FLOW OF WATER IN A CHANNEL LINED WITH KIKUYU GRASS

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SUMMARY

The retardance effect of kikuyu grass was found to be similar to that of Bermuda grass. In terms of the Stillwater retardance curves, a thick stand of long green kikuyu grass fitted curve B and the same stand of kikuyu grass grazed to an average height of 3·5 in. fitted between curves C and D.

I. INTRODUCTION

Hydraulic problems relating to the capacities and velocities of grassed waterways lined with various types of vegetation have been the subject of experimentation in the United States, notably by the Soil Conservation Service at Spartanberg from 1937 to 1941 and at Stillwater since 1941. This work was reported by various workers (Cox 1942; Palmer 1945; Smith 1946; Cox and Palmer 1948; Ree and Palmer 1949) and culminated in the development of a handbook pertaining especially to the design of channels lined with vegetation (Anon. 1947).

These American workers demonstrated that a constant value of the retardance coefficient used in flow formulae (e.g. the Manning formula) is not applicable in grassed channels as it is in channels lined with artificial linings such as concrete. Under the influence of velocity and depth of flow, vegetation tends to bend and oscillate continuously. The retardance to flow varies as these factors change. They found that the Manning retardance coefficient n varies with VR, the product of velocity and hydraulic radius, and from experimental results with different vegetal linings they developed five n-VR curves. These curves were designated A,B,C,D and E for very high, high, medium, low and very low vegetal retardance respectively.

The objectives of the present study were to find out if kikuyu grass (*Pennisetum clandestinum*) would follow these retardance curves and to determine the applicable curve for various growth stages. Due to limitations of site and limited availability of water for test flows, these objectives were only met in part,

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but some evidence was produced to show that the Stillwater retardance curves do apply to kikuyu grass waterways and a guide to the selection of curve to meet various growth stages was produced.

While the study was concerned principally with the effect of the kikuyu grass lining on the capacity of the channel, observations were also made on the ability of the grass to protect the channel from erosion.

II. EXPERIMENTAL CONDITIONS AND PROCEDURES

The waterway selected for observation was located below the spillway of a spring-fed dam. It had carried a complete kikuyu grass cover for at least five years. Water was impounded in the dam above normal spillway level by means of a control gate (Figure 1) made of $\frac{1}{8}$-in. steel plate. The control gate consisted essentially of a rectangular weir with an opening 16 ft by 2 ft. The opening was closed by a $\frac{1}{8}$-in. steel plate which could be raised and lowered by levers. Industrial sponge rubber was used to obtain a seal between the plate and the weir.

It was thus possible to pond water in the dam above spillway level and let it out as desired and to exercise control over the rate of discharge by raising or lowering the levers.

