Technical Bulletin No. T-15 September, 1942

OKLAHOMA AGRICULTURAL AND MECHANICAL COLLEGE

AGRICULTURAL EXPERIMENT STATION

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in cooperation with
SOIL CONSERVATION SERVICE
U. S. DEPARTMENT OF AGRICULTURE

TESTS ON VEGETATED WATERWAYS

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PREFACE

Vegetated channels are proving satisfactory and are becoming very popular where runoff water must be lowered from sloping areas into naturally established creeks or waterways. Very little is known about the design for small waterways used on agricultural areas as incountered in soil conservation work in this region. Previous experimentation is seldom applicable to the problem, but forms the foundation for this study. Channel design is dependent upon many factors, including available grass or other plants and their adaptability to the soil, maintenance of cover, resistance the vegetation offers to the flow, the choice of design coefficients and maximum safe velocities.

This study was made in an effort to answer as many of these questions as possible. Four grasses were tested on which observations were made to determine the protecting qualities, maximum safe velocities and design coefficients for each.

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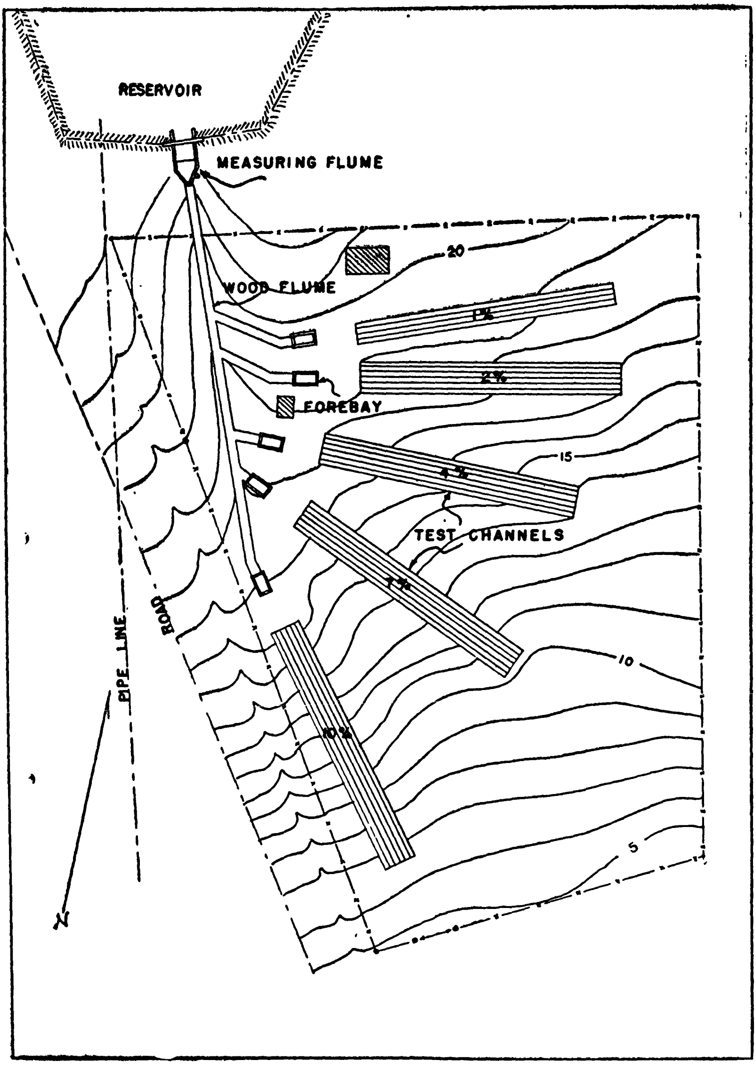

Figure 1.—Arrangement of the experimental area.

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INTRODUCTION

In the development of methods for the collection and conveyance of surplus runoff waters from agricultural areas, the farmer and the agricultural engineer have been confronted with new problems arising from the use of vegetation to protect the channels in water disposal systems from excessive erosion. The problems involved in using this type of protection fall into two general classes: the hydraulic problems, or those relating to the capacities and velocities of such channels; and the agronmic problems, or those that relate to the establishment and maintenance of the vegetation. The studies reported in this bulletin deal principally with the hydraulic elements.

Previous experimentation in the hydraulics of channel flow has provided a foundation for the design of these waterways, but it is seldom directly applicable to the types of channels which are employed on agricultural areas. Cook (1) states: "Previous hydraulic flow investigations cannot be applied with confidence to the problems confronting the designer of small channels used for farm water disposal. Channel conditions are dissimilar, and, more importantly, the channels devised must be cheap and simple enough for the individual farmer to build."

To aid in the solution of some of these problems, the Soil Conservation Service established the Spartanburg Outdoor Hydraulic Laboratory. Several valuable papers have been published by this laboratory concerning the design of channels for farm water disposal systems. However, the vegetations and conditions investigated were those of the southeastern part of the United States. There was still no information which could be applied directly to the conditions existing in other regions. Accordingly, studies were inaugurated at Stillwater, Oklahoma, to obtain information applicable to the conditions of the central regions of the United States.

