eight holes, averaging 6 inches in diameter and 2 inches in depth, appeared in channel bottom. Even where soil had been washed away to this depth, most of grass remained. A few bare spots appeared.

Experiment 2, February 1938, grass dormant and uncut. Grass, on average, 12 inches long, 100 stems per square foot. Soil firm. Equipment and observational technique same as in experiment 1, except that there were five 10-foot reaches and six stations.

Vegetation was submerged. Water surface extremely rough, with considerable quantity of entrained air, for all tests (fig. 15, *A*). Values of *n* in agreement with those for other channels lined with long dormant Bermuda grass except for final test, in which severe scour apparently increased bed roughness.

Erosion progressed slowly until final test, then lower half of channel failed completely, having been scoured out to a depth of more than 18 inches (fig. 15, *B*).

CHANNEL BE-2

Bed slope 20 percent, bottom width 1.5 feet, side slope 1.5:1, length 42 feet. Planted August 1937 by solid sodding; [illegible] sod in bottom replaced at stations 10 to 25 feet from head of reach April 1938.

Experiment [illegible], September 1938, [illegible]. Grass, on average, 15 inches long, 118 stems per square foot, a fair stand. Soil firm.

Equipment: 2-foot modified Parshall flume, gage and rod. Discharge was measured directly. After each test, flow was diverted above test channel and into flume.

During each test a single observer made water-surface measurements at four stations, progressing downstream. There were three 10-foot reaches.

Vegetation was submerged during all tests. Water surface very rough for low flows and extremely rough for [illegible] flows. Considerable aeration in lower part of channel during [illegible]. Values of *n* in agreement with those for other channels [illegible]

TABLE 3.—*Experimental conditions and*

Channel	Nominal dimensions: Bottom width, *b*	Nominal dimensions: Side slope, *z*	Experiment number	Condition of lining	Test number	Date of testing	Discharge	Area of section, *A*	Mean velocity, *V*
1	2	3	4	5	6	7	8	9	10
TRAPEZOIDAL SHAPE,									
	Feet						*Cu. ft. per sec*	*Sq. ft.*	*Ft. per sec.*
B1-1	1.5	1:1	1	Green, long	1	Oct. 23, 1936	0.96	0.307	3.09
					2	Oct. 26, 1936	1.86	.430	4.30
					3	Oct. 27, 1938	2.90	.547	5.30
					4	...do...	3.75	.672	5.58
					5	Oct. 28, 1936	4.90	.790	6.20
					6	...do...	2.90	.545	5.32
					10	Oct. 30, 1936	5.02	.758	6.62
			2	Dormant, long	11	Feb. 11, 1938	3.03	.536	5.66
					12	Feb. 14, 1938	5.32	.706	7.54
					13	Feb. 24, 1938	7.32	.947	7.73
TRAPEZOIDAL SHAPE,									
B1-2	1.5	1.5:1	1	Green, long	1	Sept. 2, 1938	4.20	0.838	5.01
					2	Sept. 7, 1938	6.50	.976	6.66
					3	...do...	9.86	1.27	7.77
					4	Sept. 8, 1938	13.4	1.55	8.64
					5	Sept. 12, 1938	17.3	1.82	9.48
					6	Sept. 13, 1938	21.6	2.19	9.88
					6a	Sept. 16, 1938	21.3	2.13	10.00
			2	Dormant, long	1	Feb. 12, 1940	27.3	2.93	9.31
B1-6	1.5	4:1	1	Green. Short, cut shortly before testing.	1	Sept. 19, 1941	.951	.449	2.12
					2	Sept. 20, 1941	3.02	.733	4.12
					3	Sept. 23, 1941	4.68	.930	5.04
					4	Sept. 24, 1941	9.40	1.40	6.72
					5	...do...	14.28	1.79	7.98
					6	Sept. 26, 1941	19.17	2.17	8.86
					7	Sept. 29, 1941	23.65	2.39	9.89
					8	Oct. 4, 1941	29.31	2.91	10.08
					3a	...do...	4.57	1.12	4.08
TRAPEZOIDAL SHAPE,									
B1-3	1.5	1.5:1	1	Green, long	1	Aug. 19, 1938	4.65	1.14	4.09
					2	Aug. 20, 1938	7.12	1.43	4.97
					3	Aug. 22, 1938	10.0	1.77	5.66
					4	Aug. 23, 1938	13.5	2.11	6.40
					5	Aug. 24, 1938	17.9	2.53	7.07
					6	Aug. 25, 1938	23.0	2.95	7.80
					7	Aug. 27, 1938	28.1	3.49	8.06
			2	Dormant, long	1	Feb. 13, 1939	26.1	3.07	8.51
					2	Feb. 14, 1939	25.9	2.96	8.74
					3	Feb. 16, 1939	26.3	3.02	8.70
					4	Feb. 16, 1939	26.3	2.98	8.82
					5	Feb. 17, 1939	26.1	2.93	8.90
B1-5	1.5	4:1	1	Green, long	1	Sept. 21, 1939	1.04	1.11	.940
					2	Sept. 22, 1939	2.96	1.52	1.94
					3	...do...	4.94	1.86	2.66
					4	Sept. 25, 1939	9.84	2.52	3.90
					5	...do...	15.21	3.05	4.98
					6	Sept. 26, 1939	20.82	3.52	5.93
					7	Sept. 28, 1939	25.84	3.94	6.56
					8	Oct. 3, 1939	30.44	4.31	7.07
					9	Oct. 4, 1939	35.46	4.72	7.51
			2	Most of grass green. Short, kept cut.	1	Nov. 8, 1940	.979	.620	1.58
					2	Nov. 12, 1940	2.82	.953	2.96
					3	...do...	4.71	1.21	3.90
					4	Nov. 15, 1940	9.93	1.75	5.67
					5	...do...	14.7	2.24	6.56
					6	Nov. 18, 1940	19.8	2.66	7.44
					7	...do...	24.6	3.05	8.06
					8	Nov. 22, 1940	29.8	3.42	8.74

results for channels lined with Bermuda grass

Wetted perimeter, P	Hydraulic radius, R	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, n_m	Coefficients: Kutter, n_k	Value of VR
11	12	13	14	15	16	17	18	19	20	21
BED SLOPE 24 PERCENT										
Feet	*Feet*		*Feet*	*Min.*	*°F.*	*In. per hour*				
2.10	0.146	0.2345	0.22	30	......	......	16.74	0.0648	0.0392	0.461
2.27	.180	.2308	.28	30	......	......	20.66	.0546	.0361	.813
2.43	.225	.2276	.33	30	......	......	23.40	.0494	.0344	1.19
2.71	.248	.2346	.38	10	......	......	23.20	.0509	.0358	1.38
2.87	.276	.1932	.40	15	......	......	26.92	.0445	.0328	1.70
2.44	.224	.2262	.33	30	......	......	23.72	.0490	.0341	1.19
2.96	.256	.2135	.40	......	......	......	28.32	.0418	.0310	1.70
2.27	.236	.2350	.39	65	56	0.86	24.08	.0484	.0342	1.34
2.52	.280	.2287	.48	110	55	-.07	20.95	.0403	.0303	2.11
2.72	.348	.2307	.60	150	54	.19	27.59	.0468	.0347	2.69
BED SLOPE 20 PERCENT										
2.92	0.287	0.1926	0.43	35	71	-0.13	21.31	0.0567	0.0398	1.44
3.09	.316	.1944	.50	53	72	-.03	26.00	.0457	.0342	2.10
3.36	.378	.1954	.58	57	72	.22	28.61	.0442	.0341	2.94
3.51	.442	.1931	.60	48	73	.32	29.62	.0438	.0347	3.82
3.70	.491	.1974	.81	64	66	.39	30.46	.0434	.0349	4.66
4.05	.541	.1964	.87	62	68	.24	30.36	.0442	.0359	5.35
4.06	.525	.2049	.85	58	68	-.02	30.88	.0438	.0355	5.25
4.67	.628	.194	1.10	30	50	5.30	26.82	.0514	.0416	5.85
3.30	.136	.1054	.21	55	70	.01	13.00	.0824	.0466	.288
4.07	.180	.1979	.27	40	67	.13	21.63	.0518	.0344	.742
4.47	.208	.1961	.31	40	66	.11	24.91	.0460	.0322	1.05
5.34	.262	.1994	.41	40	66	.37	29.32	.0404	.0302	1.76
5.78	.308	.2012	.49	35	66	.27	32.12	.0380	.0294	2.46
6.35	.342	.1990	.54	30	68	.28	33.95	.0367	.0290	3.03
6.69	.358	.2062	.60	40	70	.15	36.66	.0362	.0278	3.54
7.16	.408	.1977	.66	40	68	.15	35.71	.0359	.0292	4.09
4.71	.238	.1078	.35	20	68	.03	18.82	.0622	.0414	.971
BED SLOPE 10 PERCENT										
3.18	0.369	0.0916	0.56	35	71	0.17	22.86	0.0565	0.0412	1.47
3.64	.404	.0906	.63	30	70	.47	26.26	.0495	.0378	2.01
3.90	.455	.0907	.75	32	74	.07	28.05	.0470	.0365	2.68
4.18	.505	.0906	.86	40	74	.13	30.08	.0445	.0357	3.23
4.69	.540	.0884	.96	47	74	.18	32.63	.0416	.0341	3.82
5.06	.584	.0874	1.03	44	73	.10	34.80	.0394	.0331	4.56
5.41	.645	.0845	1.16	50	73	.06	34.74	.0402	.0340	5.20
4.94	.622	.0842	1.05	31	48	.16	37.26	.0369	.0316	5.29
4.89	.606	.0872	1.00	30	48	.17	38.06	.0360	.0307	5.30
4.92	.614	.0880	1.02	30	49	-.09	37.48	.0366	.0312	5.34
4.88	.611	.0846	1.02	30	48	.26	38.88	.0352	.0303	5.39
4.86	.603	.0857	1.02	30	45	.06	39.18	.0349	.0300	5.37
4.66	.238	.1024	.36	28	67	.09	6.03	.196	.1039	.224
5.30	.287	.1009	.44	19	......	.10	11.42	.1064	.0654	.557
6.00	.310	.0988	.51	40	66	.07	15.10	.0811	.0535	.822
6.93	.364	.0985	.62	40	65	.10	20.64	.0610	.0438	1.42
7.56	.404	.0982	.69	35	67	.10	24.94	.0512	.0388	2.01
8.22	.428	.0966	.74	40	68	.10	29.18	.0442	.0348	2.54
8.70	.454	.0974	.78	41	70	.06	31.20	.0418	.0335	2.98
9.05	.476	.0964	.84	40	67	.05	33.04	.0398	.0324	3.36
9.87	.479	.0980	.88	40	68	.06	34.64	.0380	.0312	3.60
3.65	.170	.1010	.25	21	51	.04	12.02	.0922	.0529	.269
4.37	.218	.1012	.33	19	52	-.01	19.90	.0580	.0388	.645
4.76	.254	.1000	.39	40	54	.05	24.45	.0484	.0345	.991
5.72	.306	.0984	.50	40	47	.01	32.07	.0373	.0290	1.74
6.44	.348	.0980	.57	40	46	.01	35.50	.0351	.0282	2.28
7.15	.372	.0999	.63	40	45	.02	38.57	.0326	.0268	2.77
7.64	.400	.0977	.68	40	47	.03	40.83	.0312	.0261	3.22
8.02	.426	.1002	.73	40	57	.04	42.30	.0305	.0258	3.72

TABLE 3.—*Experimental conditions and results*

TRAPEZOIDAL SHAPE,

Channel	Nominal dimensions: Bottom width, *b*	Nominal dimensions: Side slope, *z*	Experiment number	Condition of lining	Test number	Date of testing	Discharge	Area of section, *A*	Mean velocity, *V*
1	2	3	4	5	6	7	8	9	10
	Feet						*Cu. ft. per sec.*	*Sq. ft.*	*Ft. per sec.*
B2–7	4	1.5:1	1	Green, long	1	July 26, 1938	4.09	2.61	1.63
					1a	July 27, 1938	4.00	2.42	1.69
					2	July 29, 1938	6.87	2.93	2.34
					3	Aug. 1, 1938	9.76	3.60	2.79
					4	Aug. 2, 1938	14.0	4.00	3.50
					5	Aug. 3, 1938	18.8	4.59	4.10
					6	Aug. 4, 1938	23.3	5.14	4.54
					7	Aug. 5, 1938	29.0	5.77	5.03
			2	Dormant, long	1	Mar. 13, 1939	.093	.412	.226
					2	Mar. 14, 1939	.215	.715	.301
					3	Mar. 15, 1939	.356	.982	.363
					4	Mar. 16, 1939	.561	1.30	.432
					5	Mar. 17, 1939	.748	1.41	.530
					6	Mar. 27, 1939	1.04	1.51	.687
					7	.....do......	1.76	1.68	1.05
					8	Mar. 28, 1939	2.69	1.87	1.44
					9	.....do......	4.38	2.16	2.03
			3	Dormant. Long in test 1, short in tests 2–10.	1	Oct. 24, 1939	3.89	2.06	1.88
					2	Oct. 26, 1939	1.05	1.06	.990
					3	Oct. 27, 1939	2.96	1.42	2.08
					4	Oct. 30, 1939	4.92	1.74	2.82
					5	Nov. 1, 1939	9.86	2.38	4.14
					6	Nov. 7, 1939	14.94	3.04	4.94
					7	Nov. 9, 1939	20.63	3.67	5.63
					8	Nov. 10, 1939	25.94	4.27	6.07
					9	Nov. 13, 1939	28.47	4.55	6.26
					10	Nov. 14, 1939	35.42	5.28	6.72
B2–8	1.5	1.5:1	1	Green, long	1	Aug. 9, 1938	3.99	1.72	2.32
					2	Aug. 10, 1938	6.51	2.22	2.93
					3	.....do......	9.91	2.78	3.57
					4	Aug. 11, 1938	13.7	3.32	4.13
					5	Aug. 12, 1938	18.5	3.98	4.65
					6	Aug. 15, 1938	24.2	4.76	5.08
					7	Aug. 17, 1938	30.3	5.64	5.37
			2	Green. Long in test 1, short in tests 2–10.	1	Oct. 5, 1939	3.95	1.60	2.46
					2	Oct. 6, 1939	1.09	.634	1.72
					3	Oct. 7, 1939	2.93	1.03	2.85
					4	Oct. 9, 1939	4.86	1.45	3.35
					5	Oct. 10, 1939	9.85	2.20	4.46
					6	Oct. 11, 1939	15.2	2.94	5.18
					7	Oct. 12, 1939	20.2	3.56	5.68
					8	.....do......	24.6	4.08	6.04
					9	Oct. 20, 1939	29.8	4.73	6.30
					10	.....do......	34.8	5.30	6.57
B2–18	1.5	4:1	1	Green. Short, cut shortly before testing.	1	Sept. 19, 1941	.939	1.42	.660
					2	Sept. 20, 1941	2.98	2.10	1.42
					3	Sept. 23, 1941	4.68	2.54	1.84
					4	Sept. 24, 1941	9.44	3.58	2.64
					5	.....do......	14.39	4.37	3.29
					6	Sept. 26, 1941	19.66	5.21	3.78

TRAPEZOIDAL SHAPE,

Channel	Bottom width, *b*	Side slope, *z*	Experiment number	Condition of lining	Test number	Date of testing	Discharge	Area of section, *A*	Mean velocity, *V*
B2–17	1.5	4:1	1	Partially dormant. Short, kept cut.	1	Nov. 8, 1940	0.980	1.62	0.606
					2	Nov. 12, 1940	2.82	2.64	1.07
					3	.....do......	4.74	3.38	1.40
					4	Nov. 15, 1940	9.92	4.84	2.05
					5	.....do......	14.63	5.95	2.46
					6	Nov. 18, 1940	19.68	6.99	2.82
					7	.....do......	24.67	8.00	3.09
					8	Nov. 22, 1940	30.00	8.83	3.40

for channels lined with Bermuda grass—(Continued)

BED SLOPE 3 PERCENT

Wetted perimeter, P	Hydraulic radius, R	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, n_m	Coefficients: Kutter, n_k	Value of VR
11	12	13	14	15	16	17	18	19	20	21
Feet	*Feet*		*Feet*	*Min.*	°*F.*	*In. per hour*				
5.78	0.435	0.0324	0.60	38	71	−0.23	13.78	0.0943	0.0646	0.709
5.70	.425	.0322	.59	49	75	−.09	14.48	.0892	.0614	.718
6.00	.488	.0319	.68	43	74	.08	18.85	.0700	.0516	1.14
6.41	.546	.0318	.77	65	70	.25	21.28	.0636	.0484	1.52
6.75	.594	.0318	.85	58	70	−.07	25.63	.0536	.0427	2.08
7.14	.644	.0318	.92	41	68	.07	28.97	.0481	.0395	2.64
7.47	.689	.0323	1.02	32	68	−.30	30.77	.0460	.0384	3.13
7.81	.740	.0312	1.10	35	71	−.15	33.48	.0427	.0364	3.72
3.61	.114	.0319	.14	40	56	.01	3.74	.277	.116	.0258
4.06	.176	.0320	.22	44	66	0	4.01	.277	.130	.0530
4.27	.230	.0327	.30	35	52	−.01	4.19	.278	.139	.0835
4.62	.282	.0323	.36	40	56	0	4.52	.266	.141	.122
4.70	.301	.0314	.38	22	51	−.05	5.46	.223	.123	.160
4.75	.318	.0308	.41	40	56	.02	6.93	.177	.102	.218
4.90	.343	.0312	.44	24	57	.04	10.20	.122	.0762	.360
5.08	.368	.0321	.48	26	58	0	13.21	.0952	.0631	.530
5.27	.410	.0329	.53	22	58	.06	17.51	.0731	.0518	.832
5.28	.390	.0337	.52	40	62	.07	16.50	.0768	.0537	.733
4.63	.229	.0322	.31	39	64	.06	11.73	.0991	.0592	.227
4.93	.288	.0328	.38	27	65	.07	21.50	.0562	.0396	.599
5.15	.338	.0332	.46	40	57	.07	26.65	.0465	.0350	.953
5.64	.422	.0352	.56	40	52	.05	34.01	.0378	.0306	1.75
6.17	.493	.0356	.67	40	47	.08	37.35	.0354	.0296	2.44
6.58	.558	.0355	.76	40	51	.09	40.08	.0336	.0289	3.14
6.97	.613	.0354	.86	40	52	.10	41.32	.0332	.0288	3.72
7.19	.634	.0354	.91	40	53	.08	41.94	.0329	.0288	3.97
7.69	.688	.0348	1.01	40	52	.08	43.62	.0322	.0284	4.62
3.03	.438	.0359	.76	35	68	.02	18.59	.0699	.0506	1.02
4.40	.505	.0361	.90	40	70	−.06	21.86	.0608	.0462	1.48
4.90	.568	.0370	1.03	43	70	−.02	24.72	.0548	.0432	2.03
5.29	.628	.0365	1.16	45	72	.07	27.32	.0505	.0410	2.60
5.84	.682	.0354	1.30	49	73	−.01	30.01	.0465	.0387	3.17
6.34	.752	.0352	1.46	52	73	.14	31.64	.0450	.0381	3.82
6.81	.828	.0352	1.60	32	73	.10	31.93	.0453	.0388	4.45
3.84	.418	.0360	.69	40	65	.05	20.36	.0632	.0462	1.03
2.53	.250	.0318	.36	26	65	.10	19.31	.0611	.0412	.430
3.18	.324	.0335	.60	22	66	.10	27.36	.0450	.0339	.924
3.60	.393	.0346	.64	40	66	.04	28.69	.0414	.0346	1.32
4.43	.496	.0340	.82	40	68	.09	34.38	.0385	.0318	2.21
5.04	.583	.0341	1.00	40	68	.16	36.71	.0370	.0314	3.02
5.48	.650	.0344	1.15	40	68	.09	37.98	.0364	.0313	3.69
5.86	.698	.0342	1.26	40	68	.13	39.20	.0357	.0311	4.22
6.29	.752	.0348	1.39	40	58	.09	38.94	.0364	.0319	4.74
6.64	.798	.0348	1.48	40	60	.12	39.47	.0363	.0320	5.24
5.07	.280	.0314	.43	53	70	−.05	7.04	.1710	.0964	.185
5.93	.364	.0310	.54	60	67	.01	13.62	.0918	.0607	.503
6.55	.388	.0312	.63	42	66	.06	16.74	.0760	.0529	.714
7.75	.462	.0315	.76	40	66	0	21.97	.0594	.0447	1.22
8.44	.518	.0312	.86	13	66	.18	25.94	.0514	.0404	1.70
9.34	.558	.0312	.96	17	......	.05	28.67	.0472	.0384	2.11
BED SLOPE 1 PERCENT										
5.38	0.301	0.0098	0.48	60	51	0.01	11.49	0.1082	0.0672	0.182
6.84	.386	.0097	.64	38	51	.02	17.66	.0723	.0508	.413
7.55	.448	.0103	.74	41	53	.04	20.82	.0629	.0466	.627
8.93	.542	.0108	.93	44	47	.04	26.96	.0501	.0398	1.11
9.88	.602	.0111	1.04	46	46	−.03	30.22	.0456	.0373	1.48
10.86	.644	.0101	1.15	47	44	.04	35.28	.0395	.0335	1.82
11.63	.688	.0102	1.25	50	46	−.03	37.06	.0370	.0326	2.13
12.30	.718	.0102	1.31	49	56	.02	40.07	.0353	.0308	2.44

TABLE 3.—*Experimental conditions and results*

RECTANGULAR SHAPE (METAL SIDE

Channel	Nominal dimensions: Bottom width, *b*	Nominal dimensions: Side slope, *z*	Experiment number	Condition of lining	Test number	Date of testing	Discharge	Area of section, *A*	Mean velocity, *V*
1	2	3	4	5	6	7	8	9	10
	Feet						*Cu. ft. per sec.*	*Sq. ft.*	*Ft. per sec.*
B2-19-1	1	0	1	Dormant. Short, kept cut.	1	Dec. 5, 1940	.099	.154	.643
					2	Dec. 6, 1940	.306	.217	1.41
					3	Dec. 9, 1940	.471	.247	1.91
					4	...do......	.694	.286	2.42
					5	Dec. 11, 1940	1.13	.339	3.34
					6	.....do......	1.43	.399	3.58
					7	.. do......	1.66	.432	3.84
					8	Dec. 12, 1940	2.12	.483	4.40
					9	Dec. 17, 1940	2.92	.565	5.17
					10	..do......	4.88	.758	6.45
					11	Dec. 18, 1940	6.37	.905	7.05
					12	.....do......	7.81	1.02	7.68
B2-19-2	2	0	1	Dormant. Short, kept cut.	1	Dec. 6, 1940	.096	.248	.388
					2	Dec. 6, 1940	.301	.339	.896
					4	Dec. 9, 1940	.689	.425	1.62
					6	Dec. 11, 1940	1.44	.572	2.52
					8	Dec. 12, 1940	2.12	.664	3.20
					9	Dec. 17, 1940	2.90	.775	3.74
					10	.....do ...	4.86	1.00	4.84
					11	Dec. 18, 1940	6.45	1.17	5.49
					12	...do ...	7.85	1.30	6.00
					13	Dec. 19, 1940	10.6	1.56	6.82
					14	....do ..	13.4	1.79	7.50
B2-19-3½	3.5	0	1	Dormant. Short, kept cut.	2	Dec. 6, 1940	.300	.528	.568
					4	Dec. 9, 1940	.686	.620	1.09
					6	Dec. 11, 1940	1.44	.810	1.78
					8	Dec. 12, 1940	2.12	.935	2.27
					10	Dec. 17, 1940	4.86	1.33	3.66
					12	Dec. 18, 1940	7.79	1.66	4.69
					14	Dec. 19, 1940	13.45	2.20	6.12
					15	.....do.....	17.10	2.51	6.84
					17	Dec. 20, 1940	21.95	2.99	7.36
					18	.....do ...	24.00	3.21	7.48
B2-19-6	6	0	1	Dormant. Short, kept cut.	2	Dec. 6, 1940	.300	.828	.363
					5	Dec. 11, 1940	1.14	1.14	1.000
					8	Dec. 12, 1940	2.12	1.34	1.59
					10	Dec. 17, 1940	4.84	1.80	2.68
					13	Dec. 19, 1940	10.8	2.54	4.25
					16	Dec. 20, 1940	19.1	3.11	6.15
					17	.....do......	22.0	3.66	6.02
					18	.....do......	23.9	3.86	6.20
TRAPEZOIDAL SHAPE,									
Supply canal, tangent reach	4	1.5:1	4	Green. Short, cut shortly before testing.	1	Aug. 26, 1940	1.18	3.35	0.353
					1a	Sept 30, 1940	1.29	3.48	.372
					2	Aug. 27, 1940	2.75	4.60	.597
					3	...do......	4.72	5.80	.813
					3a	Sept. 30, 1940	4.75	5.83	.814
					4	Aug. 28, 1940	10.1	8.55	1.18
					5	.....do......	14.9	10.7	1.40
					5a	Sept. 30, 1940	15.1	10.8	1.40
					6	Aug. 29, 1940	20.2	13.0	1.55
					7	... do ...	25.1	15.4	1.64
					7a	Sept. 30, 1940	24.7	15.3	1.62
					8	Sept. 3, 1940	30.4	17.7	1.71
					9	...do.....	34.8	20.3	1.71
					9a	Sept. 30, 1940	35.7	21.0	1.70

for channels lined with Bermuda grass—(Continued)

WALLS; BED SLOPE 3 PERCENT

Wetted perimeter, P	Hydraulic radius, R	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, n_m	Coefficients: Kutter, n	Value of VR
11	12	13	14	15	16	17	18	19	20	21
Feet	*Feet*		*Feet*	*Min.*	*°F.*	*In. per hour*				
...	.154	.0297	...	...	41	...	9.52	.114	.0613	0.0090
...	.218	.0301	...	...	41	...	17.40	.0666	.0430	.307
...	.246	.0294	...	...	43	...	22.54	.0524	.0364	.470
...	.287	.0290	...	...	44	...	26.50	.0458	.0337	.694
...	.338	.0278	...	...	44	...	34.52	.0360	.0286	1.13
...	.399	.0278	...	...	44	...	34.01	.0375	.0302	1.43
...	.432	.0279	...	...	44	...	35.04	.0368	.0301	1.66
...	.482	.0278	...	...	45	...	38.14	.0346	.0290	2.12
...	.565	.0276	...	...	46	...	41.58	.0326	.0282	2.92
...	.757	.0267	...	...	47	...	45.76	.0312	.0280	4.88
...	.902	.0264	...	...	44	...	46.54	.0317	.0288	6.36
...	1.016	.0270	...	...	45	...	47.31	.0319	.0294	7.80
...	.126	.0298	...	...	41	...	6.35	.166	.0785	.0490
...	.172	.0302	...	...	41	...	12.43	.0894	.0518	.154
...	.216	.0304	...	...	44	...	20.00	.0579	.0386	.350
...	.290	.0300	...	...	44	...	27.03	.0448	.0332	.731
...	.337	.0298	...	...	45	...	31.98	.0388	.0302	1.08
...	.395	.0298	...	...	46	...	34.46	.0370	.0298	1.48
...	.512	.0303	...	...	47	...	38.80	.0342	.0290	2.48
...	.598	.0304	...	...	44	...	40.76	.0335	.0290	3.28
...	.666	.0309	...	...	45	...	41.88	.0332	.0291	4.00
...	.796	.0310	...	...	44	...	43.62	.0328	.0294	5.43
...	.911	.0307	...	...	44	...	44.84	.0326	.0296	6.83
...	.152	.0298	...	...	41	...	8.45	.129	.0669	.0863
...	.181	.0296	...	...	44	...	14.92	.0752	.0456	.197
...	.232	.0296	...	...	44	...	21.59	.0542	.0371	.413
...	.269	.0295	...	...	45	...	25.56	.0468	.0340	.611
...	.382	.0294	...	...	47	...	34.52	.0366	.0295	1.40
...	.479	.0300	...	...	46	...	39.14	.0336	.0283	2.25
...	.634	.0300	...	...	44	...	44.39	.0310	.0274	3.88
...	.720	.0294	...	...	44	...	47.08	.0299	.0268	4.92
...	.860	.0284	...	...	47	...	47.12	.0308	.0280	6.33
...	.924	.0270	...	...	48	...	47.42	.0310	.0284	6.91
...	.138	.0292	...	...	42	...	5.74	.186	.0880	.0501
...	.184	.0294	...	...	44	...	14.03	.0804	.0482	.184
...	.222	.0293	...	...	45	...	19.74	.0588	.0392	.353
...	.301	.0294	...	...	48	...	28.55	.0428	.0322	.807
...	.424	.0305	...	...	44	...	37.40	.0346	.0285	1.80
...	.519	.0332	...	...	45	...	46.92	.0285	.0250	3.19
...	.610	.0316	...	...	48	...	43.36	.0316	.0277	3.67
...	.643	.0312	...	...	49	...	43.80	.0316	.0278	3.99

BED SLOPE 0.2 PERCENT

11	12	13	14	15	16	17	18	19	20	21
6.16	0.514	0.00188	0.74	...	75	...	11.06	0.1214	0.0837	0.192
6.24	.558	.00174	...	...	...	...	11.83	.1130	.0791	.208
6.93	.664	.00202	.95	...	73	...	16.31	.0851	.0642	.396
7.59	.764	.00208	1.13	...	73	...	20.39	.0697	.0555	.621
7.61	.766	.00192	...	...	...	...	21.23	.0670	.0537	.624
8.97	.953	.00213	1.50	...	75	...	26.19	.0563	.0478	1.12
10.04	1.063	.00199	1.74	...	79	...	30.39	.0494	.0433	1.49
10.04	1.074	.00185	...	...	...	...	31.52	.0477	.0420	1.50
10.91	1.192	.00178	2.00	...	77	...	33.73	.0453	.0408	1.85
11.79	1.302	.00141	2.22	...	75	...	38.15	.0407	.0373	2.14
11.78	1.297	.00144	...	...	...	...	37.43	.0415	.0379	2.10
12.72	1.394	.00127	2.44	...	78	...	40.72	.0386	.0358	2.38
13.56	1.492	.00111	2.66	...	79	...	42.10	.0377	.0354	2.55
13.79	1.624	.00108	...	...	...	...	41.92	.0380	.0358	2.59

TABLE 4.—*Dimensions and vegetal-lining conditions of channels lined with long dormant Bermuda grass from which the data represented by the n-VR curves in figure 13 were obtained*

Channel	Experiment	Nominal dimensions			Vegetation stand count	
		Bed slope	Bottom width	Side slope	Height	Stems per square foot
		Percent	*Feet*		*Inches*	*Number*
B1–1	2	24	1.5	1 :1	12	100
B1–3	2	10	1.5	1.5:1	15	190
B2–7	2	3	4	1.5:1	12	250
	3	3	4	1.5:1	11	250

Some damage to channel, but no drastic change. Grass seemed to have thinned out slightly. About six small holes 2 to 3 inches deep appeared in channel bottom, and there seemed to be some scour over entire channel bottom.