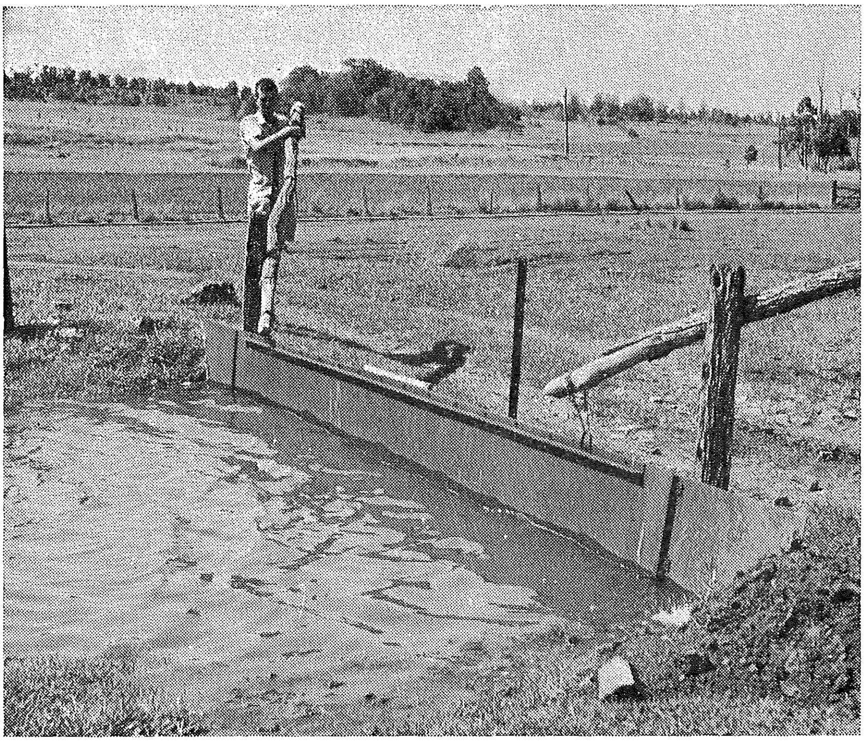

Fig. 1.—Control gate made of steel plate.

In the spillway below the control gate, a 10-ft sharp crested weir with suppressed end contractions (Figure 2) was installed to measure the flow. From the flow-measuring weir the water flowed 15 ft in a grass-lined channel into the kikuyu-lined waterway section under study. This had a flat bottom and sloping sides with a nominal bottom width of 4 ft and with one side slope of 4:1 and the other 2:1. Subsequent cross-section measurements showed the cross-section to be almost parabolic in shape.

As water became available in the dam, the test waterway was subjected to a measured flow for a period long enough to enable water surface measurements to be made, usually 10 or 15 min. As the surface of the dam lowered during a test, the control gate was adjusted to maintain a steady rate of flow. Where successive tests were made, the progression was from low to high flows.

III. MEASUREMENTS AND OBSERVATIONS

(1) Measurement for Discharge Calculations

Measurements were made of head of water flowing over the measuring weir and also of velocity in the test channel itself.

Measurement of head over the measuring weir (Figure 2) was made from a piano wire stretched across the approach channel 6 ft above the weir. Measurement to water surface was made using a piece of ½-in. dowelling to which was attached a sharp metal point. Distance from water surface to the top of the wire was marked with a sharp pencil. A peg was fixed directly below the

Fig. 2.—Measuring weir. Measurement of head of water flowing over the weir is being made from a piano wire stretched across the approach channel 6 ft above the weir.

wire with a nail head in the peg set at weir crest level. A dumpy level was used for this operation, and a plastic measuring scale graduated in 0·001 ft as a staff. Distance from top of the wire to the nail head set at crest level was measured with the same wooden dowel as was used for the water surface reading and again marked with a pencil. Distance between the two pencil marks was measured with the scale and taken as head over the weir. Difference in elevation between the bottom of the level approach channel and the weir crest was measured, using a dumpy level and surveyor's staff.

Velocity in the test channel was measured with a simple pitot tube made from 0·22-in. inside diameter glass tubing bent at right-angles near one end and drawn out to an orifice of 0·1-in. diameter. The tube was fixed with rubber bands to the hollowed thin edge of a piece of 3 ft x 2 in. x $\frac{3}{8}$ in. pine cover strip. In use, the pitot tube was moved to the desired distance beyond the end of the wooden backing and then lowered into the water until the wood just touched the surface. Height of the head of water in the tube was marked with a waterproof pencil on the wood and the position in the channel recorded against the mark. After the flow was over, the distance from each mark to the end of the wooden strip was measured with a plastic measuring scale and this distance recorded as head of water at that point.

Velocity measurements were made at one cross-section only (Station 2). A measuring tape was stretched across at this point so that distance from a point on the right-hand edge of the waterway could be recorded. Velocity measurements were made at 1-ft intervals across the channel at a depth of 0·1 ft below the surface. At the deepest and fastest moving point in the stream, velocities were recorded at 0·1-ft depth, 0·2-ft depth, and so on in 0·1-ft intervals down to the bottom.