This bulletin presents the results of studies made on four important grasses. These were Bermuda (**Cynodon dactylon**), Buffalo (**Buchloe dactyloides**), Blue Grama (**Bouteloua gracilis**), and Weeping Love grass (**Eragrostis curvula**). These studies sought to determine:

1. The velocities obtained with different depths of flow for each of the grasses on several different slopes.
2. The maximum velocity which each vegetation could withstand.
3. The probable length of time that different grasses could protect the channel under sustained high velocities.
4. The effect of these flows on the grasses.

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* The manuscript has been reviewed and approved by M. L. Nichols, Chief of Research, Soil Conservation Service, Aug. 12, 1942.

** Assistant Agricultural Engineer; Cooperative Agent, Oklahoma Agricultural Experiment Station and Soil Conservation Service, with headquarters at Guthrie, Okla. The experiments reported herein were supervised by the author, with the assistance of Mr. Arthur L. Rhodes of the Department of Agricultural Engineering, Oklahoma A. and M. College. This work was made possible through the special interest of L. S. Ellis, former vice-director of the experiment station, and much assistance was received from the personnel of the Red Plains Conservation Experiment Station, Guthrie, Oklahoma. Valuable technical assistance was received from W. O. Ree of the Stillwater Hydraulic Laboratory of the U. S. Soil Conservation Service.

Figure 2.—Installing a channel on one percent slope, using 2″ x 12″ boards to hold the sheet iron separators to true alignment.

DESCRIPTION OF LABORATORY

The field work for this study was conducted on a natural slope, classified as Dougherty silt loam, located immediately below the fill dam of Lake Carl P. Blackwell. This lake is located six miles west of Stillwater, Oklahoma, on the area developed by the Land Utilization Division of the U. S. Resettlement Administration, and now under lease to the Oklahoma A. and M. College.

Figure 1 shows the general layout of the laboratory. Water for the tests was drawn from the lake through the intake tower, impounded in the old creek channel, and pumped to the reservoir. The pipe line which conveyed this flow, and the reservoir, are shown on the diagram. The tests channels are located down hill of the reservoir and the water was brought to the channels by means of wooden flumes. The reservoir was used to store a large quantity of water so that flows could be obtained which were in excess of the capacity of the pump.

DESCRIPTION OF TEST CHANNELS

Channels were tested on five different slopes. These were 1, 2, 4, 7, and 10 percent. The channels were located on slopes of the ground in such a manner that a minimum of cutting and filling was necessary to obtain the desired grade. The top soil was removed from the slope where the channels were to be located and the subsoil was brought to grade 12 inches below the finished grade. The sheet iron separators were placed in position and brought to true alignment by the use of 2″ x 12″ boards (Fig. 2). For the channels that were to be grassed by solid sodding, the topsoil was then replaced and tamped in the channels to within 4 inches of the final grade, after which sods 4 inches thick were carefully placed and rolled to exact grade. The channels that were to be seeded were filled to exact grade and

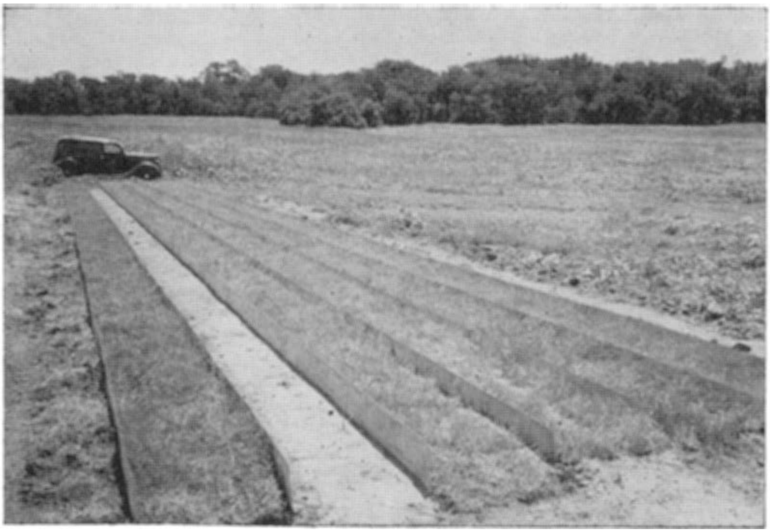


Figure 3.—Test channels on 4 percent slope, showing the sheet iron separators extending six inches above the surface of the ground.

seeded according to the best recommendations available. All the channels were made 2 feet wide and 100 feet long, and the grass was established on the various slopes as shown in Table I. Figure 3 shows the sheet-iron separators between the channels. These separators were installed before the channels were sodded, so that the grass roots could become established along the sides of the iron to aid in the elimination of erosion at this point. The extension sides, as shown in Figure 5, were placed on top of the separators so that flows greater than the height of the separators could be obtained. The low sheet iron separators were employed to eliminate leakage along the channel sides and to prevent the effect of shade upon the growth of grass.

