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## S <br> T A RT




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## 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 zoil 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." The study dealt with plant species adapted primarily to the Southeastern and South Central States. Extensive experimentation was carried out with Bermuda grass (Cynodon dectylon), common lespedeza (Lespedeza striata), sericea lespedeza (Lespedeza cuneata), and a mixture of orchard grass (Dactylis glomerata), redtop (Agrostis alba), Italian ryegrass (Lolium multiforum) 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 thanbergiana) 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 channelmaintenance 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

[^1]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 "permissibie."

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) cleveloping 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 sither 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.

## Constuecthes avb Puephang Channels

The trapezoidal channets used in the study resembled those commonly used on agricultural land in the Southeast, except that they were somewhat smailer. 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 leet. The hydraulic behavior of channels of this smooth-sided type was found tr, 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 traperoidal channels tanged 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 chamels, most of the excavating was done by hand; occasionally a mule team and a slip scraper were used.


Ficeuf: L--Dam, hentgrate, weir, and masonry-lined portion of canal conveying water to experimental chanmels.




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|  | 3 |  |  |  |  |
|  |  |  |  |  |  |

[^2]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.

## Measuaements and Obsehyations DISCIAARGE

In the earlier experiments, discharge was mensured 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 previousty calibrated rate-measuring flume. During a test the weir head was measured with a point gage and a waterlevel recorder. Becalise 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,


Figeres 3.—Two-foot H-rate-measuring fome having auxiliary gage for zeroing, point gage for measuring head, and recording tate for recording lepth of llow. filling it with water, and determining the rate at which its water surface dropped.

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 atddition, 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 chamnel 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.

## 

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 chamnel, 10 feet apart, between previously leveled stakes on the two sides. The horizontal coordinates of the channel cross section were marked by tying tuits 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 meta! rod. For the first tests the distance between strings was measured horizontally; later, it was measured along the slope. Measuring along the slope was formel to be more convenient both for laying out distance and for amalyoing the data. For slopes up to 10 percent the difference between measurement on the slope and hori\%ontal measarement is practically negligible. The graduated rod was heid in a vertical position except in measuring chanmels of 10 -percent or steeper slope, when it was held normal to the channel grade. A small level was aftixed 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-anci-rod method.

To obtain better measurements, a more precise cross-sectioning method was developed. Instead of a string a structural-steel angle, usually a $3->3-\because$, 1 -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-adijustable 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 ol' 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 chanmel 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 betore and after each test flow and water-surface measurements during each flow. The methors and equipment used in making


 ments.

These mbenurements were changed and improved as the wort progressed. larticularly, the number and order of water-surface meastarements were chatiged. The number of stations wherecross sections werretaken in a chanmel rafod from three to six.

During efoh test in the nally expriments one observer made water-surliace mexsurements at all stations, begimming at the shation lambest unstream and proceeding downstream, making onls one traverse at meth station. Lecatase of the lengeth of time ferbired fon making these measumements. the hast was made to to . 0 mimtes later than the first. If considerable erosiom had
 wexations flom slope dedemination) and the eross-sectional areas.
 Haftsaremmats at all stations. A water-sarfate traverse was
 into the chanmen ats stats low wowabed ame again just belore the How was shat wit With this procedare the corrections to the cross-


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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 dlue to differences in observers would to some extent balance out.

## VESETATION

To identify and describe the vegretation in ench channel, careful stand counts were made at locations where, to the eye, channel lining conditions seemed to be typical. A number of 6 -inch spatares 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 MEASURENEN'IS AND OBSEIVATIONS

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 COMPDTATION AND ESTIMATE Drymathe Combertions

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 coeflicient, $n$, 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.
$r=$ Wetted perimeter in feet.
$Q=$ Discharge in cubic feet per second.
$n=\frac{i}{i} \cdots$. Hydraulic malius in feet.
$S_{0}=$ Shope of water surface in feet per foot.
$\therefore \quad \because$ Hydrablie gradient or slope of specific energy line in feet per foot.
u, ©. Coeflicient of retardance in Maming's formula.
ne . ('oellicient of returdane in Kutter's formula.
The Manning formula is:

$$
\text { Q } A \frac{1.480}{n_{n 1}} R \cdot K \cdot 1=
$$

The Kutter formula is:

$$
Q=A\left[\frac{4 .(6): \frac{0.002 \Omega 1}{S_{r}}+\frac{1.811}{n_{t}}}{1+\frac{m_{1}}{\sqrt{2} h^{-}}\left(41.65+\frac{0.00881}{S_{e}}\right)}\right] \sqrt{\pi S_{e}}
$$

In the study reported in this publication the slope term $\frac{0.00281}{S_{0}}$ was omitted from the Kutter formula in calculating $u_{k}$ 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 $n_{w_{k}}$ 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 cstimated 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 lound that retardance coefficients for vegetation-lined channels vary with shape of channel cross section, slope of bed, and depth of flow.


Puere s.-... Relation between Kutter's $u$ and Maming's $n$.

The Manning and Kutter retardance coeflicients 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 ratemeasuring 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 chamnels 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


Hicure 6.-Variation of Manning's $n$ ( $n_{m}=\frac{1.480}{V} d^{2 / 3 /} S_{x^{1 / 2}}$ ) with depth of flow for rectangular Bermuta grass-lined chamel 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, $S_{a}$, instead of using the channel-bed or water-surface slope. To compute $S_{c}$ for every test flow, the watersurface slope, computed by dividing the drop in elevation by the slope distance, was corrected for changes in velocity by use of the formula-

$$
S_{t}=S_{w}-\frac{V}{g^{\prime}}\left(V_{2}-V_{1}\right)
$$

in which
$S_{\text {.m }}=$ 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.
$g$ 三 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.

## Scoun Computatrons

The effect of each test flow on the channel was determined by computing, for each of several stations, the difference in crosssectional 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 Peralssible Velocifles
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 piotted 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 retardedi.

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 lespedea sericea produced another type of resistance-depth relation, shown by the graph for channel 52-10B 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 piants 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.

## Txfluence of Bed Slope

For flows of sufficient depth to bend over and submerge the channel vegretation, 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 ot vegetation likely to differ. For short plants it values tend not to vary significantly untess 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 (lormant), and cut common lespedeza are all included within a elatively 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 . Channei $\mathrm{B} 2-11 \mathrm{~B}$ had a thin stand that offered very little resistance, and chamel B2-15A had only short bare stems. Sericea lespetle\%a channel B2-10C also had only short stems when lested, yet its in values were significantly higher than those of channel $B 2-15 \mathrm{~A}$. 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 lespedera. Channel B2-15B had a very good stand with an average height of $4 \frac{1}{2}$ inches and an average density of 290 plants per square foot.


Figute 8.-Vaviation of Mantang's " with hydrathe ratias and bed some for channels (B1-2, [ $1-3$, and $\mathrm{B}^{2}-8$ ) lined with long green Bermatar frass, having bed slopes of 20,10 , and 3 pereent, respectively, and having a bottom witith of $1 . \overline{5}$ feet and a sitle slope of $1 . \overline{5}: 1$.

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.

## Infleence 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 $u$ 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 crosssectional area it occupies, and its behavior when bent over and submerged change as these factors change. Seasonal variation, particularly of foliage effect. is ilfustrated by the graphs in figure 6 for channels lined with long sericea lespedeza. For channel B214C, 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.

## Effegt of Cetting Vegetation

If vegetation is cut short instead of being left to grow rank, cbviously 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 preater 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.

## Inflatence of Sifape of Cilannel

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 triangu-lar-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 P2-8, shown in fifure 10, for test 1 . in which their hydraulic radii were approximately equal, might be attributed to chamel shape.

[^3]

Figurf 9.-Variation of retardance coefficient with kind and condition of vegetation and with depth of how, for channels having a bed slope of 3 percent subjected to low and then to high flows: «, Short dormant Bermuda grass, good stand kept cut, $21 / 2$ inches tall when tested (channel B2-19-2, test in December) ; $b$, tong green sericea lespedeza, good stand 22 inches tall, not yet woody (chamel B2-10B, test in Jane); c, long dormant sericea lespedeza, yood stand 17 inches tal!, stems bare, bed covered with leaves (chamel B?14 C , test in March) ; $d$, whort green sericen lespedeza, good stand cut to 2 inches just before test (channel B2-14A, test in October); c , short dormant


Frouks 10.-Effect of cutting of a Bemmuta grass lining on retardance coefficient. Data from experiment 3 on channel $B 2-7$ and experiment 2 on thannel E2-8, 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 chamels, 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.

## Inflience of Ohoer 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 fows. 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.

[^4]a subsequent low flow encounters resistance not merely from stens 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 $u$ with decrease in volume of flow. It is probable that the retardance coefficients for tests 4 and \& 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 regetation.

Figure 11 iilustrates 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.


Prame 11,-Effect of order of tests on melation of hylraulic radits (depth of low) and retardance coefficient. Numbers mbicate order of tests. (Test $3 a$ followed test 8.) A, Channel B1-6, lined with short green Bermada grass. led slope 20 pereent, bottom width 1.5 feet, side slope $4: 1$. $f$, Channel B2-3, lined with long dead Sudian grass. Red shope if fercent, bottom width 2 feet, side slope 3:1.

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

## VR AS AN INDEX OP RETARDANCE

At the present time the product of mean velocity and hydraulic radius, $V R$, suggests itself as a suitable criterion for estimating $u$, 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 veiocity, 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 $V R$ as an index of retardance. Figure 12 illustrates the $n_{m}-V R$ relation for five channel:s 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 vegtal-fining conditions of channels from which the riata represented by the hol-W ctrves in figme 12 were obtained

CHANNELS LINED WITH SHORT GEEEEN HERMUDA GKASS (FIG, 12, A)

| Chamel | Nominal dimensions |  |  |  | Vegetal-lining conditions |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Expert. ment | ised slone | liottom witith | Side slope | Mowinx: | Height | Stems per suynre ft. |
|  |  | frecent | Fert |  |  | Inshrs | Fumber |
| 519, ${ }^{\text {a }}$ | 1 | 96.0 | 1.5 | 1 :1 | $!$ | 3.5 | 208 |
| $111-5$ | 2 | 10.0 | $\pm .5$ | 1 : | 2 | $\square$ | 480 |
| 512 | 1 | 3.0 | 1.5 | 4 : | ? | 4 | 320 |
| 5f2 8 | 2 | 3.0 | 1.5 | 1.5:1 | 1 | 4 | $\underline{310}$ |
| Supriz emand |  | . 2 | 4,0 | 1.5:1 | 1 | 4 | 160 |



| 459-7 | 3 | 3.0 | 4.6 | 1.5:1 | 1 | 4 | $\square 0^{2}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 129 -19 | $\underline{2}$ | 3.0 | $\underline{9}$ | Vertical | 2 | 2.51 | .100 |
| \%2-17 | 1 | 4.1) | 1.4 | + 11 | $\underline{9}$ | , | 180 |



1 it Mowed shartly before tach. 2 Mowetl fegphaty.
? Vexelation frisiy Imxuriant.
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 17 for given values of $V R$ 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-bining conditions of the channels are presented in table 2. The vegetation was exmpletely 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 $n-V R$ 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 $n-V R$ 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 $V R$ 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 $V R$. 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 associited with $V R$. Further significant changes in $n$ are due chiefly to roughening of the channel bed by scour.

The evidence that the relation between $n$ and $V R$ is reliable for Bermuda grass chamels differing widely in slope and shape suggests that $V R$ 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 $n-V R$ relation.