Experiment 2, February 1940, grass dormant and uncut.—Grass probably 15 inches long and as dense as in experiment 1. Soil firm.

Equipment: 2-foot modified Parshall flume, point gages. Discharge was measured indirectly. Procedure same as in experiment 1.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

At start of test, gate between supply canal and test channel was opened too fast and too much. As a result, considerable water was drawn from supply canal storage during first few minutes. Severe scour is believed to have occurred at start of test because of heavy flow overload.

Vegetation was submerged. Flow was extremely rough, and considerable self-aeration took place (fig. 16). According to figure 13 the n value for long dormant Bermuda grass when VR equals 5.84, as in this test, is about 0.036. In this instance the considerably higher n value of 0.051 resulted from increase in bed roughness due to severe scour and actual removal of sod.

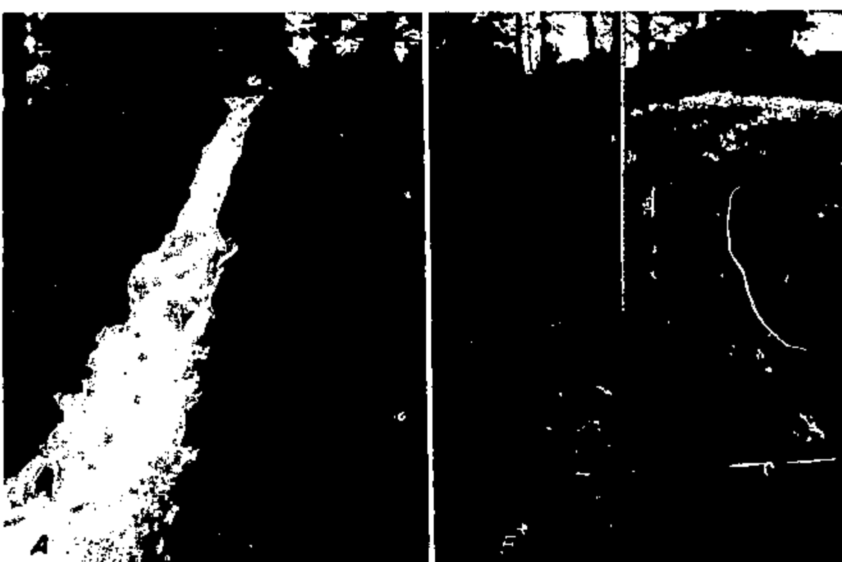

FIGURE 15.—Bermuda grass channel B1–1, experiment 2: *A*, View during test 3; *B*, scoured portion at completion of testing.

Channel definitely failed. Most of sod was torn off lower 20 feet of channel. Sod had failed to root to subsoil, and a plane of weakness may have developed through frost action. However, this channel had withstood higher flows the previous summer without severe damage.

FIGURE 16.—Bermuda grass channel B1-2 during test 1, experiment 2.

CHANNEL B1-6

Bed slope 20 per cent, bottom width 1.5 feet, side slope 4:1, length 50 feet, planted December 1940 by solid sodding. Channel very uniform in slope and cross section.

Experiment 1, September 1941, Grass green and recently cut for first time.—Cutting had left only stiff brown base stalks 3½ inches long. Density 208 stems per square foot (fig. 17). Soil hard.

Equipment 2-foot modified Parshall flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each man making one at each station. There were two 10-foot reaches.

Vegetation was submerged during all tests. Water surface varied from very rough for low flows to extremely rough for high flows. Some aeration during all tests apparently increasing as flow increased. Aeration increased with distance along channel. Values of n in fair agreement with those for other channels having similar linings.

Considerable erosion. In some places, bottom was scoured to a depth of about 2½ inches. Very few plants were torn out, and no large bare spots or holes developed.

CHANNEL B1-3

Bed slope 10 percent, bottom width 1.5 feet, side slope 1.5:1, length 50 feet, planted July 1937 by solid sodding. Channel fairly uniform in slope and cross section. Some irregularities due to variation in thickness of sod used.

Experiment 1, August 1938, grass green and uncut.—Grass, on average, 18 inches long, stems per square foot 340 on sides and 214 on bottom. Soil firm.

Equipment: 2-foot modified Parshall flume, rod and string.

During each test a single observer made water-surface measurements at four stations, progressing downstream. There were three 10-foot reaches.

Vegetation was submerged during all tests. Water surface very rough during every flow. Slight aeration during higher flows. Owing to channel entrance condition, a wave occurred in channel at 5-foot station; this is believed not to have affected results. Values of n in agreement with those for other channels with similar linings.

Some erosion occurred in channel during tests, but no serious damage resulted. Grass was slightly thinned out, a little soil was taken off channel bottom, and two holes about 2 inches deep and 6 inches in diameter appeared.

Experiment 2, February 1939, grass dormant and uncut.—Grass, on average, 15 inches long, stems per square foot 190 on bottom, 155 on sides. Soil firm. Lining thin. Channel in slightly eroded condition as result of previous test. Channel bed contained a few holes about 2 inches deep.

Equipment and observational technique same as in experiment 1 except that there were only two 10-foot reaches and three stations.

Procedure deviated from the ordinary in that five tests about the same as to discharge and duration were conducted, one daily for five consecutive days.

Vegetation was submerged during all tests. Water surface was very rough

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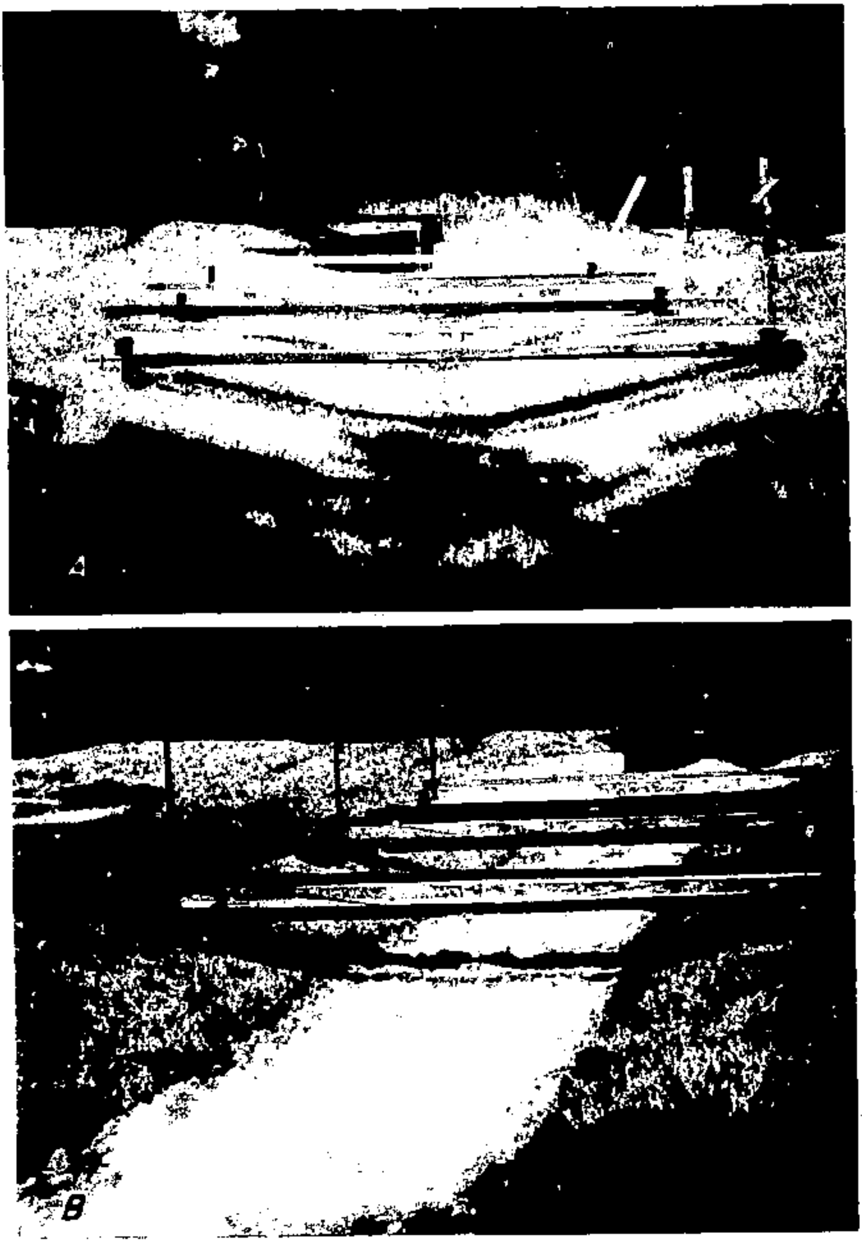

FIGURE 17.—Bermuda grass channel B1-6, experiment 1: *A*, View before testing; *B*, view during test 6.

and some aeration occurred (fig. 18). No apparent increase in bed roughness due to scour. A slight decrease in n from tests 3 to 5 is evident, probably reflecting thinning out of cover. Values of n in agreement with those for other channels with similar linings.

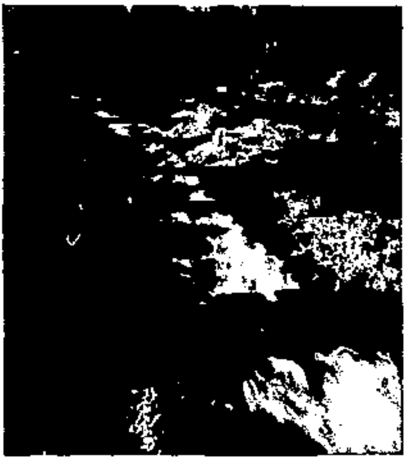

FIGURE 18.—Bermuda grass channel B1-3 during test 1 of experiment 2.

No serious damage to channel. At end of experiment grass seemed to have thinned out considerably, but all parts of channel bed still had cover. Some areas were scoured to a depth of about 1 inch, and there were five holes about 2 inches deep and 6 inches in diameter.

CHANNEL B1-5

Bed slope 10 percent, bottom width 1.5 feet, side slope 4:1, length 50 feet, planted May 1939 by solid sodding. Channel uniform in cross section and slope.

Experiment 1, September 1939, grass green and uncut.—Grass, on average, 14 inches long, 312 stems per square foot (fig. 19). Soil firm.

Equipment: 2-foot modified Parshall flume, point gages.

During each test three men made water-surface measurements simultaneously at three measuring stations, each making two at the same station. There were two 10-foot reaches.

Vegetation was submerged except at edges during all tests. Water surface was rough for lowest flow and increased in roughness until it was extremely rough for highest flow. Some aeration. Values of n in agreement with those for other channels having similar linings.

No damage to channel could be detected by visual inspection (fig. 19, *C*). No grass had been torn out and no holes appeared. Cross-section measurements showed, however, that channel bottom had been eroded evenly about one-half inch.

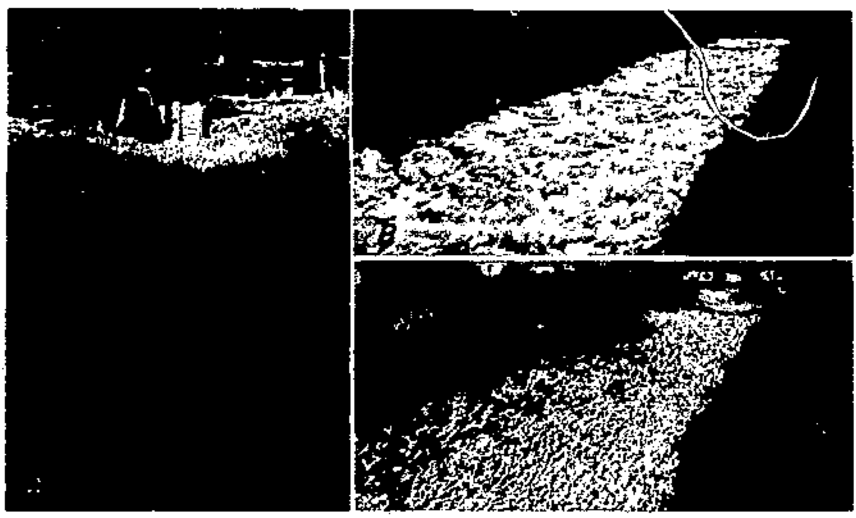

FIGURE 19.—Bermuda grass channel B1-5, experiment 1: *A*, View before testing; *B*, view during test 6; *C*, view at completion of experiment.

Experiment 2, November 1940, grass mostly green, kept cut.—Grass about 2 inches long, density believed to have been about 480 stems per square foot. Soil firm.

Equipment and observational technique same as in experiment 1.

Vegetation was submerged during all tests. Water surface was very rough for lowest flow and increased in roughness until it was extremely rough for highest flow. Some aeration. Values of *n* in fair agreement with those for other channels having similar linings, but generally lower—probably because of unusual shortness of grass.

No apparent damage to channel. Cross-section measurements revealed less than ¼-inch scour.

Channel B2-7

Bed slope 3 percent, bottom width 4 feet, side slope 1.5:1, length 50 feet, planted July 1937 by solid sodding. Channel uniform in slope and cross section. Some roughness in bottom owing to small difference in sod thickness.

Experiment 1, July and August 1938, grass green and uncut.—Grass, on average, 8 inches long, 330 stems per square foot. Soil firm.

Equipment: 2-foot modified Parshall flume, string and rod.

During each test a single observer made water-surface measurements at five stations, progressing downstream. There were four 10-foot reaches.

Vegetation was submerged during all tests. Water surface was slightly rough for lowest flow and became rougher until it was decidedly rough for highest flow. Slight aeration occurred during highest flow. Values of *n* in agreement with those for other channels with similar linings.

Practically no scour occurred. After the higher flows a few thin spots in the grass cover were noticed.

Experiment 2, March 1939, grass dormant and uncut.—Grass, on average, 12 inches long, 350 stems per square foot (fig. 20). Soil firm.

Discharge measured volumetrically for first four tests, with 2-foot modified Parshall flume for remaining tests. Cross sections measured with point gages.

During each test a single observer made water-surface measurements at two stations, progressing downstream. There was one 10-foot reach only.

During tests 1 to 4 the vegetation was not submerged—in fact, it hid the water. During test 5 it was approximately 30 percent submerged. Submergence increased until final test, when flow submerged grass except at edges of channel. Water surface slightly rough.

FIGURE 20.—Bermuda grass channel B2-7 before experiment 2.

In this experiment with shallow flows of low velocity, almost identical *n* values prevailed for the three lowest flows, which coursed through the mass of stems and leaves without causing more than slight bending or movement. The roughness or retarding element remained unchanged. A rapid decrease in *n* occurred as soon as bending and submergence began. Values of *n* for the higher *VR* values are in agreement with those for other channels having similar linings.

No scour occurred.

Experiment 3, October and November 1939, grass dormant, uncut and cut.—Grass was uncut and 11 inches long on average in test 1, was cut to length of 4 inches before other tests (fig. 21). Density, 250 stems per square foot. Soil firm.

Equipment: 2-foot modified Parshall flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Vegetation was submerged during all tests. Water surface was slightly rough during first test and became rougher as flow increased until it was very rough for final test. Slight aeration occurred during tests 8 and 9. Values of *n* in agreement with those for other channels having similar linings.

Slight scour occurred. A few holes appeared in channel bed, of which one was 4 inches in diameter and 3 inches deep. Vegetation appeared rather thin after tests.

CHANNEL B2–8

Bed slope 3 percent, bottom width 1.5 feet, side slope 1.5:1, length 50 feet, planted July 1937 by solid sodding. Channel fairly uniform in slope and cross section. Some roughness in bottom due to small differences in sod thickness. Section 32 to 36 feet from head of channel about 2.5 inches low.

Experiment 1, August 1938, grass green and uncut.—Grass 12 inches long on average, 345 stems per square foot. Soil firm.

Equipment: 2-foot modified Parshall flume, string and rod.

During each test a single observer made water-surface measurements at five stations, progressing downstream. There were four 10-foot reaches.

FIGURE 21.—Bermuda grass channel B2-7 before test 2, experiment 3, when grass had been cut to length of 4 inches.

FIGURE 22.—Bermuda grass channel B2-8 before test 2, experiment 2, when grass had been cut to length of 4 inches.

Vegetation was submerged during all tests. Water surface was slightly rough during test 1 and became rougher as flow increased until it was very rough during final test. Low spot in channel grade at 34-foot station caused a wave and considerable roughness below. Values of *n* in agreement with those for other channels having similar linings.

No measurable scour occurred. Lining appeared thin in a few places, but no holes or bare spots formed during tests.

Experiment 2, October 1939, grass green, uncut and cut.—Grass was uncut and 12 inches long on average in test 1, was cut to length of 4 inches before other tests (fig. 22). After being cut it had the appearance of dormancy. Density, 220 stems per square foot. Soil firm.

Equipment: 2-foot modified Parshall flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Vegetation was submerged during all tests. Water surface was slightly rough during test 1 and became rougher as flow increased until it was very rough during final test. Low spot in channel grade at 34-foot station again caused a wave and additional surface roughness. Values of *n* in fair agreement with those for other channels having similar linings.

Slight scour occurred. Some bare spots formed, but no holes appeared in channel bed.

Channel B2-18

Bed slope 3 percent, bottom width 1.5 feet, side slope 4:1, length 50 feet, planted January 1941 by solid sodding. Channel very uniform in slope and cross section.

Experiment 1, September 1941, grass green and recently cut for first time.—Cutting had left only stiff brown base stalks 4 inches long (fig. 23). Density, 320 stems per square foot. Soil hard.

Equipment: 2-foot modified Parshall flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each man making one at each station. There were two 10-foot reaches.

Figure 23.—Bermuda grass channel B2-18 before experiment 1.

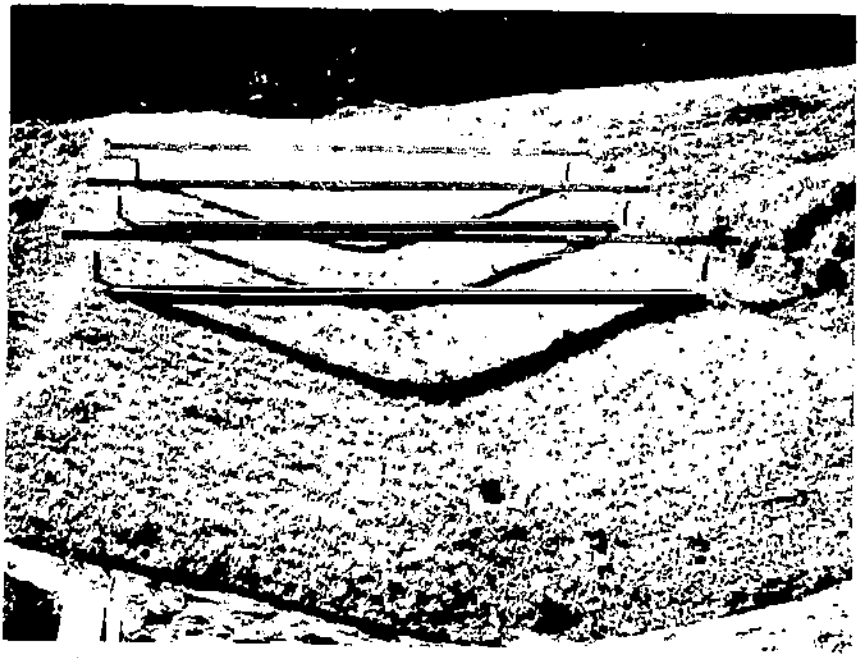

FIGURE 21. Bermuda grass channel B2-47 before experiment 1.

Vegetation was submerged during all tests. Water surface varied from fairly rough for lowest flow to moderately rough for highest. Values of *n* in agreement with those for other channels having similar linings.

Slight scour was indicated by measurements, although it was not apparent on visual inspection.

CHANNEL B2-47

Bed slope 1 percent, bottom width 1.5 feet, side slope 4:1, length 50 feet, planted May 1940 by solid sodding. Channel uniform in slope and cross section, most regular and "smooth" of all those at the laboratory.

Experiment 1, November 1940, grass in fairly dormant, kept cut. Grass about 2 inches high, 180 stems per square foot, appearance that of a grazed pasture (fig. 21). Soil firm.

Equipment: 2-foot modified Parshall flume, point gages.

A tailwater sill was used with all flows (except in test 1, measurement 2), the height of which was 0.12 foot above grade for tests 1-5, 0.50 foot above grade for tests 6-8.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Vegetation was submerged, except at the edges, during all tests. Water surface was fairly smooth (maximum differences in elevation across one section ranged from 0.01 foot for low flows to 0.07 foot for highest flow). A few waves and boils. No aeration. Values of *n* in agreement with those for other channels having similar linings.

No erosion of channel bed could be detected.

CHANNELS B2-49-1, B2-49-2, B2-49-3½, B2-49-6

Bed slope 3 percent, bottom widths 1 foot, 2 feet, 3.5 feet, and 6 feet, respectively (side vertical (sheet metal side walls used)), length 35 feet, planted by heavy sprigging June 1940. Four channels very regular in cross section, bed, and alinement.

Experiment 1, December 1940, grass dormant, kept cut. Estimated average length of grass 2½ inches; estimated density about 400 stems per square foot (fig. 25). Growth of grass had not been affected by metal channel walls, which had been erected about a month before tests. Cover very uniform. Soil firm.

Equipment: 3-foot H-flume (for measuring discharge into channels), 1-foot H-flume (for measuring discharge out of channel in tests 1–4), point gages.

During each test three men made water-surface measurements simultaneously at three stations, each making one. There were two 10-foot reaches.

Vegetation was entirely submerged (fig. 25) except during first two tests on each channel, when submergence was estimated to have been at least 75 percent. Water surface was rough in all cases, and was "frothy" in channel 1 during tests 10–12 and in channel 2 during tests 11–14. Values of n in fair agreement with those for trapezoidal channels having similar linings. For the higher VR values, the agreement is excellent.

Very little scour was apparent on visual inspection. Measurements showed a little erosion.

SUPPLY CANAL, TANGENT REACH

Bed slope 0.2 percent, bottom width 4 feet, side slope 1.5:1, length of reach 99.92 feet, planted in 1937 by sodding. Cross section and slope fairly uniform.

Experiment 4, August and September 1940, grass green, kept cut.—Grass 3½ to 4 inches long, 169 stems per square foot.

Equipment: 2-foot modified Parshall flume, point gages. Water-stage recorders used at ends of reach to check steadiness of flow.

Five repeat tests designated 1a, 3a, etc., made as checks on water-surface slope.

Vegetation on bottom of canal was submerged by all flows. Water surface fairly smooth for all flows (fig. 26). Values of n in agreement with those for other channels having similar linings.

No scour was apparent.

Hydraulic Behavior of Bermuda Grass

Bermuda grass, being very flexible, bends and readily becomes submerged as depth and velocity of flow increase. With cessation of flow the stems reassume their erect position rapidly unless excessive deposition has occurred. Even if covered with a shallow deposit of sediment, Bermuda grass has the capacity to develop rapidly into a satisfactory cover.

These characteristics, prevailing both when the plants are green

Figure 25.—Bermuda grass channels B2–19–2 and B2–19–1 during test 6.

FIGURE 26.—Bermuda grass-lined tangent reach of supply channel as viewed upstream during test 3, experiment 4.

and when they are dormant, together with the density of the cover generally formed and the relative ease and rapidity of cover establishment, make this grass desirable for use in channels. The ready flattening of the stems produces a relatively smooth channel surface (fig. 19, C), if the channel bed itself is not rough, which offers relatively low resistance.

The curves for the n-VR relation for channels lined with short green, short dormant, long green, and long dormant Bermuda grass (figs. 12 and 13) indicate that this relation differs very little according to whether the grass is green or dormant; practically, one curve would suffice for each length.

An increase in bed roughness during the final test on channel B1-4 led to an increase in the retardance coefficient (fig. 13). This result is not uncommon in vegetation-lined earth channels.

Stability of a Channel Lined with Bermuda Grass

LONG GREEN GRASS

A plotting of scour rates against velocities for five channels lined with long green Bermuda grass, presented as figure 27, illustrates the difficulty of estimating permissible velocities from such data alone. Scour rate appears to decrease after long grass is thoroughly flattened. Aside from this, no correlation is apparent between velocity and scour rate.

The reason for this lack of correlation may lie in the method of determining scour rates. As a basis for computing a rate for the entire channel, change in channel bed due to scour or deposition was determined at only a few stations. In addition, it is believed that the apparatus and the observing technique were not very suitable for determining small changes in depth. Study of a large number of the diagrams made shows that scour rates higher than 0.2 inch per hour usually are definite rates increasing with velocity of flow but that lower rates scatter considerably.

Sometimes higher scour rates resulted from low flows than from succeeding high flows. This was probably due to "wash-off" of loose material present on the channel surface when the tests began.

A careful study of the data suggests the following as permissible velocities of flow for channels, similar to those used in the experiments, lined with long green Bermuda grass: Slopes up to and including 10 percent, 8 feet per second; slopes over 10 and up to 20 percent, 7 feet per second. These velocities are recommended only for channels free from sharp irregularities in cross section, alinement, slope, or bed surface and having dense, uniform stands of vegetation.

SHORT GREEN GRASS

Permissible velocities of flow for channels lined with short Bermuda grass differ according to whether the grass has just been mowed after being allowed to grow long or has been kept short by repeated mowing.

Channel B1–5, experiment 2, is an example of a waterway in which the grass has been kept short. It withstood a flow of 8.7 feet per second with practically no erosion. The permissible

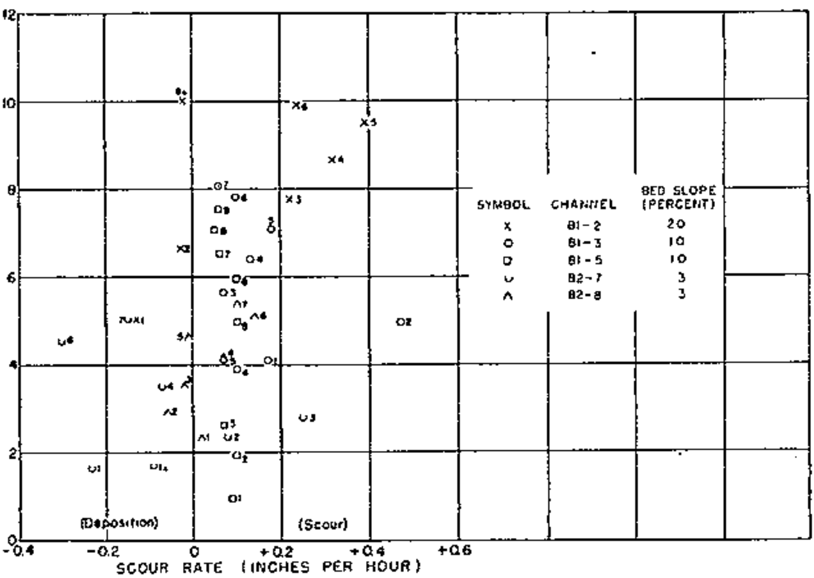

FIGURE 27.—Scour rate in relation to velocity of flow, for channels lined with long green Bermuda grass. Plus quantities indicate scour; minus quantities, deposition. Figures beside symbols are test numbers. On inspection of the channels, these observations were made: B1–2, some scour over entire channel, six small holes 3 inches deep, grass thinned; B1–3, no serious damage, grass thinned, some scour, two small holes 2 inches deep; B1–5, slight uniform scour, no apparent damage; B2–7, practically no scour, grass thinned slightly; B2–8, no scour apparent.

velocity for a channel having a bed slope of 10 percent or less and a well-maintained lining in this state is at least 9 feet per second.

Channel B1–6 was mowed just before being tested. Scour at high rates resulted from velocities between 5 and 6 feet per second. These are rather low velocity figures for this type of cover, but it should be noted that the channel had a slope of 20 percent. Velocity of flow for a smooth, regular channel of this type and steepness having a dense, uniform cover should not exceed 5 feet per second. Channels with less than 10-percent slope having linings of Bermuda grass recently cut for the first time probably can withstand flows of 6.5 feet per second.

LONG DORMANT GRASS

Two of the most complete failures occurred in channels lined with Bermuda grass that was dormant and long. However, these channels were the steepest tested. During experiment 2 on channel B1–1, which had a 23.7-percent slope, a high rate of soil loss was associated with a velocity of only 5.7 feet per second. This channel was somewhat irregular. For a very steep, rough channel lined with long dormant Bermuda grass the velocity of flow should probably be limited to 5 feet per second.

The channel with 20-percent slope, B1–2, failed completely in experiment 2 under a velocity of 9.3 feet per second after only 30 minutes of flow. The lower 20-foot portion of the channel was for the most part washed bare of sod. Examination revealed that the sod had never rooted to the subsoil, although it had been in place 2½ years. The failure in this February test may have been due in part to development of a plane of weakness at the base of the sod layer through frost action.

Channel B1–3, with 10-percent slope, under long dormant Bermuda grass (experiment 2) withstood velocities of more than 8 feet per second without serious damage. Some holes appeared in the channel bottom, but none of these were very large.

Study of the data available suggests that the following velocities of flow are permissible for relatively smooth channels lined with long dormant Bermuda grass in excellent condition: Slopes of 10 percent and less, 8 feet per second; slopes of 10 to 20 percent, 6 feet per second.

SHORT DORMANT GRASS

Channels having dormant Bermuda grass linings that had been kept cut, the B2–19 series, carried flows of velocities as great as 7.6 feet per second with negligible scour. It is believed that for a channel having a good lining of this kind a velocity of 8 feet per second is permissible.

The channel having a lining of dormant stubble, B2–7–3, was subjected to velocities as high as 6.7 feet per second without serious damage. However, study of this channel gave rise to the opinion that 6.0 feet per second is the maximum velocity of flow to which a recently cut dormant Bermuda grass lining should be exposed. This applies to smooth, regular channels having dense, uniform covers and subjected only to flows of relatively short duration.

CENTIPEDE GRASS EXPERIMENTS

Centipede grass forms a heavy sod and is especially adapted to the Gulf Coast Region. It competes successfully with other vegetation, but its spread can be checked by plowing. Therefore it offers promise as a grass to be used for lining channels in localities where farmers object to the vigorous spreading characteristics of Bermuda grass. It is not generally recommended for pastures, but offers promise for use where a turf is desired on droughty soil of low fertility.

One channel was sprigged with centipede grass, and was tested both when the grass was green and when it was dormant.

Experimental conditions and results for the channel lined with centipede grass are presented in table 5, and further information regarding the experiment on this channel is summarized in the following material in small type. The relation between n and VR for long centipede grass is shown in figure 28.