At the time of testing, the vegetation in all channels was green and had not been cut. Data on the average length of stems are given in Table I.

TESTING PROCEDURE

The method employed to measure the flow (Q) through the 3-foot type H rate measuring flume and the wood flume used to convey the water to the test channels is shown in Figure 4. The wood flume was constructed of flooring and made water tight by the use of a thick coat of asphalt.

The tests were conducted by flows of given quantities of water down each of the channels for 30-minute periods, during which time measurements were made of the rate and the cross-sectional area of the flow along the channel. Each flow was established through the measuring flume and conducted through the wood flume to a concrete forebay; from there it was directed to the test channel by a movable duct (Fig. 5). The use of movable gates along the conveying flume made it possible to establish flows through an idle forebay before it was released into the test channel, and also made it possible to shut off the flow at the termination of a test.

The cross-sectional area of the flow was measured by the use of point gages mounted on angle iron supports as shown in Figures 5, 6, and 7. Point gage measurements were taken at 0.2-foot intervals across the bottom of the channel before and after each run (Fig. 7), and two sets of readings were taken at the same intervals across the surface of the water during the run. The first set was taken immediately after the flow was estiblished and the second set was taken just before the flow was shut off (Fig. 6). The width of the channel was carefully measured at the bottom and at the surface of each flow at each point gage location.

The amount of protective cover on the channels was determined by a volumetric measure. The measurement was accomplished by separating the grass into small bunches or clumps and twisting it to form a compact round section. The diameter of each section was determined with an outside-diameter scale and recorded with the average length of stems for that bunch. From these measurements the cubic inches of forage per square foot of channel were computed as shown in Table I. The air-dry weight of forage measured by this method was found to be 8.63 grams or .01903 pound per cubic inch, which is 32.88 pounds per cubic foot. The variation in weight was very small for the different grasses. This method of establishing the amount of vegetation on the channel was used in an attempt to incorporate the number, size and lengths of stems into a single figure. It also offers a simple method for comparisons in field channels and can be accomplished with a very small amount of technical training.

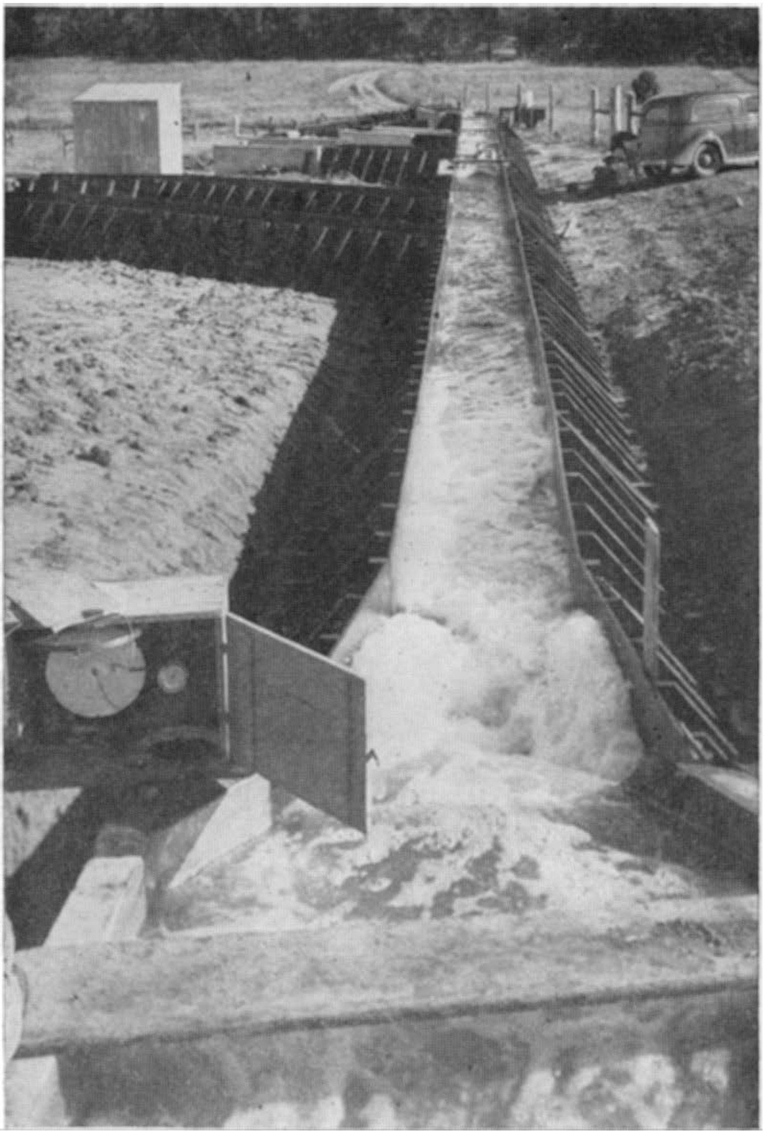


Figure 4.—A flow of 22 cubic feet per second through the type "H" rate-measuring flume and the wood flume used to convey the water to the test channels.