(2) Measurement of Cross-Section, Wetted Perimeter and Slope

Measurements were made at four cross-sections at 10-ft intervals in the test channel (Figure 3), designated Stations 1, 2, 3 and 4. At each station a piano wire was stretched across and levelled. The vertical co-ordinates of channel cross-section were measured by measuring down from these wires with a piece of $\frac{1}{2}$-in. wooden dowelling tapered to a $\frac{1}{4}$-in. point. Horizontal co-ordinates were measured with a graduated measuring tape tied across above the piano wire. Measurements were made at 0·5-ft intervals, the procedure followed being to mark the vertical co-ordinate on the dowelling with a sharp pencil and to identify the mark with the horizontal co-ordinate. A separate measuring stick was used for each station and the marks on the sticks were measured in turn, using a plastic rule graduated in 0·001 ft. Measurements were recorded in 0·001 ft but the nature of the surface did not permit an accuracy of more than 0·01 ft.

The procedure followed in making water surface measurements (Figure 4) during the test flows was identical except that pieces of dowelling with sharp metal points attached were used, and measurements were made at 1-ft intervals. This measuring procedure was adopted for the water surface measurements because of the limited availability of water and the necessity to take numerous

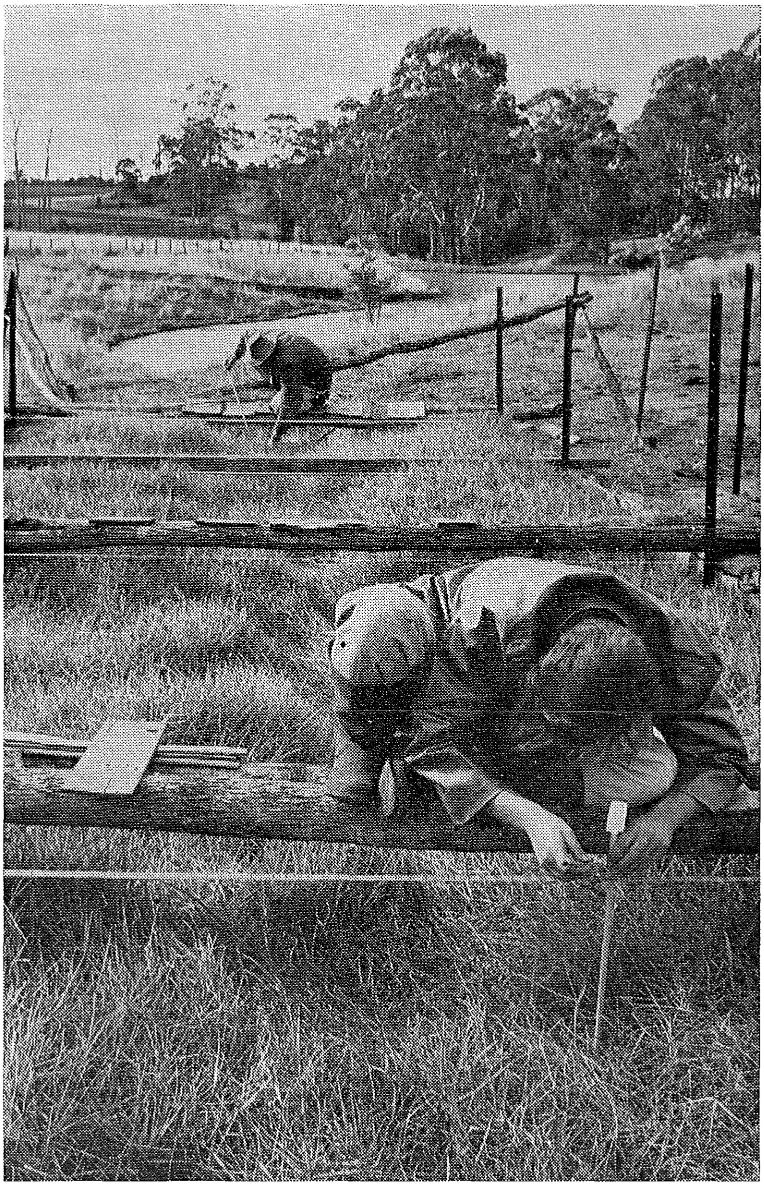

Fig. 3.—Cross-section measurements being made before a test flow (Test 2).