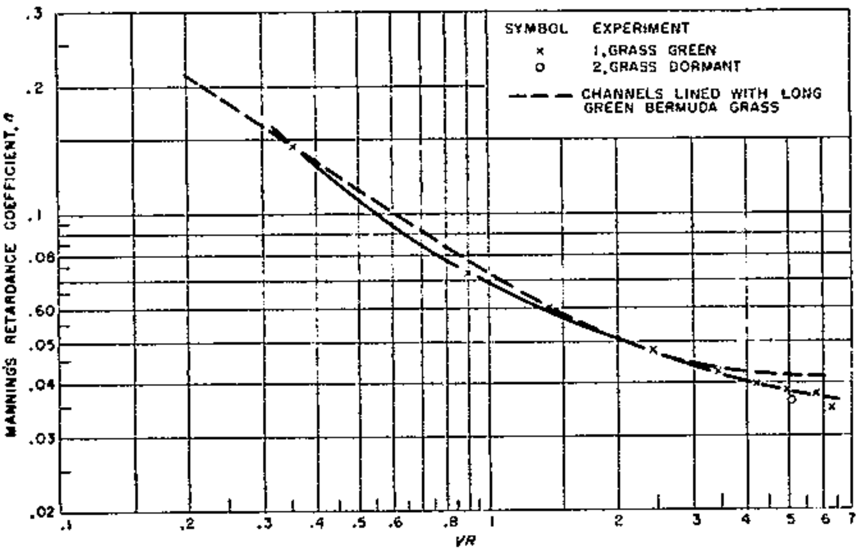

FIGURE 28.—Relation of Manning's n and VR for a channel (B1-4) lined with uncut centipede grass averaging 6 inches in length and 160 stems per square foot, in contrast with that for channels lined with long green Bermuda grass. Nominal dimensions of channel: Bed slope 10 percent, bottom width 1.5 feet, side slope 1.5:1. Vegetation completely submerged by all flows. Value plotted for experiment 2 is average for tests 2 to 5, in all of which discharge was approximately the same.

RECORD OF EXPERIMENTS

CHANNEL B1-4

Bed slope 10 percent, bottom width 1.5 feet, side slope 1.5:1, length 50 feet, planted April 1938 by sprigging. Channel very uniform in cross section, slope, and alinement.

Experiment 1, August 1939, grass green and uncut.—Grass, on average, 6 inches long, 160 stems per square foot (fig. 29). Soil soft.

Equipment: 2-foot modified Parshall flume, point gages.

TABLE 5.—*Experimental conditions and results for channel B1–4, lined with centipede grass*

TRAPEZOIDAL SHAPE, BED SLOPE 10 PERCENT, BOTTOM WIDTH 1.5 FEET, SIDE SLOPE 1.5:1

Experiment number	Condition of lining	Test No.	Date of testing	Discharge	Area of section, A	Mean velocity, V	Wetted perimeter, P	Hydraulic radius, R	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, n_m	Coefficients: Kutter, n	Value of VR
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Cu. ft. per sec.	*Sq. ft.*	*Ft. per sec.*	*Feet*	*Feet*		*Feet*	*Min.*	*°F.*	*In. per hour*				
1	Green, long	1	Aug. 25, 1939	1.04	0.776	1.34	2.96	0.263	0.0992	0.40	33	71	−0.01	8.26	0.144	0.0826	0.352
		2	Aug. 26, 1939	2.92	.993	2.94	3.28	.303	.1005	.47	56	70	.01	16.88	.0721	.0486	.891
		3	Aug. 28, 1939	4.94	1.26	3.92	3.56	.354	.1006	.54	60	69	−.01	20.82	.0600	.0432	1.39
		4	Aug. 29, 1939	9.96	1.78	5.60	4.12	.432	.0984	.66	40	70	.02	27.21	.0476	.0370	2.42
		5	do	15.2	2.20	6.92	4.48	.492	.1001	.76	40	72	0	31.33	.0423	.0342	3.40
		6	Aug. 30, 1939	20.5	2.67	7.67	4.88	.548	.0945	.89	40	72	.11	33.75	.0399	.0331	4.20
		7	Aug. 31, 1939	25.2	3.04	8.28	5.08	.599	.0902	.98	40	73	−.09	35.66	.0384	.0324	4.96
		8	Sept. 5, 1939	30.8	3.48	8.85	5.32	.654	.0884	1.08	40	74	.06	36.92	.0378	.0322	5.70
		9	Sept. 7, 1939	35.2	3.71	9.50	5.59	.664	.0862	1.12	40	74	.01	39.71	.0350	.0304	6.31
2	Dormant, long	1	Feb. 12, 1940	26.8	3.16	8.50	5.20	.608	.0924	1.00	30	50	−.04	35.88	.0382	.0323	5.17
		2	Feb. 13, 1940	26.5	3.02	8.78	5.10	.592	.0899	.96	30	52	.09	38.09	.0358	.0306	5.20
		3	Feb. 14, 1940	25.3	2.97	8.54	5.10	.582	.0919	.94	31	48	−.03	36.95	.0368	.0312	4.97
		4	Feb. 15, 1940	25.4	2.93	8.66	5.05	.580	.0928	.94	32	44	0	37.36	.0363	.0308	5.02
		5	Feb. 16, 1940	25.4	2.91	8.74	5.02	.580	.0932	.92	30	46	.03	37.60	.0362	.0307	5.07

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Vegetation was submerged during all tests. Grass stems flattened and shingled readily (fig. 30, *A*). Water surface was rough for first test and

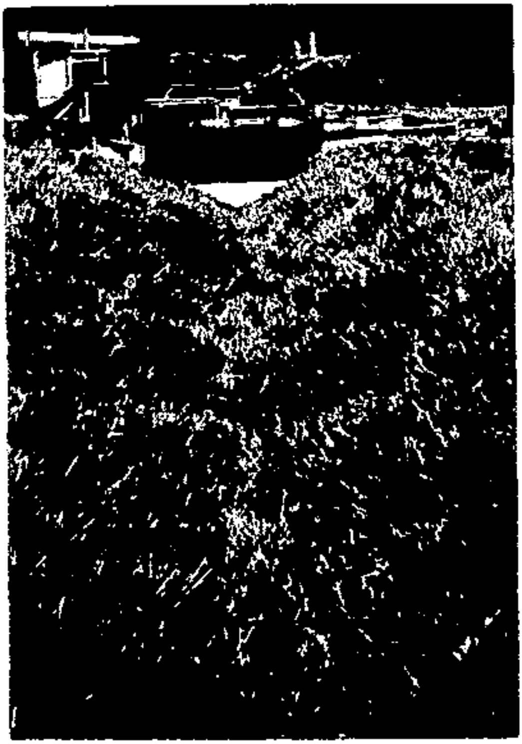

FIGURE 29.—Centipede grass channel B1–4 before experiment 1.

became rougher as flow increased (fig. 30, *B*) until it was extremely rough for final test. Some aeration along channel edges. Values of *n* approximate those for long green Bermuda grass.

Practically no erosion occurred. A few small spots were eroded along left edge of channel bottom. Vegetation remained intact.

Experiment 2, February 1940, grass dormant and uncut.—Grass, on average, 6 inches long, 160 stems per square foot. Soil soft.

Equipment and observational technique same as in experiment 1. Experiment deviated from the ordinary in that five tests of about the same discharge and duration were conducted, one daily for five consecutive days.

Vegetation was submerged during all tests. Water surface very rough. Self-aeration occurred. Value of *n* practically constant for all five tests and almost identical with that for long dormant Bermuda grass at the same *VR* value.

After the tests the channel was still in very good condition. There were about six bare spots along the left edge, averaging 4 inches in diameter and having a maximum depth of one-half inch. In seven places the lining seemed to have thinned out. At the end of the channel the grass had a frayed

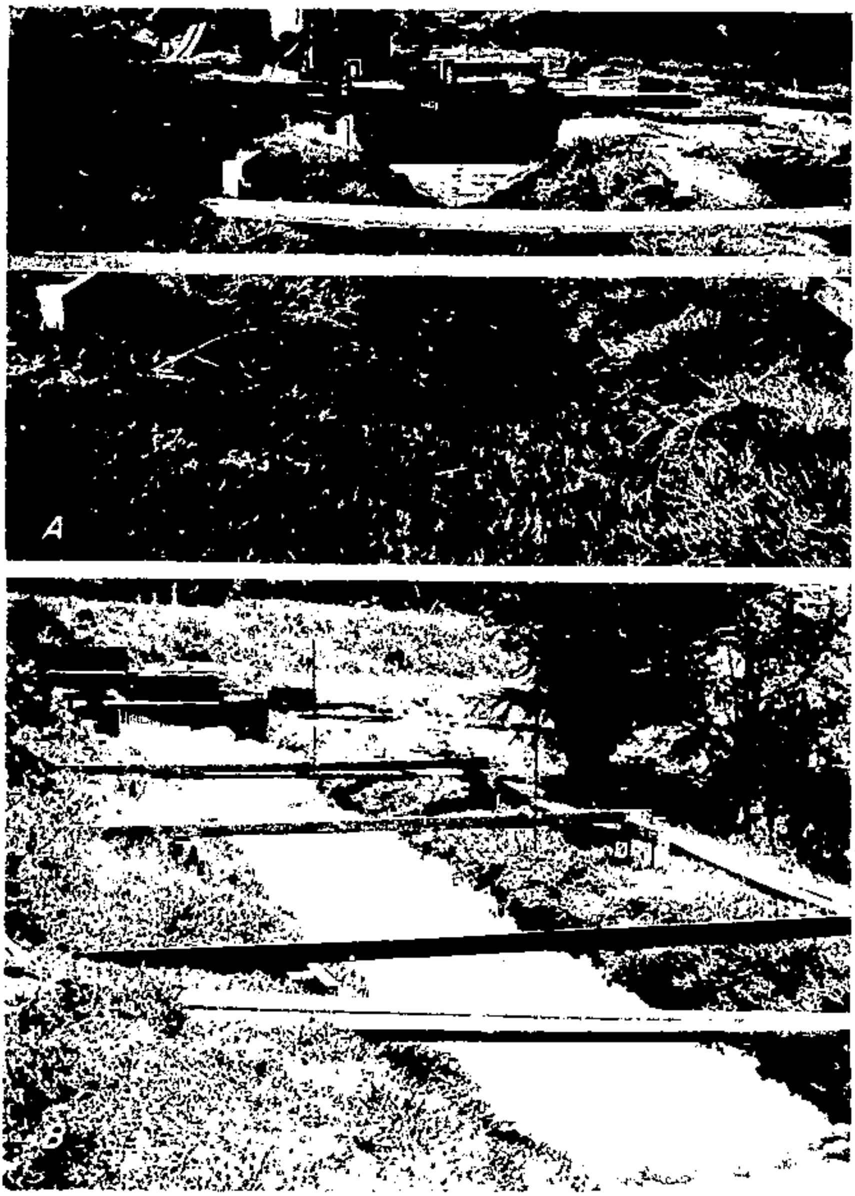

FIGURE 30. Centipede grass channel B1-1, experiment 1: *A*, View after test 5; *B*, view during test 8.

appearance (fig. 31). In the spring it was discovered that about 70 percent of the grass had been killed. It is not known whether this was due to the exceptionally cold weather of the 1939-40 winter or to the February tests or to both.

FIGURE 31.—Centipede grass channel B1-4 at completion of experiment 2.

HYDRAULIC BEHAVIOR OF CENTIPEDE GRASS

Centipede grass resembles Bermuda grass in the physical properties having an important bearing on hydraulic behavior; it forms a dense sod and a uniform cover, and the short uncut vegetation readily flattens to the channel surface under flow and quickly straightens up again when flow ceases. According to the *n-VR* curves (fig. 28) the two grasses have a similar retarding influence on flow of water. Until more data are available, those obtained in this study for Bermuda grass may be used as a guide in estimating *n* for centipede grass.

STABILITY OF A CHANNEL LINED WITH CENTIPEDE GRASS

Centipede grass appears to be a channel lining capable of "taking considerable punishment" from flowing water and continuing to afford protection. The denseness of the sod and the resilient character of the stems result in high protective capacity.

Because of its short growth, centipede grass is unlikely to be mowed.

It appears that an uncut green stand of centipede grass is capable of taking a velocity of 9 feet per second and that the same stand when dormant can take a velocity of 8 feet per second. These estimates apply only to excellent stands in uniform channels, having slopes not greater than 10 percent, that are subjected to flows of short duration.

DALLIS GRASS-CRABGRASS EXPERIMENT

Dallis grass is a long-lived perennial now gaining increasing favor as a forage plant for both meadow and pasture. It has a strong root system, and its branches grow 2 to 4 feet high. If its seed is added to those of other grasses planted in a channel, the resulting cover affords better protection against erosion. Dallis grass occurs abundantly from North Carolina to Florida and west to Arkansas and Texas. It is one of the best winter-pasture grasses for heavy, moist black soils, because it remains green all winter where severe frosts do not occur.

One experimental channel was seeded with Dallis grass. Only a partial stand was obtained, and a considerable quantity of crabgrass volunteered. It was realized that the same thing was likely to occur in field channels, therefore the experiment was continued.

Experimental conditions and results for the channel lined with Dallis grass and crabgrass are presented in table 6 and further information regarding the experiment on this channel is summarized in the following material in small type. The relation between n and VR for channels lined with long green grass of these two species is shown in figure 32.

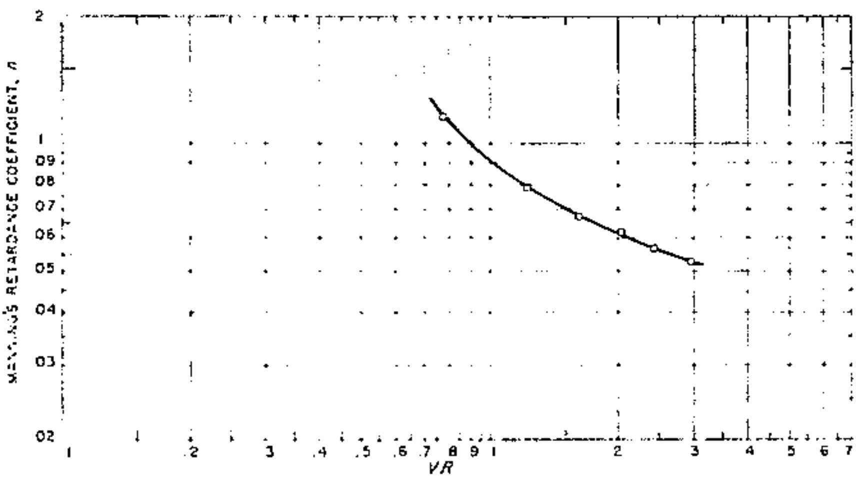

FIGURE 32.—Relation of Manning's n and VR for a channel (B2-6) lined with uncut green Dallis grass and crabgrass averaging 30 inches in length and 75 stems per square foot. Nominal dimensions of channel: Bed slope 6 percent, bottom width 2 feet, side slope 3:1. Vegetation was completely submerged by all flows.

RECORD OF EXPERIMENT

CHANNEL B2-6

Bed slope 6 percent, bottom width 2 feet, side slope 3:1, length 50 feet. Dallis grass planted by seeding in March 1938, reseeded in May 1938 and twice in June 1938. Stand 20 percent Dallis grass, 80 percent crabgrass. Channel fairly uniform in slope and alinement. The left side was a little low, and a wooden wall had to be erected along this side to contain the flow for tests 5 and 6.

TABLE 6.—*Experimental conditions and results for channel B2–6, lined with long green Dallis grass and crabgrass*

TRAPEZOIDAL SHAPE, BED SLOPE 6 PERCENT, BOTTOM WIDTH 2 FEET, SIDE SLOPE 3:1

Test No.	Date of testing	Discharge	Area of section, A	Mean velocity, V	Wetted perimeter, P	Hydraulic radius, R	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, nm	Coefficients: Kutter, nk	Value of VR
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Cu. ft. per sec.	*Sq. ft.*	*Ft. per sec.*	*Feet*	*Feet*		*Feet*	*Min.*	*° F.*	*In. per hour*				
1	Oct. 14, 1938	5.54	3.09	1.79	7.14	0.434	0.0592	0.66	60	65	0.09	11.14	0.116	0.0767	0.777
2	do	9.00	3.31	2.73	7.37	.448	.0599	.71	35	66	−.19	16.66	.0782	.0556	1.22
3	Oct. 15, 1938	12.7	3.82	3.33	7.87	.485	.0596	.77	53	71	.20	19.59	.0673	.0498	1.62
4	Oct. 17, 1938	16.8	4.36	3.86	8.32	.525	.0592	.81	48	74	.11	21.02	.0617	.0466	2.03
5	Oct. 18, 1938	21.5	5.04	4.27	8.87	.569	.0567	.90	44	76	.33	23.44	.0567	.0447	2.43
6	Oct. 19, 1938	26.9	5.51	4.89	9.15	.603	.0590	1.01	44	72	.52	25.93	.0527	.0423	2.95

FIGURE [illegible]. — Dallis grass [illegible] during test 2 and (B) [illegible]

Experiment 1, October 1938, grass green and uncut.—Grass length averaged 30 inches, varying from 10 to 48 inches. Density averaged 75 stems per square foot. Soil firm to loose (at sides).

Equipment: Sharp-crested weir, string and rod.

During each test a single observer made water-surface measurements at four stations, progressing downstream. There were three 10-foot reaches.

Vegetation was submerged and water surface was rough during all tests. Plot of *n-VR* relation (fig. 32) approximately parallels that of long green Bermuda grass, but at a higher level.

Although the long grass tended to hide the scoured areas by shingling over them (fig. 33), numerous holes and rills ranging in depth from 3 to 5 inches were found. Little damage was observed until the fifth test.

Hydraulic Behavior of Dallis Grass and Crabgrass

Both Dallis grass and crabgrass are flexible, bending and flattening readily when subjected to water flow. The flow-retarding influence of the long green lining tested was relatively high—higher than that of a long Bermuda grass lining in a similar channel, although the Bermuda grass lining was much more dense. Probably the high retarding influence of the Dallis grass and crabgrass was due in considerable degree to greater length of stems. The high retardance coefficients were due in part to roughness of the channel bottom resulting from the erosion that took place during the later tests.

Stability of a Channel Lined with Dallis Grass and Crabgrass

In comparison with other linings, the Dallis grass and crabgrass afforded rather poor protection to the channel. They permitted severe scour to occur at a flow velocity of 4.3 feet per second. The tests indicate that for a channel lined with a fair stand of long grass of these species a flow velocity of approximately 3½ feet per second is permissible.

KUDZU EXPERIMENTS

Kudzu is a deep-rooted, vigorous perennial leguminous plant, introduced from the Orient, that provides a dense cover of vines and broad-leafed foliage during the growing season. It drops its leaves after the first killing frost in the fall. The fallen leaves, together with the vines, form a heavy layer of absorptive organic material that reduces runoff and erosion during the winter. The vines grow very rapidly during the spring and summer. Kudzu makes hay of excellent quality, with a feeding value as high as that of alfalfa, and can be depended upon to yield fairly well each year, since it is not seriously affected by seasonal droughts (*1*). It has been used successfully in large natural waterways of slight slope where moderate reduction in cross section of waterway is not objectionable.

Kudzu has been grown successfully on most of the soils found in the Southeast, but is not well adapted to areas having poor drainage. It has a wide climatic range, extending from Florida to Maryland, but is best adapted to the middle and lower South, where the growing season is long and annual rainfall relatively high. It would be of little value where winter weather is severe enough to kill all vines back to the original crowns each year.

An experimental channel lined with kudzu was subjected to five series of tests, at times when the kudzu was in various conditions.

Gullies are sometimes controlled in the Southeast by planting kudzu along the edges and, after the vegetation becomes established, plowing in the banks. Often, satisfactory waterways are thus developed. The plowing is usually done in the spring when the new growth is just starting. It reduces the steepness of the sides, and fills the bottom of the gully with soil and kudzu plants with the result that the latter become established in the bottom and help to stabilize the gully. Plowing is repeated for several years until a wide and shallow cross section is achieved.

In an attempt to evaluate the effects of this practice on the stability of the waterway, the sides of the experimental kudzu channel were plowed in on April 1, 1941, when the new growth was just beginning to bud. This operation changed the side slopes of the channel from 1.5:1 to approximately 2:1 and the bottom to a parabolic section. After the plowing, the channel was rolled. At this time the waterway was bare of cover except for a few scattered, torn-up vines and roots.

Experimental conditions and results for the channel lined with kudzu are presented in table 7, and further information regarding the experiments on this channel is summarized in the following material in small type. The variation of Manning's n with hydraulic radius for the channel lined with kudzu is shown in figure 34, and the relation of Manning's n and VR for this channel is shown in figure 35.

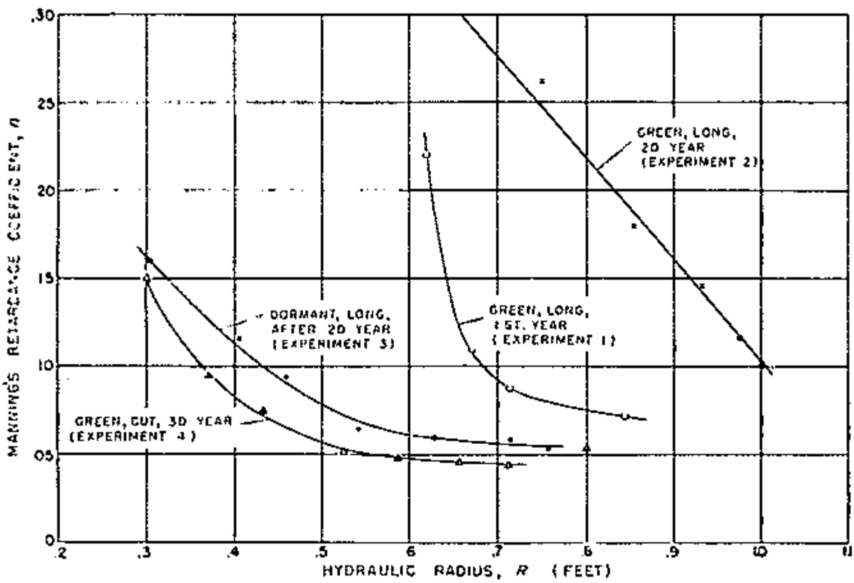

FIGURE 34.—Variation of Manning's n with hydraulic radius for a channel (B2-9) lined with kudzu when the lining was in four different conditions. Nominal dimensions of channel: Bed slope 3 percent, bottom width 4 feet, side slope 1.5:1.

TABLE 7.—*Experimental conditions and results for channel B2–9, lined with kudzu*

TRAPEZOIDAL SHAPE, BED SLOPE 3 PERCENT, BOTTOM WIDTH 4 FEET, SIDE SLOPE 1.5:1

Nominal dimensions: Bottom width, *b*	Nominal dimensions: Side slope, *z*	Experiment number	Condition of lining	Test No.	Date of testing	Discharge	Area of section, *A*	Mean velocity, *V*	Wetted perimeter, *P*	Hydraulic radius, *R*	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, *C*	Coefficients: Manning, *n*	Coefficients: Kutter, *n*	Value of *VR*
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
						Cu. ft. per sec.	*Sq. ft.*	*Ft. per sec.*	*Feet*	*Feet*		*Feet*	*Min.*	*°F.*	*In. per hour*				
4	1.5:1	1	Green. Long,	1	Nov. 4, 1938	4.19	4.52	0.925	7.30	0.620	0.0348	0.86	70	61	0.13	6.31	0.219	0.145	0.574
			first-season	2	Nov. 8, 1938	9.48	5.12	1.85	7.63	.671	.0318	.95	100	61	.04	12.79	.1098	.0801	1.24
			growth.	3	Nov. 9, 1938	13.7	5.63	2.43	7.89	.714	.0314	1.05	70	54	.03	16.38	.0864	.0659	1.74
				4	Nov. 10, 1938	19.5	6.73	2.90	8.39	.803	.0313	1.17	90	52	.05	18.56	.0783	.0618	2.33
				5	...do.....	24.4	7.36	3.32	8.72	.845	.0322	1.26	75	51	.01	20.34	.0716	.0578	2.80
4	1.5:1	2	Green. Long,	1	Aug. 2, 1939	2.24	4.09	.548	7.04	.581	.0323	.82	60	74	.03	4.01	.340	.211	.318
			second-	2	Aug. 3, 1939	5.16	6.06	.852	8.10	.750	.0331	1.08	60	72	.04	5.42	.262	.178	.639
			season	3	Aug. 4, 1939	10.2	7.40	1.38	8.68	.854	.0346	1.25	60	72	.03	8.06	.180	.131	1.18
			growth.	4	Aug. 5, 1939	15.6	8.58	1.82	9.22	.932	.0354	1.40	60	73	.03	10.06	.146	.111	1.70
				5	Aug. 7, 1939	21.1	9.28	2.28	9.51	.976	.0326	1.50	60	70	.03	12.81	.116	.0904	2.22
				6	Aug. 8, 1939	27.2	9.80	2.78	9.78	1.001	.0362	1.58	65	71	...	14.78	.1019	.0812	2.78
4	1.5:1	3	Dormant.	1	Feb. 19, 1940	1.17	1.64	.716	5.39	.304	.0290	.40	40	44	.01	7.69	.159	.0923	.218
			Heavy	2	Feb. 20, 1940	2.98	2.38	1.25	5.87	.406	.0317	.55	39	47	.08	11.08	.116	.0756	.508
			mulch of	3	...do.....	4.92	2.86	1.72	6.24	.459	.0330	.63	40	47	.18	14.00	.0934	.0648	.789
			vines	4	Feb. 21, 1940	10.20	3.62	2.82	6.67	.543	.0327	.78	40	46	.08	21.21	.0634	.0484	1.53
			and	5	...do.....	15.18	4.53	3.35	7.21	.628	.0337	.94	41	46	.12	23.10	.0596	.0470	2.10
			leaves.	6	Feb. 23, 1940	20.34	5.47	3.72	7.68	.713	.0336	1.05	41	44	.22	24.10	.0583	.0472	2.65
				7	...do.....	25.19	6.02	4.18	7.95	.757	.0319	1.18	41	44	.22	26.92	.0529	.0437	3.16
4	1.5:1	4	Green. Short,	1	Aug. 26, 1940	1.20	1.51	.793	5.04	.300	.0314	.40	77	75	.01	8.21	.150	.0878	.238
			cut just	2	Aug. 27, 1940	2.74	2.04	1.34	5.52	.370	.0271	.56	43	73	.09	13.43	.0943	.0626	.496
			before	3	...do.....	4.74	2.52	1.88	5.82	.433	.0267	.67	42	73	.06	17.52	.0745	.0532	.814
			testing.	4	Aug. 28, 1940	10.02	3.30	3.04	6.27	.526	.0262	.78	41	75	.10	26.02	.0514	.0405	1.60
				5	...do.....	14.98	4.01	3.74	6.83	.589	.0294	.88	40	79	.11	28.46	.0481	.0390	2.20
				6	Aug. 29, 1940	20.20	4.72	4.28	7.19	.657	.0305	.97	40	77	.12	30.34	.0459	.0381	2.81
				7	...do.....	25.03	5.35	4.67	7.52	.712	.0306	1.07	40	75	.15	31.66	.0446	.0376	3.32

Changed by plowing . . .	5	Dead vines. "a" test; green, uncut, "b," "c," and "d" tests.	8	Sept. 3, 1940	30.85	6.24	4.95	7.80	.800	.0424	1.26	40	78	.32	26.84	.0534	.0445	3.96
			1a	Apr. 18, 1941	.951	.378	2.52	2.64	.143	.0320	.14	41	63	1.73	37.79	.0286	.0214	.360
			1b	May 15, 1941	.962	.556	1.73	3.13	.178	.0285	.24	40	65	85	24.46	.0474	.0321	.308
			2b	. . .do	2.60	1.12	2.33	4.00	.280	.0293	.39	41	65	1.26	25.98	.0448	.0330	.652
			1c	June 2, 1941	.866	.978	.886	3.57	.274	.0242	.46	41	72	—.04	10.85	.110	.0672	.243
			2c	. do.	2.65	1.90	1.40	5.15	.370	.0246	.70	40	69	—.04	14.66	.0863	.0582	.518
			3c	.do.	4.60	2.08	1.72	6.12	.438	.0252	.85	40	69	.05	16.41	.0792	.0562	.753
			4c	June 3, 1941	9.30	3.88	2.40	7.26	.535	.0254	1.00	40	71	.14	20.60	.0652	.0494	1.28
			1d	June 23, 1941	1.00	1.50	.666	4.57	.826	.0247	.58	39	69	—.08	7.42	.166	.0977	.218
			4d	do.	9.31	4.56	2.04	7.75	.589	.0269	1.12	39	70	.10	16.32	.0834	.0618	1.20
			5d	June 24, 1941	14.08	5.38	2.62	8.40	.640	.0290	1.21	40	70	0	19.34	.0714	.0550	1.68
			6d	. . .do.	19.52	6.40	3.05	8.99	.711	.0294	1.34	40	72	—.11	21.14	.0666	.0527	2.17
			7d	. . . .do.	23.40	7.08	3.31	9.53	.744	.0291	1.43	40	73	.07	22.62	.0626	.0505	2.46

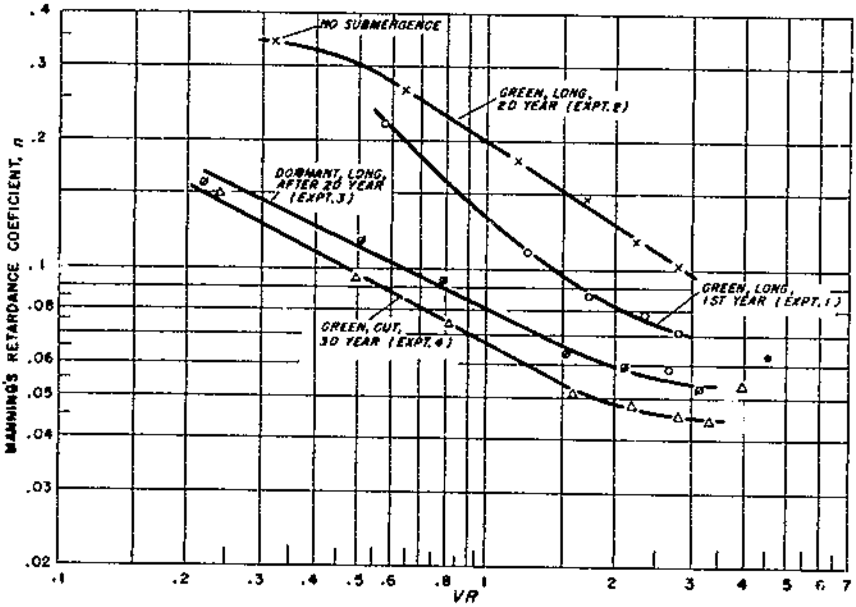

FIGURE 35.—Relation of Manning's n and VR for a channel (B2–9) lined with kudzu when the lining was in four different conditions. Nominal dimensions of channel: Bed slope 3 percent, bottom width 4 feet, side slope 1.5:1.