Figure 5.—A very turbulent flow at about 11 feet per second down a 10 percent slope. Note point gage mount and movable duct used to connect upper end of the channel to the concrete forebay.

Figure 6.—Taking point gage measurements across the surface or the water. Note that the Bermuda grass is not completely submerged by this flow, which is approximately six inches deep.

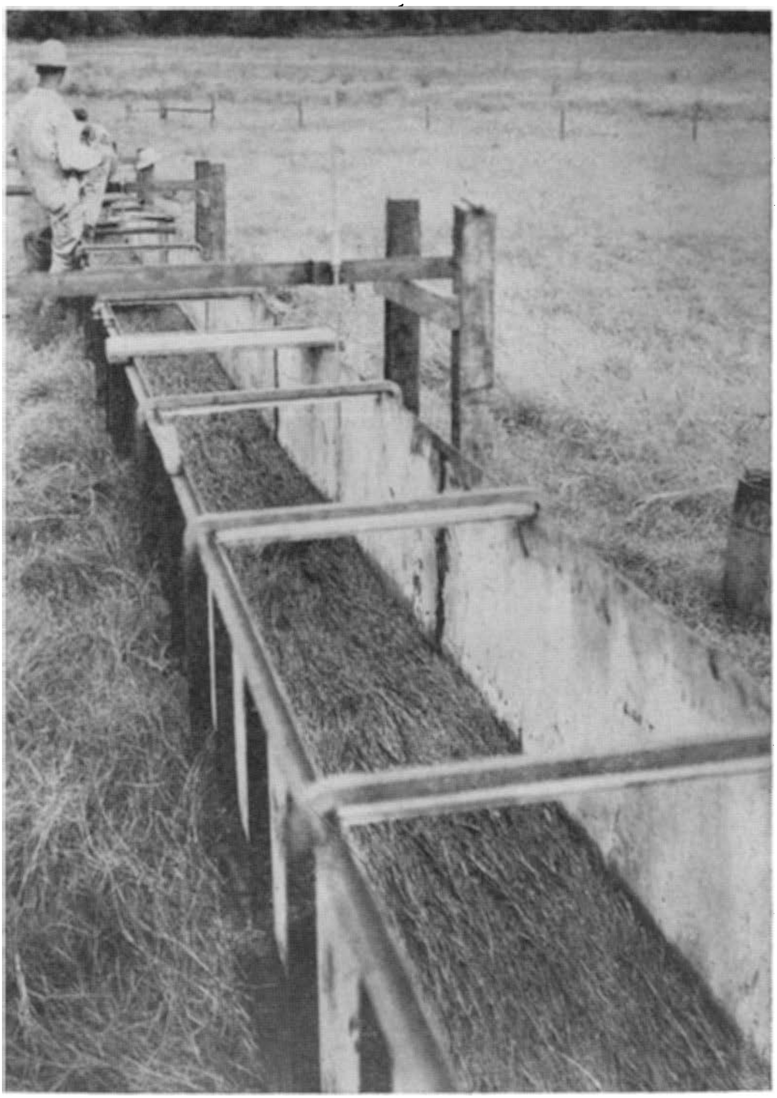


Figure 7.—Bermuda channel shown in Figure 6 after a heavy flow. The grass is completely flattened in shingle fashion. Men have just completed taking point gage readings across the bottom of the channel.

RESULTS

Protective Characteristics

The damage to a channel as a result of a test flow was determined by measuring the amount of soil which was removed from the channel bed by the flowing water. The protection afforded the channel was determined by studying these soil loss rates—the greater the protection the smaller was this soil loss rate. The soil loss was determined by the difference in the point gage readings taken before and after each run. The decrease in channel elevation was applied to the entire length of the channel and computed as surface inches of soil removed. Data relative to the grass, soil loss, and forage cover are shown in Tables I and II. The soil loss is tabulated as inches per hours, which indicates the average amount the surface of the channel was lowered per hour of testing. The total quantities of water used for the velocity study tests were approximately the same for each channel, but total quantities used in the destruction runs were quite different. The time of flow for the runs of the destruction tests was 60 minutes or 120 minutes each.

Table I.—Soil Loss and Forage Cover for Channels Used in Velocity Study.