## BERMCDA GRISS 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 require: 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 100 th meridian the northern limit of its profitable growth is about the same as the southern limit of that of Kentucky bluerpass. It is not common north of the Potomac and Ohio Rivers or north of central Missouri and southcastern 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 rectangalar 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 regarting the experiments on these channels is sumarized in the following material in small type. The relation between $u$ and $V R$, 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 tormant. Dimensions and data on vegetal covers for the channels represented in figure 13 are given in table 4.

 formant hemoda brass. Dimessions ant regetathining conditions of the chamels are presented in table 4 .

## Record of Expermamis

Gituswel I31-1
Beei stope $2 ? .7$ percent, botiom widh approximately 1.5 fect, side slope aphoximately $\quad: 1$, length fo feet, slope and cross section jrregular but almement true phented September $193 \overline{3}$ by solid sodding.
 मrass, 9 inches; stand described as "failly luxuriant" (fig. 14). Soil firm.

Equipment: Shary-erested weir, rod and string.
Durime enth test a single observer made water-surfae measurements at there stations, progressity foswistren. There were two 10 -foot reaches.

Vegetation was wabmaged luring atl tests. Water surface very rouga for all fows Some selfactation during all tests. Values of 4 unasually













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 1.. 1\%

## (indNi.B1: -
















Table 3.-Experimensat conditions ant

results for channels lined with Bermuda grass

HED SLOPE 24 PERCENT

|  |  |  |  |  | 皆 |  | Coeftelents |  |  | $\begin{aligned} & \text { * } \\ & \text { 总 } \\ & \text { H区 } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  | 0 | 熍 | ＊ |  |
|  |  |  |  |  |  |  | 0 | \％ | $\underline{4}$ |  |
| 11 | 12 | 121 | 14 | 15 | 16 | 17 | 18 | 15 | 20 | 21 |
| Feret | Fres |  | Fert | Min． | ${ }^{\square} \mathrm{F}$ ． | In，fer howr |  |  |  |  |
| 2.10 | 0.146 | 0.2345 | 0.22 | 50 | $\ldots$ |  | 16.74 | 0.0648 | 0.0492 | 0.462 |
| 2，27 | ． 180 | ． 2408 | ． 28 | 30 |  |  | 20．1313 | ． 0.046 | ．0361 | ． 813 |
| 2.43 | ．225 | ． 2476 | ．${ }^{2} 1$ | 30 |  |  | 23，49 | ． 0494 | ． 0344 | 1.15 |
| 2.71 | ． 248 | ． 24.411 | .38 | 10 |  |  | 23.20 | － 0 a09 | ．0353 | 1.38 |
| 2，87 | ． 278 | ． 1032 | ． 40 | 15 |  |  | 26.92 | ． 0.145 | ． 0328 | 1.70 |
| 2.44 | ． 22.4 | ． 22 52 | ，35 | 30 |  |  | 23.72 | .0400 | ． 0841 | 1.10 |
| 2.96 | ． 256 | ． 2135 | ． 40 |  |  |  | 28，32 | ． 0.118 | ． 0810 | 1.70 |
| 2.27 | ． 2313 | ． 2350 | ． 89 | 15 | 56 | 0.80 | 24.08 | ． 0481 | ． 01442 | 1.174 |
| 2.62 | ． 280 | ． $2 \underline{2} 87$ | ． 48 | 110 | 55 | －． 07 | 20.95 | ． 0163 | ． 01303 | 2.11 |
| 2.72 | ． 348 | ．2307 | ． 60 | 150 | 5.4 | .19 | 27．59 | ． 0468 | ． 0347 | 2.69 |

BED SLOPE 20 PERGRNT

| 2.92 | 0.287 | 0.1926 | 0.43 | 415 | 71 | －0．53 | 21.31 | 0．0567 | 0.0398 | 1.44 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 3.012 | ． 316 | ，10．1．1 | ． 50 | 53 | 72 | －． 03 | 26.00 | ． 0457 | ．0342 | 2.10 |
| 3，36 | ． 1778 | ． 1954 | ． 58 | 57 | 79 | ． 22 | 98.61 | ． 0442 | ．0341 | 2.94 |
| 3.61 | ． 442 | .1031 | ． 60 | 48 | 73 | ． 32 | 29， $\mathrm{H}_{2}$ | ． 0438 | ． 0847 | 3.82 |
| 3.70 | 491 | ． 1974 | ． 81 | 6.1 | 66 | ． 39 | 30.46 | ．04：34 | ． 0349 | 4，65 |
| 4.05 | ． 511 | ． 1964 | ． 87 | 85 | 68 | ． 2.1 | 30.36 | ． 0442 | ．0359 | 5．115 |
| 4.06 | ． 525 | .2049 | ． 85 | 58 | G8 | －． 02 | 30.88 | ． 8.138 | ． 0855 | 5.25 |
| 4．67 | ． 628 | .194 | 1.10 | 40 | $\square 0$ | 5.30 | 26．82 | ． 0514 | ．0416 | 5.85 |
| 3.150 | .130 | ． 1054 | ． 21 | 55 | 70 | ． 01 | 13.00 | ． 0824 | ． 0466 | ．288 |
| 4.07 | ． 180 | ． 1079 | ，27 | 40 | 67 | .13 | 21.63 | ． 0518 | ． 0344 | ． 742 |
| 4.47 | ． 208 | ． 1961 | ． 31 | 40 | 69 | ． 11 | 24，91 | ． 0460 | ．0820 | 1.05 |
| 5.34 | ． 202 | ．1954 | ． 41 | 40 | 66 | .37 | 20.32 | ． 0404 | ． 0302 | 1.76 |
| 5.78 | .308 | ，2012 | ，49 | 35 | 66 | ． 27 | 22.12 | ． 0380 | ． 0294 | 2.46 |
| 6.155 | ． 3 \＄2 | ． 1090 | ．5．1 | 30 | 68 | ． 28 | 33.95 | ．0367 | $\checkmark$ | 3.0 .1 |
| 6.699 | ． 358 | ． 2042 | ． 60 | 40 | 70 | .15 | 36.65 | ． $0: 162$ | ． 0278 | 3.54 |
| 7.16 | ． 406 | ． 1077 | dif | 40 | 69 | .15 | 35.71 | ． 0359 | ．0292 | 4.01 |
| 4．71 | ．238 | ． 1078 | .35 | 20 | 68 | ． 03 | 18.82 | ． 0629 | ． 0.414 | ． 971 |

BED SLOPF 10 PERCENT

| 3，18 | 0.350 | 0.0916 | 0.56 | 35 | 71 | 0.17 | 22．86 | 0.0565 | 0.0412 | 1.47 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 3.80 .1 | ． 40.1 | ． 0906 | ． 63 | 30 | 70 | ． 47 | 26.26 | ． 0.405 | ． 0178 | 2． 01 |
| 3.90 | ． 480 | ．0907 | .75 | 32 | 74 | ． 07 | 28.05 | ． 0470 | ． 0365 | 2.58 |
| 4.18 | ． 505 | ．0906 | ． 815 | 40 | 74 | ．13 | 30.08 | ． 0445 | ． 0357 | 8.23 |
| 4．613 | ． 540 | ． 0884 | ． 1.15 | 47 | 74 | ． 18 | 82，93 | ． 0416 | ．0341 | 3.82 |
| 5.018 | ． 188 | ．0874 | 1.04 | 44 | 715 | .10 | 34.80 | ．0394 | ．0831 | 4.56 |
| 5，41 | ． 645 | ． 0845 | 1.15 | 50 | 73 | ． 016 | 44.74 | ． 0402 | ． 0340 | 5.20 |
| 4.0 .1 | ．623 | ． 0842 | 1.05 | 31 | 48 | .16 | 37.35 | ． 0369 | ． 0316 | 5.29 |
| 4.89 | ．f615 | ．0872 | 1.00 | 30 | 48 | .17 | 38．06 | ．0360 | ． 0307 | 5.30 |
| 4.92 | ． 614 | ．0880 | 1.02 | 80 | 49 | －． 09 | 37.48 | ．0366 | ．0819 | 5，84 |
| 4.88 | ． 611 | ． 0846 | 1.02 | 30 | 48 | ． 26 | 88.88 | ． 0352 | ． 0303 | 5.39 |
| 4.86 | ．603 | ．0857 | 1.02 | 30 | 45 | ． 06 | 39.18 | ． 0349 | ． 03300 | 5.37 |
| 4.65 | ．238 | .1034 | ． 36 | 28 | 67 | ． 09 | 6.03 | ． 196 | ． 1039 | ＋224 |
| 6.30 | ． 287 | .1009 | ． 4.4 | 19 |  | .10 | 11，42 | .1064 | ． 0654 | ． 557 |
| 6.00 | ． 310 | ．0988 | ． 51 | 40 | 66 | .07 | 15.10 | ． 0811 | ． 0535 | ． 822 |
| 6.93 | ． 364 | ． 0988 | ． 62 | 40 | 65 | .10 | 20.64 | ． 0610 | ．0488 | $1.42{ }^{\text {a }}$ |
| 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 | ． 0.348 | 2.54 |
| 8.70 | －450．4 | ． 0974 | ． 78 | 41 | 70 | ． 06 | 31.20 | ． 0418 | ． 0335 | 2.07 |
| 9.05 | .1718 | ． 0964 | ． 81 | 40 | 67 | ． 05 | 38.04 | ． 0388 | ． 032.4 | 3.36 |
| 0.87 | ，478 | ． 0980 | ． 88 | 40 | 68 | ． 06 | 34.64 | ．0380 | ． 0312 | 3.60 |
| 3.95 | .170 | ． 1010 | ． 25 | 21 | 51 | ． 0.1 | 12.02 | ． 0923 | ． 0529 | －26．64 |
| 4.37 | ． 218 | ． 1012 | ． 34 | 19 | 62 | －． 01 | 19.90 | ． 0530 | ．0388 | －645 |
| 4.76 | ． 25.1 | ． 10080 | .30 | 40 | 54 | ． 05 | 24.45 | ． 0484 | ． 0345 | ． 991 |
| 6.72 | .306 | ，0084 | ． 511 | 40 | 47 | .01 | 32.67 | ． 0373 | ． 0290 | 1.74 |
| 6.44 | A 3 1， | ． 01 MB | ．17 | 413 | 4 F | .01 | 35， 50 | ． 03.51 | ． 0262 | 2.28 |
| 7.15 | ． 379 | ．0099 | ．fi3 | 40 | 45 | ． 02 | 38.57 | ． 0326 | ．0968 | 2.77 |
| 7.64 | .100 | ．0077 | ． 68 | 10 | 47 | ． 03 | 40．R2 | ． 0312 | ． 0261 | 3.22 |
| 8，02 | ． 124 | ＋1002 | .73 | 411 | 57 | ． 04 | 42，80 | ． 0805 | ． 0258 | 3.72 |

Table 3.-Experimental oonditions and regults

TRAPEZOIDAL SHAPE,

for channels lined with Bermuda grass-(Continued)

BED SLOPE 3 PERCENT


BED SLOPE 1 TERCENT

| 5.38 | 0.301 | 0.0098 | 0.18 | 60 | 51 | 0.01 | 11.49 | 0.1089 | 0.0635 | 0.189 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| fi,8.4 | . 387 | .nfif 7 | . 6.4 | \$8 | 51 | . 02 | 17.66 | . 0723 | .0503 | . 113 |
| 7.55 | . 448 | .01103 | . 3.4 | 41 | - 3 | . 0.4 | 20.82 | . 0629 | . 0465 | . 627 |
| 8.933 | 5.12 | ,fi08 | .93 | 44 | .17 | . 0.4 | 26.96 | . 0501 | .0398 | 1.11 |
| 4,88 | . 602 | . 0111 | 1.0 .1 | 46 | 44 | -. 03 | 30.22 | . 0455 | . 0873 | 1.48 |
| 10.46 | .644 | .0101 | 1.17 | 47 | d | (6) | 35.28 | . 0385 | .03345 | 1.82 |
| 12.63 | . 688 | . 1102 | 1,25 | 50 | 45 | -.033 | 37.0f | .0370 | .0326 | 2.13 |
| 12.30 | .718 | . 0102 | 1.31 | 15 | 86 | .92 | 40.07 | .0353 | .0:108 | 2.44 |