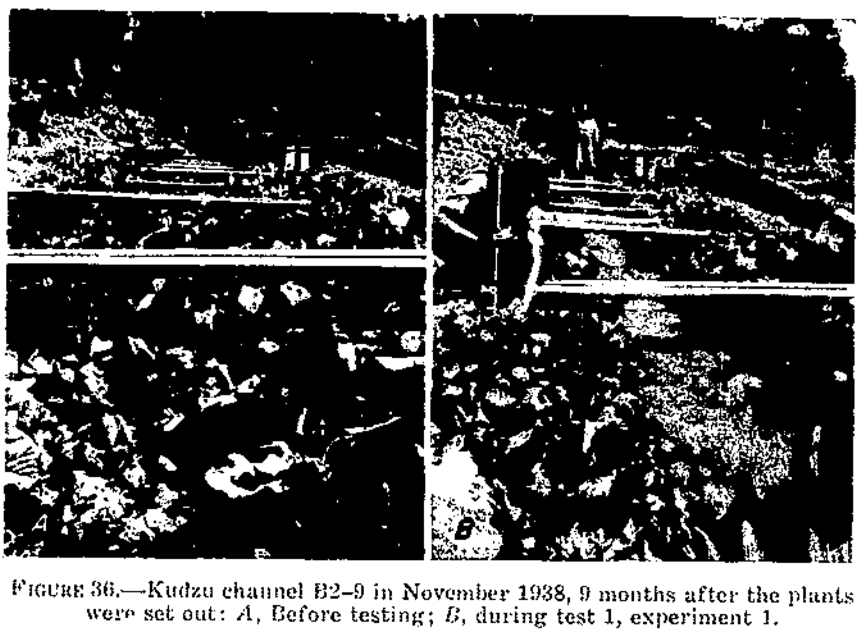

FIGURE 36.—Kudzu channel B2–9 in November 1938, 9 months after the plants were set out: *A*, Before testing; *B*, during test 1, experiment 1.

RECORD OF EXPERIMENTS

CHANNEL B2–9

Bed slope 3 percent, bottom width 4 feet, side slope 1.5:1, length 50 feet, planted February 1938 by setting plants. Channel fairly uniform in cross section, slope, and alinement.

Experiment 1, November 1938, kudzu green and uncut.—The mass of vegetation filled the channel (fig. 36, *A*). The usual stand count could not be made. It was observed that, on an average, 10 vines crossed 1 square foot of channel, and that five nodes per square foot had rooted to the channel surface. Soil firm.

Equipment: 2-foot modified Parshall flume, string and rod.

During each test a single observer made water-surface measurements at five stations, progressing downstream. There were four 10-foot reaches.

Vegetation was submerged in central portion of channel in all tests, but upright vines and leaves filled considerable portions of the cross section of the flow (fig. 36, *B*). Water surface was fairly rough for first test and became rougher until during last test it was very rough, with some rather large waves. Curve of n–VR relation approximately paralleled that for long green Bermuda grass, but at a much higher level. At completion of experiment, n was still decreasing as depth and velocity of flow increased.

Slight erosion occurred, but channel remained in very good condition. Rates of erosion were higher for first two tests than for later tests with higher flows, probably because of initial washing out of loose material.

Experiment 2, August 1939, kudzu green and uncut.—Channel was filled with a very dense growth of kudzu (fig. 37, *A*). Soil firm.

Equipment same as in experiment 1.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Vegetation remained erect during first test, completely hiding the water surface. That in center of channel was submerged in second test. More of the kudzu was submerged by succeeding flows, but in large corner areas the vegetation still extended above the water surface. In test 1 the water surface was fairly smooth except for small ripples, in later tests it was rough. Values of n were at a considerably higher level than in experiment 1, owing to increased density of cover.

The vines and leaves were pushed to the edges of the channel or broken down in its center. There was but little scour of the channel bottom (fig. 37, *B*).

Experiment 3, February 1940, kudzu dormant.—Channel was covered by a heavy mulch of vines and leaves (fig. 38). Soil firm, unfrozen.

Equipment: 2-foot modified Parshall flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Flow was very rough and very irregular in all tests (fig. 38). Vegetation tended to pile up in clumps and cause a very irregular flow pattern. Flow during test 6 was characterized by standing waves approximately 5½ inches high from trough to crest at stations 12, 18.5, 23.5, 30.5, 37.0, 44.0, and 50.5 feet from head of channel. During test 7, waves were not so high or so well defined. Floating vegetation blocked out a considerable part of the water cross section along channel sides. Curve of n–VR relation considerably lower than that for long, green kudzu.

During early tests much of the loose mulch was washed off channel bottom and there was some scour in upper part of channel and some deposition in lower part along edges of flow. The higher flows produced some erosion and left no deposition. No severe failure occurred, but channel bottom was left in poor condition.

Experiment 4, August and September 1940, kudzu green and cut.—Cutting of what appeared to be very dense growth revealed that there were very few plants growing on bottom but a good growth on sides of channel. A mass of cut leaves and vines lay on bottom and sides of channel (fig. 39, *A*). Previous

FIGURE 37.—Kudzu channel B2-9 in August 1939: A, View during test 1 of [illegible] 2, [illegible] water-surface measurements; B, [illegible] 2.

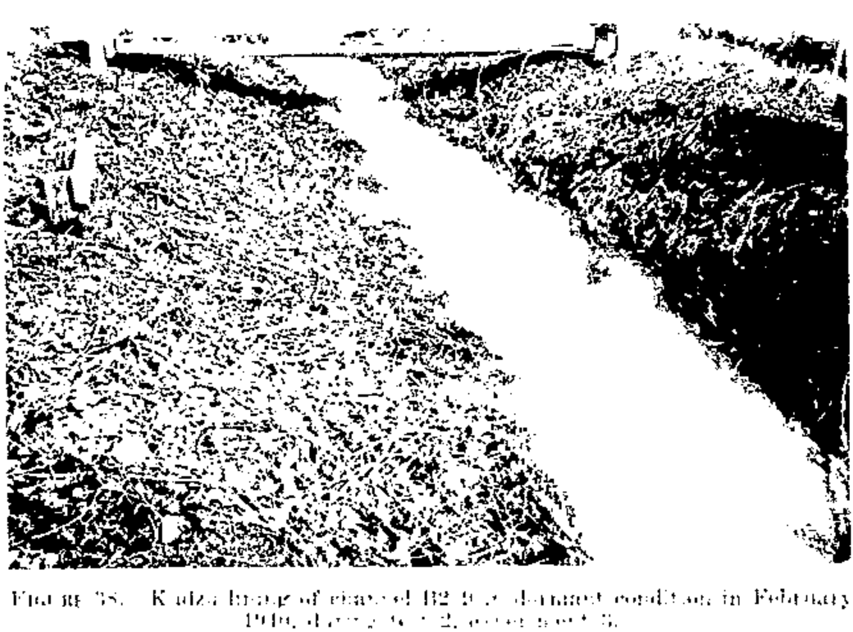

FIGURE 38.—Kudzu lining of channel B2-9 in dormant condition in February 1940, during test 2, [illegible].

tests had left channel a little irregular in cross section. Soil firm. Tests were made immediately after cutting.

Equipment and observation procedure same as in experiment 3.

Vegetation was submerged except at edges of channel (fig. 39, *B*). Water surface rough for all tests. During lower flows, flow pattern very irregular; water seemed to wind its way between clumps of vegetation. Higher flows more uniform.

Vegetation was washed off channel bottom, leaving it nearly bare (fig. 39, *C* and *D*). Slight scour occurred over most of channel, and in a few places there was erosion of greater depth.

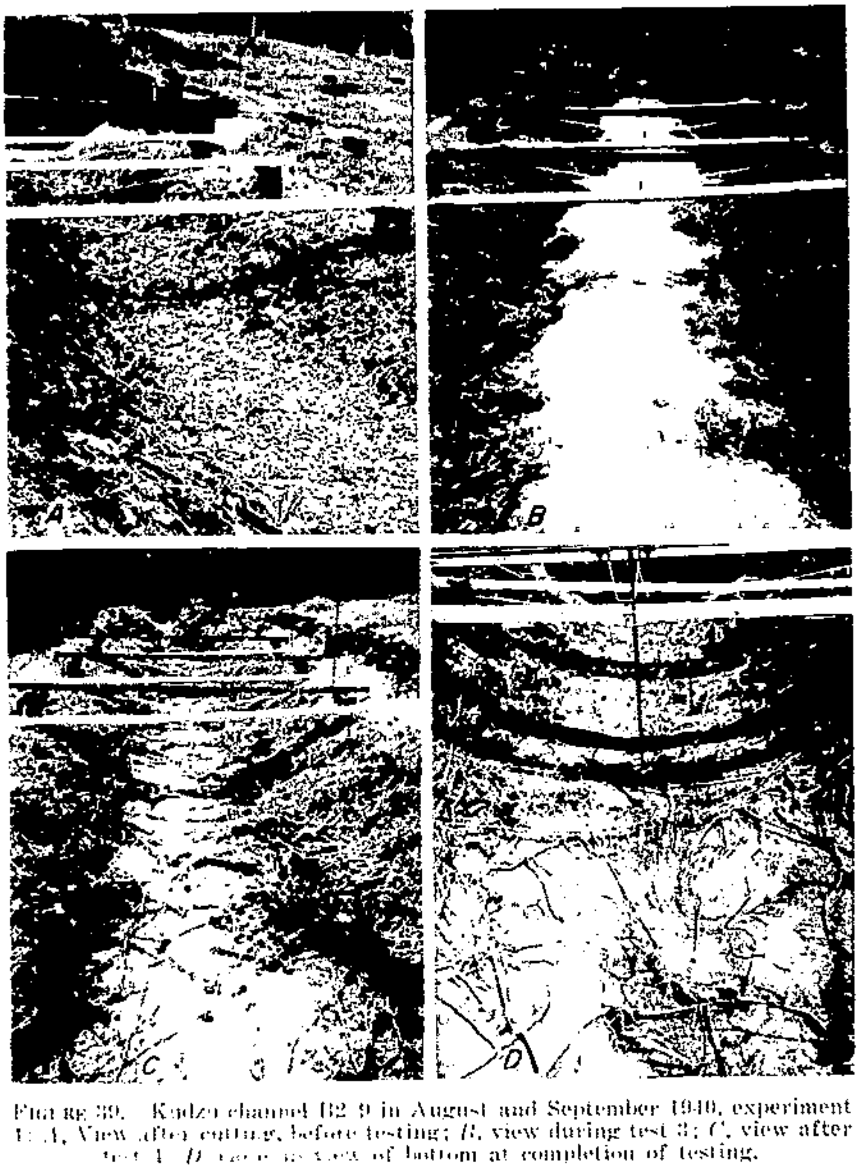

FIGURE 39. Kudzu channel B2-9 in August and September 1940, experiment 1: *A*, View after cutting, before testing; *B*, view during test 3; *C*, view after test 4; *D*, close-up view of bottom at completion of testing.

E[illegible] [illegible] 1[illegible] [illegible] 2[illegible], channel [illegible] [illegible] [illegible] by plan [illegible] [illegible] [illegible] [illegible] [illegible] 2.2. Test a, April 18, S[illegible] had [illegible] [illegible] since flowing and was [illegible] rather loose. Kudzu had [illegible] [illegible] started to grow. Only a few dead [illegible] [illegible] projected above ground surface.

Te[illegible] [illegible], May 15 and 16, 1941. Damage caused by test a had been repaired [illegible] [illegible] [illegible] [illegible] [illegible] of channel. Soil more settled than during test a [illegible] [illegible] a little loose. Kudzu had made fair growth, and lightly covered about 40 percent of channel surface (fig. 10, A).

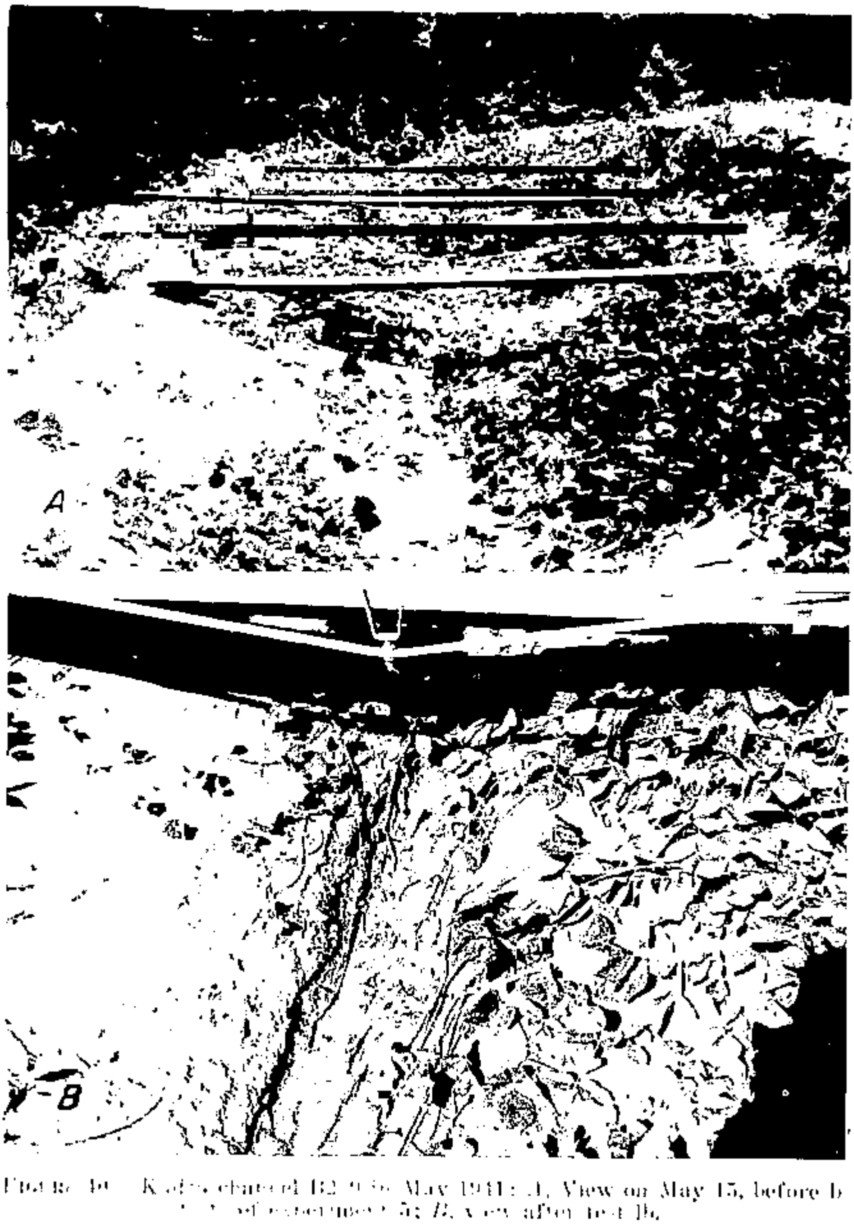

Figure 10.—Kudzu channel [illegible] [illegible] May 1941: A, View on May 15, before b[illegible] [illegible] [illegible] of experiment [illegible] 5; B, view after test [illegible].

Test c, June 2, 3, and 4, 1941. Soil moist and firm. A fair growth of kudzu, about, covered about 90 percent of channel (fig. 11, A).

Test d, June 23-25, 1941. Soil firm. A good growth of kudzu now covered channel completely (fig. 12, A).

Equipment: 2-foot modified Parshall flume, point gages.

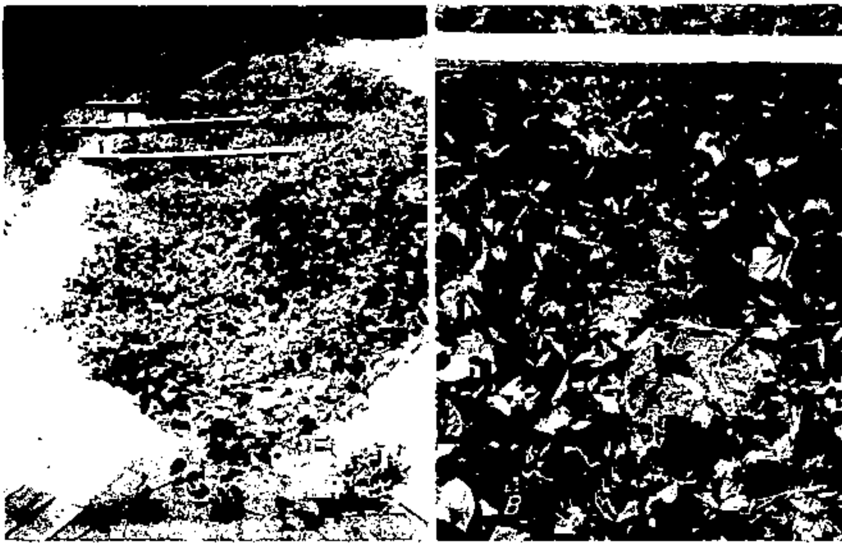

FIGURE 11.—Kudzu channel B2 9 in June 1941: A, View on June 2, before c test of experiment 5; B, view after test de.

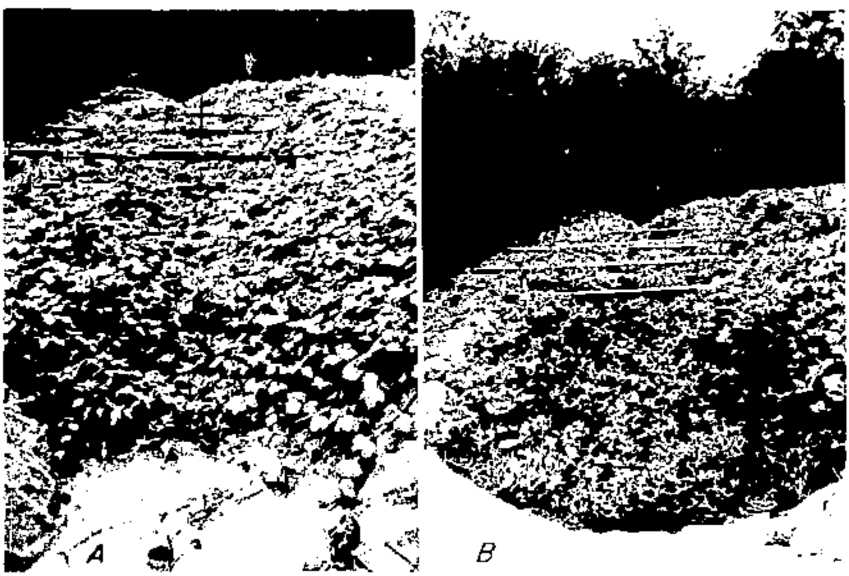

FIGURE 12.—Kudzu channel B2 9 in late June 1941: A, View on June 23, before d test of experiment 5; B, view after d test.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

In test a, water surface was rough and flow changed considerably, increasing in depth and decreasing in width owing to scour. In b tests, scour in upper reach deepened and narrowed flow during test 1. During test 2, flow was extremely nonuniform owing to variation in cover and scour development;

FIGURE 43.—Kudzu channel B2–9 on April 18, 1941, after test a of experiment 5.

acceleration took place to 25 feet from head of channel, a jump at 25 feet, retardation at 25 to 37 feet, an overfall at 37 feet, and rough but uniform flow at 37 to 50 feet. In c tests, during test 1 the flow exhibited the same characteristics as during test 2b. Water surface was rough, and vegetation was submerged in center part of channel. During tests 2 and 3, flow was still nonuniform but without such sharp breaks as in test 1. In test 4, water surface was rough and flow showed same nonuniformity as in test 1. In d tests, vegetation was not submerged during test 1. Flow was hidden. In second test (4d), flow submerged the vines and was rough but uniform. The three later flows were rough but fairly uniform.

During these tests, *n* values increased as kudzu became reestablished.

Effect of test flows on channel: In test a, channel was eroded considerably (fig. 43). In test b, channel was scoured considerably in upper portion (fig. 40, *B*); much of the sediment was deposited in lower reaches of channel. In tests c, slight scour occurred in upper end of channel (fig. 41, *B*), and some deposition in lower end of waterway. In tests d, practically no scour occurred (fig. 42, *B*).

HYDRAULIC BEHAVIOR OF KUDZU

Kudzu has a considerable retarding influence on flow of water, because its great mass of leaves and vines, which do not flatten so readily as those of Bermuda or centipede grass, occupies a relatively large part of the cross section of the channel and greatly disturbs the flow. The reduction in velocity thus effected results in increase of depth of flow and decrease in channel capacity. With regard to scour, the reduction in velocity may be advantageous. It was observed that when subjected to flow the kudzu vines tended to roll up into large clumps, which acted as dams and obstructions. These clumps create considerable disturbance in the deeper, swifter flows.

In figure 34 the retardance coefficient is seen to vary strikingly with age, condition, and treatment of the kudzu. The tests on the first-year growth yielded relatively high values of n. The next year's tests yielded still higher values, explained by increased number of plants and by growth. The first-year growth in the experimental channel was probably the equivalent of 2 years' growth in a field waterway; the heavy planting rate and the favorable growth conditions at the laboratory promoted very rapid establishment. In the second year, the stand achieved what is thought to be probably maximum density for this plant.

When a channel lining of kudzu is dormant, dead leaves and stems form a thick mulch on the channel surface (fig. 38) and the bulk of vegetation in the channel is considerably less than when the plants are green. Accordingly, retardance of flow is much lower. Cutting of the vegetation at this stage leaves the channel with still less cover and results in the lowest n values.

Stability of a Channel Lined with Kudzu

Kudzu was found to have a much lower protective capacity than any of the grasses tested. This, however, does not preclude its use as a lining for waterways; other characteristics such as rapid establishment sometimes make it a desirable choice as a channel lining, within the permissible range of flow velocity. The protective value of kudzu seems to lie chiefly in its property of reducing velocities of flow near the soil surface; it provides little actual protective cover for the surface of a channel.

A study of the tabulated scour rates and of the general appearance of the channel after each test indicates the following velocities as permissible for the various conditions tested:

	Feet per second
Live, heavy growth:	
Uncut	4
Cut	3
Dormant, heavy growth, uncut	2.5

These velocities are classed as permissible only for dense, uniform covers in channels free from sharp changes in grade, alinement, or cross section. Under less favorable conditions, and also on the lighter, more sandy soils, channels that are to be lined with kudzu should be designed for lower velocities.

The tests on the dormant vegetation showed that a loose mulch has very little capacity for protecting a channel against concentrated flows. Most of the heavy mulch of dead leaves, stems, and vines that covered the channel surface was washed away by the low first flow. Thereafter the only cover remaining was the vines, bare of leaves, rooted to the channel bed. The vines then had much less retarding influence on flow than when they were green, and, because they were separated by bare areas constituting a large percentage of the total surface area, offered scant protection to the channel.

Effect of Plowing a Kudzu-Lined Channel

When the altered channel B2–9 was first tested, on April 18, 1941, before growth of kudzu had started or the soil had settled to any considerable degree, a test flow of 0.9 cubic foot per second for 40 minutes scoured the channel badly (fig. 43). On May 15, when the soil of the repaired channel had become somewhat compacted and the vines had made considerable growth, the first flow of 0.9 cubic foot per second for 40 minutes caused scour (fig. 40, *B*) about half as severe as what occurred during test a. The second and higher flow had damaging results. On June 2 and 3, when the vines covered about 90 percent of the channel area, the standard test 1 resulted in no perceptible scour. After the three other c tests, in which the flows ranged from 2.65 to 9.3 cubic feet per second, testing was stopped because of high scour rates (fig. 41, *B*). On June 24, about 12 weeks after the plowing, when a good growth of kudzu completely covered the channel, a discharge of 23.4 cubic feet per second caused practically no scour (fig. 42, *B*).

A plotting of retardance coefficients against hydraulic radius for all the tests of the plowing experiment appears in figure 44. The increase of the coefficient with time is readily apparent. As the growth of the vegetation progressed the retarding influence

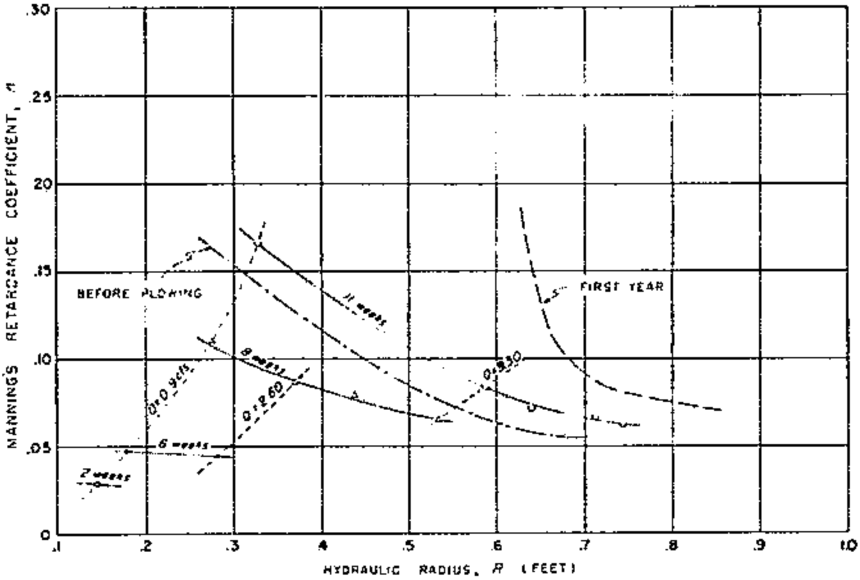

FIGURE 44.—Relation of Manning's *n* and hydraulic radius at various intervals after April 7, 1941, for kudzu channel B2–9, the sides of which were plowed in on that date, and for the same channel at earlier times. The "before plowing" curve represents estimates based on results of tests made when the kudzu was dormant. Values for first year (7 months' growth of uncut vines) are probable maxima for that year.

increased. Also plotted in figure 50 are lines of equal discharge rates. These illustrate how a flow of given discharge necessarily becomes deeper if, through increase of vegetal growth, retardance is increased. A flow of 0.9 cubic foot per second, which had a velocity of 2.5 feet per second 2 weeks after the plowing, was slowed to 0.7 foot per second 9 weeks later. The corresponding reduction in velocity of larger flows is not so great.

A study of the scour rates shows that the permissible velocities increase as cover increases. In a bare, unsettled channel, such as the experimental channel 2 weeks after its sides were plowed in, the soil will be washed away by flows having velocities of 1 foot per second or even less. For a channel lined with a good growth of kudzu, such as this channel 12 weeks after the plowing, flow velocities of at least 3.5 feet per second and probably 4.0 feet per second are permissible.

From these studies it can be concluded that a channel lining of kudzu requires at least 8 weeks of growth after plowing to develop adequate protective capacity. It can be seen, then, that to plow a kudzu-lined channel completely is to take a risk. If a heavy flow occurs shortly after the plowing, the channel is likely to be seriously gullied. However, if excessive runoff does not take place for at least 2 months it may be expected that a good lining capable of offering considerable protection to the channel will develop within that time. If a temporary diversion is provided, this safeguards the channel while the reestablishment of kudzu is taking place. If the sides only are plowed in and the bottom is left undisturbed, with capacity for ordinary volumes of runoff, the likelihood of failure is reduced.

COMMON LESPEDEZA EXPERIMENTS

Common lespedeza is a slender annual plant, with small leaflets, that usually grows prostrate except in dense stands. It begins to grow late in spring, grows most rapidly in midsummer, seeds in late summer or early fall, and is killed by the first severe freeze. Its optimum range in the United States is the region lying south of the Potomac and Ohio Rivers and including central and southern Missouri and southeastern Kansas. It is widely used for soil conservation, and proper attention to management and to combining other crops with it is likely to lead to its being used even more widely in the future (*6*). It is probably the most widely useful and productive leguminous forage crop in the South and makes excellent hay. Although perennial plants are usually preferred for planting in waterways, common lespedeza is often used for this purpose, particularly in meadow-type outlets.

An extensive series of experiments was made on common lespedeza, including tests of uncut green vegetation, fall dead stubble, spring dead stubble, and cut stubble.

Experimental conditions and results for the channels lined with common lespedeza are presented in table 8, and further information regarding the experiments on these channels is summarized in the following material in small type. The relation between n and VR for channels lined with common lespedeza is shown in figure 45. Dimensions and data on vegetal covers for the channels represented in figure 45 are given in table 9.