Channel slope (%)	Grass	SURFACE SOIL LOSS (Inches per hour)*		FORAGE COVER			
				Cubic in./sq. ft.		Average length of stems (Inches)	
		1940	1941	1940	1941	1940	1941
1	Bermuda	.111	.037	23.57	23.54	11.8	14.2
2	Bermuda	.013	.022	30.88	35.98	14.5	17.5
4	Bermuda	.120	.026	33.93	23.42	13.7	13.7
7	Bermuda	.278	.032	33.14	17.23	15.3	14.0
10	Bermuda	.211	.097	25.86	19.77	11.7	12.1
2	Buffalo	.119	.055	4.11	3.08	4.3	4.2
4	Buffalo	---	.053	---	2.67	---	3.9
7	Buffalo	.262	.118	9.57	3.83	3.2	4.0
10	Buffalo	.271	.166	4.25	3.78	6.1	4.9
1	Blue grama	.087	---	18.99	---	10.7	---
2	Blue grama	.093	---	21.41	---	16.4	---
4	Blue grama	.154	---	18.06	---	12.3	
7	Blue grama	.127	---	12.15	---	11.9	---
10	Blue grama	.101	---	15.86	---	11.7	---
1	Love	---	.063	---	8.15	---	15.3
4	Love	---	.066	---	4.22	---	12.8
7	Love	---	.125	---	6.34	---	12.6
10	Love	---	.220	---	8.45	---	11.4

* The average amount the surface of the channel was lowered per hour of testing.

Forage Cover and Soil Loss

An attempt was made to establish the relationship between soil lost and the amount of forage cover. There appears to be no direct correlation between these factors that can be established with the observations taken from this study. The data in Table I appear to indicate that the type of grass, the slope of the channel, and possibly other factors have more effect upon the rate of soil loss than does a slight change in the amount of cover.

Table II.—Destruction Tests on Steep Channels.

Run	Date	Time (Hrs.)	Soil Loss (in./hr.)[1]	V (Ft./sec.)	Forage[2]	Channel conditions
			7% Bermuda 1940			
1	10/18	2	.012	9.50	33.15	Dry
2	10/19	2	.126	8.63		Wet
3	10/19	2	.024	8.87		Wet
Total		6	.324			
			7% Bermuda 1941			
1	8/18	2	.038	6.78	17.23	Wet
2	8/18	2	.023	6.96		Wet
3	8/18	1	.018	6.95		Wet
4	8/19	2	.035	7.06		Wet
5	8/19	2	.009	7.09		Wet
Total		9	.228			
			7% Buffalo 1940			
1	10/26	2	.162	10.69	9.57	Dry
2	10/26	1	.108	9.94		Wet
Total		3	.332			
			10% Bermuda 1940			
1	9/27	1	.120	10.46	25.86	Dry
2	9/30	1	.384	10.46		Moist
3	9/30	1	.060	10.64		Wet
4	9/30	1	.096	10.38		Wet
5	10/5	1	.204	10.37		Dry
6	10/5	1	.096	10.37		Wet
7	10/5	1	.264	10.36		Wet
8	10/5	1	.060	10.20		Wet
Total		8	1.284			
			10% Blue Grama 1940			
1	10/11	1	.228	11.37	15.50	Moist
2	10/12	1	.168	11.16		Wet
Total		2	.396			

[1] Surface inches of soil removed per hour of testing.
[2] Forage cover in cubic inches per square foot.

Slope of Channel and Soil Loss

There was considerable difference in the amount of soil loss from the Bermuda and the buffalo channels for the two testing seasons, as shown in Figure 8. The channels were the same both years except for repair work done at damaged spots. The reason for the difference in soil loss is not readily apparent, but may be explaned as follows: The light, fluffy humus layer accumulation which was less resistant to erosion was removed the first year, thus leaving the tighter soil exposed the second year. Another factor to consider is that the moisture content of the soil was higher the second year because of the excessive rains which occurred during the growing season of the grasses. Only one year's data was obtained on the blue grama because of failure to obtain a stand from seed the second year, and

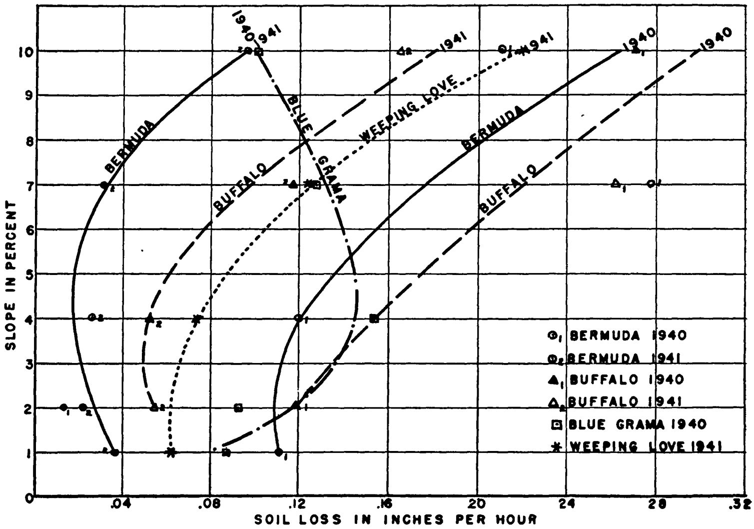


Figure 8.—Relation between amount of soil loss and the slope of the channel for the different grasses.

only one year's data on the love grass, which was established from seed for the second year's testing. There is no apparent explanation for the reverse shape of the grama curve, when all the other tests seem to follow a definite trend. In general, however, this information indicates that grass channels are very efficient when the slope does not exceed four or five percent.