Table 3.-Experimental conditions and results

RECTANGULAK SHAPE (METAL SIDE


TRAPEZOIDAL SHAPF.,

| Sunply ensal. Lampent rencis | 411.5:1 |  | 4 | Green. Short. cut shartly hefore testing. | $\left(\begin{array}{l}1 \\ 1 \\ 13 \\ 2 \\ 3 \\ 3 \\ 3 \\ 4 \\ 5 \\ 5 a \\ \\ 6 \\ 7 \\ 7 \\ 7 n \\ 8 \\ 9 \\ 9 n\end{array}\right.$ | Aur. 9 fi, 1040 | 1.18 | 3.35 | 0.353 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Sept 30, 99.19 |  |  | 1.29 | 3.48 | . 372 |
|  |  |  | Aug. 27. 1940 |  |  | 2.75 | 4.68 | . 507 |
|  |  |  | Sept. 30.1940 |  |  | 4.72 4.75 | 5.80 5.83 | .813 |
|  |  |  | Sept. 30. 1948 Aug. 28, 10.40 |  |  | 40.75 | 5.83 8.55 | 1.18 |
|  |  |  | ....do. ${ }^{\text {do. }}$ |  |  | 14.9 | 10.7 | 1.40 |
|  |  |  | Sept, 10. 1940 |  |  | 15.1 | 10.8 | 1. 60 |
|  |  |  | Aust. 29, 196 |  |  | 20.2 | 13.0 | 1,55 |
|  |  |  | dar do |  |  | 25.1 | 15.4 | 1.6.1 |
|  |  |  | Sept. 30. 1940 |  |  | 24.7 | 15.3 | 1.fiz |
|  |  |  | Sept, 3, 1980 |  |  | 30.4 | 17.7 | 1.71 |
|  |  |  |  |  |  | 34.8 | 20.3 | 1.71 |
|  |  |  | Seits 30. 1940 |  |  | 35.7 | 21.0 | 1.70 |

for ehamels lined with Dermuta arass- (Continued)

WALIAS ISED SLOPE ; PEIECENT

: IAED SLOPE 0.2 PERCENT

| 6.26 | 0.514 | 0,00188 | 0.74 |  | 75 |  | 11.00 | 0.1214 | 0.0837 | 0.102 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 6.24 | . 5 ²8 | . 0017.4 |  |  |  |  | 11, 1314 | . 1130 | . 0791 | . 205 |
| 6.98 | -1is. | .002093 | . 91 |  | 73 |  | 16.31 | . 08.51 | , 1515 | .336 |
| 7.59 | . 764 | . 00008 | 1.13 |  | 73 |  | 20.39 | . 0697 | . 0555 | .f2 |
| 7.615 | .766 | . 000199 |  |  |  |  | 91.23 | . 0630 | .05:3 | .f24 |
| $\begin{array}{r}8.97 \\ \hline 10.4\end{array}$ | . 953 | .00213 | 1.70 |  | 75 | -... | 2tic 19 | . 05163 | .0478 | 1.12 |
| 10.04 | 1.003 | .00199 | $1 . \overline{7} 4$ | $\cdots$. | 70 | $\cdots$ | 30.39 | .0.494 | .04:33 | 1.49 |
| 10.04 | 1.074 | -06185 |  | . . |  |  | \$1.59 | .0.477 | . 0130 | 5.50 |
| 10.91. | 1.192 | .00178 | \% 00 | - . . | 7 |  | 33.73 | . 0453 | . 0408 | 1.85 |
| 11.78 | 1.302 | . 00111 | 2,5.3 | $\cdots$ | \%5 |  | $3 \mathrm{~S}, 15$ | . 0.40 | .0373 | 2.14 |
| 11.78 | 1.297 | . 00114 |  |  |  |  | 37,43 | . 0.45 | .0179 | 2.10 |
| 12.73 | 1.304 | .00127 | 2.44 |  | 78 |  | 40.72 | .0.asf | 0.358 | 2.18 |
| 13.57 | 1.493 | .00111 | 2.66 |  | 79 |  | 48.10 | . 0373 | .0354 | $\stackrel{.}{2.58}$ |
| 13,79 | 1.624 | .00108 |  |  |  |  | 41.92 | +0k80 | +0375 | $\mathbf{7} .55$ $\mathbf{2 . 5 9}$ |

'IAble 4--Dimersions aml Brgetst-lininy conditions of chennels lined with lony dormant benmada arass fom which the data represented by the $n=-V R$ carves in figtre 15 were obtained

| Cbunnel | Experlment | Nominal dimenalons |  |  | Veselation stand culant |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\underset{\text { Hed }}{\text { slope }}$ | Bettam with | Side slope | Heisht | Stems prer shuare foot |
|  |  | Percent | Fect |  | inches | Number |
| 181-1 | $\stackrel{2}{2}$ | 24 10 | 1.5 1.5 | $1.0{ }^{1}$ | 12 | 100 |
|  | $\underline{2}$ | 4 | 4 | 1.5:1 | 12 | 2150 |
|  | 3 | 3 | 4 | 1.5:1 | 11 | 250 |

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

Experiment \& Febrtary 1940, gritss dormant and tencut.-G:ass probably 15 inches long and as dense as in experiment 1. Soil firm.
Equipment: 2 -foot modified Parshall fume, 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 openel 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.

Veretation was submerged. Flow was extremely rough, and considerable self-ueration took place (fig. 16). According to figure 13 the $u$ value for long dormant Bermuda grass when $V R$ 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.
('hamel definitely faileci. Most of sod wat tom of lower 20 feet of chanme. Sod had failed to root to subsuil, and a plane of wakness may have developeed through frost action. However, this chanmel hat withstood higher thows the previous summer without severe damage.


Figure 16.-Bermurla grass chamel B1- ${ }^{2}$ during test 1 , exieriment 2.

## Cbannel B1-6

Bed slope 20 ner cent, bottom width 2.5 feet, side slope $4: 1$, lemgth $\overline{5} 0$ fect, phanted December 1940 by solid sodding. Channel very uniform in slope and cross section.

Experiment 1, September 1941, Grass green and recently cat for first time.-Cutting had left only stiff brown base stalks $31 / 2$ inches long. Density 208 stens per square foot (fig, 17). Soil hatd.

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 $x$ in fair agreement with those for other chanzels having similar linings.
Considerable erosion. In some maces, bottom was scoured to a depth of about 2 kin inches. Very few plants were torn out, and no large bare spots or holes developed.

## Channef. Bl-3

Bed slope to percent, bottom width 1.5 feet, side slope $1.5: 1$, length 50 fect, planted July 1037 by solid sodding. Chamel fairly uniform in sope and cross section. Some irregularities due to variation in thickness of sod used.

Experinent 1, Aughst 1 IS3s, gruss green and ment.-Gimass, on average, 18 inches long, stems per square foot 340 on sides and 914 on bottom. Soil firm.

Eftuipment: 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 chanmel entrance condition, a wave occurred in chamel at 5 -foot station: this is beileved not to have affected results. Values of $n$ in agrement with those for other chamels with similar linings.

Some erosion occurred in channel during tests, but no serious damage resulted. Grass was slightly thinned out, a littie soil was taken off chamel trotton, and two holes about 2 inches deep and 0 inches in diameter appeared.
 age, 15 inches long, stems per square foot 100 on bottom, $15 \overline{5}$ on sides. Soil firm. Lining thin. Chamel in slightly eroded condition as result of previous Lest. Channel bed contaned a few holes about 2 inches deep.

Equipment and ofservational technique same ats 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 conduted, one taily for five consecutive days.

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


Fitetne 17.-Mermudn grass chamel B1-G, experiment 1: A, View before lesting; $B$, view during test 6 .
and some aeration occurred (fig. 18). No apparent increase in bed roughness due to scour. A slight decrease in from tests 3 to 5 is evident, prolably 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 al! parts of channel bed still had covel. 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.

Channei B1-5
Bed slope 10 percent, bottom width 1.5 feet, side slope $4: 1$, length 50 feet, planted May 1939 by solid sodding. Chamel uniform in cross section andi slope.

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

Eguipment: 2 -foot modified Parshall tlume, 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 hirhest flow. Some aeration. Values of $n$ in agreement with those tor other chamels having similar linings.

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


Fifure 19.-Bermuda grass chamel Bi-5, experiment 1: A, View before testing; $l$, view during test $6 ;{ }^{\prime}$, view at completion of experiment.

Experiment 2, November 1940, grass moxtly 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 sabmerged during all tests. Water surface was very rough for lowest flow and increased in roughness antil it was extremely rough for highest flow. Some acration. Values of $a$ in fair agreement with those for other ehannels having similar linings, but generally lower-probably because of thenual shortness of grass.

No apparent damage to channel. Cross-section measurements revealed less than 3 -inch scour.

## Chanvel B2-7

Bed slope 3 percent, hottom width $\&$ feet, side slope $1.5: 1$, length 50 feet, planted July 1937 by solid sodding. Chanmel uniform in slope and cross section. Some roughness in bottom owing to small difference in sod thickness.
 averuge, 8 inches long, 330 stems per square foot. Soil firm.

Fquipment: 2 -foot modified fatshall hame, string and rod.
During each test a single observer made water-surface measurements at five stattons, progressing downstrem. There were four 10 -foot reaches.

Vergetation was submergef during all tests. Water surface was slightly rough for lowest flow and beetame rougher until it was decidediy rourh for highest llfow. Slight aeration oecurred during highest flow. Valtes of $u$ in agreement with those for other chamels with similar linings.
fracticaly zo seour occurved. After the higher flows a fow thin spots in the grass cover were notied.

Erperiment 2 , Mareh $199^{2}$ gruss domant und ancut.-Grass, on average, 12 inches long, 350 stems per sputare foot (fig. 20). Soil firm.
biseharge measured volumetrically for first four tests, with 2-foot modifed 1'arshall flame 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 butil finat test. when flow submerged grass except at edges of chamel. Water surface slightiy rough.


Figher 20.-- Bermuda grass chanel B2-7 before experiment 2.

In this experment with shallow flows of low velucity, abmost jdentical $n$ values preyalled for the three lowest flows, which coursed through the mass of stems and leaves without catasing more than sight bending of movement. The roughess or retarding element remained unchanged. A ratid decrease in u oceared as soon as bending and submergence began. Values of $n$ for the higher $f R$ valaes are in agrement with those for other chamels having similar limmgs.

No scour ocenred.
Experiment S, October and Novomber 1939, grass dormant, nucut and eut..Grass was uncul and 11 inches Jong on avemge in test !, was cut to lengeth of 4 inches before other tests (fig. 21 ). Density, 250 stems per sfatre foot. Soil firm.

Equipment: ${ }^{-}$-foot modifed Parshall fume, point gages.
Duriag each test thre men made water-surface measarements simaltaneous!y 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 becme rougher as fow increased until it was very rough for final test. Slight aeration occurved during tests 8 and 9. Values of "in agreement with those for other channets having similar linings.

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

## Cinnveg B2-8

Bed slope 3 jercent, bottom widh 1.5 feet, side slope $1.5: 1$, length 50 feet, planted duly 1937 by solit sodding. Chamel faily uniform in slope and eross section. Some roughness in bottom due to small differences in sod thickness. Section 32 to 36 feet from head of chamel about 2.5 inches low.
 on average, $34 \overline{5}$ stems per square foot. Soil firm.