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TABLE 8.—*Experimental conditions and results for channels lined with common lespedeza*

TRAPEZOIDAL SHAPE, BED SLOPE 6 PERCENT, BOTTOM WIDTH 2 FEET, SIDE SLOPE 3:1

Channel	Condition of lining	Test No.	Date of testing	Discharge	Area of section, A	Mean velocity, V	Wetted perimeter, P	Hydraulic radius, R	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, n_m	Coefficients: Kutter, n_k	Value of VR
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Cu. ft. per sec.	*Sq. ft.*	*Ft. per sec.*	*Feet*	*Feet*		*Feet*	*Min.*	*°F.*	*In. per hour*				
B2-2	Dead, uncut	1	Nov. 19, 1937	4.61	1.57	2.94	5.45	0.288	0.0552	0.47	35	42	0.04	21.6	0.0553	0.0397	0.847
		2	do	7.08	2.06	3.44	6.14	.336	.0550	.56	35	42	.09	23.3	.0534	.0389	1.16
		3	Nov. 20, 1937	11.8	2.64	4.47	6.77	.390	.0524	.67	44	39	−.02	28.6	.0445	.0347	1.74
		4	Nov. 22, 1937	15.3	2.99	5.11	6.92	.432	.0637	.73	41	38	1.98	30.9	.0418	.0335	2.21
B2-5	Green, long	1	Sept. 21, 1938	5.49	2.54	2.16	6.71	.379	.0501	.59	56	[illegible]	.09	14.30	.0887	.0601	.819
		2	Sept. 22, 1938	8.92	2.90	3.07	6.87	.425	.0609	.64	42	62	.04	19.17	.0672	.0487	1.30
		3	Sept. 23, 1938	12.6	3.37	3.74	7.39	.461	.0609	.71	42	64	.01	22.31	.0586	.0442	1.72
		4	Sept. 24, 1938	16.7	3.82	4.38	7.50	.510	.0508	.79	57	68	.12	24.97	.0533	.0415	2.23
		5	Sept. 26, 1938	23.0	4.38	5.25	7.74	.566	.0609	.91	60	68	.14	28.28	.0478	.0386	2.97
		6	Sept. 28, 1938	27.6	4.70	5.87	7.88	.597	.0601	.97	53	69	−.02	31.02	.0440	.0363	3.59

RECTANGULAR SHAPE, L-D SLOPE 4 PERCENT, BOTTOM WIDTH 2 FEET

B2-17B	Green, uncut	1	June 16, 1941	0.624	0.427	1.46		0.214	0.0306	...	40	69	0.01	18.30	0.0632	0.0412	0.312
		2	do	1.04	.500	2.08		.251	.0309	...	40	68	0	28.80	.0498	.0452	.522
		3	June 17, 1941	1.92	.628	3.06	...	.314	.0301		40	68	.12	31.75	.0387	.0293	.961
		4	June 18, 1941	3.76	.790	4.76	...	.396	.0300	...	40	71	.45	43.92	.0292	.0246	1.88
		5	do	5.74	1.01	5.68		.506	.0297	...	40	71	.64	46.68	.0286	.0250	2.87
B2-15C	Dead, long	1	Mar. 8, 1940	.0172	.091	.189		.016	.0393		56	49	.03	5.16	.224	.0647	.0087
		2	Mar. 15, 1940	.0503	.168	.302		.084	.0291	...	30	48	.08	6.09	.162	.0692	.0254
		3	Mar. 18, 1940	.0952	.220	.415		.116	.0288		44	58	−.07	7.18	.145	.0741	.0481
		4	Mar. 19, 1940	.1750	.328	.513		.167	.0280	...	42	52	.07	7.82	.143	.0783	.0890
		5	Mar. 20, 1940	.2860	.441	.646	...	.226	.0266	...	21	52	0	8.38	.140	.0705	.146
		6	Mar. 21, 1940	.5120	.501	1.022		.254	.0272	...	22	51	−.12	12.3	.0972	.0595	.260
		7	Mar. 22, 1940	1.092	.523	2.00		.266	.0268	...	42	51	.31	24.9	.0488	.0350	.556
B2-15B	Green, uncut	1	June 25, 1940	.742	.663	1.12	...	.334	.0294	...	40	68	.03	11.22	.1102	.0697	.374
		2	June 27, 1940	1.12	.715	1.57		.356	.0209	...	41	67	−.01	15.29	.0820	.0554	.559
		3	June 28, 1940	2.14	.850	2.52		.425	.0291	...	40	67	.03	22.60	.0571	.0426	1.07
		4	July 1, 1940	4.16	1.11	3.73		.557	.0292	...	40	68	−.03	29.34	.0461	.0373	2.08
		5	July 2, 1940	6.39	1.33	4.81	...	.663	.0289	...	40	70	.03	34.90	.0396	.0338	3.19
		6	July 3, 1940	8.70	1.51	5.78	...	.750	.0287	...	40	71	.11	39.64	.0359	.0314	4.34
B2-15A	Green, cut before testing	1	Oct. 9, 1940	.665	.385	1.73	...	.193	.0294	...	41	59	.03	22.94	.0493	.0336	.334
		2	Oct. 10, 1940	1.10	.491	2.24	...	.247	.0303	...	40	59	.01	25.88	.0456	.0328	.553
		3	Oct. 11, 1940	2.24	.638	3.52		.319	.0299		41	58	.05	36.18	.0311	.0270	1.12
		4	Oct. 12, 1940	4.12	.853	4.84		.428	.0288	...	41	60	.04	43.65	.0296	.0252	2.07
		5	Oct. 14, 1940	6.16	.998	6.17	...	.501	.0286	...	41	61	.02	51.60	.0267	.0228	3.09
		6	do	8.37	1.15	7.27		.578	.0270	...	41	63	.01	58.20	.0233	.0214	4.20

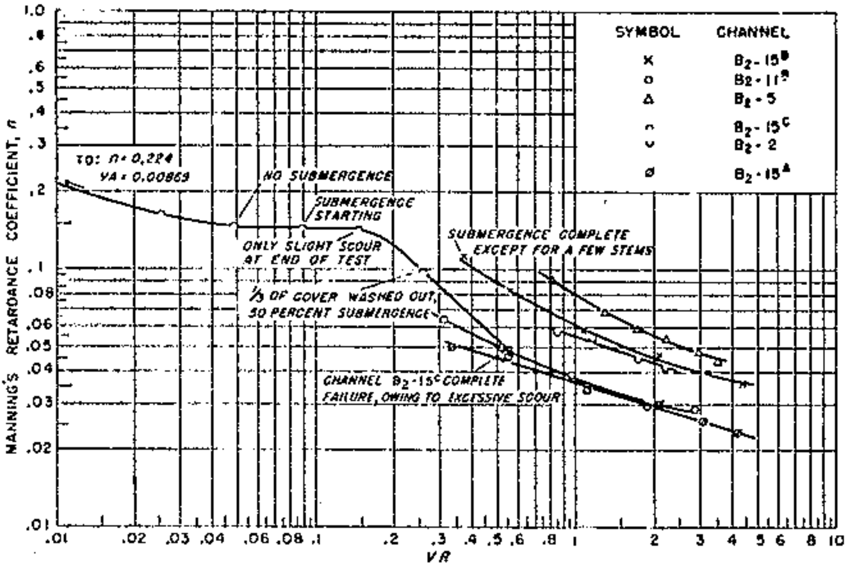

FIGURE 45.—Relation of Manning's n and VR for channels lined with common lespedeza. Data in each instance are from experiment 1. Dimensions and vegetation data for the channels represented are given in table 9.

RECORD OF EXPERIMENTS

CHANNEL B2–2

Bed slope 6 percent, bottom width 2 feet, side slope 3:1, length 50 feet, planted by seeding May 17, 1937, and again June 12, 1937. Channel fairly uniform in cross section, alinement, and cover. The right side was a little low, and it was necessary to erect a wooden wall along this edge to contain the higher flows within the channel.

Experiment 1, November 1937, lespedeza mostly dead, uncut.—Lespedeza averaged probably 4 inches in height, 36 plants per square foot. Soil firm for first three tests. Between tests 3 and 4 the ground froze; during test 4 it thawed out and became very soft and loose.

Equipment: Sharp-crested weir, string and rod.

TABLE 9.—*Dimensions and vegetal-lining conditions of lespedeza channels from which the data represented by the n_m–VR curves in figure 45 were obtained*

Channel	Nominal dimensions: Bed slope	Nominal dimensions: Bottom width	Nominal dimensions: Side slope	Time of experiment	Stand count: Height	Stand count: Stems per square foot
	Percent	*Feet*			*Inches*	*Number*
Lining green and uncut:						
B2–5	6	2	3:1	Sept.	11	150
B2–15B	3	2	Vertical	June	4½	299
B2–11B	3	2	do	do	4	17
Lining dead, uncut:						
B2–2	6	2	3:1	Nov.	4	36
B2–15C	3	2	Vertical	Mar.	10	43
Lining green, cut:[1]						
B2–15A	3	2	do	Oct.	2	(2)

[1] Only bare stems remained.
[2] Density good.

FIGURE 16.—Lespedeza channel B2-2 after test 2, November 20, 1937.

During each test a single observer made water-surface measurements at four stations, progressing downstream. There were three 10-foot reaches. Vegetation was submerged during all tests. Water surface very rough.

There was very little scour during tests 1-3 (fig. 16). During test 4 considerable erosion took place, owing partly to thawing of the ground.

CHANNEL B2-5

Bed slope 6 percent, bottom width 2 feet, side slope 3:1, length 50 feet, planted by seeding May 17, 1937, and again June 12, 1937. Channel fairly uniform in cross section, alinement, and cover. The left side was a little low, and a vertical wooden wall was used to contain all flows except the first.

Experiment 1, September 1938, lespedeza green and erect. Lespedeza, on average, 11 inches long, 150 plants per square foot (fig. 17, *A*). Soil firm.

Equipment: Sharp-crested weir, string and rod.

During each test a single observer made water-surface measurements at four stations, progressing downstream. There were 3 10-foot reaches.

Vegetation was submerged during all flows except for small areas at edge of flow. Water surface very rough for all tests. Curve of n-VR relation parallel to and only slightly higher than that for a good cover of long green Bermuda grass.

Very little erosion took place until test 4, when small holes appeared along center of channel. When testing had been completed (fig. 17, *B*) many small eroded areas were found along channel, of which average depth was about 2 inches and maximum depth about 6 inches.

CHANNEL B2-11B

Bed slope 3 percent, bottom width 2 feet, sides vertical (sheet-metal walls used), length 50 feet, planted May 193[illegible] by seeding, after which stand had maintained itself by reseeding.

Experiment [illegible], June 19[illegible], lespedeza green and erect. Lespedeza averaged [illegible] inches in height, about 17 plants per square foot. Soil fairly firm.

Equipment: 2-foot H-flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each man [illegible] each station. There were two 10-foot reaches.

FIGURE 17.—Lespedeza channel B2-5 (A) before testing and (B) after completion of testing.

Vegetation was 90 percent submerged during test 1, completely submerged during remaining tests. Water surface rough. Level of *n* values low owing to sparseness of cover.

Scour was considerable, reaching depth of 4 inches in some places, and about 15 percent of the plants were washed out (fig. 48).

FIGURE 48.—Lespedeza channel B2–1B after testing.

CHANNEL B2–15C

Bed slope 3 percent, bottom width 2 feet, sides vertical (sheet-metal walls used), length 50 feet, stand maintained by natural reseeding.

Experiment 1, March 1940, lespedeza dead and uncut.—Lespedeza averaged 10 inches in length, 43 plants per square foot (fig. 49, *A*). Soil firm.

Equipment: For measuring inflow, 1-foot H-flume in tests 1–3, 2-foot H-flume in other tests; for measuring outflow, weighing tank in tests 1–4 1-foot H-flume in test 5; point gages.

Three men made water-surface measurements simultaneously at three stations, making one set for each of tests 1–6, two sets for each other test. Observers did not rotate positions for second measurements. There were two 10-foot reaches.

Submergence of vegetation did not begin until test 4. During test 6, vegetation still projected above half of water-surface area. High initial *n* was probably due to influence of mulch on flow only 0.05 foot deep. During tests 2–5 *n* remained practically constant, indicating no change in position of dead stems and leaves as depth of flow increased. Hydraulic behavior during tests 6 and 7 was influenced by rapid scour rate and actual washing out of portions of cover.

Little or no scour occurred during tests 1–4. A little erosion took place during test 5. In test 6 about a third of the cover was washed out and considerable erosion took place. Channel failed completely in test 7 (fig. 49, *B*).

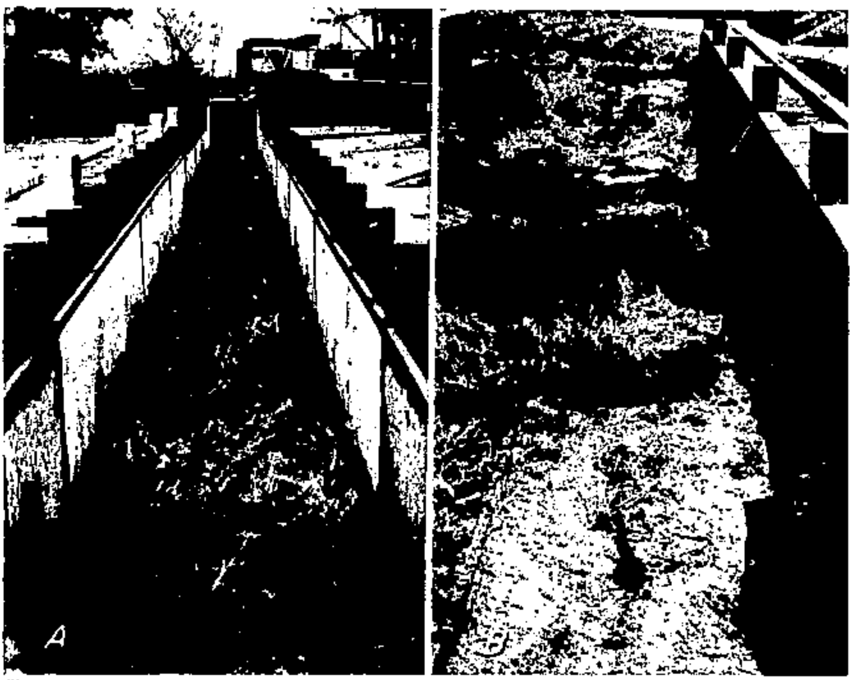

FIGURE 49.—Lespedeza channel B2–15C, with sheet-metal side walls, (*A*) before testing and (*B*) after completion of testing.

CHANNEL B2–15B

Channel description same as that of channel B2–15C.

Experiment 1, June 1940, lespedeza green and uncut.—Lespedeza, on average, 4½ inches high, 290 plants per square foot (fig. 50, *A*). Soil firm.

Equipment: 2-foot H-flume, point gages.

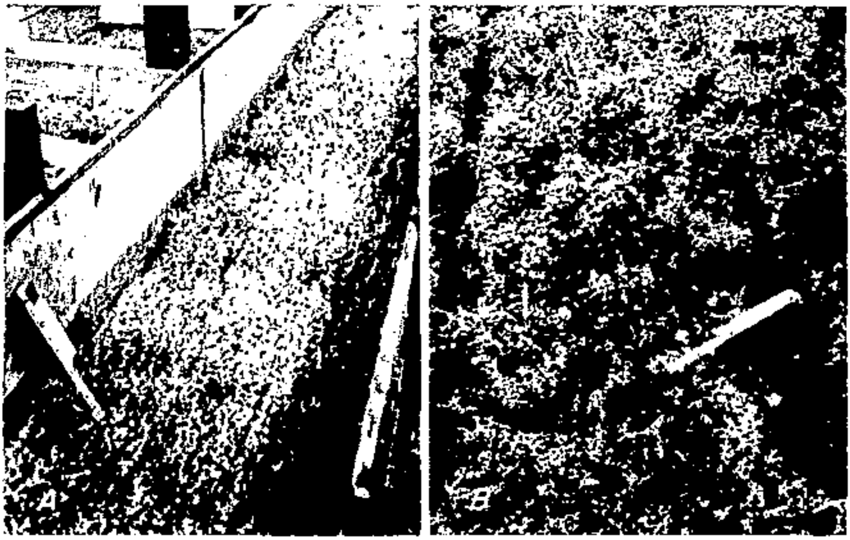

FIGURE 50.—Lespedeza channel B2–15B, with sheet-metal side walls, (A) after test 3 and (B) after completion of testing.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Vegetation was submerged, with exception of a few stems, during test 1. Water surface was covered with small waves during test 1 and became rougher as flows increased until it was decidedly rough in final test.

At completion of testing (fig. 50, B), practically no scour was found except at one spot, where it may have been caused by disturbance of soil in placing metal walls.

CHANNEL B2–15A

Channel description same as that of channel B2–15C.

Experiment 1, October 19[illegible], lespedeza green and cut. Cutting of good stand of lespedeza had reduced length to about 2 inches, leaving only bare stems. No stem count made. Stand described as good.

Equipment: 2-foot H flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Vegetation was submerged during all tests. Stems seemed to remain erect. Water surface was rough, with small waves.

Very little scour occurred.

HYDRAULIC BEHAVIOR OF COMMON LESPEDEZA

Green common lespedeza is rather short and very pliant. It flattens readily under flow and, if sufficiently dense, provides a good cover for a channel surface. In the spring the dead stubble is rotted at the base and tends to break off easily. Flowing water piles lespedeza in this condition into bunches, with the result that flows are very irregular until all vegetation has been washed out of the channel. The fall-dead stubble is not so easily broken loose and permits more uniform flow.

The effect of density of stand is illustrated by the results for channels B2–14B and B2–15B, presented in figure 9. These channels had poor and good stands, respectively, of green lespedeza of approximately the same height. For flows 0.5 foot deep,

TABLE 10.—*Experimental conditions and results for channels lined with sericea lespedeza*

TRAPEZOIDAL SHAPE, BED SLOPE 6 PERCENT, BOTTOM WIDTH 2 FEET, SIDE SLOPE 3:1

Channel	Condition of lining	Test number	Date of testing	Discharge	Area of section, *A*	Mean velocity, *V*	Wetted perimeter, *P*	Hydraulic radius, *R*	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, *C*	Coefficients: Manning, n_m	Coefficients: Kutter, n_k	Value of *VR*
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
				Cu. ft. per sec.	*Sq. ft*	*Ft. per sec.*	*Feet*	*Feet*		*Feet*	*Min.*	*°F.*	*In. per hour*				
B2-1	Dormant, long	1	Dec. 1, 1937	4.77	1.54	3.04	5.36	0.287	0.059	0.43	51	49	0.49	23.4	0.0517	0.0370	0.872
		2	Dec. 2, 1937	7.63	2.11	3.62	6.00	.352	.060	.55	48	48	.26	25.0	.0502	.0373	1.27
		3	do	12.8	2.8[illegible]	4.58	6.52	.430	.059	.66	43	48	.42	28.7	.0450	.0352	1.97
		4	Dec. 3, 1937	15.8	3.49	4.53	7.10	.492	.061	.77	52	47	.66	26.2	.0505	.0394	2.23
		5	Dec. 4, 1937	23.2	4.43	5.24	7.69	.576	.063	.95	40	46	1.12	27.5	.0490	.0395	3.02
B2-4	Green. Medium long, woody.	1	Oct. 6, 1938	5.41	2.94	1.84	6.87	.429	.0648	.65	45	68	.14	11.06	.117	.0771	.789
		2	do	9.03	3.59	2.51	7.15	.502	.0655	.77	55	68	.20	13.90	.0955	.0671	1.26
		3	Oct. 7, 1938	12.8	4.27	3.00	7.65	.559	.0623	.85	50	66	.22	16.16	.0836	.0612	1.68
		4	do	16.9	4.82	3.51	7.69	.628	.0662	.96	39	67	.08	17.28	.0799	.0603	2.20
		5	Oct. 8, 1938	23.3	5.47	4.26	7.89	.695	.0656	1.06	51	61	.25	20.02	.0701	.0550	2.96
		6	Oct. 10, 1938	27.3	5.98	4.56	7.88	.760	.0655	1.20	57	65	.21	20.49	.0693	.0554	3.46

RECTANGULAR SHAPE, BED SLOPE [illegible] PERCENT, BOTTOM WIDTH 2 FEET

B2-10C	Dormant.	1	Apr. 8, 1941	0.646	0.385	1.68		0.194	0.0292		42	56	0.06	22.24	0.0498	0.0338	0.326
	Short,	2	do	1.02	.473	2.16		.240	.0284		40	55	.03	26.26	.0448	.0323	.518
	cut pre-	3	Apr. 9, 1941	2.12	.670	3.17		.339	.0278		40	55	.24	32.64	.0380	.0298	1.07
	vious	4	do	3.95	.920	4.30		.466	.0278		42	56	.18	37.34	.0346	.0288	2.00
	fall.	5	Apr. 10, 1941	5.76	1.13	5.02		.578	.0272		40	56	.27	40.10	.0338	.0290	2.89
		6	do	7.59	1.36	5.58		.690	.0266		40	58	.29	41.20	.0340	.0297	3.85
B2-10B	Green. Long,	1	June 16, 1941	.576	.70	.824		.348	.0279		41	68	-.01	8.37	.149	.0904	.287
	not yet	2	do	1.09	1.08	.927		.538	.0299		41	68	.01	7.33	.183	.119	.499
	woody.	3	June 17, 1941	1.88	1.45	1.30		.721	.0320		40	69	-.01	8.58	.164	.116	.937
		4	do	3.78	1.70	2.22		.854	.0333		41	70	.03	13.16	.110	.0846	1.90
		5	June 18, 1941	5.67	1.87	3.03		.936	.0318		40	70	.04	17.58	.0838	.0674	2.84
		1	Mar. 7, 1940	.0157	.140	.112		.071	.0332		71	52	.06	2.31	.416	.144	.0080
		2	Mar. 15, 1940	.0498	.202	.246		.103	.0326		45	48	-.02	4.24	.241	.1012	.0253
		3	Mar. 18, 1940	.0940	.274	.343		.138	.0325		46	58	.06	5.13	.209	.0966	.0473
		4	Mar. 19, 1940	.1712	.386	.444		.196	.0316		31	53	-.03	5.70	.201	.1016	.0870
		5	Mar. 20, 1940	.2838	.548	.517		.280	.0289		33	52	.01	5.84	.213	.1164	.145
B2-14C	Dormant, long	6	Mar. 21, 1940	.5100	.744	.686		.379	.0274		23	51	.06	6.84	.190	.1138	.260
		7	Mar. 22, 1940	1.092	1.02	1.071		.518	.0281		49	52	.03	8.97	.152	.1003	.555
		8	Mar. 28, 1940	2.052	1.20	1.713		.608	.0294		40	49	.01	12.90	.1070	.0770	1.04
		9	Mar. 29, 1940	4.012	1.31	3.06		.666	.0297		41	52	-.01	21.90	.0641	.0506	2.04
		10	Apr. 2, 1940	6.072	1.45	4.18		.758	.0343		41	57	.25	28.28	.0506	.0420	3.08
		11	Apr. 3, 1940	7.852	1.60	4.92		.837	.0346		41	62	1.43	27.89	.0518	.0435	4.12
		1	June 25, 1940	.743	1.07	.693		.534	.0326		40	68	-.05	5.27	.254	.160	.370
		2	June 26, 1940	1.14	1.34	.852		.665	.0312		40	67	.03	5.94	.234	.156	.566
B2-14B	Green, long	3	June 28, 1940	2.14	1.53	1.40		.762	.0311		40	67	-.19	9.10	.156	.112	1.07
		4	July 1, 1940	4.16	1.72	2.43		.853	.0295		40	68	.05	15.38	.0947	.0738	2.07
		5	July 2, 1940	6.37	1.91	3.29		.964	.0302		40	70	.06	19.34	.0767	.0627	3.17
B2-14A	Green.	1	Oct. 9, 1940	.665	.426	1.56		.215	.0347		41	59	.07	18.17	.0634	.0413	.335
	Short,	2	Oct. 10, 1940	1.10	.519	2.16		.258	.0352		41	59	.07	22.72	.0523	.0368	.557
	cut before	3	Oct. 11, 1940	2.24	.701	3.20		.354	.0352		41	58	.03	28.70	.0438	.0836	1.13
	testing.	4	Oct. 12, 1940	4.14	.956	4.33		.482	.0346		41	59	.07	33.74	.0394	.0322	2.09
		5	Oct. 14, 1940	6.20	1.13	5.46		.575	.0334		41	60	.05	39.61	.0345	.0296	3.14
		6	do	8.50	1.33	6.40		.670	.0322		42	62	.06	43.77	.0319	.0282	4.29

in channels of 3-percent slope the retardance coefficients were 0.028 and 0.050. For shallower flows the difference was much greater.

Cutting a good stand of green lespedeza to 2-inch length, so that only bare stems remained, in channel B2–15A lowered the retardance coefficient for flows deeper than 0.5 foot on a 3-percent slope to less than 0.025. Fairly high n values were obtained for good stands that were green and uncut (fig. 45). The n–VR curve established for long green Bermuda grass (fig. 12, *C*) lies between these for lespedeza and approximates their shape.

Results of the tests made on the stubble that remained after cutting of the vegetation in channel B2–15A are rather surprising. Although there was not much cover on the channel surface to protect it from erosion, a flow velocity of more than 7 feet per second caused very little damage. The low scour rate was probably due to the very firm condition of the channel bed. In view of the results obtained on the other channels it is believed that the permissible velocity for this type of lining is not greater than 4.5 feet per second.

The permissible-velocity figures suggested apply only to channels of uniform alinement, slope, and cross section that have good stands of vegetation and are subject to flows of short duration. For channels not meeting this description, permissible velocities are lower.

Comparison of the experimental results for the two channels lined with uncut dead lespedeza is difficult because the channels differed in shape and slope and the range of VR values was not the same for both. The difference in results evident in figure 45 may be attributed to actual removal of vegetation from channel B2–15C. The final test flow caused complete failure (fig. 49, *B*).

Stability of a Channel Lined with Common Lespedeza

The scour rates obtained in the tests on lespedeza linings revealed that an uncut green lining gives a waterway fairly good protection. Channels B2–5 and B2–15B both withstood a velocity of more than 5 feet per second without appreciable damage. The permissible velocity of flow when the vegetation is in this condition is about 5.5 feet per second.

Results of the tests made on channel B2–15C in the spring show that a lining of dead lespedeza stubble gives a channel practically no protection. The permissible velocity for a lining in this condition is approxmately 1 foot per second. In the fall, however, the protective capacity of the dead stubble is much greater. The results of the tests on channel B2–2 indicate that the permissible velocity for fall-dead stubble may be as high as 3.5 feet per second. The excessively high scour rate during test 4 on this channel resulted from a heavy frost that occurred the night before. When the water was discharged down the channel in the morning the surface soil thawed out and was quickly eroded from the channel bed.

SERICEA LESPEDEZA EXPERIMENTS

Sericea lespedeza is a deep-rooted perennial legume. Plants grown from broadcast seed may attain heights of 12 to 18 inches the first year if weather conditions are favorable, and in the second year usually develop into a dense, well-branched stand having a height of from 2 to 5 feet, according to moisture and soil conditions. Sericea lespedeza is valuable as a pasture and hay crop. Spring growth is rapid, and if the herbage is cut early it makes excellent hay. In the soil conservation program sericea has been found very useful for the region to which it is adapted (7). It has been employed extensively for lining waterways of the meadow type. So far as present knowledge goes, the plant appears to be adapted to the territory from perhaps 100 miles north of the Ohio River to the Gulf of Mexico and from the Atlantic coast to central Kansas and Oklahoma.

Because of its importance, sericea lespedeza was subjected to an extensive series of tests in growth conditions including long dormant, stubble, uncut green, freshly cut green, and green with some growth since cutting.

Experimental conditions and results for the channels lined with sericea lespedeza are presented in table 10, and further information regarding the experiments on these channels is summarized in the following material in small type. The relation between n and VR for long and short green and short dormant sericea lespedeza is shown in figure 51, *A*, and that for long dormant sericea lespedeza in figure 51, *B*. Dimensions and vegetal-lining conditions of the channels represented in figure 58 are given in table 11.

TABLE 11.—*Dimensions and vegetal-lining conditions of channels lined with sericea lespedeza from which the data represented by the n_m–VR curves in figure 51 were obtained*

Lining condition and channel	Nominal dimensions			Stand count	
	Bed slope	Bottom width	Side slope	Height	Stems per square foot
	Percent	*Feet*		*Inches*	*Number*
Vegetation long and green:					
B2-10B	3	2	Vertical	22	80
B2-11B	3	2	do	16	135
Vegetation long and dormant:					
B2-1	6	2	3:1	18	13
B2-10C	3	2	Vertical	17	88
Vegetation short and green:					
B2-4	6	2	3:1	6	(1)
B2-14A	3	2	Vertical	2	(2)
Vegetation short and dormant:					
B2-10C	3	2	do	1	[3] 50

[1] No count. Stand described as good, woody.
[2] No count. Stand, cut just before tests, described as very good.
[3] Cutting in preceding fall had left only stiff stalks.

RECORD OF EXPERIMENTS

CHANNEL B2-1

Bed slope 6 percent, bottom width 2 feet, side slope 3:1, length 50 feet, planted May 17, 1937, by seeding. Channel fairly uniform in cross section, slope, and alinement. The right side was a little low, and a wood side wall was erected along it to confine the higher flows to the channel.

Experiment 1, December 1937, vegetation dormant and uncut.—Sericea lespedeza, on average, probably 18 inches high, 13 plants per square foot. Soil fairly firm.

Equipment: Sharp-crested weir, string and rod.

During each test a single observer made water-surface measurements at four stations, progressing downstream. There were three 10-foot reaches.

Most of vegetation remained erect for first two tests (fig. 52). No record available of vegetation's behavior in tests 3 and 4; it is believed that only vegetation in center portion of channel was submerged. Water surface very

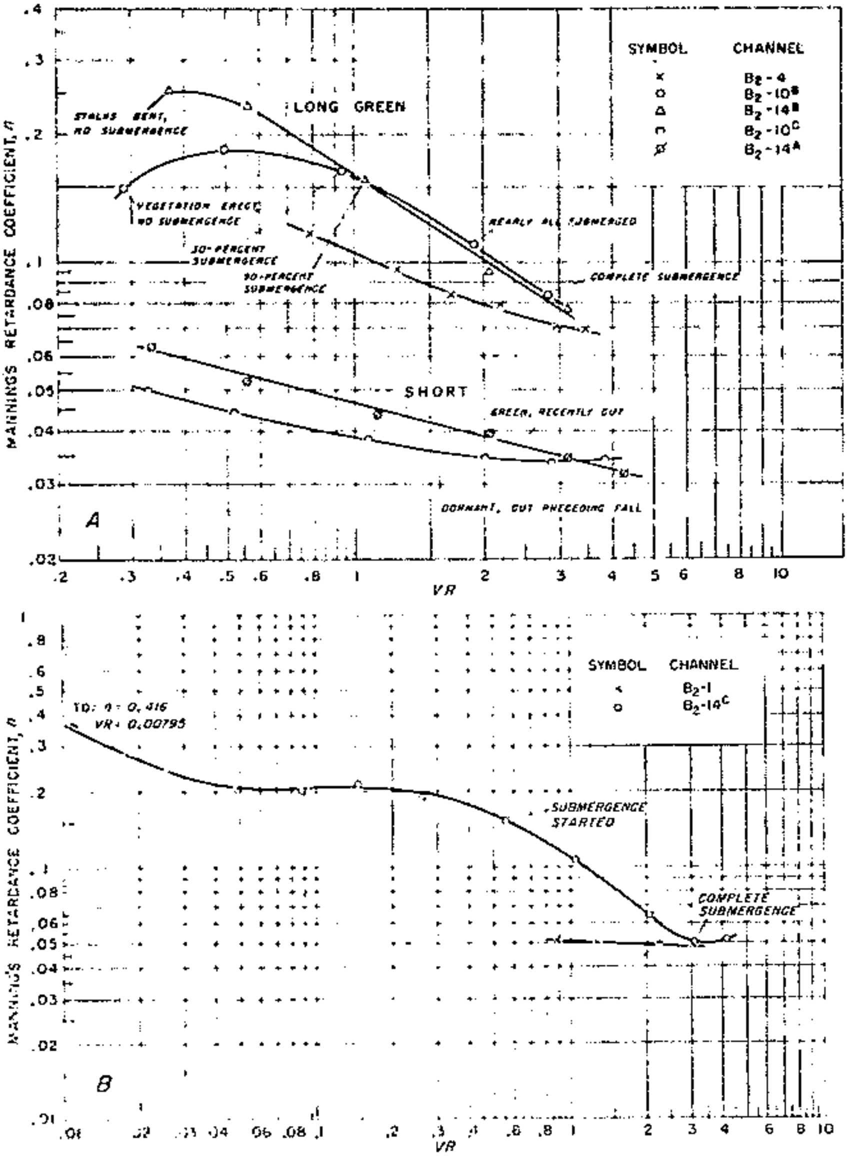

FIGURE 51.—Relation of Manning's *n* and *VR* for channels lined with (*A*) long green, short green, and short dormant sericea lespedeza and (*B*) long dormant sericea lespedeza. Vegetation in channel B2–1 remained erect during tests 1 and 2; for the other tests, no record is available.

rough for all tests. The fact that values of *n* were unusually low even for first two tests can be attributed to sparseness of cover. Value of *n* did not decrease much when submergence increased, probably because of increase of bed roughness by scour.