Velocity and Soil Loss

The relation between velocity and rate of soil loss in surface inches per hour of testing is shown in Figure 9. This graph presents the soil loss for two series of tests on Bermuda and buffalo, and one on love and blue grama grasses. These curves are drawn through the mean of all soil loss and velocity points for each channel. This presentation is offered to show only the trend as indicated by the available data. These curves indicate that blue grama withstood higher velocities for intermittent flows than any of the other grasses. Observation and inspection of the channels during testing indicated the same trend. The high soil loss for velocity of the love grass may have been caused by its bunch form and also by a poor stand due to too much rain during the early part of the growing season.

Destruction Tests

Five tests of high velocity were conducted on different grasses to determine the length of time required to produce permanent damage. The testing was terminated on each channel when sufficient damage had been inflicted to render the bottom of the channel rough enough to cause jumps in the flow and accelerated erosion. This limit was termed as "failure" but not complete destruction. The measure of soil loss shown in Table II does not necessarily indicate all the soil that was removed because holes developed along the channel that were seldom located where point gage meas-

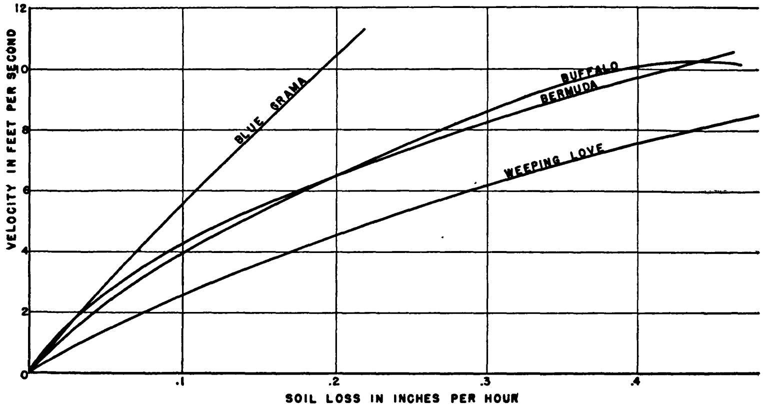


Figure 9.—Relation between the velocity of the water and the rate of soil loss for the different grasses.

urements were made. The development of these holes in the channel determined the extent of the destruction runs. The soil losses for the tests as shown in Table II indicate that soil moisture condition and time of previous flow have a pronounced effect upon the rate of soil loss. The rate of soil loss on the Bermuda channels which were carried on for two or more days showed a high rate of loss during the first run each day, but appeared to diminish during each of the succeeding runs. This condition may be the cause of the apparently high rate of soil loss in the grama channel on the 10 percent slope. The soil loss for all channels was similar for some of the runs but the buffalo and grama channels developed destructive holes in less time than the Bermuda channels under the pounding action of high velocity. The nature of the growth of Bermuda grass allows it to remain intact after a large amount of the soil has been removed from around its roots. Buffalo and grama did not withstand the same abuse.

HYDRAULIC CHARACTERISTICS

The hydraulic characteristics of a channel lining are usually expressed by means of a coefficient used with some accepted flow formula. In this bulletin the discussion and computations have been confined to the Manning formula, which is written in this report as:

$$V = \frac{1.486}{n} D^{2/3} S^{1/2}$$

From this equation:

$$n = \frac{1.486}{V} D^{2/3} S^{1/2}$$

Where

V = mean velocity in feet per second = Q/A.
Q = cubic feet per second.
A = cross sectional area of the flow in square feet.
D = depth of the flow in feet.
S = slope of the energy grade line.
n = a coefficient depending upon all of the characteristics of a channel which cause retardation of flow, such as roughness of material in the bed and sides, irregularity of bed and sides, irregularity in profile and cross-section, vegetation, and so on.

The depth of flow (D) is used in this equation in the place of hydraulic radius (R). Tests at the Spartanburg hydraulic laboratory have indicated that smooth sidewalls have no appreciable effect when the bottom roughness is great as it is in grass channels. This appeared to be true for channels up to one foot in depth and as narrow as one foot. Using depth of flow as hydraulic radius in effect omits the sidewalls from the wetted perimeter.

MANNING'S "n" WITH DEPTH

The variation of Manning's "n" with the depth of flow for the different grasses is shown in Figure 10, pages 20 and 21. The curves for Bermuda and buffalo grasses show the results of two years testing. The 1941 field data included a larger number of observations for flows from .05′ depth to the depth that caused the grass to bend down or become completely submerged. The curves plotted from the 1940 data on Bermuda and Blue grama include a straight section from the first point to the second point because it is believed that this curve should extend above this line, but no observations were made to establish the location.