Equipment: 2-foot modified Parshall flume, string and rofl.
During each test a single observer made water-surface measurements at five stations, progressing downstream. There were four 10 -foot reaches.


Ftiane 21.- Bermuda grass channel Be-7 hefore test 2 , experiment 3, when grass had been cut to length of 4 inehes.


Figure 29--Bermuda grass channel 153-8 before test 2 , experiment 2 , when grass had heen cut to length of 1 inches.

Vegetation was stbmerged during all tests. Water surface was slighty rough during test 1 and became rougher as fow increased until it was very rough during final test. Low spot in channel grade at 34 -foot station caused a wave and considerable roughess below. Values of $n$ in agrement with those for other channels having similar linings.

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

Experiment 2 , October $19 \% 9$, brass green, wheat and cut.-Grass was uncat and 12 inches long on average in test $i$, was cut to length of 4 inches before other tests (fig. 22). After being cut it had the mpearance of dormancy. Deasity, 220 stems per square foot. Soll firm.

Equipment: 2 -foot modified Parshall fume, point gages.
Buring each test three men made water-surface measurements simaltaneously ut three stations, each making two at the same station. There were two 10 -foot retheles.

Vegetation was submerged during all tests. Water surface was slighty rough during test 1 and became rougher as flow increased until it was very rough during fanal test. Low spot in channel grade at 3 -foot station again caused a wave and udditional surface roughmess. Values of $n$ in fair agreement with those for other chamels having similar linings.
Slight scour oceurred. Some bare spots formed, but no holes appeared in channel bed.

## Chanvec [32-18

Bed slope 3 pereent, bottom width 1.5 feet, side slope $4: 1$, length 50 feet, planted danary 1041 by solid sodding. Channel vers uniform ia slope and eross section.
Experiment 1 Sepfember 19.1 , grets green and recently cut for forst time. _-Cutting had left only stiff brown base stalks 4 inehes !ong (fig. 23). Density, 320 stems per square foot. Soil hard.

Equipment: efoot modifed parshall fame, boint gages.
During each test thee men made water-surface measurements simutaneously at three stations, each man making one at each station. There were two 10 -foot reaches.


Fifure 29.-mermuda grass chanel B2-18 before experiment 1.







## (illvill 13: !












 If fint lowion.







## 







foot (ing. 25). Growth of grass had not been affeeted by metal ehamel walls, which had been erected about a month before tests. Cover very uniform. Soi! fm .

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

During cauh 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 chamel, when submergence was estimated to have been at least 75 percent. Water surface was rough in all eases, and was "frothy" in chamel 1 durng tests 10-12 and in channel 2 during tests 11-14. Values of $u$ in fair agreement with those for trapeoodal channels having similar linings. For the higher $V / R$ values, the agreement is excellent.
Very little scour was apparent on visual inspection. Measurements showod a little erosion.

## subply ganal. taneent beach

Bed slope 0.2 percent, botiom width 4 feet, side siope $1.5: 1$, length of reach 90.92 fect, planted in 1937 by sodding. Cross section and slope failly uniform.

Fxperineml h, August and Scptember 1040, grass green, hept eut.-Grass 34 to 4 inches long, 160 stems per spuare foot.
Equipment: 2-toot modified Parshall flume, noint gages. Water-stage recorders used at ends of reach to check steadiness of how.
Five repeat tests designated 1 a, 3a, ete., made as checks on water-surface slope.

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

No scour was apparent.
Myomable Bemation of Bermema Grass
Bermuta frass, 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 .



and when they are dirmant, tugether with the density of the cover pentrally formed and the redative ease and rapidity of cover astablishmont, make this grass thenable low ane in channels. The ferely flat thinge of the stems produces a relatively smooth chamed stretace (lig. 19, '), if the chamed bed itselt is not rough, which whirs relatisedy low resistance.

The emeses for the " $1 / 2$ refation for chanmels lined with short Frem, shod domam, hong weren, and long dormant Bermuda Prass (figs 12 and li:) indicate that this relation differs very fithe aroming to whe her the grass is ween or dormant; practi-


An incrats in bed routhess during the finat test on channel
 result is met wemman in requation-lined arth chamels.

##  

A photing of somb rathe abainst velocilies for fise chanmeds
 thastrales the difienty of astimating permissible velueities from sheh data abone. scour rate appors to decerase after longexass is thennghls mathened. Aside from this, mo corvelation is apfarent betwem wowity and seome mate.

The rasen fon this lack of empretam mas lio in the method of dovemining serum ratus. As a basis for computing a rate for
 fion was datomined at moly a fow stations, fordation, it is


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.

## SHOMT GAEEN 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


Picure 27.-Scour rate in relation to velocity of flow, for channels lined with long green Bermuda grass. Plus quantities indicate scour; minus guantities, 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 thimed; B1-3, no serious damage, grass thinned, some scour, two small holes 2 inches deep; B1-5, slight uniform scour, no apparent damage; $\mathrm{E}=-7$, practically no scour, grass thinmed shightly; $\mathrm{B} 2-8$, no scour a,pmarent.
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 steephess 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 DORDANT gRASS

Two of the most complete failures occurred in channels lined with Bermuda geass 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 loned 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 chamel 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 $21 / 2$ 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.

Chamel 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 follow, ng velocities of flow are permissible for relatively smooth channels lined with long dormant Bermude grass in excellent condition: Slopes of 10 percent and less, 8 feet per second; slopes of 10 to 20 percent, 6 teet per second.

## SHORT DOLMANT eRASS

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 EXPERDMENTS

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 generaily 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 $V R$ for long centipede grass is shown in figure 28.


Figure 28.-Relation of Manning's $"$ and $V R$ 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 , $i n$ all of which discharge was approximately the same.

## Recomo of Exprbiments

Chander. Bl-4
Bed slope 10 percent, bottom willh 1.5 feet, side slope 1.5:1, length 50 feet, planted April 1038 by sprigging. Chanal very uniform in eross section, slope, and alinement.
Experinent $t$, August [989, grass gyeen and wacut.-Grass, on average, is inches long, 100 stems per square foot (fig. 29). Soil soft.

Equipment: 2-foot mothfed Parshall flume, point gages.
Table 5.-Experimental conditions and resalts for channel b1-4, lined with centipede grass

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Durimy eath lest thee men made water-sarface measurements simultaneonsly at three stations, each making two at the same station. There were two to-foct reaches.

Vegetation was stbmerged during all tests. Grass stoms fattened an! shingled readily (fig. 30, A). Water surface was lough for first test ant


Fileume 20)-Centipede grass chanmel B1-4 before experiment 1.
became rougher as flow increased (firg. $30, I$ ) until it was extremely rough for final test. Some aeration along channel efges. Vahues of 4 approximate those for long grean Bermuida grass.

Practically no erosion oecured. A few small spots were aroded along left cdge of channel bottom. Vegetation remained intact.
 age, 6 inches long, 160 stems per square foot. Soil soft.

Equipment and observational techaique same as in experiment 3. Experiment deviated from the ordimary in that five fests of about the same discharge and doration were conducted, one daly for five eonsecutive days.

Vegetation was submerged during all tests, Water surface very rough. Sdi-acration werured. Vatue of $n$ practically constant for all five tests and amost identical with that for long domant Bormula grass at the same $\boldsymbol{Y} R$ value.

After the tests the chamel was still in very grod condition. There were about six bare spots atong the lelt celfe averaring 4 inches in flameter and having a maximum depth of one-half ineh. In seven phaces the lining seemed to have thimed out. At the end of the chamel the grass hat a frayed



appearance (fig. 31). In the spring it was discovered that about 70 percent of the gruss had been hilled. 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.


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

## Jyohatore Behayion of Centipede Grass

Centipede grass resembles Bermuda grass in the physical properties having an important bearing on hydratulic behavior; it forms a dense sod and a uniform cover, and the short uncut vegetation readily flattens to the channel surface under fow and quickly straightens up again when flow ceases. According to the $n-y R$ 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 tor Bermuda grass may be used as a guide in estimating $u$ for centipede grass.

Sthabirty of a Ciavael Laned whth Centipede Grass
Contipede grass appears to be a channel lining capabte 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.

Becanse 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 0 feet per second and that the same stand when dormant can take a velocity of 8 feet per second. These extimates apply only to excellent stands in unitorm channels. having slopes not groater than 70 peremt, that are subjected to flows of short duration.

## DALLIS CRASS.CRABGRASS EXPERIMENT

Datlis grass is a long-lived peremial now gaining increasing lavor 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 heayy, 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 voluntered. It was realized that the same thing was likely to oceur in field chamels, 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 $V^{\prime} R$ for chamels lined with long green grass of these two species is shown in figure 32 .

 with uncut green thallis grass and erabgrass averaging 30 inches in length and 75 stems per square tout. Nominal dimensions of channel: Bed slope ${ }^{6}$ pereent, bottom width 2 feet, side slope $3: 1$. Vegetation was completely submerged by all flows.

## Recomi of Fopeninexy

## Chavel B2-g

lied slope if peremt, lwotom width $\because$ teet, side shope $3: 1$, length 50 feet. Dallis grass phanted by seeding in Mareh 1038, reseeded in Mas 1938 and twice in June bass. Stand 20 pereant ballis grass, Su pereent crabgrass. Chane fairly uniform in shone and atinement. The lett site wats a little low, and if woden wall hat to be areeted alomen this sitle to contaill the flow for tests 5) antl th.
Table ti-Enperimental conditions and rentis for channel D2-t, lined with long green Dallix yretss and crabgrass



 30 inches, varyink 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 nade water-surface measurements at four stations, progressing downstream. There were three 10 -foot reaches.

Verctation was submerged and water surface was rough during all tests. $P^{P l o t}$ of $n-V R$ reiation (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 (figs. 43), numerous holes and rills ranging in depth from 3 to 5 inches were found. Little damage was observed until the fifth test.

## Hymallic Behavior of Dallis Guass anj 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 highhigher 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 Look place during the later tests.

## Stablaty of a Ceannef. Lined with Dallis Gbass and Crabgrass

In comparison with other linings, the Dallis grass and crabyrass 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 $31 / 2$ feet per second is permissible.

## KCDZU 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 dhaing 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 tach year, since it is not seriously affected by seasonal droughts (1). It has been used sticcessfully in large natural waterways of slight slope where moderate reduction in cross section of waterway is not objectionable.

Kudza 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 guily. 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 tc 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 $u$ with hydraulic radius for the channe! lined with kudzu is shown in figure 34, and the relation of Maning's $n$ and $V R$ for this channel is shown in figure 35.


Figeres B4--Variation of Manning's $u$ with hydraulic matius for a chamel (B2-9) lined with kudzu when the liming was in four different conditions. Nominal dimensions of channel: Bed slope 3 percent, botom widh 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 $1.5: 1$




F'IGURE 35.-Relation of Manning's $x$ and $V R$ for a channel (B2-9) lined with kudza when the lining was in four different conditions. Nominal dimensions of channel: Bed sloue 3 percent, bottom width 4 feet, side slope 1.5:1.

 were set out: $A$, Before testiner $E$, during test 1 , experiment 1 .

## Recorb of Expemments

## Channel B2-9

Bed slope 3 pereent, bottom wiath 4 feet, side slope $1.5: 1$, Jength 50 feet, planted February 1938 by setting plants. Chamel fairly uniform in cross section, slope, and alinement.
Experiment 1, November 1938, hudza green and antud.-The mass of vegetation filled the chanmel (fig. 36, A). The usual stand count could not be made. It was obsorved that, on an average, 10 vines crossed 1 square foot of chamel, and that five nodes jer square foot had rocted to the chamel surface. Soil firm.

Equipment: 9 -foot modified Parshall flume, string and yod.
During each test a single observer made water-surface measurements at five stations, progressing downstream. There were four 10 -foot yeaches.