Considerable scour occurred.

Channel B2–4

Bed slope 6 percent, bottom width 2 feet, side slope 3:1, length 50 feet, planted May 17, 1937, by seeding. Channel fairly regular in cross section, slope, and alinement. The left side was low, and a wood side wall was erected along it to confine the higher flows to the channel.

Experiment 1, October 1938, vegetation green and cut.—Cutting, 2 months before testing, had reduced height of sericea lespedeza to about 6 inches. Some new growth had taken place, but vegetation was still relatively short. No stand count made; uncut stand described as good. Soil firm.

Equipment: Sharp-crested weir, string and rod.

During each test a single observer made water-surface measurements at four stations, progressing downstream. There were three 10-foot reaches.

Vegetation was submerged during all tests. Water surface very rough. Some stalks stood up against flow and caused splashes 6 inches high.

Some scour took place. A fairly large number of holes in the channel bottom were more than 3 inches deep (fig. 53).

Channel B2–10C

Bed slope 3 percent, bottom width 2 feet, sides vertical (sheet-metal side walls used), length 50 feet, planted May 1939 by seeding. Channel very regular in cross section, slope, and alinement.

FIGURE 52.—Sericea lespedeza channel B2–1 during test 2.

Experiment 1, April 1941, vegetation dormant and cut.—Cutting, in preceding fall, had left only stiff stalks about 1 inch high. Average density 50 stems per square foot. Soil slightly disturbed where metal walls had been erected a few weeks before tests. Channel bed covered with fairly thick mulch of dead leaves and stem (fig. 54, *A*).

FIGURE 53.—Sericea lespedeza channel B2–4 after completion of testing.

Equipment: 2-foot H-flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each man making one at each station. There were two 10-foot reaches.

Vegetation was submerged during all tests. Water surface rough during all tests.

Loose mulch on channel bed was washed out during beginning of low first flow. Channel was eroded very uniformly over entire length. Numerous holes, one-half to 1 inch deep and 3 to 6 inches in diameter, scoured at intervals of 6 to 18 inches over entire channel bottom, giving bottom a rough, pitted appearance. Most roots exposed to depth of 1 to 2 inches. Scour slightly greater near side walls, owing to disturbance of soil by installation. Very little or no material deposited in channel (fig. 54, *B*).

CHANNEL B2–10B

Channel description same as that of channel B2–10C.

Experiment 1, June 1941, vegetation green and uncut.—Stems, on average, 22 inches long, and not yet woody (fig. 55, *A*). Density 80 stems per square foot. Sheet-metal side walls had not affected plants, having been erected about 2 weeks before tests. Soil slightly disturbed where walls had been installed.

Equipment: 2-foot H-flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each man making one at each station. There were two 10-foot reaches.

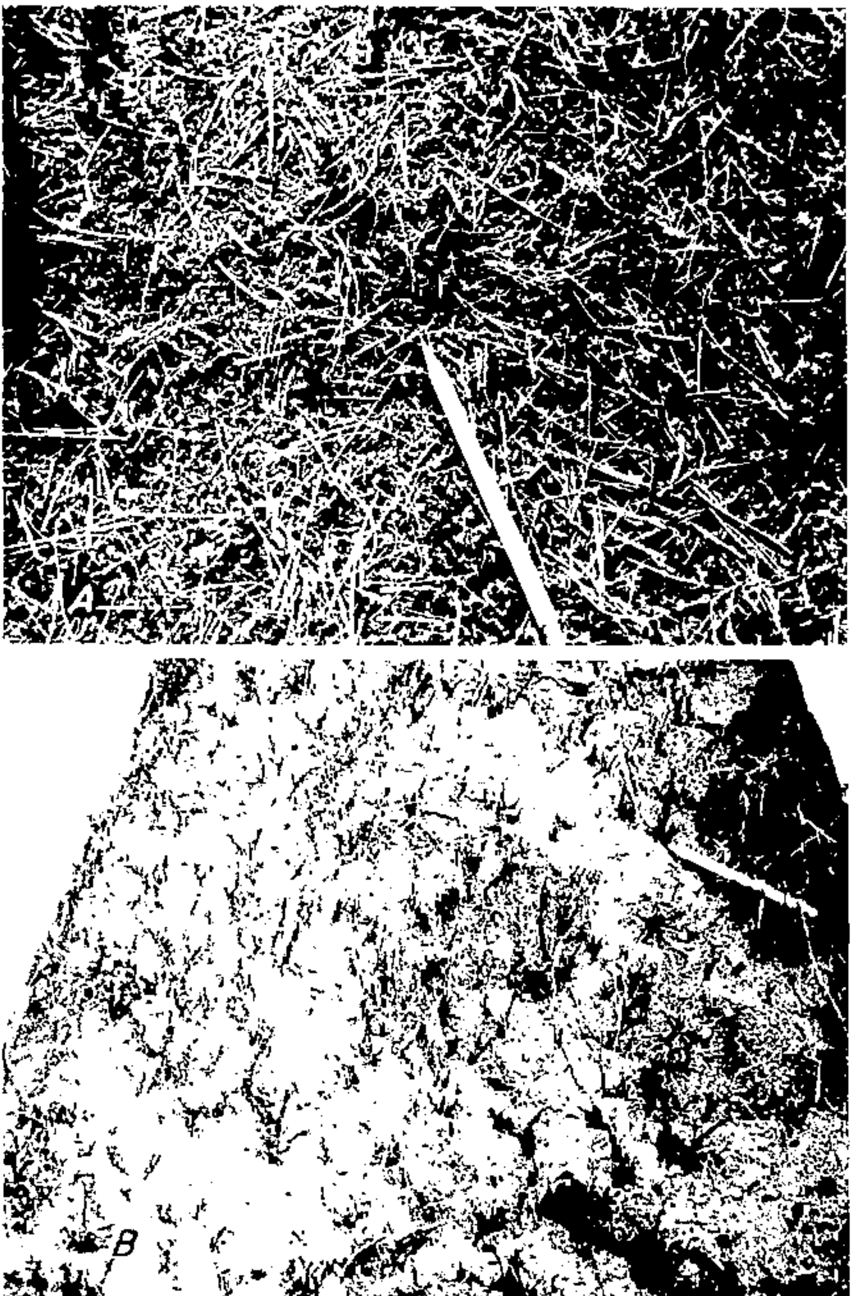

FIGURE 51.—Sericea lespedeza channel B2 100' (A) before testing and (B) at conclusion of testing.

FIGURE 55.—Sericea lespedeza channel B2–10B (*A*) before testing and (*B*) during test 3.

Stems remained erect during test 1; bent slightly during test 2; bent farther, and a third of them became submerged, during test 3 (fig. 55, *B*). All but a few were submerged during test 4, and all were submerged during test 5. Water surface rough. Value of n was lower for test 1 than for test 2 because foliage did not occur in abundance on stems to height of about 0.15 foot above ground line. At completion of tests, value of n was still decreasing rapidly as depth and velocity of flow increased.

Scour was almost imperceptible. Even some dead leaves and other mulch remained in place on bed. Some scoured material was deposited on downstream side of stems.

Channel B2–14C

Bed slope 3 percent, bottom width 2 feet, sides vertical (sheet-metal side walls used), length 50 feet, planted May 1939 by seeding. Channel very regular in cross section, slope, and alinement.

Experiment 1, March 1940, vegetation dormant and uncut.—Sericea lespedeza on average 17 inches high, 88 plants per square foot (fig. 56, *A*). Soil surface covered by layer of dead leaves. Soil firm.

Equipment: For measuring inflow, 1-foot H-flume in tests 1–3, 2-foot H-flume in other tests; for measuring outflow, weighing tank in tests 1–4, 1-foot H-flume in test 5; point gages.

Three men made water-surface measurements simultaneously at three stations, making one set for each of tests 1–6 and making two for each of the remaining tests without rotating positions. There were two 10-foot reaches.

In tests 1–3, flow was practically hidden by mulch in channel. The loose material was washed out by succeeding tests, until at the completion of test 8 it was gone. Submergence of vegetation started during test 7 (fig. 56, *B*), and was complete during test 10. Water surface was fairly smooth until

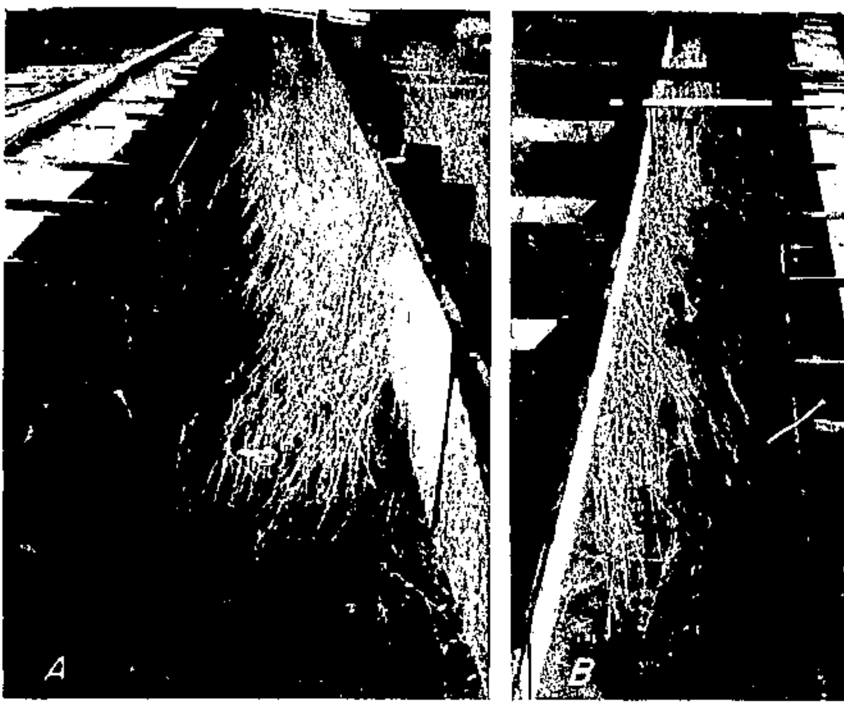

FIGURE 56.—Sericea lespedeza channel B2–14C (*A*) before testing and (*B*) during test 7.

test 7. In this and later tests the surface became more and more rough until it was very rough in test 11. A high initial value of n resulted from resistance of the layer of dead leaves to a flow 0.07 foot deep. Retardance remained practically constant during flows 2–6, and no marked change in n occurred until depth and velocity of flow became great enough to effect considerable bending and submergence.

Slight scour occurred in final test, practically none in earlier tests. All loose mulch was washed out, and a few stalks were broken off.

Channel B2–14B

Channel description same as that of channel B2–14C.

Experiment 1, June 1940, vegetation green and uncut.—Sericea lespedeza, on average, 16 inches high, 135 plants per square foot. Soil firm.

Equipment: 2-foot H-flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

In test 1 vegetation bent slightly but remained above water surface; in test 2 it bent farther and a few stems became submerged (fig. 57, *A*). In test 3 all but 10 percent of the stalks were beneath the water surface. In test 4 all vegetation was submerged and the flow was decidedly rough. High level of n values in agreement with those for other channels having similar linings. At completion of experiment values of n were still decreasing rapidly as depth and velocity increased.

Practically no scour took place (fig. 57, *B*). After the testing, the vegetation rapidly recovered its upright position (fig. 58).

Channel B2–14A

Channel description same as that of channel B2–14C.

Experiment 1, October 1940, vegetation green and recently cut.—Sericea lespedeza averaged probably 2 inches in height (fig. 59). No stand count made; uncut stand described as very good. Soil firm.

Equipment: 2-foot H-flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Vegetation was submerged except for a few stems during tests 1 and 2, and was completely submerged during other tests. Water surface rough.

Very little erosion occurred.

Hydraulic Behavior of Sericea Lespedeza

The retarding influence of sericea lespedeza on water flow varies widely according to season, length, density, age, and maintenance. The magnitude of the variation is illustrated by figure 60, which presents results from channels identical in cross-sectional shape and slope and having good linings that were closely similar. Long woody stalks, not tested, would cause even greater retardance.

The stems of tall green sericea not yet in a woody condition are relatively large in diameter but sufficiently pliant to bend when subjected to flows of the depths and velocities common in field waterways. Figure 51, presenting n–VR relations, includes data on the behavior of long green sericea as the value of VR increased. When VR reached a value of about 0.3, bending started. At $VR = 0.9$, submergence was well advanced. The bending and flattening presumably continued somewhat beyond $VR = 4.0$, as n had not begun at that point to approach a constant value. For long green Bermuda grass, n had reached a constant value when VR equaled 4. In comparison with n values for Bermuda grass those for sericea lespedeza at given values of VR are considerably higher. At $VR = 1.0$, the n value for the lespedeza is more than twice as great as that for Bermuda grass.

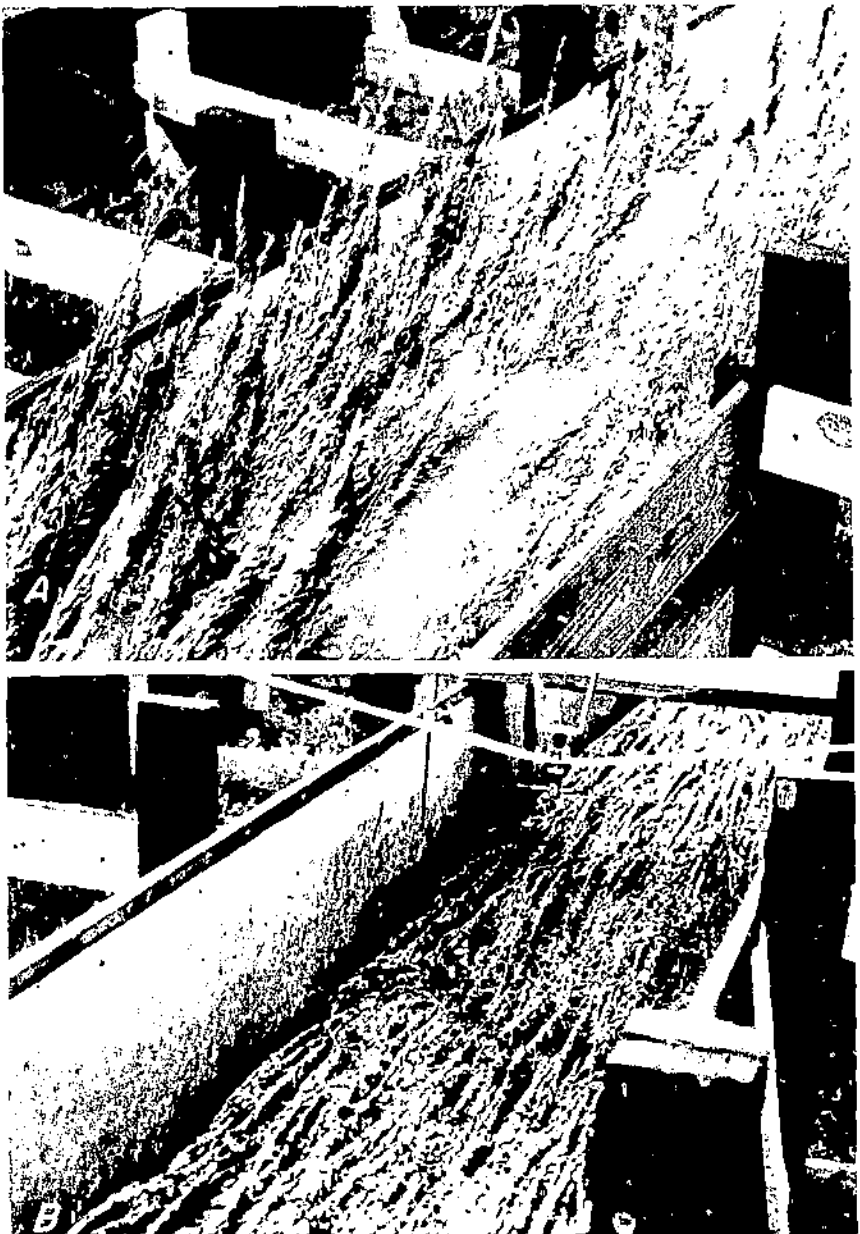

FIGURE 57. Sericea lespedeza channel B2-11B (A) during test 2 and (B) at completion of testing.

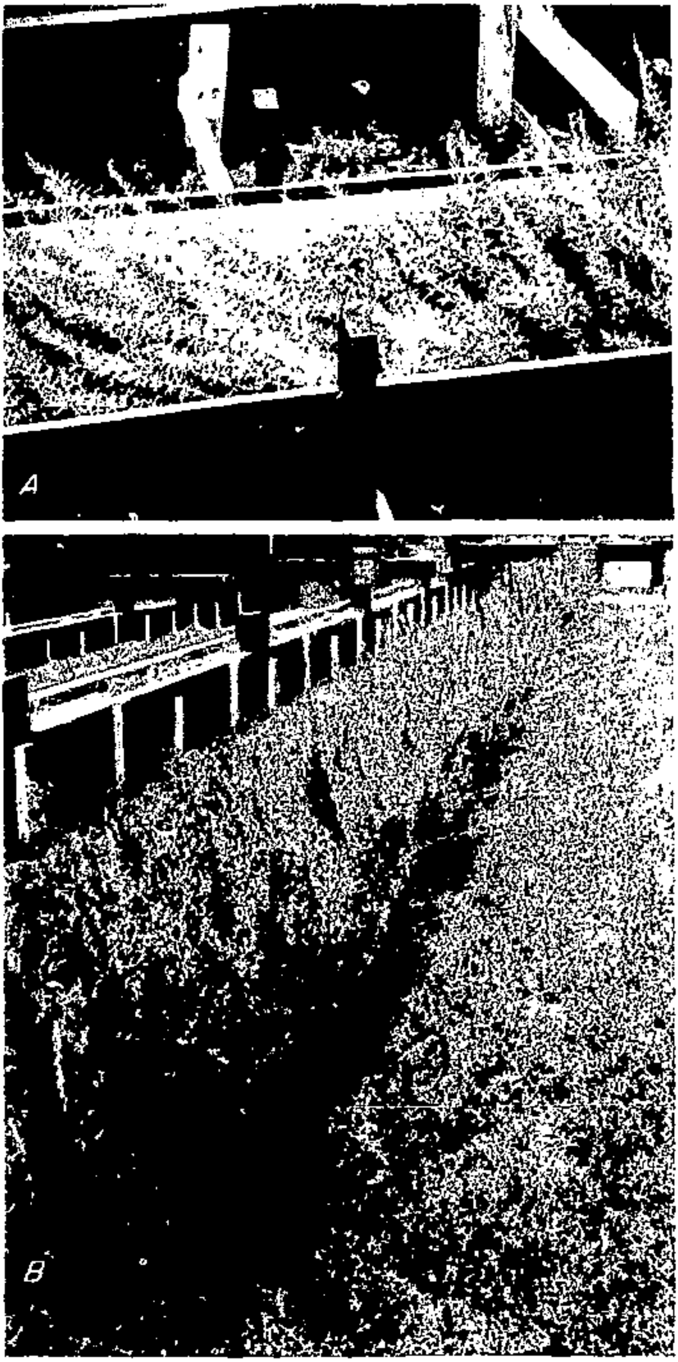

FIGURE 58.—Sericea lespedeza channel B2–14B (*A*) 24 hours and (*B*) 9 days after being subjected to a series of five 40-minute test flows.

The n–VR relation for two channels lined with long dormant sericea lespedeza is presented in figure 51, *B*. The retardance coefficients reflect the wide difference in vegetation density that existed between these channels. Channel B2–14C had a good stand that when green would be comparable to those of channels B2–10B and B2–14B. At the same VR value the dormant plants,

FIGURE 59.—Sericea lespedeza channel B2–14A. View of channel bottom before testing.

devoid of foliage, offered about 50 percent less resistance to flow. However, owing to the stiffness of the stalks and their resistance to bending the retardance coefficients were maintained at a high level until VR was 0.3.

When sericea lespedeza was cut short all that remained of it was stiff stalks that offered low resistance not greatly different from that of cut common lespedeza. Short Bermuda grass causes greater flow retardance at a given VR value less than 2.5 than short sericea lespedeza, because it covers the ground more completely.

Stability of a Channel Lined with Sericea Lespedeza

Sericea lespedeza in a woody state permitted considerable scour. The turbulence set up around each stiff stem scoured the soil at the base of the stem. This was noticed both in the tests on channel B2–1 and in those on channel B2–4. The scour rates were somewhat higher in channel B2–1, where the lining was in a dormant state. From these experiments it appears that the permissible velocity of flow for a channel having a dormant uncut lining is approximately 2.5 feet per second and that for a channel having a woody green lining is approximately 3 feet per second.

The tests on the two channels having green uncut linings (B2-10B and B2-14B) caused no appreciable scour. The retardance coefficients were so high that the capacity of each channel was exceeded before scouring velocities were produced. It is believed that the protective capacity of green sericea lespedeza exceeds that of green annual lespedeza. Accordingly, until more information is available it is recommended that the permissible velocity for a channel having a green uncut lining of this species not yet in the woody stage be set not lower than 5.5 feet per second.

Tests of rectangular channels showed 3 feet per second to be the maximum permissible velocity of flow for channels lined with dormant vegetation, either short or long. The test of channel B2-14A when the lining was green and short caused very little scour even though the flow reached a velocity of 6.4 feet per second. The soil in the bottom of the channel was hard during these tests. If the soil had been less firm, erosion certainly would have taken place. It is believed that 3.5 feet per second is a permissible velocity for a lining in this condition.

Results of the experiments on sericea lespedeza indicate that in the green pliant stage this plant is an excellent cover for channels. Because of the scour produced when the vegetation is in the woody state, it seems desirable to cut it before it reaches that

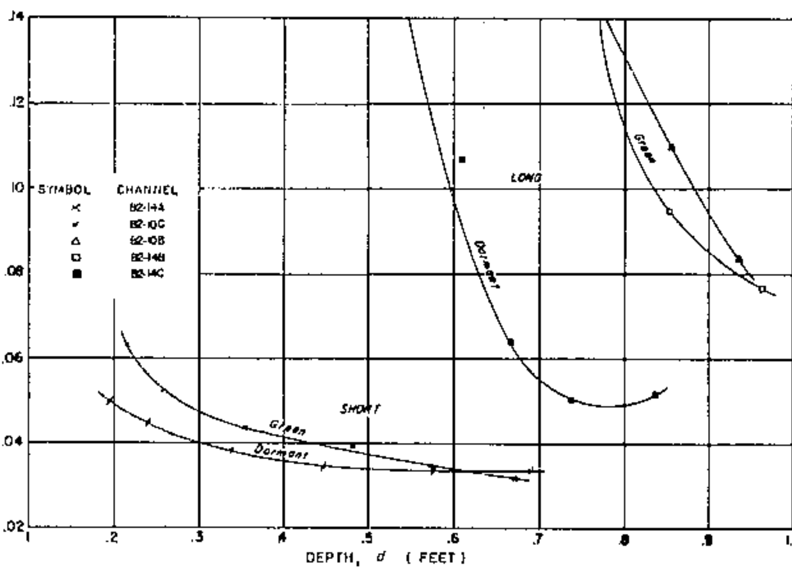

FIGURE 60.—Relation of Manning's n and depth of flow for channels lined with short green, short dormant, long green, and long dormant sericea lespedeza. Bed slope 3 percent, bottom width 2 feet, sides vertical (sheet-metal side walls used). Time of testing: B2-14A, October; B2-10C, April; B2-10B, June; B2-14B, June; BC-14C, March. The increase in n_m for channel B2-14C was due to scour.

state. This recommendation concurs with the usual practice of cutting sericea lespedeza for hay before it becomes woody.

SUDAN GRASS EXPERIMENT

Sudan grass is a rapidly growing annual very widely used in the United States (*11*). It is particularly adapted for lining waterways where the flow cannot be diverted and a rapidly established cover is needed for temporary protection until perennial grasses can become established. When seeded broadcast it grows 2 to 5 feet high and has stems about 3/16 inch in diameter. It is one of the most productive and palatable of all annual pasture grasses for summer grazing. It is primarily a hay grass, its feeding value being equal to that of millet, timothy, Johnson grass, and other nonleguminous roughage species.

Experimental conditions and results for the channel lined with Sudan grass are presented in table 12, and further information regarding the experiment on this channel is here summarized.

Record of Experiment

Channel B2–3

Bed slope 6 percent, bottom width 2 feet; side slope 3:1, length 50 feet, planted by seeding May 17, 1937, and again June 12, 1937. Channel fairly uniform in cross section, slope, and alinement.

Experiment 1, November 1937, grass mostly dead and uncut.—Length of stems was 2 to 4 feet, density 20 plants per square foot. Soil firm.

Equipment: Sharp-crested weir, string and rod.

Tests were run in order of decreasing flow magnitude. During each test a single observer made water-surface measurements at four stations, progressing downstream. There were three 10-foot reaches.

Vegetation was submerged during all tests. Water surface rough (fig. 61).

Figure 61.—Sudan grass channel B2–3.

TABLE 12.—*Experimental conditions and results for channel B2-3, lined with long dead Sudan grass*

TRAPEZOIDAL SHAPE, BED SLOPE 6 PERCENT, BOTTOM WIDTH 2 FEET, SIDE SLOPE 3:1

Test No.	Date of testing	Discharge	Area of section, A	Mean velocity, V	Wetted perimeter, P	Hydraulic radius, R	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, n_m	Coefficients: Kutter, n_k	Value of VR
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		Cu. ft. per sec.	*Sq. ft.*	*Ft. per sec.*	*Feet*	*Feet*		*Feet*	*Min.*	*° F.*	*In. per hour*				
4	Nov. 5, 1937	15.5	3.21	4.83	7.60	0.422	0.0594	0.73	.....	48	......	30.6	0.0421	0.0335	2.04
3	Nov. 10, 1937	11.9	2.77	4.30	7.07	.392	.0600	.63	45	58	0.12	28.1	.0455	.0352	1.68
2	Nov. 11, 1937	7.27	1.83	3.96	5.91	.310	.0606	.49	44	55	.08	28.8	.0426	.0323	1.23
1	do	4.58	1.42	3.23	5.11	.278	.0634	.43	35	55	.46	24.2	.0497	.0358	.898

The fact that n increased for the final (lowest) flow is probably due chiefly to an increase in bed roughness by scour rather than to a decrease in depth and velocity.

Considerable erosion took place but did not damage the channel to the extent of complete failure.

Hydraulic Behavior of Sudan Grass

The stems of the Sudan grass were not woody, and they readily bent over and shingled under the force of the flowing water, which was not extremely turbulent. The values of Manning's retardance coefficient obtained in this experiment, with its relatively narrow range of depths, do not vary greatly from 0.045. If the tests had been run in order of increasing magnitude, as in all other experiments in this study, it is believed that retardation of flow at the lower stages would have been greater than it was.

Stability of a Channel Lined with Sudan Grass

The results of the experiment on Sudan grass indicate that a good stand of this grass growing on Cecil sandy loam in a channel of moderate slope may endure a velocity of 4 feet per second when full-grown and green. This velocity is believed to be too great for a Sudan grass lining that is young or that is grown on light sandy soil.

GRASS-MIXTURE EXPERIMENTS

For outlets that are to be grazed, a mixture of plant species is sometimes desirable (*10*). In addition to providing better pasture, a mixture may give better service as a channel lining. If the plants differ as to periods of flush growth and dormancy, better year-around protection is likely to result. Tests were con-

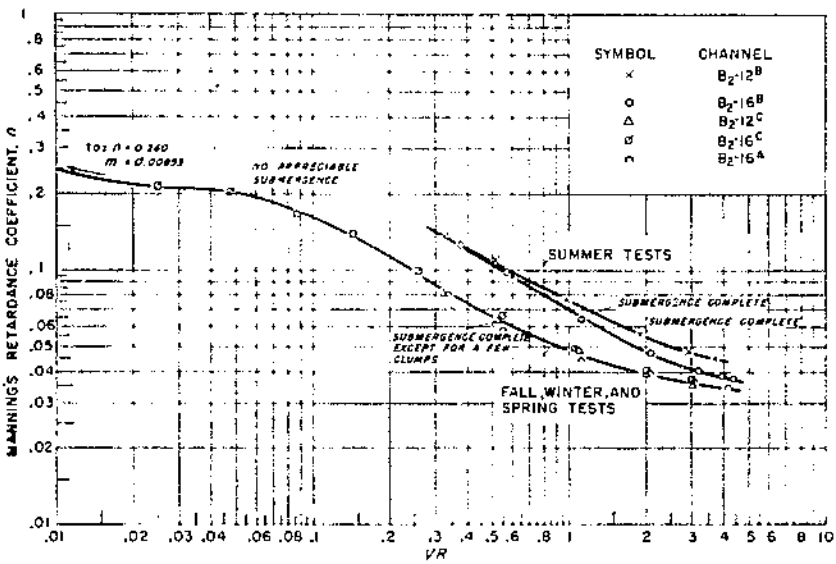

FIGURE 62.—Relation of Manning's n and VR for channels lined with a mixture of orchard grass, redtop, Italian ryegrass, and common lespedeza. Bed slope 3 percent. Data on test conditions are given in table 14.