The data are presented for each year to show the limits of all points rather than combine the two years' data into single curves for each slope. The variation in the locations of the curves is probably due to differences in amounts of forage in the channels, or roughness in the channel beds. The curves representing the 1940 data are drawn with solid lines through points indicated by small circles and a dotted line between the first two points where there appears to be insufficient points to delineate the curve. The 1941 data are represented by the curves drawn with a dashed line through points marked by crosses. Where the curves are not drawn directly through all points, the offset points are numbered according to the percent slope of the channel represented by the curve.

The curves for the longer grasses, such as Bermuda, blue grama and weeping love, indicate that "n" has an increasing value from the very low stages (.05 ft.) to the stage where most of the grass is partially submerged, then the values drop off rapidly as more of the grass becomes pressed down. When the flows are great enough to completely submerge all the grass, the values of "n" tend to converge into a single line along a constant value. The change in direction of the curves for "n" for the long grasses was also encountered in the tests at the Spartanburg Hydraulic Laboratory as reported by Burt and Ree (3).

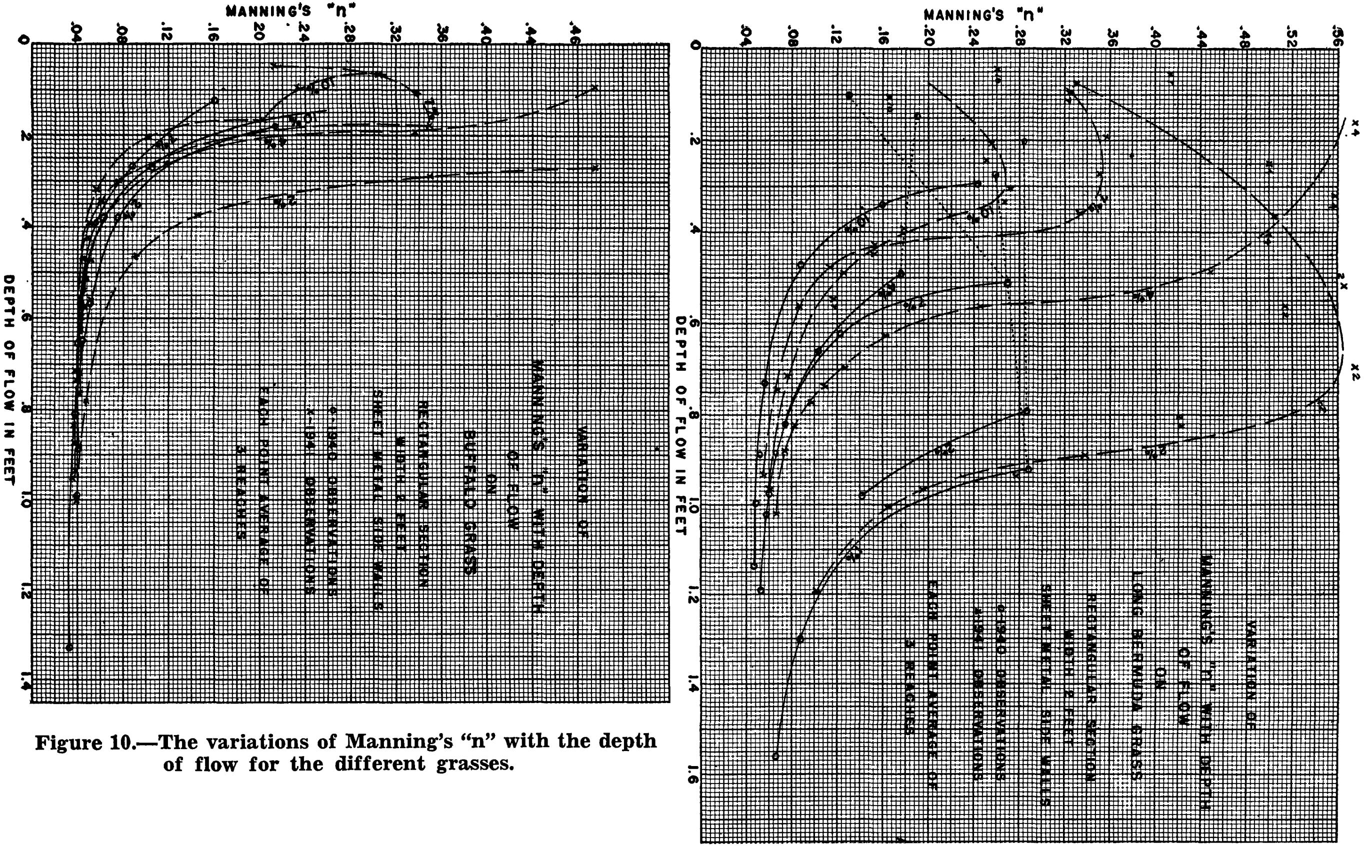
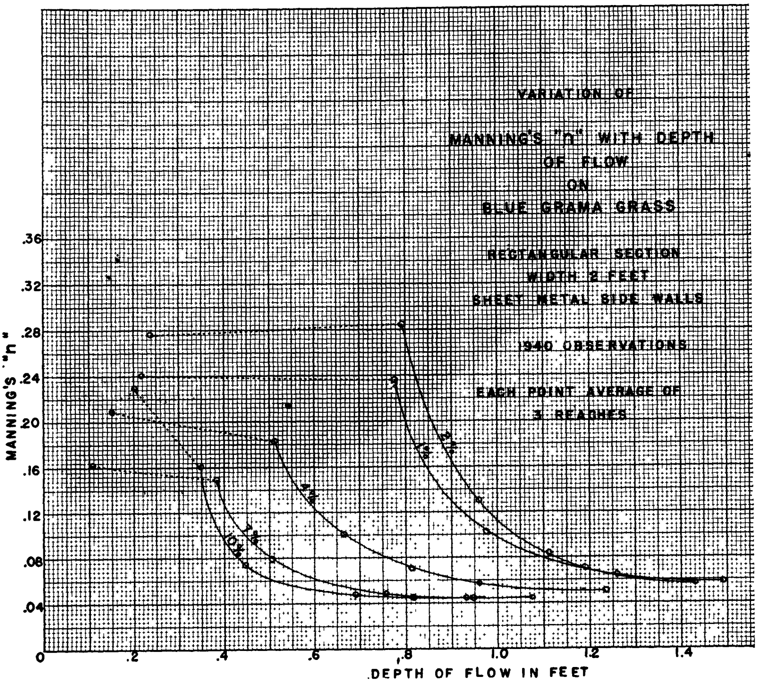