Vegetation was sumerged in centrai portion of chamel in all tests, but upright vines and leaves filed considerable portions of the cross section of the llow (fig. 36, b). Water suriace was fairly rough for first test and beame rougher until during last test it was very rough, with sons tather large waves. Curve of $n-V / 2$ relation approximately paralleled that for tong green Bermuda grass, but at a much higher level. At completion of experiment, $n$ was still decreasing as fiepth and velocity of flow inereased.

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

Experiment $Q$, August $19, \%$, kudzu grech and wout.-Chamel was filled with a very dense growth of kudau (fig. 37, A). Soil firm.

Equipment same as in experiment 1 .
During each test three men maxie water-surface measurements simultancously 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 chamel was submerged in second test. More of the kudar was submerged by suceeding flows, but in large corner areas the vegetation still extenfed above the water surface. In test the water surface was faimy smooth except for small ripples, in later tests it was rough. Values of $n$ were at a considerably higher level than in experiment 1 , owimg to inereased 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, E).

Experiment 3, February toho, hudzw domutht.-Chanmel 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-sarface measurements simultancously at three stations, each making two at the same station. There were two 10 -frot reaches.

Flow was very rough and very irregular in all tests (hg. 38). Vegetation tented to pile up in champs and cause a very irregular flow pattern. Flow during test 6 was characterized by standing waves approximately $51 / 2$ inches high from trough to erest at stations $12,18 . \overline{2}, 23.5,30.5,37.0,44.0$, 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 consideralble part of the water eross section along chamel sides. Curve of $u-V R$ velation 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 seour in upper part of channel and some deposition in lower part along edres of flow. The higher flows protuced some erosion and left no feposition. No severe failure occurred, but chamel bottom was left in poor condition.
Experiment 4, Aumust ford September 10:0, hulze green and cut.-Cutting of what apmeared 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 cat leaves and vines lay on bothom and sides of channel (fig. 30, A). Previous







 were mate immodiately ater cultam.

Eftupment ant obervation procedure same as in experment ${ }^{3}$.

 water semerl to wind its way betweon dump of vegetation, higher flows more suiftrm.

Fogetation was washed ofl chamel bothom, leavins it nearly bare (fig. 30 , ( and ( ) ) Shotht seour werred wer most of channel, and in a few phaces there was erowion of greater depth.



























During each test three men made water-surface measurements simultaneously at three stations, cach 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 deemened and narrowed flow during test 1. During test 9 , flow was extremely nonunform owing to variation in cover and scour development;


Froure 43.-Kudzu channel B2-9 on April 18, 1541, after test a of experiment 5.
aceeleration took phate to $2 \overline{5}$ feel frum head of chamel, a jump at $2 \overline{0}$ feet, retardation at $\cong 5$ to 47 freet, an overfall at 37 feet, and rough but uniform fow at 37 to 50 feet. In c tests, during test 1 the flow exhibited the sume characteristics ats during test $\underline{l n}_{3}$. Water surface was rough, and vegetation was submerged in center part ol chamel. During tests 2 and 3 , flow was stil! nonuniform but withont such sharl breaks as in test I. In test 4, water surface was tough and flow showed same nonuniformity as in test 1 . In al tests, vegetation was not submerged during test 1. Flow was hidden. In second test (fd), flow submerged the vines and was rough but uniform. The thee later flows were rough but tairly uniform.

During these tests, " values increased as kudzu became reestablished.
Effect of test flows on channel: In test a, chamel was eroled gonsiderably (fig. 43), In test b, channel was senured considerably in upper portion (fig. 40, $t)$; much of the sediment was teposited in lower reaches of channel. In tests $c$, slight scour accured in under end of channel (fig. 41, $B$ ), and some deposition in bower ent of waterway. In tests d, praticatly no scour occurred (lig. 42, B).

## Jhimat lic: Rebaviol of Kidoze

Kudzu has a considerable retarding influence on flow of water, becaluse its great mass ol leaves and vines, which do not flatten so readily as those of Bermuda or centipede grass, oceupies a rela-
tively large part of the cross section of the chamnel and greatly disturbs the flow. The reduction in velocity thus effected results in increase of depth of flow and decrease in chamel capacity. With regard to scour, the reduction in velocity may be adrantageous. 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 $\mu$. 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 lavorable 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 chamel 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 channe! 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.

## Stablity of a Channel Lened 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 characteristies 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:

Live, heavy growth:

| Uneut | Fect per secont |
| :---: | :---: |
| Cut | 3 |
| meret, heayy growth, uncut | 2.5 |

There 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 Eudzu should be clesigned for lower velocities.

The tests on the dormant veretation showed that a loose mulch has very little capacity for protecting a channel against concentrated flows. Most of the heary 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, rootel to the channel bed. The vines then had much less retarding influence on flow than when they were
grean, 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 Plownes a Kldze-Lined Channel

When the altered channel B2-9 was first tested, on April 18. 1941, belore 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 chamnel, 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 tigure 44. The increase of the coefficient with time is readily apparent. As the growth of the vegetation progressed the retarding influence


Figoue 44.-Relation of Manning's $\boldsymbol{n}$ and hydraulic matias at vatious intervals after April 3, 1fM, for kudza chamel Be-9, the sides of which were plowed In on that dite, and for the same chamel at carlice times. The "before plowing" eurve represents estimates based on results of tests made when the kudza was dormant. Values for inst year ( $\overline{7}$ montins' growth of uncut vines) ave 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 morease as cover increases. In a bare, ansettled 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 chammel lined with a good growth of kudzu, such as this channel 12 weeks after the plowing, flow velocities of at least $3 . \overline{5}$ 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 adeguate 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 alter the plowing, the chamel 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 (fffering considerable protection to the chamel will clevelop within that time. If a temporaty 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 falure is reduced.

## COMMON LESPEDEZA EXPERIMENTS

('ommon lespedeat is a slender ammal 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 ontimum 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 ( $\sigma$ ). It is probably the most widely useful and productive leguminous forare crop in the South and makes excellent hay. Although perennial plants are usually preferred for planting in waterwass. common lespedeza is often used for this purpose, particularly in mealow-type outlets.

An extensive series of experiments was made on common lespecle\%, inchuding tests of uncut green regetation, fall dead stubble, spring dead stubble, and cut stubble.

Experimental conditions and results for the chamels lined with common lespedera 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 $V R$ for channels lined with common lespedeza is shown in figure 45. Dimensions and data on vegotal covers for the chamels represented in figure thare given in table 9.

Table 8.-Experimental conditions and results for chamels lined with conmon lespedea thapezoidal shape, bed slope of percent, botton width 2 feet, side slope a:l





PIGube 45.-Relation of Manning's $n$ and $V R$ for channels lined with common lespedera. Data in each instance are from exporiment 1 . Dimensions and vegetation data for the chameis zepresented are given in table 9.

## Recobs of Expebments

## Channel B2-2

Bed slope 6 perent, bottom width 2 feet, side slone $3: 1$, length 50 feed, planted by seeding May 17, 1937, and again June 12, 1937. Chamel fainly uniform in eross section, alimement, and cover. The fight side was a little low, and it was necessary to erect a wooton wall along this edge to contain the figher flows within the channel.
 averaged probably 4 inches in height, 36 ptants per square foot. Soil firm for first three tests. Between tests 3 and 4 the ground fro\% during test 4 it thawed out and became very soft and loose.

Equipment: Sharp-erested weir, string and rod.
Pabs: 9.-Dimensions and vegethl-liming conditions of lespecdeza chatzels from which the detaremersented by the $H_{m}-V R$ eurves in fibure 35 were obtained


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## Channel. B2-15C

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

Experiment 1, Mareh 1040 , lespedeza dead and noncut.-Lespedeza averaged 10 inches in length, 43 plants per square foot (fig. 40, A). Soil firn.

Equipment: For measuring inflow, 1 foot H-flume in tests $1-3$, 2 -foot HIflume 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 simultancously at three stations, making one set for exth 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 d. 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 $2-5 \pi$ 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 tue seour occurred during tests 1-4. A little erosion took place ('uring test 5 . In test 6 about a third of the cover was washed out and considerable erosion took wace. Chamel failed completely in test 7 (fig. 4!), E ).


F'ICURE 49.-Lespedera channel B2-15C, with sheet-metal side walls, (A) before testing and (b) after completion of testing.

## Channel B2-15B

Chamel tescription same as that of channel B2-15C.
 average, $41 / 2$ inches high, 290 plants per square foot (fig, 50, A). Soil firm.

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










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Table 10－－Experimental conditions and results for chamels lined with sericea lespedeza TRAPEKOIDAL SHAPE，BED SLOPE 6 PERCENT，BOTTOM WIDTH 2 FEET，SIDE SLOPE $3: 1$

|  | $$ | 皆 | $\frac{e_{2}^{2}}{\frac{2}{E}}$ |  | $\begin{aligned} & \text { d } \\ & \frac{2}{巳} \\ & \text { E } \\ & \frac{2}{2} \end{aligned}$ |  |  | 总 |  | $\begin{aligned} & 5 \\ & \frac{5}{3} \\ & 5 \\ & \hline 5 \\ & \hline \end{aligned}$ | 导 |  | $\begin{aligned} & 0 \\ & \frac{3}{3} \\ & \end{aligned}$ | oefficien | s |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $1 \% \quad \because$ | ： | 4 － | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14. | 15 | 16 | 17 | 18 |
|  |  |  | Cu. It. <br> perser． | Sq．It | Ft．per sec． | Fect | Fett |  | reat |  | $F$ | 1n．per hutar |  |  |  |  |
|  | 1 | Dee．1． 1937 | 4．77 | 1.95 | 3.04 | 5.36 | $0.2 \times 5$ | 0.039 | 0.43 | 51 | 49 | 0.49 | 23.4 | 0.0517 | 0.0370 | 0.872 |
|  | 2 | Dec．2， 1937 | 7.63 | 2，1 | 3.63 | 6.00 | ． 332 | ． 060 | ． 55 | 48 | 48 | ， 26 | 05.0 | ． 0502 | ． 0373 | 1.87 |
| 13201 $\quad$ Dormant，long， |  | D do ．rio | 19.8 |  | 4.5 S | 6.52 | 40 | ． 059 | ． 66 | 43 | 48 | ． 42 | 28.7 | ． 0450 | ． 0352 | 1.97 |
| － | 4 | Dee．$\quad 1.1937$ | 15.8 | 3.49 | 4.63 | 7.10 | ． 492 | ． 061 | ． 77 | 59 | 47 | ． 66 | 36.2 | ． 0505 | ． 0394 | 2.23 |
|  | 5 | Dee．4． 1937 | 23.2 | 4.43 | 5.24 | 7.69 | ． 576 | ． 063 | ． 95 | 40 | 46 | 1.12 | 97.5 | ． 0490 | ． 0395 | 3.02 |
| $132-4.9$ Green． | 1 | Oct．6， 1038 | 5.41 | 2.94 | 1.84 | 6.87 | － 429 | ． 06488 | .65 | 45 | 68 | ． 14 | 15.06 | ． 117. | ． 0771 | ． 789 |
| Meliu | 2 | $\cdots$ do | 9.08 | 3.9 | 2.51 | 7.15 | ． 5.5 | 00655 | ． 77 | 55 | 68 | ， 20 | 13.90 | ． 0955 | ． 06671 | 1.28 |
| lons． | 3 | Oct．7．1938 | 19.5 | 4.27 | 3.00 | 7.65 | ． 059 | ．0623 | ． 85 | 50 | 66 | 9 | 16.16 | －0836 | ． 0612 | 1.68 |
| woody． | 4 | $\ldots \mathrm{do}$ dis | 16.9 | 4．83 | 3.51 | 7.69 | ．628 | ．0609 | ． 96 | 39 | 67 | ．08 | 17.98 | ． 0799 | ．0603 | 2.20 |
| wour． | 5 | Oct．S． 1938 | 23.3 | 5.47 | $42)$ | 7.89 | ． 605 | ． 0656 | 1.06 | 51 | 61 | .25 | 90.02 | ． 0701 | ． 0555 | 2.96 |
|  | 6 | Oct．10．193s | 27.3 | 5.98 | 4.56 | 7.88 | ． 760 | ． 0655 | 1.20 | 57 | 65 | ．21 | 20.49 | ． 0693 | ． 0554 | 3.46 |

RECIANGULAR SHAPE, BED SLOPE PERCLANT, BOTTOM WIDHH 2 FEET

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

Cutting a good stand of green lespedeza to 2 -inch length, so that only bare stems remained, in channel B2-15A lowered the 1 etardance coeflicient for flows deeper than 0.5 foot on a 3 -percent - lope to less than 0.025 . Fairly high $n$ values were obtained for good stands that were green and uncut (fig. 45). The $n-V / i$ curve established for long green Bermuda grass (hg. 12, C) lies between these for lespedeza and approximates their shape.