TABLE 13.—*Experimental conditions and results for channels lined with a grass mixture*

RECTANGULAR SHAPE, BED SLOPE 3 PERCENT, BOTTOM WIDTH 2 FEET

Channel	Condition of lining	Test number	Date of testing	Discharge	Area of section, A	Mean velocity, V	Hydraulic radius, R	Effective slope	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, nm	Coefficients: Kutter, nk	Value of VR
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
				Cu. ft. per sec.	*Sq. ft.*	*Ft. per sec.*	*Feet*		*Min.*	*°F.*	*In. per hour*				
B2–12C ...	Green and dormant, short	1	Apr. 8, 1941	0.645	0.520	1.24	0.264	0.0267	42	57	0.05	14.78	0.0806	0.0517	0.327
		2	...do	1.03	.591	1.74	.300	.0274	40	55	.01	19.16	.0635	.0438	.522
		3	Apr. 9, 1941	2.16	.775	2.79	.394	.0274	40	55	.03	26.84	.0475	.0364	1.10
		4	....do	4.02	1.00	4.02	.506	.0278	41	56	–.04	34.00	.0390	.0322	2.03
		5	Apr. 10, 1941	6.00	1.19	5.03	.604	.0280	42	57	.03	38.68	.0353	.0303	3.04
		6	...do	7.97	1.38	5.76	.702	.0282	41	58	.03	41.06	.0342	.0300	4.04
B2–12B	Green and dormant, long	1	June 16, 1941	.651	.699	.934	.348	.0286	40	69	.04	9.36	.134	.0822	.325
		2	June 17, 1941	1.04	.814	1.28	.404	.0288	40	69	.02	11.88	.108	.0710	.517
		3	.....do	1.93	.958	2.02	.480	.0330	40	69	.03	17.47	.0756	.0548	.970
		4	June 18, 1941	3.76	1.18	3.19	.590	.0290	40	69	–.01	24.42	.0558	.0442	1.88
		5	.....do	5.81	1.34	4.23	.689	.0301	41	72	.01	29.36	.0476	.0395	2.91
		6	....do	7.30	1.52	4.82	.762	.0301	40	74	–.03	31.78	.0447	.0380	3.67
B2–16C ...	Green and dormant, short	1	Mar. 8, 1940	.0172	.117	.147	.058	.0288	74	49	.05	3.60	.260	.0936	.0085
		2	Mar. 15, 1940	.0499	.196	.254	.098	.0284	37	48	–.02	4.80	.212	.0900	.0249
		3	Mar. 18, 1940	.0948	.282	.336	.141	.0282	57	58	.01	5.36	.202	.0940	.0474
		4	Mar. 19, 1940	.174	.360	.483	.180	.0279	31	51	.02	6.84	.165	.0846	.0869
		5	Mar. 20, 1940	.288	.442	.653	.220	.0276	26	52	–.05	8.38	.138	.0770	.144
		6	Mar. 21, 1940	.512	.505	1.016	.252	.0279	23	51	.03	12.12	.0978	.0594	.256
		7	Mar. 22, 1940	1.092	.622	1.757	.311	.0284	40	52	.01	18.72	.0654	.0452	.546
		8	Mar. 29, 1940	2.068	.761	2.72	.381	.0289	38	51	.04	25.94	.0490	.0370	1.04
		9	Apr. 2, 1940	3.99	.990	4.04	.496	.0298	41	56	.04	33.14	.0400	.0326	2.00
		10	Apr. 3, 1940	5.93	1.17	5.05	.590	.0318	40	58	.21	36.92	.0370	.0313	2.98
		11	.....do	7.88	1.37	5.73	.691	.0350	40	60	.43	37.12	.0380	.0328	3.96

B2-16B	Green, long	1	June 26, 1940	.748	.720	1.04	.362	.0274	40	67	.10	10.54	.1240	.0756	.376
		2	June 27, 1940	1.12	.809	1.40	.404	.0283	40	67	.04	13.12	.0975	.0654	.566
		3	June 28, 1940	2.19	.928	2.36	.469	.0281	40	67	0	20.70	.0634	.0472	1.11
		4	July 1, 1940	4.14	1.12	3.70	.563	.0296	40	68	.03	28.75	.0470	.0380	2.08
		5	July 2, 1940	6.32	1.29	4.89	.651	.0307	40	70	0	34.63	.0400	.0338	3.18
		6	July 3, 1940	8.59	1.46	5.86	.740	.0318	40	72	0	38.16	.0371	.0323	4.34
B2-16A	Green and dormant, short	1	Oct. 9, 1940	.665	.520	1.28	.259	.0287	41	59	0	14.96	.0794	.0509	.332
		2	Oct. 10, 1940	1.10	.579	1.90	.289	.0288	41	59	.02	21.02	.0576	.0404	.549
		3	Oct. 11, 1940	2.24	.755	2.97	.378	.0284	41	58	.07	28.86	.0438	.0330	1.12
		4	Oct. 12, 1940	4.10	.995	4.12	.498	.0298	40	60	0	33.80	.0391	.0321	2.05
		5	Oct. 14, 1940	6.12	1.18	5.16	.594	.0310	41	61	-.04	37.77	.0360	.0308	3.06
		6	...do	8.24	1.37	6.01	.686	.0317	41	64	.02	40.92	.0341	.0299	4.12

ducted on a mixture of orchard grass, redtop, Italian ryegrass, and common lespedeza.

Experimental conditions and results for the channels lined with this grass mixture are presented in table 13, and further information regarding experiments on these channels is summarized in the following material in small type. The relation between n and VR for channels lined with this mixture is shown in figure 62. Test conditions for the channels represented in figure 62 are indicated in table 14.

TABLE 14.—*Time of testing and vegetal-lining conditions of channels lined with grass mixture from which the data represented by the n_m–VR curves in figure 62 were obtained*

Channel	Time of test	Vegetal cover		Remarks
		Height	Quality	
		Inches		
B2–12B	June	8	Fair	Cover "clumpy"; soil 30 percent bare.
B2–16B	do	6	Good	Cover fairly uniform.
B2–12C	April	4½	Fair	Cut previous fall.
B2–16C	March	4	do	Do.
B2–16A	October	5	do	Cut just before tests.

RECORD OF EXPERIMENTS

CHANNEL B2–12C

Bed slope 3 percent, bottom width 2 feet, sides vertical (sheet-metal side walls used), length 50 feet, planted May 1939 by seeding. Channel very uniform in cross section, slope, and alinement.

Experiment 1, April 1941, grasses varying in condition, cut preceding fall.—New growth of grass averaged 4½ inches in length. There were about 6 plants per square foot and about 10 grass blades per plant. About half the cover was small Italian ryegrass plants; the other half was redtop and orchard grass (fig. 63, *A*). A light growth of ground moss covered 10 percent of the channel bottom. Soil firm.

Equipment: 2-foot H-flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each man making one at each station. There were two 10-foot reaches.

Vegetation was submerged, except for a few stems, during tests 1 and 2. Water surface rough during all tests. Values of n in agreement with those for other channels having similar linings of grass mixtures that were tested in spring and fall.

No erosion was apparent on areas covered by ground moss, and little serious scour elsewhere (fig. 63, *B* and *C*). Surface of channel was washed clean of loose mulch, and fine roots were exposed in a few small areas. Many small deposits of coarse sand were located at downstream side of larger clumps of vegetation. Very little increase in erosion near side walls.

CHANNEL B2–12B

Channel description same as that of channel B2–12C.

Experiment 1, June 1941, grasses varying in condition, uncut.—Orchard grass and redtop were the only grasses evident, and they were green; Italian ryegrass was dead or dormant (fig. 64, *A*). Stems were 25 inches long, the mass of blades 8 inches long. About 3 plants per square foot, and about 2 stems and 20 blades to each plant. At least 30 percent of area was bare of cover. Soil firm and compact, but not hard.

Equipment: 2-foot H-flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each man making one at each station. There were two 10-foot reaches.

Grass blades were not completely submerged until test 3 and stems were not submerged until test 4. Water surface rough (fig. 64, *B*). Level of *n* values, high for a rather thin cover, is due largely to nonuniform and clumpy nature of cover.

Practically no change in channel bed resulted from tests.

Channel B2–16C

Channel description same as that of channel B2–12C.

Experiment 1, March 1940, grasses varying in condition, cut preceding fall.—Redtop and orchard grass were dormant, ryegrass green; dead plants but no seedlings of lespedeza present (fig. 65). No appreciable growth since cutting. Stems averaged about 4 inches in length. Average number of plants per square foot: Ryegrass, 9; redtop, 1; orchard grass, 2; dead lespedeza, 3. Average number of stems or leaves per grass plant approximately 8. Soil firm.

Equipment: For measuring inflow, 1-foot H-flume in tests 1–3, 2-foot

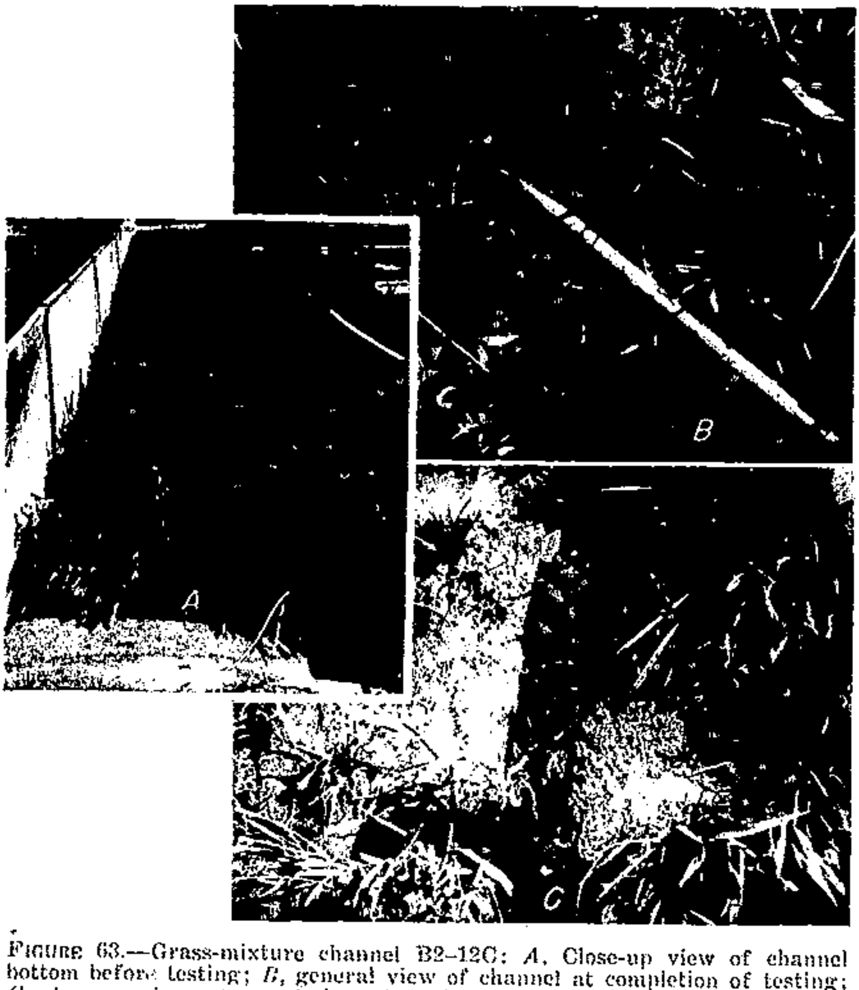

FIGURE 63.—Grass-mixture channel B2–12C: *A*, Close-up view of channel bottom before testing; *B*, general view of channel at completion of testing; *C*, close-up view, at completion of testing, of area having least cover and showing greatest erosion.

H-flume in other tests; for measuring outflow, weighing tank in tests 1-4, 1-foot H-flume in test 5; point gages.

Three men made water-surface measurements simultaneously at three stations, each man making one for each of tests 1-6 and two, at the same station, for each of the other tests. There were two 10-foot reaches.

No vegetation sumerged during test 1. Submergence began in test 2 and increased with discharge until during test 7 it was complete. Water surface was fairly smooth during test 1 but gradually roughened as discharge increased until it was decidedly rough during final test. Values of n in agreement with those for other channels having similar linings of grass mixtures that were tested in spring and fall.

There was no erosion during tests 1-8; during later tests very slight scour occurred.

Channel B2-16B

Channel description same as that of channel B2-12C.

Experiment 1, June 1940, grasses varying in condition, uncut.—Orchard grass, redtop, and lespedeza were green, Italian ryegrass had already seeded and turned brown; grasses averaged about 7 inches in length, lespedeza about 3½ inches (fig. 66, *A*). Plants per square foot: Orchard grass or redtop, 3; Italian ryegrass, 5; lespedeza, 82. Soil firm.

Equipment: 2-foot H-flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

During test 1 all the lespedeza was submerged but about 30 percent of the grass remained above water; during test 2 a few grass stems remained above water; during later flows, vegetation was completely submerged. Water surface rough during all tests, becoming rougher as flow increased. High level of n values due to fact that common lespedeza cover was fairly dense and uniform and to effect of scattered clumps of orchard grass and redtop.

Practically no scour took place (fig. 66, *B*).

Channel B2-16A

Channel description same as that of channel B2-12C.

Experiment 1, October 1940, grasses varying in condition, cut.—Orchard grass and redtop green; some lespedeza green, some dead; ryegrass dormant. Grass length 4 to 6 inches. No record of stand count; photographs indicate fair density (fig. 67). Soil firm.

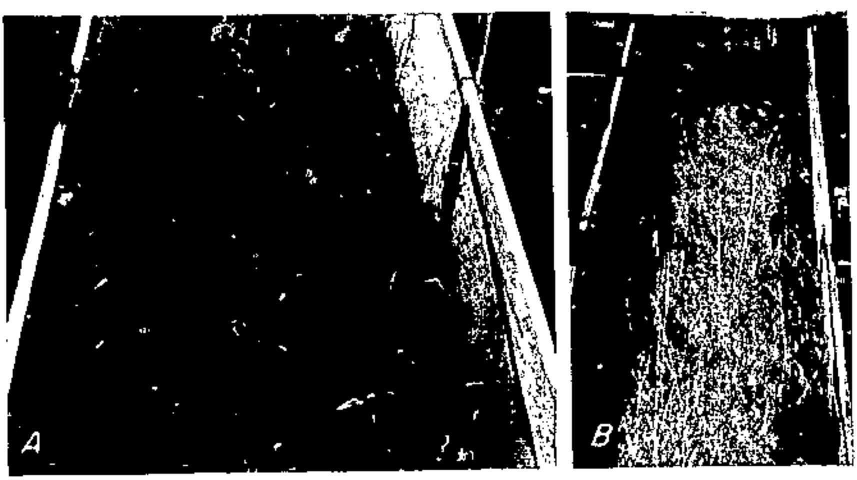

FIGURE 64.—Grass-mixture channel B2-12B (*A*) just before testing and (*B*) during test 3.

FIGURE 65.—Grass-mixture channel B2-16C before testing.

Equipment: 2-foot H-flume, point gages.

During each test three men made water-surface measurements simultaneously at three stations, each making two at the same station. There were two 10-foot reaches.

Vegetation, except for a few clumps, was submerged during tests 1 and 2. Water surface was rough; it appeared to be less rough during test 4 than during test 3, but increased in roughness in tests 5 and 6. Values of n in agreement with those for similar channels lined with the grass mixture that were tested in spring and fall.

Channel bottom remained practically unchanged.

Hydraulic Behavior of Grass Mixture

Of the grasses used in mixture to line channels B2-12 and B2-16, both the orchard grass and the redtop tend to grow in heavy clumps. A lining of these two grasses without other grasses or vegetation between them tends to cause rather rough and irregular flow. However, when depth of flow is great enough to submerge the plants and stems of the grasses completely these irregularities are to some extent drowned out. When other vegetation is growing between the clumps, making the cover more uniform, more satisfactory hydraulic behavior results.

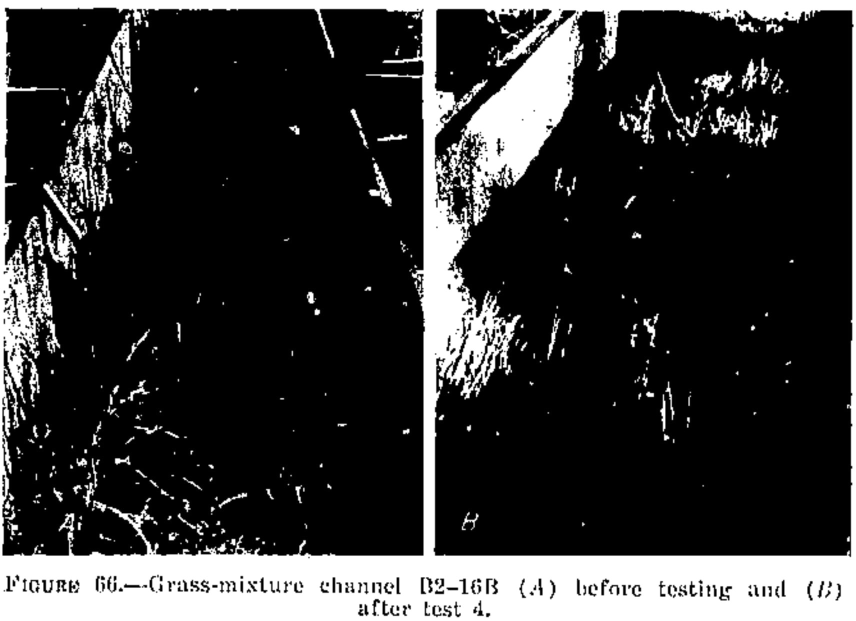

FIGURE 66.—Grass-mixture channel B2-16B (*A*) before testing and (*B*) after test 4.

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FLOW OF WATER IN CHANNELS PROTECTED BY VEGETATIVE LININGS
REE, W.O., PALMER, V.J. 2 OF 2

The relation of n and VR for the two series of grass-mixture channels, B2–12 and B2–16, which had similar bed slope and cross-sectional shape, varies considerably with season and height of

FIGURE 67.—Grass-mixture channel B2–16A, before testing.

grass (fig. 62). It is not possible to do more than generalize on the effect of each of these variables. The three experiments conducted in the fall, winter, or spring were on vegetation cut in the fall to a length of 4 to 5 inches. The n–VR relation is almost identical with that obtained in tests of channels lined with dormant Bermuda grass of about the same height.

With Italian ryegrass and common lespedeza dominating the mixture, the channels had some green protective cover at every season. In the summer a good stand of lespedeza in channel B2–16B formed a rather dense, fairly uniform cover that resulted in an n–VR relation similar to that for channels lined with long green Bermuda grass. During the late fall, winter, and spring, Italian ryegrass afforded a fair cover, helping to maintain values of n again on a level with those for a channel having a uniform cover like Bermuda grass.

Channel B2–12B, tested in June, showed values of n relative to VR comparable to those for channel B2–16B, even though very little lespedeza was present. The cover consisted of clumps of green orchard grass and redtop with stems 25 inches long and the mass of blades 8 inches long. At least 30 percent of the surface area was bare. The nature of the cover and the length and bulk of the vegetation tended to develop and maintain excessive turbulence resulting in high n values.

Stability of a Channel Lined with Grass Mixture

The mixture of grasses and lespedeza offered good all-year protection for the channel. In early spring, when the grasses were dormant and the new lespedeza seedlings had not yet appeared, the Italian ryegrass was green and offered good protection to the channel. For a channel having a lining in this condition the permissible velocity of flow is 5 feet per second.

In the tests made on uncut grass in June, velocities were not high enough to cause appreciable scour of the channel bed. On the basis of experience with grass linings it is believed that the permissible velocity for a channel lined with this grass mixture in the summer is about 6.5 feet per second. Permissible velocity for fall when the lining is short can be set at 6.5 feet per second.

BARE-CHANNEL EXPERIMENTS

Experiments were conducted on three bare-earth channels. By comparing the soil losses in these channels with those in vegetation-lined channels otherwise identical with them, some measure of the protection afforded by the vegetation is derived.

Experimental conditions and results for the bare-earth channels are presented in table 15, and further information regarding the experiments on these channels is here summarized.

Record of Experiments

Channel B2–3

Bed slope 6 percent, bottom width 2 feet, side slope 3:1, length 50 feet; topsoil placed, graded, and tamped April 5, 1938. Channel very uniform in cross section, slope, and alinement.

Experiment 1, April 19–23, 1938.—Soil still loose.

Equipment: Sharp-crested weir, string and rod.

During each test a single observer made water-surface measurements at four stations, progressing downstream. There were three 10-foot reaches.

Water surface was decidedly rough except at start of first test. Erosion during each test changed flow characteristics during the test. A general increase in n as testing progressed resulted from increase in bed roughness through scour.

The channel was scoured rapidly. Even the lowest flow eroded the lower portion of the channel to the stiff underlying clay.

Channel B2–13C

Bed slope 3 percent, bottom width 2 feet, sides vertical (sheet-metal side walls used), length 50 feet; topsoil placed and graded May 1939. Channel uniform in cross section, slope, and alinement.

Experiment 1, April 1941.—Weed pulling and light raking had disturbed the surface, but the soil base was firm (fig. 68, *A*).

Equipment: 2-foot H-flume, point gages.

Three men made water-surface measurements simultaneously at three stations.

During test 1 two measurements were made at each station; during each of the remaining tests, each man made one measurement at each station. There were two 10-foot reaches.

Water surface was slightly rough during test 1 and became rougher until during test 3 it was wavy and very rough.

Considerable scour took place (fig. 68, *B*), particularly along walls of channel.

Channel B2–13B

Channel description same as that of channel B2–13C.

Experiment 1, June 1941.—Soil was firm; it had been disturbed slightly by pulling of a few small weeds.

Equipment: 2-foot H-flume, point gages.

TABLE 15.—*Experimental conditions and results for bare channels*

TRAPEZOIDAL SHAPE, BED SLOPE 6 PERCENT, BOTTOM WIDTH 2 FEET

Channel	Side slope, z	Experiment number	Test No.	Date of testing	Discharge	Area of section, A	Mean velocity, V	Wetted perimeter, P	Hydraulic radius, R	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, n_m	Coefficients: Kutter, n_k
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
					Cu. ft. per sec.	*Sq. ft.*	*Ft. per sec.*	*Feet*	*Feet*		*Feet*	*Min.*	*°F.*	*In. per hour*			
B2-3	3:1	2	1	Apr. 19, 1938	2.93	0.471	6.22	2.84	0.166	0.0731	0.22	33	61	1.05	57.4	0.0199	0.0167
			2	Apr. 26, 1938	4.75	.680	7.00	3.32	.205	.0676	.33	45	62	1.19	62.4	.0191	.0166
			3	Apr. 27, 1938	7.56	1.07	7.09	3.86	.277	.0578	.43	31	64	.94	57.5	.0212	.0185
			4	Apr. 28, 1938	11.4	1.42	8.01	4.49	.317	.0727	.48	41	65	1.19	53.8	.0232	.0201

RECTANGULAR SHAPE, BED SLOPE 3 PERCENT, BOTTOM WIDTH 2 FEET

Channel	Side slope, z	Experiment number	Test No.	Date of testing	Discharge	Area of section, A	Mean velocity, V	Wetted perimeter, P	Hydraulic radius, R	Effective slope	Center depth	Duration of flow	Water temperature	Average rate of scour or deposition	Coefficients: Chezy, C	Coefficients: Manning, n_m	Coefficients: Kutter, n_k
B2-13C	0	1	1	Apr. 8, 1941	0.646	0.190	3.40	......	0.097	0.0344	......	40	57	1.36	59.70	0.0170	0.0140
			2	do	1.033	.242	4.26	......	.122	.0295	......	40	54	.03	70.82	.0148	.0130
			3	Apr. 9, 1941	2.16	.361	5.67	......	.192	.0258	......	15	55	1.95	80.52	.0140	.0130
B2-13B	0	1	1	June 16, 1941	.654	.220	2.97	......	.112	.0308	......	35	69	.52	51.02	.0204	.0162
			2	June 17, 1941	1.03	.250	4.11	......	.127	.0314	......	40	69	.22	65.20	.0162	.0140
			3	do	1.91	.361	5.30	......	.182	.0306	......	40	69	.34	71.11	.0158	.0142
			4	June 18, 1941	3.72	.539	6.90	......	.273	.0322	......	40	69	.40	73.99	.0162	.0150

FIGURE 68.—Bare channel B2-13C (*A*) before testing and (*B*) after only 8 minutes of test 1.

During each test three men made water-surface measurements simultaneously at three stations, each man making one at each station. There were two 10-foot reaches.

Water surface was not very rough.

Considerable scour occurred, apparently uniform over whole surface of channel.

DISCUSSION OF RESULTS ON BARE CHANNELS

At the start of each experiment, before any erosion occurred in the channel, flow was fairly smooth. As testing progressed and an irregular scour pattern developed, flow generally became rougher. The retardance coefficients for channel B2-3, experiment 2, show that the channel became rougher as testing progressed. They are at a much lower level than those for the channels lined with vegetation.

Soil-loss rates were high for all tests on the three bare-earth channels. Permissible velocities for such channels are probably not more than 1 foot per second.

FIELD APPLICATION OF RESULTS

RETARDANCE COEFFICIENTS

A graphic method of designing vegetation-lined channels has been developed on the basis of the relation between *VR*, the product of mean velocity of flow and hydraulic radius, and *n*, the retardance coefficient. Manning's flow formula is solved on this basis for various slopes and for different kinds of vegetation.

Channel design curves have been developed for long green, short green, and short dormant Bermuda grass (fig. 69–71). (The last-mentioned condition is the one in which Bermuda grass is least effective in protecting a channel from erosion.) In addition such a curve has been developed for long green sericea lespedeza (fig. 72), because such vegetation differs widely from long green Bermuda grass in structure, manner of growth, and influence on hydraulic behavior of a channel.

The first items known in a field channel problem are maximum discharge and bed slope. The design requires selection of a channel section of such size and shape that the expected volume of water can flow through the channel at a velocity not exceeding the maximum velocity permissible. This can be done directly through use of the design curves presented as figures 69–72 and the graphic solutions of elements of trapezoidal, triangular, and parabolic channel shapes presented as figures 73–79.

The following example illustrates the procedure:

1. *Given:* $Q = 100$ cubic feet per second.
$S = 0.03$ foot per foot.

2. *Problem:* Determine the section of a channel that is to be lined with Bermuda grass. Consider a long, green condition. Design for maximum velocity of 5 feet per second.

3. *Solution for required R:* Enter figure 69 at $V = 5$, proceed right to the V–VR curve for $S = 0.03$, then downward to the R–VR curve for $S = 0.03$, then right to the R ordinate scale. The value of R is found to be 0.76. This value must obtain for any section selected if the velocity is to be 5 feet per second. Note: It is not necessary to know n, since its value is represented in the design curve placement. If desired, n_m can be determined by proceeding left from the intersection of the vertical dashed line with the n–VR curve to the n ordinate scale. In this example $n_m = 0.042$.

4. *Selection of channel section:*

a. Solve for A.

b. Determine bottom width, side slope, or top width for a trapezoidal, triangular, or parabolic section (whichever shape is desired) by the intersection of R and A in figure 73, 74, 75, 76, 77, 78, or 79.

c. Determine center depth, D, using figure 73, 74, 75, 76, 77, 78, or 79, by continuing right on the R line to the intersection with the sloping line for b, z, or t.

Dashed lines in figures 74, 77, 78, and 79 continue solution of the example from the determination of R as 0.76 foot. The area required is 20 square feet. Channel sections meeting these requirements are:

Channel shape	Side slope, z	Bottom width, b Feet	Center depth, D Feet	Top width, t Feet
Trapezoidal	3:1	21	0.85	
	6:1	14	1.01	
Triangular	8.5:1		1.53	
Parabolic			1.16	26

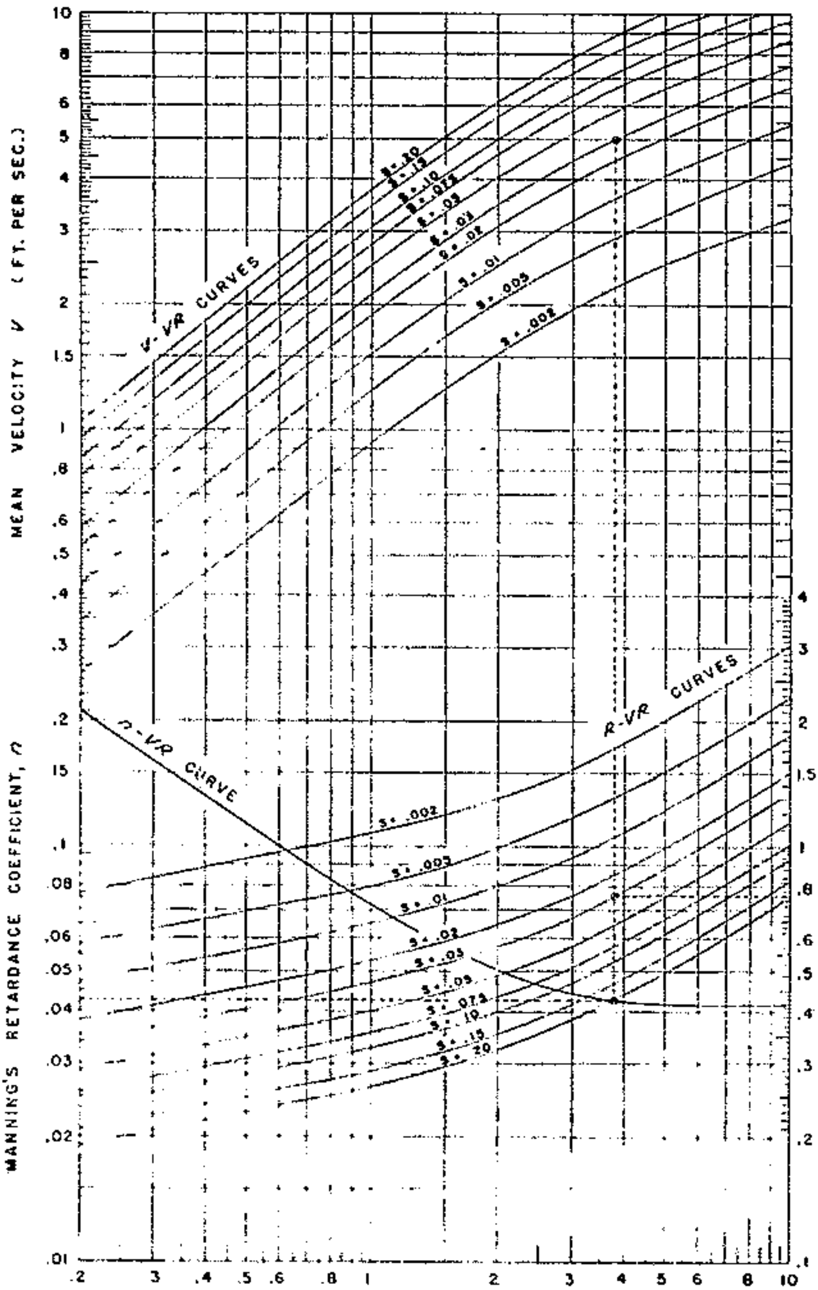

FIGURE 69.—Channel design curves for long green Bermuda grass.