Figure 10.—The variations of Manning's "n" with the depth of flow for the different grasses.



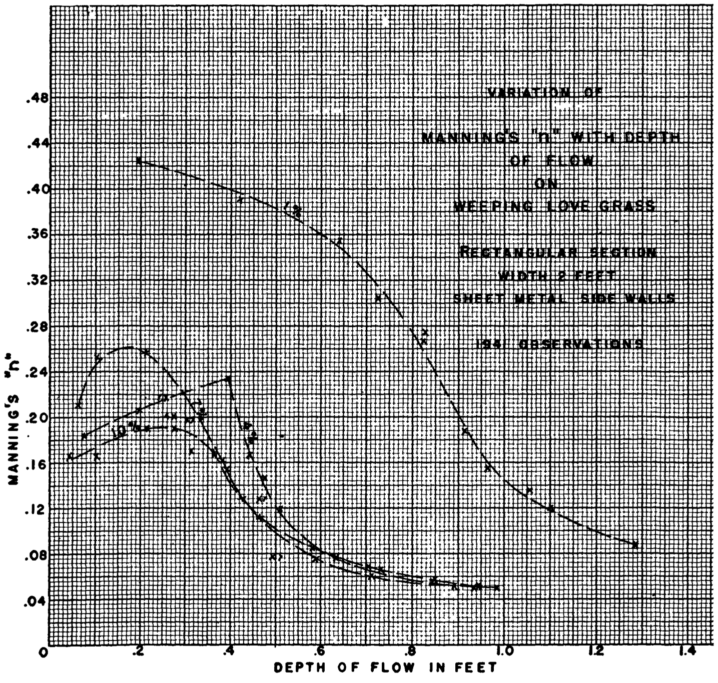


Figure 10.—(Continued.)

CONCLUSIONS

1. Channels of this type are well adapted for study of the protective qualities of the different grasses and legumes that can be used in open channels.
2. The soil from a channel is dependent upon the condition of the soil at the time of the runoff. If the surface of the soil is loose or open, the rate of loss is greater than it will be after this part has been removed. The duration of flow and time between flows or wettings apparently has a considerable effect on soil removal rate.
3. Under equal conditions of flow ranging from small depths (.05′) to greater depths (1.3′) for short duration (30 to 60 minutes), Blue grama was superior to other grasses tested in preventing erosion in the channels. Bermuda and buffalo were approximately the same in erosion resistance, and weeping love grass (**Eragrostis curvula**) was the least effective.
4. From observations during the test, it appeared that Bermuda could withstand more soil loss from around the roots than any of the other grasses studied without being removed completely from the channels by the water.
5. Under sustained high velocities (11 ft./second) Bermuda was superior to the other grasses in protecting the channels from erosion.
6. The data indicate that Manning's "n" varies with several factors, including type and condition of the grass, slope of the channel, and the depth of the flow.
7. Manning's "n" for long green Bermuda, buffalo, blue grama and weeping love grasses appears to approach the following values for the depths and slopes included. For lesser depths or gentler slopes, higher values were obtained.

	Manning's "n"	Depth (feet)	Slope (%)
Bermuda	.06	.9	4
Buffalo	.04	.5	2
Blue grama	.05	.7	4
Weeping love	.05	.7	4

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