Results of the tests made on the stubble that remained after catting of the vegetation in channel $\mathrm{B} 2-15 \mathrm{~A}$ are rather surprising. Although there was not mach 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 mate 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 teet 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 mecting this description, permissible velocities are iower.

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 $V R$ 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 P2-15C. The final test flow caused complete failure (fig. 49, B).

## Stambery of a Chavtre baned whth Common Lespebeza

The scour rates obtained in the tests on lespedea linings revealed that an uncut green lining yives a waterway fainly goot mrotection. Chamels $\mathrm{B} 2-5$ and $\mathrm{B} 2-15 \mathrm{~B}$ both withstood a velocity of more than $\overline{5}$ leet per second without appreciable damage. The permissible velocity of flow when the veretation is in this condition is about $\overline{5} \bar{b}$ leet per second.

Results of the tests made on chamel 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 toot per second. In the fall, however, the protective capacity of the dead stubble is much greater. The results of the tests on chamel 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 moming: the surface soi! thawed out and was quickly eroded from the channel bed.

## SERICEA IREPEDE:A EXPERDIENTS

Sericea lespedeza is a deep-rooted peremial legume. Plants grown from broadeast seed may attain heights of 12 to 18 inches
the first year it weather conditions are faromble, and in the second year usually develop into a dense, weil-branched stand having a height of from 2 to $\overline{5}$ feet, aceoreling 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 carly it makes excellent hay. In the soil conservation program sericea has been lound very useful for the region to which it is adapted (\%). It has bern 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 Attantic 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 :ome 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 $u$ and $V$ for long and short green and short dormant sericea lespedcza 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.
 scricet lespedesa from which the dale remesemted but the $H_{m}-V R$ cteress in fighere os trere obtained

| finins vondition ant rhatnet | Nominn! dimensions |  |  | Statad court |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\begin{aligned} & \text { liedi } \\ & \text { aloper } \end{aligned}$ | Huthem walsh | Sitte slope | Hirishl | Stems wer southe fout |
|  | fratre | Hent |  | Inthiss | Number |
|  13! 1116 | 3 | $\underline{2}$ |  | 29 | 80 |
| V H2 11t | 3 | $\underline{9}$ | do | 10 | 135 |
| Verctation has sad thatmatt: <br> IR 1 | fi | 2 |  |  |  |
| 18, | 3 | $\underline{2}$ | Crictica | 17 | [818 |
| Wextiatims short and ureme |  |  |  |  |  |
|  | ${ }^{G}$ | 吕 | 3: | ${ }_{6}$ | (1) |
| Verestat wh wort and dormam: | 3 |  | MיMdial | 2 | $1=1$ |
| 112 $106^{*}$ | 3 | $\underline{\square}$ | (b) | 1 | 511 |





## Racomon Eivpiminems <br> Cuaval Blo-1


 slope, and atinement. The right side was atitle low and a wood side wall was ereeted along it to contime the higher flows to the channel.
 lespedeza. on average, mobably is inches high, iat phats fer wuare foot. Suil faidy tirm.

Squipment: Sharp-crested woir, string and soud.
During coth test a simgle observer made water-surface measarements at four stations, protressing downstream. There were thre 10 -foot reaches.

Most of vegetation renatined ereet for first two tests (fige 52). No record avaitable of vegetation's behavior in tests 3 and 4 ; it is believed that only regetation in center portion of channel was submerged. Water surface very


Figeter 51, Relation of Maming's $n$ und T'R for chamels lined with (A) long green, short freen, and shont dormant sericea despedea and ( $D$ ) lonts dormant soricen lepedeza. Vegetation in channel [te-1 remaned erect furing tests 1 and 2 ; for the other tests, no record is available.
rough for all tests. The fact that values of $n$ were unusualig low even for first two tests can be attiobuted to sparseness of cover. Value of $\mu$ did not decrease much when submergence increased, probably because of inerease of bed roughaess by scour.

Considerable scour occurred.

## Chandel B2-4

Bed slope 6 percent, bottom width 2 fect, side slope 3:1, length 50 fect, planted May 17, 1937, by seeding. Channel fairly regular in cross sectinn, siope, 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 frech and cat.-Cutting, 2 months before testing, had reduced height of sericea les!edeza 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 fownstream. There were three 10 -foot reaches.
Vegetation was sabmerged during all tests. Water surface very rough. Some stalks stood up) against flow and caused splashes ( inches high.
Some scour took phace. A fainty large number of holes in the channel botom were more than 3 inches deep (fig. 53 ).

## Channel B2-10C

Bed slope 3 percent, bottom width $\geq$ feet, sides vertieal (sheet-metal side walls used), length 50 feet, planted May $193!$ by seeding. Chamel very regular in eross section, slope, and alinement.


Ficere 52... Sericea lespedeza chanel Be-I during test 2.

Experiment 1, April 1941, vegelation domant and cat.-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 $u$ few weeks before tests. Channel bed covered with fairly thick mulch of dead leaves and stem (fig. 54, A).


Ftgure 53.-- Sericea lespedeza chamel B2-4 after completion of testing.

Equipment: 2-foot H-flume, point gages.
During ench lest three men made water-surface measurements simutlaneously at three stations, each man making one at each station. There were two $10-$ not reaches.
Vegotation was submerged during all tests. Water surface rough during all tests.
toose mulch on chamel bed was washed out during beginning of low first llow. Chumel was eroded very aniformly 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 apparance. Most roots exposed to depth of 1 to 2 inches. Scour slightly greater near side walls, owing to distumbuce of soil by installation. Very little or no material deposited in chamel (fig. $5 \cdot 1, D$ ).

$$
\text { Channel } B=-10 \mathrm{~B}
$$

Chamel description same as that of chanal B2-10C.
E.periment 1 , Jome 1011, vegftation yeen and whent.-Stems, on average, xe inches long, and not yet woody (fig. $\overline{5}, \ldots 1$. Density 80 stems per sruare foot. Sheet-metal side walls had not affected phants, having been erected about 2 weeks before tests. Soil slightly disturbed where walls had been installed.

Equiphent: 2-foot 1 -ilume, point gares.
buring each text three men made water-surface measurements simulfamponsly at thee stations, caeh man making one at each station. There were two 10 wot rathes.



 hofore terting atd ( $B$ ) during te'st :

Stems remainerl erect during test 1 ; bent shighty daning test 2 ; bont farther, and a third of then lecame submerged, during test 3 (liz. $\sigma 5, h$ ). All but a few were submerged during test d, and all were submerged during test 5. Water surface rough. Vahte of $n$ was lower for test 1 than for test it liecause foliage did not oceur in abundance on stems to height of about 0.15 loot above ground line. At completion of tests, value of on was still decreasint mabidly as depth and velocity of flow increased.

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

## Cilannel B2-14C

Bed slope 3 percent, bottom width 2 fiet, sides vertica) (sheet-metal sidh walls used), length 50 feet, planted May 1939 by seeding. Clamnel very regufar ill cross section, slope, and alinement.

Exporiment J, March 10.0, vegetation dormant and what,-Sericea lespedeas on average 17 inches high, 88 plants per square foot (fig. $\overline{0}$ (i, 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 1h-flume in other tests; for measuring outfow, weighing lank in tests $1 \rightarrow 1$, 1 -foot H-flume in test 5 ; point gages.

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

In tests 1-3, flow was practically hidken by muleh in chanal. The loose material was washed out by succeeding tests, until at the completion of test 8 it was gone. Submergence of vegetation started shring test 7 (fig. $5(i, i f$ ), and was eomplete during test 10 , Water sariace was lairly smoolh antil


Figure 5(0.-Sericea lespodma channel B2-14C (A) before testing and (D) 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 resistanee of the layer of dead leaves to a flow 0.07 foot deep. Retardance remained practically constant during fows 2-6, and no marked change in $x$ occorred until depth and velocity of how became great enough to effect considerable bending and submergence.

Slight seour 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, fune 1940, vogetation green aud uncat.-Sericea lespedeza, on average, 16 inches high, 135 plants per square foot. Soil frm.

Equipment: 2 -foot H-flume, point gages.
During each test three men inade 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 vemained 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 $u$ values in agreement with those for other chamels having similay linings. At completion of experiment values of $n$ were still decreasing trapidly as depth and velocity increased.

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

## Chinnnel B2-14A

Channel desc:iption same as that of channel B2-14C.
Enperiment 1, October 1940, vegetation green and recently cut.-Sericea lespredear averaged probably 2 inches in height (fg. 55). 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 ciosely 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 $\pi-V R$ relations, includes data on the behavior of long green sericea as the value of $V R$ increased. When $V R$ reached a value of about 0.3 , bending started. At $V R$ $=0.9$, submergence was well advanced. The bending and flattening presumably continued somewhat beyond $V R=4.0$, 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 $V R$ equaled 4. In comparison with $n$ values for Bermuda grass those for sericea lespedeza at given values of $V R$ are considerably higher. At $V R=1.0$, the $n$ value for the lespedeza is more than twice as great as that for Bermuda grass.

 at completion ait texting.

 and (f) days ater heing subjectet to a series of five tominute test flows.

The $n-V R$ 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 $\mathrm{B} 2-14 \mathrm{C}$ had a good stand that when green would be comparable to those of channels $\mathrm{B} 2-10 \mathrm{~B}$ and $\mathrm{B} 2-14 \mathrm{~B}$. At the same $V R$ value the dormant plants,


Figura 59.-Sericea lespedeza channel B2-1 IA. 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 $V R$ 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 $V R$ value less than 2.5 than short sericea lespedeza, because it covers the ground more completely.

Stablity of a Channel Laned with Semicea Leespedeza
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 sten. 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 rreen lining is approximately 3 feet per second.

The tests on the two channels having green uncut linings (B210 B and $\mathrm{B} 2-14 \mathrm{~B}$ ) 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 lespede\%a. Accordingly, until more information is avalable it is recommended that the permissible velocity tor 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 clormant vegetation, either short or long. The tesi 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 lespedean indicate that in the green pliant stage this plant is an excellent cover for channels. Becau a of the scour produced when the vegetation is in the woody state, it seems desirable to cut it betore it reaches that


Pigure fo.-Relation of Manning's $x$ and depth of fow for chamels lined with short prep, short dormant, long green, and long domant serieea lespedeza. Bed slope 3 percent, bottom width 2 feet, sides vertical (sheetmetal side walls used). Time of testing: B2-14A, October; B2-10G, Auril;
 chamel be-bid was due to scour.
state. This recommendation concurs with the usual practice of cutting sericea lespedeza for hay before it becomes woody.