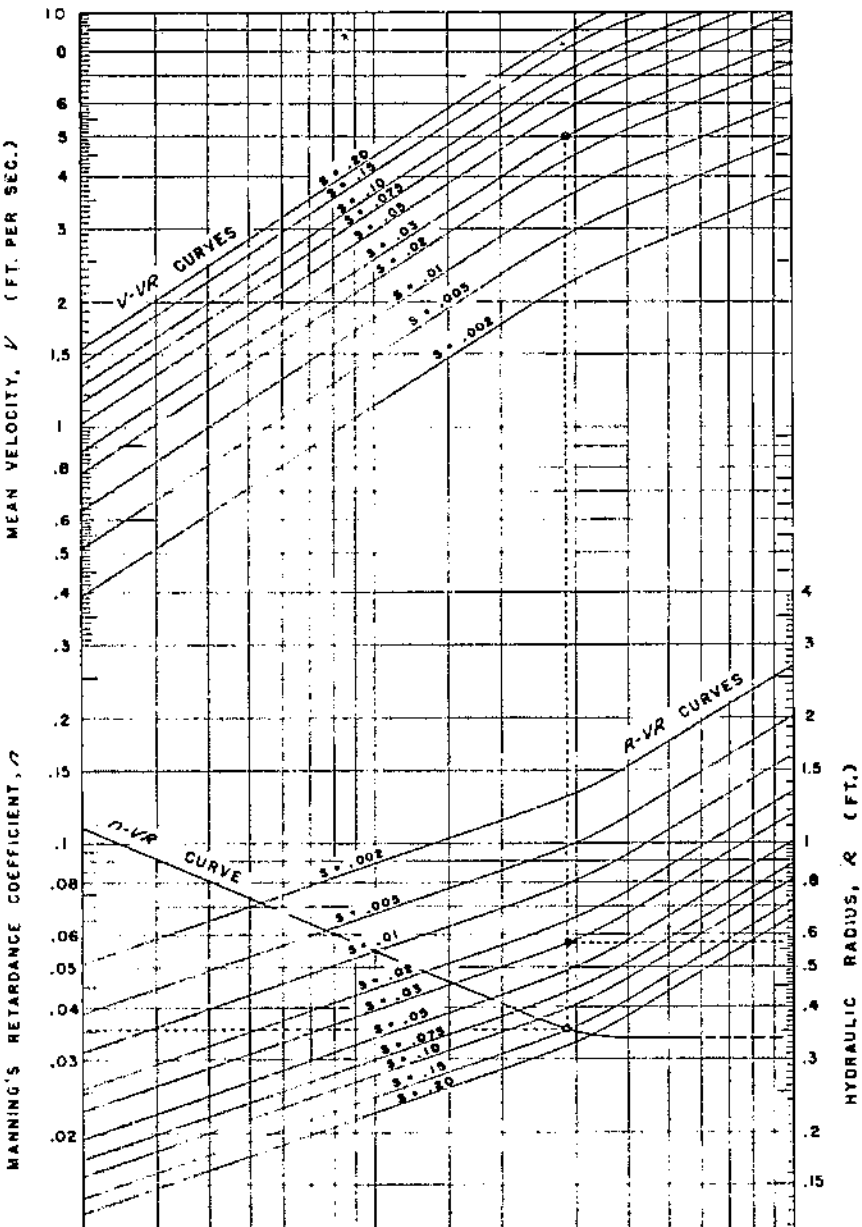

FIGURE 70.—Channel design curves for short green Bermuda grass.

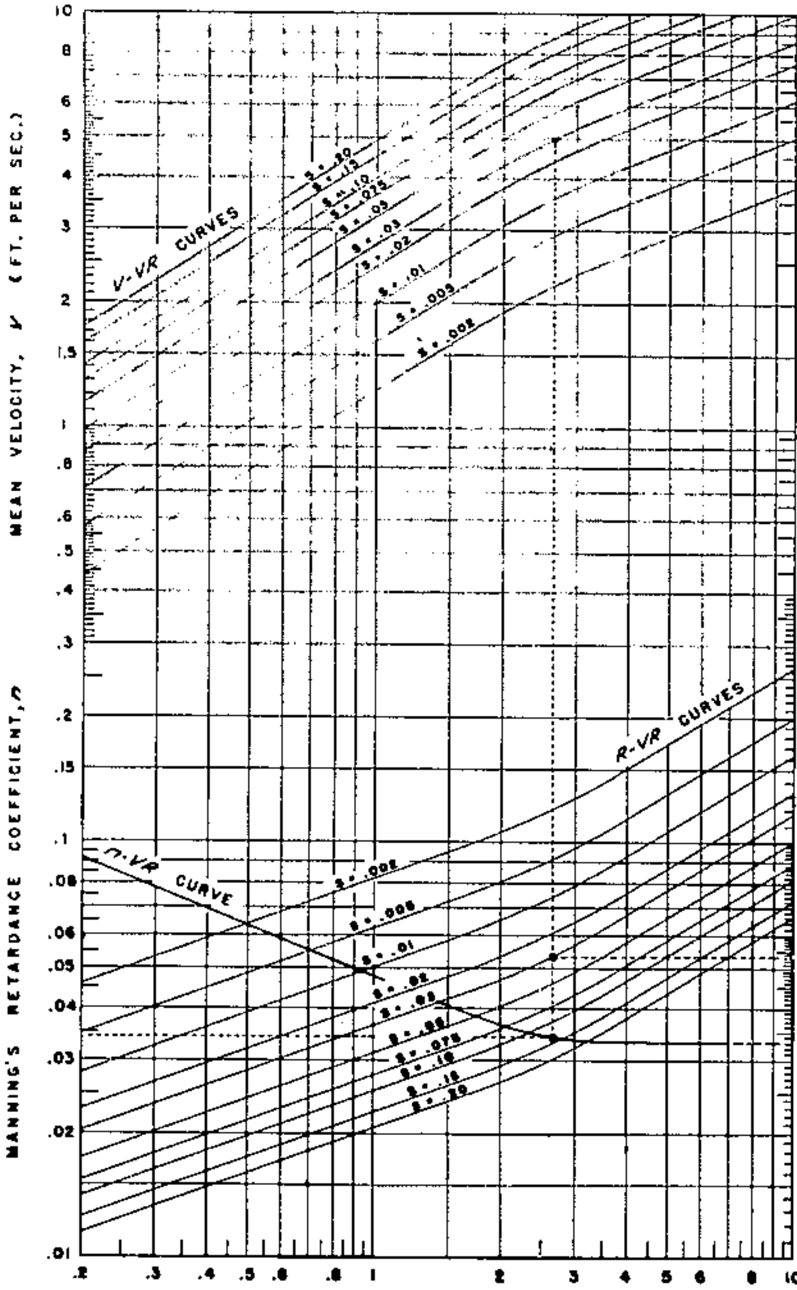

FIGURE 71.—Channel design curves for short dormant Bermuda grass.

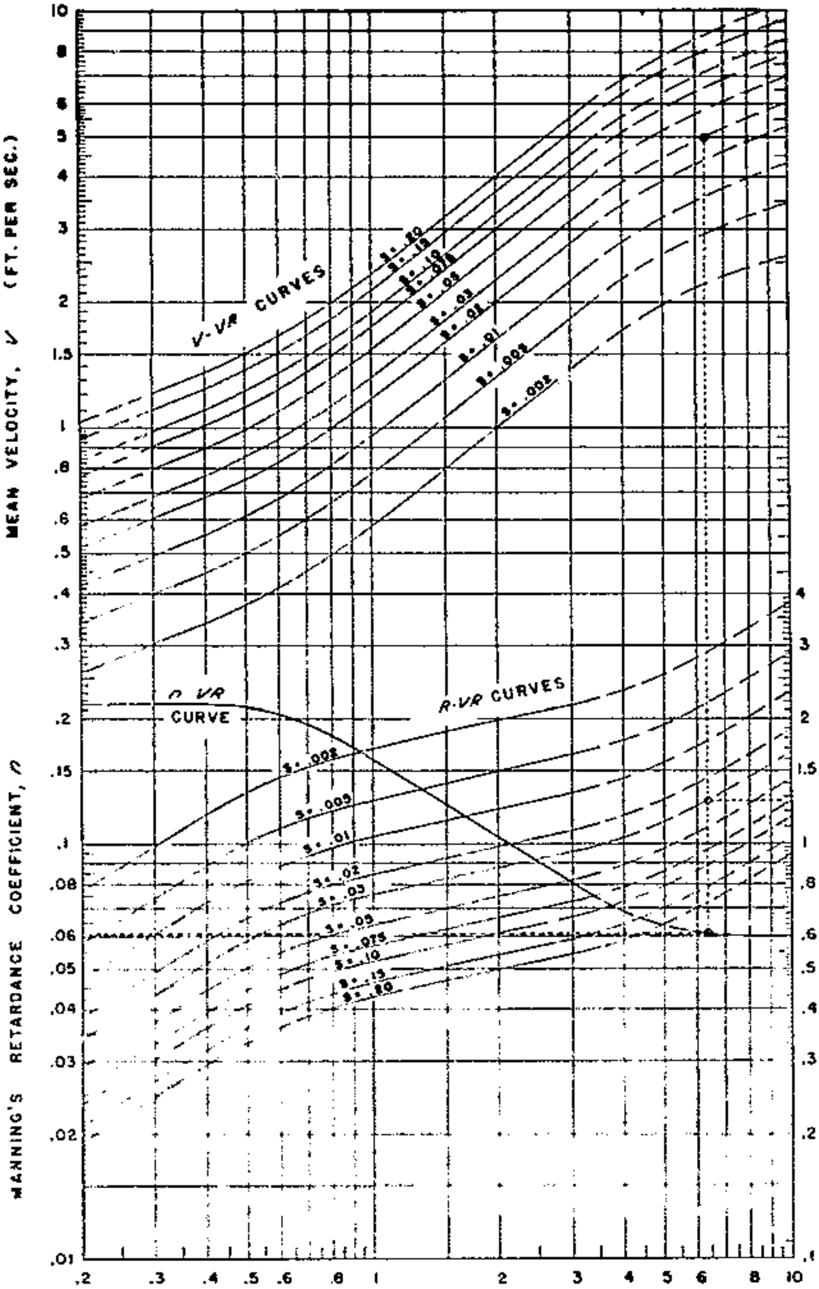

FIGURE 72.—Channel design curves for long green sericea lespedeza.

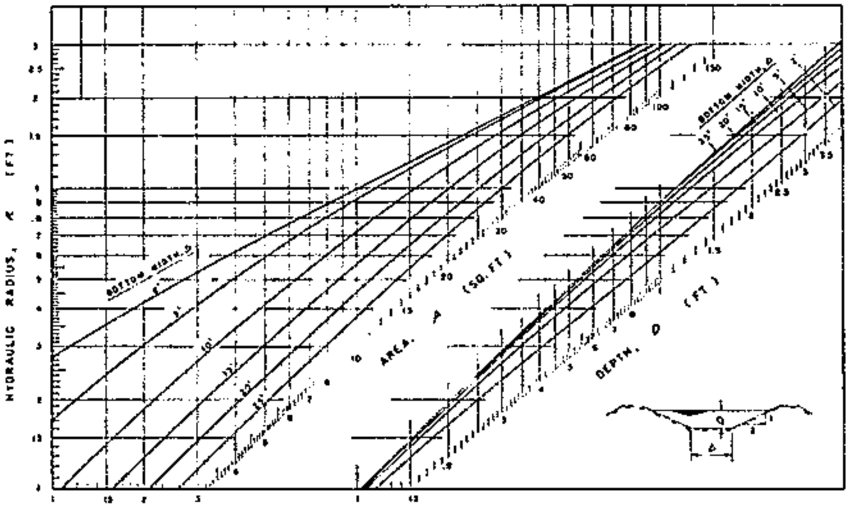

FIGURE 73.—Curves for determining the elements of trapezoidal channels with side slope 2:1.

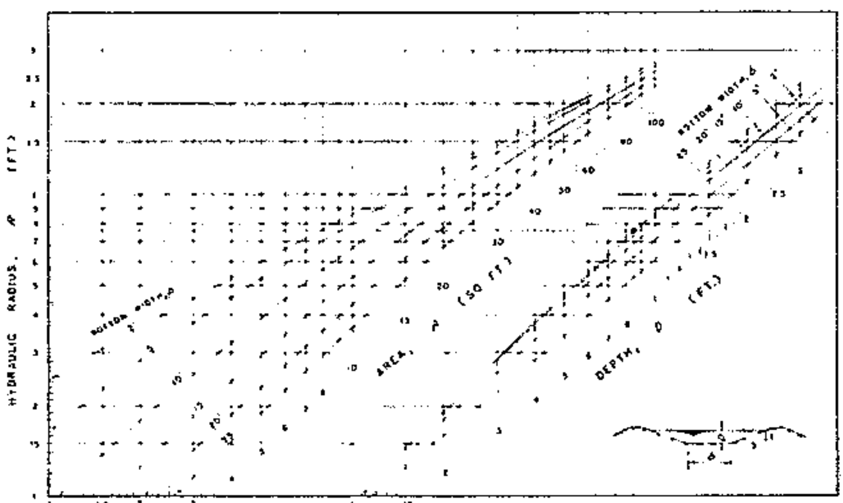

FIGURE 74.—Curves for determining the elements of trapezoidal channels with side slope 3:1.

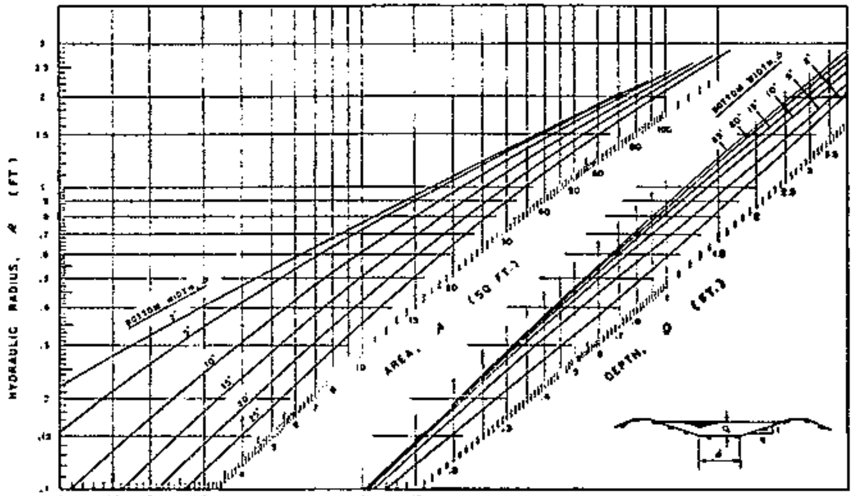

FIGURE 75.—Curves for determining the elements of trapezoidal channels with side slope 4:1.

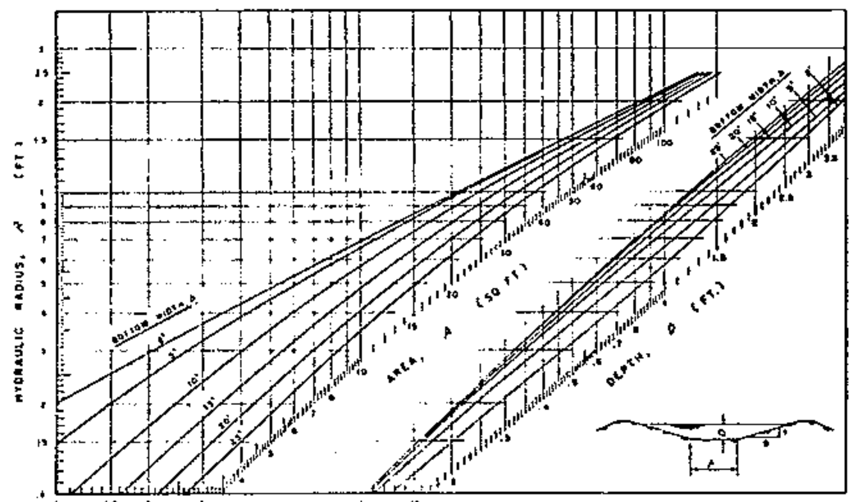

FIGURE 76.—Curves for determining the elements of trapezoidal channels with side slope 5:1.

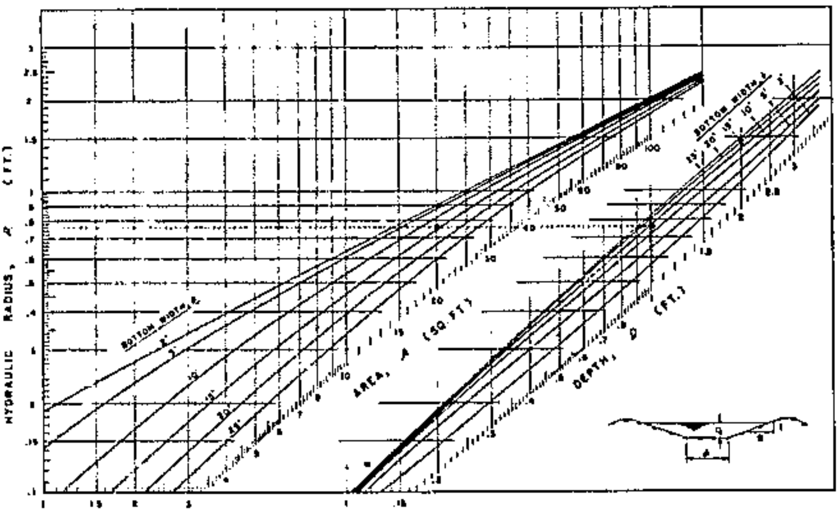

FIGURE 77.—Curves for determining the elements of trapezoidal channels with side slope 6:1.

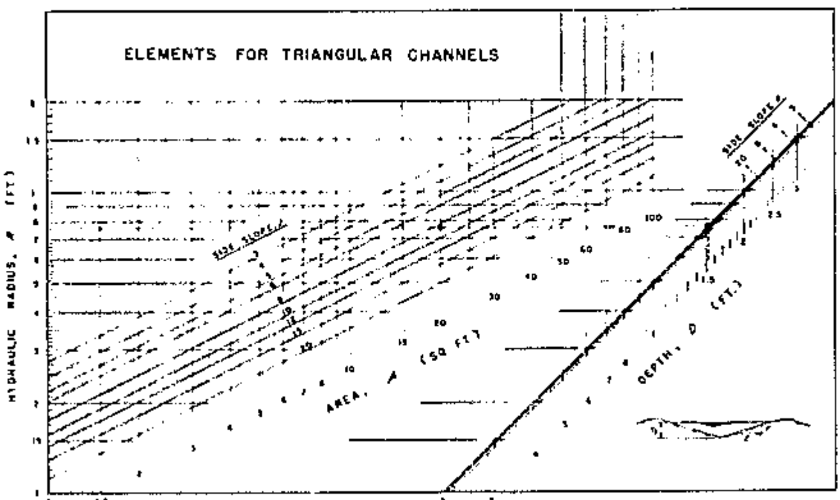

FIGURE 78.—Curves for determining the elements of triangular channels.

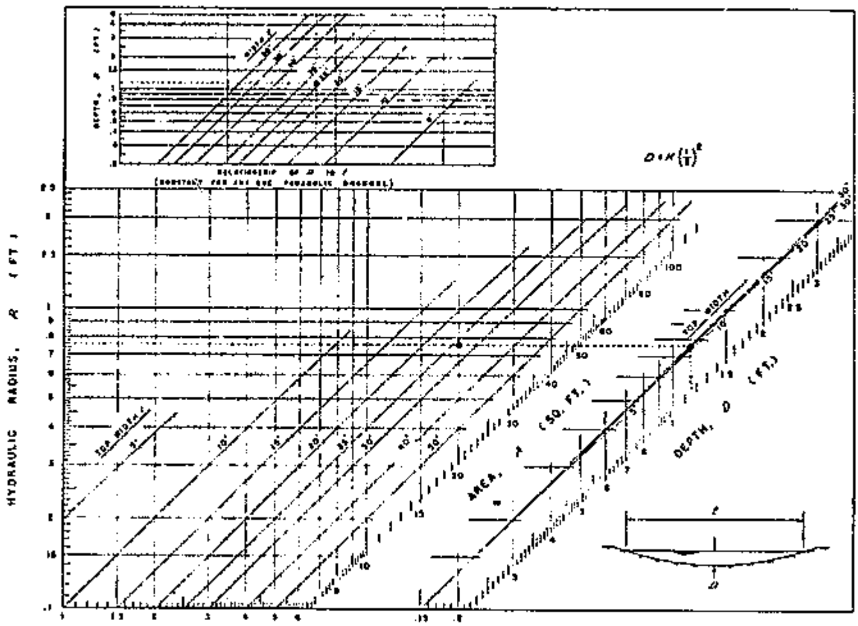

FIGURE 79.—Curves for determining the elements of parabolic channels.

The elements b, z, and t change rapidly as velocity changes. They are affected to a considerable extent by a change in velocity of as little as 0.5 foot per second. If the intersection of R and A does not lie within a graphic solution, another shape should be investigated or the velocity should be raised or lowered and the initial procedure repeated with a new R and A. Often a reselection of velocity is desirable to obtain a more favorable section.

Use of the n–VR curves developed in the study discussed here allows direct comparison of different kinds of vegetation in the principal seasonal and maintenance conditions, even though the experimental channels differed in slope and shape. Such comparisons make it possible to estimate the flow-retarding influence of other kinds of vegetation, not yet subjected to laboratory test. Thus the curves presented are of rather extensive value for application within the ranges of channel slope and depth that they represent. Figures 80–83 present n–VR curves for vegetation types and conditions other than those represented in figures 69–72, and include also the applicable n–VR curves used in the graphic solutions for Bermuda grass and sericea lespedeza. In many instances figures 69–72 may be adaptable to other covers considered to offer similar degrees of resistance to flow.

Until a given vegetal channel lining becomes well flattened toward the channel bed the value of VR indicates the degree of resistance the lining is offering. When the vegetation is prone or nearly so and well submerged, n becomes practically constant and ceases to be correlated with VR. Only scour, loss of vegetation,

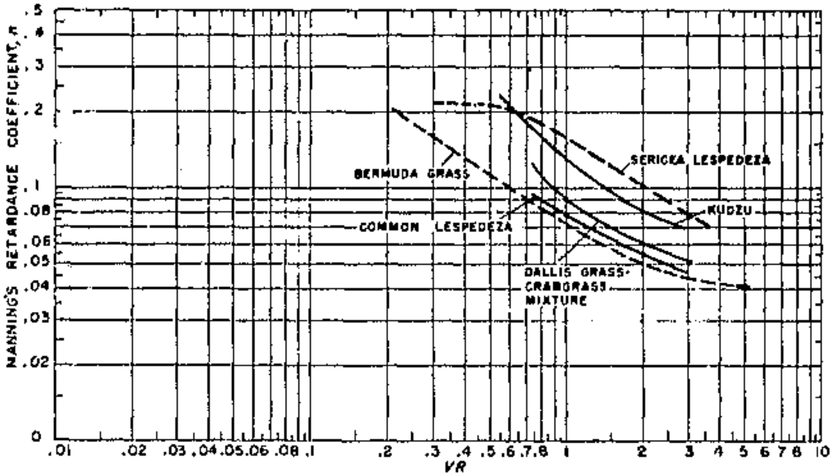

FIGURE 80.—Relation of Manning's n and VR for channels lined with dense, uniform stands of green vegetation more than 10 inches long.

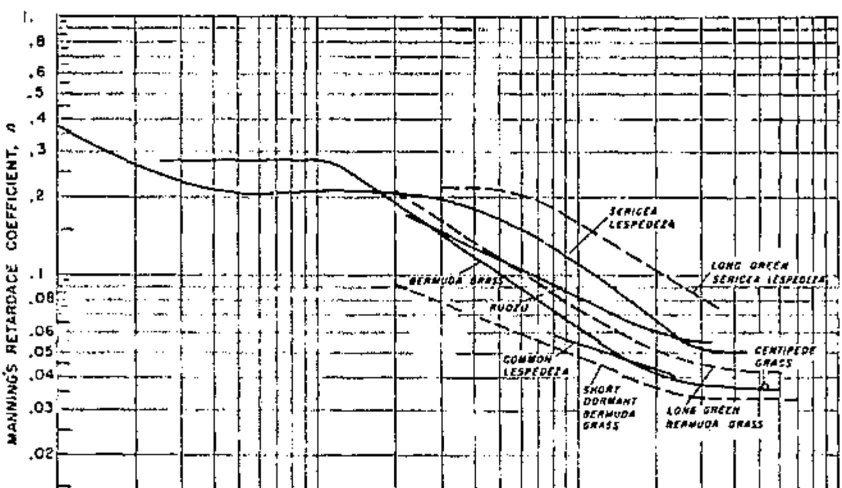

FIGURE 81.—Relation of Manning's n and VR for channels lined with dense, uniform stands of dormant vegetation more than 4 inches but less than 17 inches long. (Centipede grass value plotted represents data from five tests in which discharge was approximately the same.)

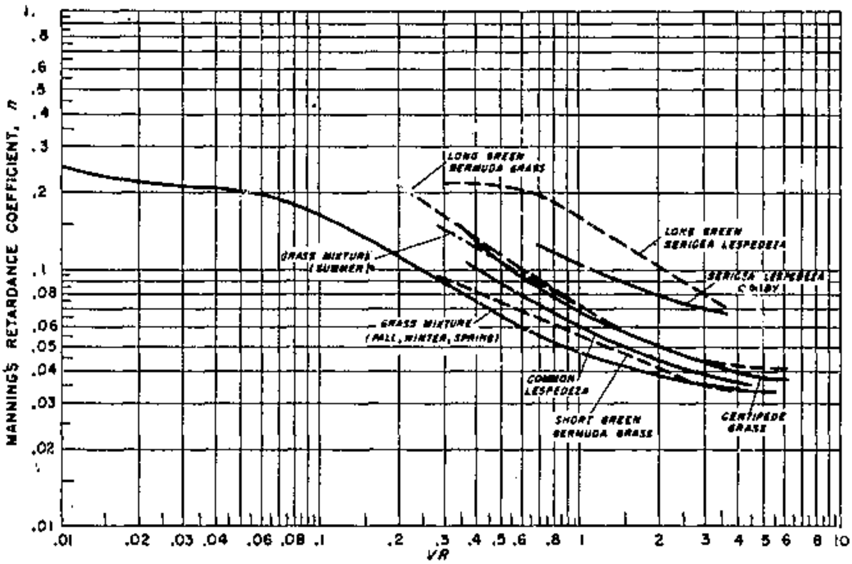

FIGURE 82.—Relation of Manning's n and VR for channels lined with dense, uniform stands of vegetation more than 4 inches but less than 8 inches long.

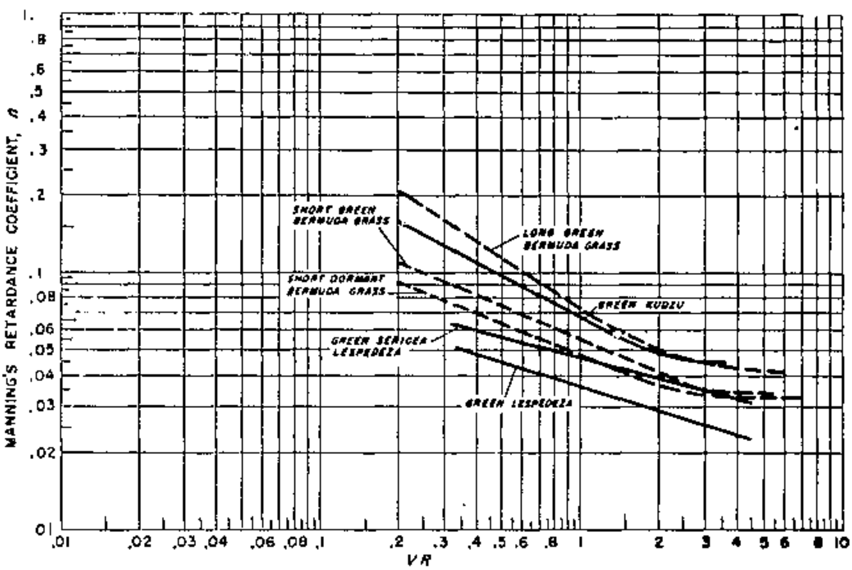

FIGURE 83.—Relation of Manning's n and VR for channels lined with dense, uniform stands of vegetation cut to a length of less than 2½ inches. (The Bermuda grass had been kept cut, the other linings had been cut for the first time just before the tests.)

and general increase in bed roughness will thereafter cause appreciable changes in n. The VR value can be used as an indicator of whether n has reached a relatively constant value. Up to a VR value of 5 for long, pliant vegetation and one of 3 for short vegetation n decreased with increase in VR. For design purposes n can be assumed to remain constant when VR values go beyond these figures.

For channels of slight slope containing vegetation that receives little or no maintenance, application of the n–VR relation has particular value. Unusually high and variable retardance coefficients may prevail under these conditions.

In applying the n–VR curves to field channels, certain general limitations should be considered. The experimental channels had relatively smooth beds, uniform cross sections, and true alinement; their covers were generally dense and uniform; and the data on which the n–VR presentation is based were obtained through tests that proceeded from low to high flows, with the vegetation upright at the start.

Permissible Velocities

Findings in this study as to permissible velocity of flow, the factor used as a common measure of the protection offered by a vegetal channel lining, are summarized in table 16. The standards of permissible velocity that have been established, for several kinds of vegetation differing widely in physical characteristics, may be adapted for similar vegetations not tested. Permissible velocity consistently decreases as slope increases, for all kinds of vegetation. The velocity values cannot safely be applied without modification to soils that are more erodible than the one soil represented in the experiments, Cecil sandy loam. They apply directly only to occasional, rather brief flows of water relatively free of sediment in channels having relatively smooth beds, true alinement, and dense, uniform plant covers. For field channels, the conditions of which differ widely from those of the test channels, permissible velocities are, in general, somewhat lower.

TABLE 16.—*Permissible velocities for channels in Cecil sandy loam having vegetal linings of the kinds studied*

Channel lining species and condition	Bed slope	Experiments	Permissible velocity
	Percent	*Number*	*Ft. per sec.*
Bermuda grass:			
Green:			
Long	3	2	(1)
	10	2	8.0
	20	2	7.0
Short, kept cut	3	None	..
	10	1	9.0
	20	None	
Short, cut just before test	3	2	(1)
	10	0	6.5
	20	1	5.0
Dormant:			
Long	3	1	(1)
	10	1	5.0
	20	1	6.0
Short, kept cut	3	5	8.0
Short, cut just before test	3	1	6.0
Centipede grass:			
Green, long	10	1	9.0
Dormant, long	10	1	8.0
Dallis grass and crabgrass:			
Green, long	6	1	3.5
Kudzu:			
Live, heavy growth:			
Uncut	3	1	4.0
Cut	3	1	3.0
Dormant, heavy growth, uncut	3	1	2.5
Lespedeza:			
Green:			
Uncut (spring)	3	1	5.5
Long (summer)	6	1	5.5
Short, cut just before test	3	1	4.5
Dead, uncut stubble:			
Spring	3	1	1.0
Fall	3	1	3.5
Sericea lespedeza:			
Green:			
Uncut (not yet woody)	3	2	5.5
Medium long (woody)	6	1	3.0
Short, cut just before test	3	1	3.5
Dormant:			
Uncut	6	1	2.5
Do	3	1	3.0
Short, cut previous fall	3	1	3.0
Sudan grass:			
Green, good stand	3	0	4.0
Dead, long	3	1	3.0
Grass mixture:			
Green, long (summer)	3	2	6.5
Green and dormant, short:			
Spring and early summer	3	2	5.0
Fall	3	1	6.5

[1] Velocity developed in tests was insufficient to permit estimate.

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