## SIDAN GRASS EXPERIMENT

Sudan grass is a mapidly 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 trasses can become established. When seeded broadcast it grows 3 to 5 feet high and has stems about "in 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 chamel lined with Sudan grass are presented in table 12, and further information refarding the experiment on this channel is here summarized.

## Recobl of Expmanext <br> Channet Ba--3

Bed slope 6 percent, botlon with 2 feet; side slope $3: 1$, length 50 feet, banted by seefing May 17 , 1937 , and arain $\mathrm{j}_{\text {une }} 12$, 1937 . Ghannel fainly uniform in cross section, slope, and alinement,
 stems was 2 to d feet, density 20 , Mants per square foot. Soil firm.

Gquipment: 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, wrogressing downstream. There were three 10 -foot reaches.

Vegetation was submerged during all tests. Water suaface rough (fig. G1).


Ficure 61.-Sudan grass chamel B2-3.

Table 12．－Expermental conditions and results for chamel E2－3，lined with long dead Sudan grass TRAPEZOTDAL SHAPE，BED SLOPE 6 PERCENT，BOTTOM WIDTH 2 FEET，SIDE SLOPE $3: 1$

| $\underset{\sim}{2}$ | $\begin{aligned} & \text { 告 } \\ & \text { Ey } \end{aligned}$ | $\frac{\stackrel{0}{2}}{\frac{2}{4}}$ |  | $\left[\begin{array}{c} \\ 3 \\ \frac{c}{3} \\ 5 \\ \frac{5}{3}\end{array}\right.$ | $\begin{aligned} & E \\ & \text { E } \\ & \text { E2 } \\ & \text { E } \\ & 3 \end{aligned}$ | $\begin{aligned} & \text { 을 } \\ & \text { 豆 } \end{aligned}$ | 安 |  |  | 年 ${ }_{\text {E }}^{\text {E }}$ |  | $\begin{gathered} - \\ 0 \\ \frac{1}{0} \\ \frac{1}{0} \end{gathered}$ |  |  | $\begin{aligned} & \text { s } \\ & \text { e } \\ & =0 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 2 |  |  |  | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14. | 15 | 16 |
|  |  | Cn. It. |  |  |  |  |  |  |  |  | In．per hour |  |  |  |  |
|  |  | per sec． | 27． $1 t$ | scc． | Fect ${ }^{7.60}$ | Fcct 0.422 | 0.0594 | $\underset{0.73}{ }$ | Ilim． | ${ }^{\circ} \mathrm{F} .48$ |  | 30.6 | 0.0421 | 0.0385 | 9.04 |
| 4 | $\begin{array}{cr}\text { Nov．} & 5.1937 \\ \text { Nov，} & 10,1937\end{array}$ | 15.5 11.9 | 2.81 | $\begin{array}{r}4.83 \\ 4.30 \\ \hline\end{array}$ | 7.607 |  | ． 0600 | ． 63 | 45 | 58 | 0.12 | 28.1 | $\bigcirc$ | ＋0352 | 1.65 |
| 2 | Nov．11， 1937 | 7.27 | 1.53 | 396 | 5.91 | ．310 | ． 0606 | .49 | 14 $\square$ |  | ． 08 | 25.8 |  | ． 0355 | $\underline{1.25}$ |
| 1 | Non do ．．．． | 4.58 | 1.42 | 3.23 | 5．：1 | ． 9 A | ． 0634 ： | ． 43 |  |  |  |  |  |  |  |

The fact that $\mu$ increased for the final (lowest) fow is probably due chiclly to an increase in bed roughness by scour rather than to a decrease in depth and velocity.

Consiterable erosion took place but did not damage the chamel to the extent of complete failure.

## Hyoradlic Behavior of Sudan Gass

The stems of the Sudan grass were not woody, and they readily bent over and shingled under the force of the fowing 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.

## Stablify of a Channel Lineb witi 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-


P'obere fg.- Relation of Maming's $n$ and $V R$ for chamels lined with a mixture of orchard grass, redtop, thalian ryegrass, and common lespedeza. Bed slope 3 porernt. Data on test conditions are givell 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


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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 $V R$ 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 testemy and vegetal-lining conditions of ohamols finced with grask mixture from whieh the datet represented by the $n_{m}-V R$ euroes in figure ge werc oblained


## Recomb of Experments

## Cilannel B2-12C

Bed slofe 3 bereent, bottom width 2 feet, sides vertical (sheet-metal side walls used), length 50 feet, planted May 1030 by seeding. Channel very unitorm in cross section, slope, and alinement.

Experinent 1 , April 19,1 , grassess varying in comdition, cat preceding fall. -New growth of grass averaged 412 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 orehard grass (fig. (i3, A). A light growth of ground moss covered 10 percent of the channel hottom. Soil firm.

Eguipment: 2 -foot H-flume, point garges.
During cach test three men made water-surface measurements simultaneously at three stations, each man making one at each station. There were two to-foot yeaches.

Vegetation was submexged, except for a few stems, during tests 1 and 2. Water surface rourh duxing all tests. Values of $u$ in agreement with those for other chancls having similar linings of grass mixtures that were tested it spring and fall.

No erosion was apparent on areas covered by ground moss, and littie serious seour elsewhere ( $\mathrm{fig} .63, b$ and $C^{C}$ ). Surface of chamel was washed ciban of loose muleh, and fine roots were exposed in a few small areas. Many small deposits of coasse sand were located at cownstream side of larger clumps of vegetation. Very little increase in crosion near side walls.

## Cunnnel B2-12B

Channel description same as that of channel B2-12C.
Experiment 1 , Jue 1041, grasses varyiza in condition, watut.--Orehard 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 blafles 8 inches long. About 3 plants per square foot, and about 2 stems and 20 blates to each plant. At least 30 percent of area was bare of cover. Soil firm and compact, but not hard.

Equipment: 2 -foot fl-flume, point gages.
During each test three men made water-surface measurements simultaneously at three stations, cach man making one at each station. There were two in-foot reaches.

Grass blates were not completely submorged until test 3 and stems were Hot sulmerget until test 4. Water surface rough (hg. (id, 1). Level of $n$ values, high for a rather thin cover, is tue largely to nontunitom and clumpy nature of cover.

Practically no change in chamel bed resulted from tests.

## Channel B2-16C

Channe! !escription same as that of channel D2-12C.
Experiment 1 , March 19月0, yrasses varying in condition, cut meceding fall.
-Redtop and orchard grass were dormant, ryegrass green; dead plants but no seedings of lespedeza present (tig. (65). No appreciabie growth since cutting. Stems averaged about if inches in length. Average number of plants per square foot: Ryograss, 9; redtop, 1 ; orchart grass, 2 ; dead lespedera, 3 . Average number of stems or leaves per grass plant approximately 8 . Soil firm.

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


Fioune 63--Grass-mixture chamel 32-120: A, Close-up view of thamel bottom before Lesting; $F$, genura! view of chamel at completion of testing; (', close-ap view, at completion of testing, of area having least cover and showing greatest erosion.

H-flume in other tests; for measuring outhow, weiphing tank in tests 1-1, 1-forl J-flume in test 5; point gages.
'Three men made water-surface measurements simutinneonsly at three stations, each man making one for each of tests 1 -(i; and bwo, al the same station, for each of the other tests. There were two 10 -foot reaches.

No verelation sumerged during test 1. Submergence began in test 2 and increased with diseharge until during tast 7 it was complete. Water surfuce was fairly smooth during test 1 but gradually roughened as discharge inereased until it was decidedly rough during final test. Vahues of $n$ in agresw ment with those for other channels having simila linings of grass mixtures that were tested in suring and fahl.

There was no erosion during tests $1-8$; during later tests very slight soour oceurred.

## Cuannel B2-16B

Channel description same as that of channel $\mathrm{B} 2-12 \mathrm{C}$.
 grass, redtop, and lespedeza were green, itahian ryegrass had idremb seeded and turned brown; grasses averaged about 7 inches in length, lespeteza about $31 / 2$ inches (tig. 66,4 ). Plants per square fout: Orchard grass or redtop, 3 ; 1talian ryegrass, 5; lespedeza, 82. Soil firm.

Equipment: 2 -foot H-flume, point garges.
During each lest three men mate wher-surface measurements simultaneously at three stations, each making two at the same stution. There were two 10 .Foot reaches.

During test I all the lespedezit was submerged but about 30 percent of the grass remained above water; during test 2 a tew grass stems remained above water: during later flows, vegetation was completely submerged. Water surTace rough durimg 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 effeet of seattered clamps of orchard grass and redtop.

Practically no seour took phace (fig. 60, $B$ ).

## Cilannel Be-1ga

Chamel description same as that of channel B2-12C.
Experiment 1, October 1940, grasses werying in conditim, cut.-Orchard grass and redtop green; some lespedeza green, some dead: ryegrass dormant. (irass length \& to 6 inches. No record of stand count; photographs indieate fair tensity (fig. 67), Soil firm.


Figure 64.-Grass-mixture channel B2-12B (A) just before testing and ( $B$ ) during test 3 .


Figule 65.-Grass-mixture channel B2-16C before testing.

Equipment: 2-fuat fl-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 alumps, was subnerged aluring tests 1 and 2. Water surface was rough; it ampeared to be less rough during test 4 than during test 3 , but increased in roughness in tests 5 and 6 . Values of $n \mathrm{jn}$ agreement with those for similat channels lined with the grass mixture that were tested in spring and Eall.

Chamel hottom remained practically anchanged.

## Hydeaulic Behavior of

 Grass MixtureOf the grasses used in mixture to line channels $\mathrm{B} 2-12$ 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 How 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 b6-Grass-mixture channel [32-16B (A) before testing and (b) after test 4.

The relation of $n$ and $V R$ for the two series of grass-mixture channels, B2-12 and B2-16, which had similar bed slope and crosssectional shape, varies considerably with season and height of


Pigene 67.-(Grass-misture channel B2-16A, before testing.
frass (fig. 62). It is not possible to do more than generalize on the effect of each of these varables. The three experiments conducted in the fall, winter, or spring were on vegetation cut in the fall to a length of a to 5 inches. The $u-V R$ relation is almost identical with that obtained in test: of chamels lined with dormant Bermuda grass of about the same height.

With Lealian ryegrass and common lespedeza dominating the mixture, the chamels had some green protective cover at every season. In the summer a good stand of lespedera in channel B2.16B Cormed a mather dense, fainly unform cover that resulted in an $H-1 R$ relation similar to that for channels lined with long green Bermuda grass. During the late fall, winter, and spring, Itatian ryegrass afforded a fair cover, helping to maintain values of $n$ arain on a level with those for a chancl having a uniform cover like Bermuda grass.

Channel B2-12B, tested in June, showed values of $n$ relative to IR comparable to those for chamel B2-16B, even though very little lespede\%a was present. The cover consisted of clumps of green orchard grass and bedtop 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 regetation tended to develop and maintain excessive turbulence resulting in high $n$ values.

## Spablety 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 EXPERTMENTS

Experiments were conducted on three bare-earth channels. By comparing the soil losses in these channels with those in vegeta-tion-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 chamels is here suminarized.

## Recond of Expenfiewts <br> Channel B2-3

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

Experiment 1, April 19-98, 1938. Soil still loose.
Eguipment: Sharp-crested weir, string and rot.
During each test a single observer made water-surface measurements at four stations, progressing downstream. There were three 10 -foot reaches.

Water surface was deeidedly rough except at start of first test. Erosion during each test changet flow characteristics during the test. A genernd increase in $\pi$ as testing progressed resulted from inerease in bed roughness through scour.

The chammel was scouref rapiliy. Even the lowest flow croded the lower portion of the channel to the stiff underlying clay.

## Cilannel B2-13C

Bed slope 3 bercent, bottom width 2 feet, sides vertical (sheet-metal side walls used), length 50 feet; topsoil placed and graded May 1939. Channel unifom in eross section, slope, and afinement.
Experiment i, fipil 194h.-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 make watar-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. $68, D$ ), particularly along walls of channel.

## Cifnnel B2-13B

Chamel description same as that of chamel Be-13C.
Experiment 1, Ime 10:7.-Soil was firm; it had been disturbed slightly by muling of a few small weeds.

Equipment: 2 -foot F-flume, point gages.
Table 15.-Experimental condidons and results for bare channels
TRAPEZOIDAL SHAPE, BED SLOPE 6 PERCENT, BOTTOM WIDTH a FEET



 8 minders of test 1 .
Durng dath dest ther men mate water-surfaer measurements simultane-
 the la-fort reasher.

Whter shface was not wers rough.
 chatati.

## 

At tho start al tach experiment, betore any erosion oxecurred in the chambel, fow wat fatily smooth. As testing progressed and :an imerular soour patern develspod, flow genorally became rougher. The retardance cobllicients for ehannel Be-3, experiment 2 , show that the ehammel beame rongher as testine profressed. They are at a muth lower lovel that those for the chammels laned with veretation.

Soll-loss rales were high for all tests on the three hare-earth ehamels. Pormissibferecties for such chammels are pobably not more than f font per secomt.

## 

## 

A fraphe methor of dosigning vegretation-lined chamols has bern developed on the basis of the relation betwen If the prodact of mean relocity of fow and hedrawic malias, and $n$, the
 batis for varons shope and for dilleme kinds al veretation.

Channel design curves have been developed for long green, short green, and short clormant Bermuda grass (fig. 69-71). (The lastnentioned 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 caln 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, trianguiar, and parabolic channel shapes presented as figures 73-79.

The following example illustrates the procedure:

1. Given: $Q=100$ cubic feet per second.

$$
S=0.03 \text { foot per foot. }
$$

2. Problem: Determine the section of a chamnel that is to be lined with Bermuda grass. Consider a long, green condition. Design for maximum velocity of 5 feet per second.
3. Sohution for required $R$ : Enter tigure 69 at $V=5$, proceed right to the $V-V R$ curve for $S=0.03$, then downward to the $R-V R$ 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 $\mu$, since its value is represented in the design curve placement. If desired, $n_{m}$ ean be determined by proceeding left from the intersection of the vertical dashed line with the $n-l^{\prime} R$ curve to the $n$ ordinate scale. In this example $n_{m}$ $=0.042$.
4. Selection of chamel section:
a. Solve for $A$.
b. Determine bottom width, side slope, or top width for a traperoidal, 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:



Fincra 69.--Chamel design eurves for long green Bermuda grass.
MANNING'S RETARDANCE COEFFICIENT, $\Rightarrow$


Figctue $\mathbf{7 0}$ - Chanmel desifn curves for short green Bermuda grass.


Figere 71.-Channel design curves for short dormant Bermuda grass.


Priere 72. - Channel design curves for tone green sericea lespedeza.


Ficure 73.-Curves for detemining the elements of trapezoidal channels with side slope 2:1.


Florra 74.-Cuves for determining the elements of trapeooidal chamels with side slope 3:1.


Figure 75.-Curves for determining the elements of trapezoidal channels with side slope $4: 1$.


Ficure 76.-Curves for determining the elements of trapezoidal channels with side slope $5: 1$.


Figurk $77 .-$ Gurves for determining the elements of trapezoidal channels with side slope 6:1.


Vigure 78 .--Curves for determining the elements of triangular channels.


Figure 79.-Curves for determining the elenments of parabolic chamels.
The elements $b, z$, and $t$ change rapidly as velocity changes. They are affected to a considerable extent by a change in velosity 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 $n-V R$ 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 $n-V R$ curves for vegetation types and conditions other than those represented in figures 69-72, and include also the applicable $n-V R$ 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 $V R$ 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 comrelated with VR. Only scour, loss of vegetation,

liguaze 80.-Relation of Manning's $n$ and $V R$ for channels lined with dense, uniform stands of greeri vegetation more than 10 inches long.


Figine 81,-Relation of Maming's $u$ and VR for chamels lined with dense, uniform stands of clormant vegetation nore than 4 inches but less then 17 inches long. (Centipede grass value plotted represents data from five tests in which diseharge was apmosimately the same.)


Figure 82.-Relation of Manning's $u$ and $V R$ for channels lined with dense, uniform stands of vegetation more than 4 inches but less than 8 inches long.


Figura 83.-Relation of Manning's $n$ and VR for channels lined with dense, miform stands of vegetation cut to a length of less than $21 / 2$ 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 $\hat{i}$. The $V R$ value can be used as an indicator of whether $n$ has reached a relatively constant value. Up to a $V R$ value of 5 for long, pliant vegetation and one of 3 for short vegetation $n$ decreased with increase in $V R$. For design purposes $n$ can be assumed to remain constant when $V R$ values go beyond these figures.

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

In applying the $n-V R$ 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 $n-V R$ presentation is based were obtained through tests that proceeded from low to high flows, with the vegetation upright at the start.

## Pelaissible Verocities

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 chanueis in Cecil saudy loam having ucyetal linings of the kinds studied

| Chaunt! lining species and condition | Bed slope | Experiments | Permiss: ble velocity |
| :---: | :---: | :---: | :---: |
|  | Percent | Number | $\begin{aligned} & \text { Ft } t \\ & \text { pit } \\ & \text { sec. } \end{aligned}$ |
|  |  |  |  |
| Green: | 8 |  | (2) |
| Long . ... | 10 | 2 | 8.0 |
|  | 40 | None ${ }^{2}$ | 7.4 |
| Short. kept cut .................. | 10 | None 1 | 9.0 |
|  | 20 | None |  |
| Short, cut just bufore test | 10 | ${ }_{9}^{2}$ | (1) |
|  | 20 | 1 | 6.0 |
| Dormant: Lons |  | 1 | (5) |
|  | 10 | i | 5.6 |
|  | 20 | $\frac{1}{5}$ | \&, 8.9 |
| Short, kept cut eut just before test | 3 3 | $\stackrel{4}{1}$ | ${ }_{6}^{8.81}$ |
| Centiperle grass: |  |  |  |
| Green, lonk ........... | 10 | 1 | ${ }_{8.0}^{9.6}$ |
| Dalfs grass and erabsrasy: |  |  |  |
| Greth. Ions | 6 | : | 3.5 |
| だadzu: |  |  |  |
| Unecat ..... . | 3 | 1 | 4.0 |
| Cut | 3 | 1 | 3.0 |
| Dermant. henvy srowth, uncut .... | 3 | 1 | 2.5 |
| Leapeetera : |  |  |  |
| Grent (apring) | 3 | 1 | 5.5 |
| Lecrix (summert) | 6 | 1 | 5. 5 |
| Shurt. eat just before test | 3 | 1 | 4.3 |
| Derth, uncut sthbble: Sprins | 3 | 1 | 1.0 |
| Fal! | 3 | 1 | 3.5 |
| Surien kespedera: |  |  |  |
|  |  |  |  |
| Meditm lony (woorly) ........... | 6 | 1 | 3.6 |
| Shert, eut just before test .......... | 3 | 2 | 3.5 |
| Dormant: |  |  |  |
| Do | ${ }_{3}^{6}$ | 1 | 8.0 |
| Short, eat prerious fall ${ }^{\text {a }}$, | 3 | 1 | 3.0 |
| Sudan grass: |  |  |  |
| Greent yrod gtand | 3 | 0 | 4.6 3.8 |
| Grasy mixture: |  |  |  |
| Green, lons (summer) | 3 | 2 | 6.5 |
| Green and tormant, short: |  |  |  |
| Fall - .... . .. | 3 |  | 6.5 |

[^6]
## LITERATLRE CITED

(1) BaiLey, R. Y.
1939. FEDZU FOR EROSION control IN THF SOUTHEAST. U. S. Dept. Agl. Farmers' Bus. 1840, 32 pp., illus.
(2) COOK, H. L.
1938. SPARTANEURG OUTDOOR hyDRAELIC LABORATORY. Civ. Engin. 8: 653-655, illus.
(3)
1938. SOMt NEW irydianlic data. Nat. Res. Coumeil, Highway Res. Bd. Proc. 18: 204-212, illus.
(4) and ChMPEELL, F. B.
1939. CHaRACTEMSTLES OF SOME MEADOW STRIP VEGETATIONS. Agr. Engin. 20: 345-348, illus.
(5) Hasthiton, C. L.
1939. TERRACF GUTLETS AND FARM DRANAGEWAYS. U. S. Dept. Ag1. Farmers' Bul. 1814, 46 pp, , illus.
(6) l'ietens, A. J.
1939. TIF ANNUAL LESPEDFZAS AS FORAGE AND SOIL-CONSERYING CROPS. U. S. Dept. Agr. Cir: 536,56 pp., illus.
1939. LESPEDEKA SERTCEA AND OTHER PFRENNIAL LESPGDEZAS FOA FORAGE ANv SOL CONSERVATION. U. S. Dept. Agr. Cir. 534, 44 pp., illus.
(8) Rassser, C. E.

1!2!. FLOW OF WATER IN gRAINAGE ChaNNELS. U. S. Dent. Agr. Tech. Pul. 129, 102 plo, illus.
(9) Res, W. O.
 Agr. Engin, 29: 27-29, illus.
(10) Sendrle, A. T., Vtsiale, H. N., ENLow, C. R., and Woooward, T. E.
1934. A PaSTLRE HANOBGOk. U. S. Dept. Agr. Mise. Pub. 194, 89 f!., illus. (Revised, 1942.)
(11) ViNstl, H. N.
1920. sudan grass. U. S. Dept. Agr. Farmers' But. 1126, 23 pp., illus. (Revised, 1941.)

İ U. S. GOVERNMENT PRINTING OFFICE: 1949-79526:

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[^0]:    1 The research reported here was begun under the supervision of $F$. $B$. Campbeli, then in charge of the outloor 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 cooneration was received from the Operations Branch of the Soil Gonservation Service, particularly from the regional office in Spartaniourg, S. C., of which T. S. Buie jhas charge as regional conservator.

[^1]:    ${ }^{2}$ Italic numbers in parentheses refer to Literature Cited, p. 115.
    ${ }^{3}$ This study and its results have been the subject of several hrief proliminary 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. 1989: 653-656, illus. [Processed.]

[^2]:    ${ }^{1}$ Cat shortly beroret text.
    \# Kept eut.
    "Changed by plowiss:
    © Cut of f-ituch height ? mopths hefore teat.
    ${ }^{5}$ Cut previous fall.

[^3]:    

[^4]:    sericea lespedeza, good stand, cut provious fall, stiff stalks I 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) ; 9 , uncut green and dormant grass mixtare, good stand 4 to 7 inehes tall (ehannel B2-16B, test in June); $h_{\text {. uncut green conmon lespedeza, very good stand } 4 / 2 \text { inches tall (channel }}^{\text {g }}$ B2-1513, test in June) ; i, unent green common lespedeas, thin stand 4 inches tall (channel B2-11B, test in June); j, short green common lespedeza, good stand, cut to 2 inches of hare stems (channel B2-15A, test in October); $k$, no vegetation (channels $82-13 \mathrm{~B}$ abd $\mathrm{B} 2-13 \mathrm{C}$ ).

[^5]:    'Only hare stems ranasitied.
    Debsity gumb.

[^6]:    : Velocity developed in tests was insufficient to permit estimate.

[^7]:    For sale by the Superintendent of Boenments. $\mathrm{l}^{\prime}$. S. Gavernment frinting Office Washingtom 23, 13. C. - Priee 35 cents