measurements in a short time. It was retained for the channel bottom measurements in an attempt to eliminate the personal error associated with marking the stick in relation to the wire. The marks were made on the top of the wire. Due to the uneven nature of the water surface, it was very difficult to obtain a reliable measurement of this factor. In an effort to reduce errors, Observer 1 changed position with Observer 2 and Observer 3 with Observer 4

Fig. 4.—Measurement of water surface being made at four stations during a test flow (Test 1).

after completing measurements across one section, so that each cross-section was measured twice and by different observers. The two measurements were averaged. Height of wires relative to one another was measured with a dumpy level and surveyor's staff. Distance between wires was measured along the bed slope with a measuring tape.

(3) Vegetative Measurements

Vegetation was measured by a stand count method. The number of stems was counted in six areas 6-in. square chosen at random. Length of stems from ground to leaf tips was also measured.

(4) Scour Measurements

Channel bottom was re-measured after each flow or pair of flows to enable calculation of scour.

(5) Vegetative Submergence

A visual observation of submergence was recorded for each test flow. Submergence was considered to occur only when the plant was completely inundated.

IV. METHODS OF COMPUTATION AND ESTIMATE

(1) Calculation of Discharge

(i) *By Weir Formula.*—Calculation of discharge through the measuring weir was made using Fteley and Stearns' supressed weir formula:

$$Q = 3{\cdot}31\, b\, (H + \propto h)^{\frac{3}{2}} + 0{\cdot}007\, b\,,$$

where

Q = flow in cubic feet per second
b = width of weir in feet
H = head
$\propto$ = a coefficient the value of which varies with head on weir and depth of channel of approach below crest
h = head due to velocity of approach.

(ii) *By Pitot Tube.*—Point velocities in the one fast-moving vertical section were used to calculate the average velocity in the vertical and a relationship established between the average velocity in the vertical and the velocity at 0·1-ft depth which will be referred to as the surface velocity. The ratios are shown in Table 1.

The ratio between average velocity in the vertical and surface velocity was applied to all other surface velocities in the same cross-section.

The cross-section of flow was plotted from the measurements of channel bottom and water surface made from the piano wire stretched across the channel. The cross-section of flow was subdivided by vertical lines at points where surface velocity had been recorded. Areas of each subsection were measured by planimeter and mean velocity computed as the average of the velocities in the vertical on each side of the subsection.

Area was then multiplied by mean velocity to give a flow in cubic feet per second for the subsection and the subsectional flows added together to give a total flow for the whole cross-section.

(iii) *Comparison between Two Methods.*—Both methods left room for errors. The main weaknesses of the weir method were the shortness of the level approach channel, which was only 12 ft with weir crest 1·4 ft above bottom of approach channel, and the difficulty of attaining an even velocity in the approach channel, even with the use of wire netting and rock baffles. Uneven approach velocities were more pronounced in the higher flows and worst in Test 2.

Weaknesses of the pitot tube method lie mainly in the low velocity heads obtained for velocities below 2·5 ft/sec. It was found when calibrating the pitot tubes by testing against a standard pitot tube that velocity could be measured with an accuracy of ±5 per cent. in the velocity range 2·5–6 ft/sec. This meant that the faster flowing water which accounted for the major part of the flow was measured with this accuracy. The slow-moving water in the unshingled grass at the sides of the waterway and again near the bottom of the waterway could not be measured accurately.

Flows calculated by the weir formula, with flow calculated from pitot tube velocity measurements in brackets, were: Test 3, 3·6 c.f.s. (4·6 c.f.s.); Test 4, 7·5 (9·0); Test 5, 2·7 (3·3); and Test 6, 5·9 (6·5). For these four tests the average value was used in calculations. For Test 1 the flow was not checked by the pitot tube and the weir flow was used. For Test 2 the weir flow (9·7 c.f.s.) was considered totally unreliable and discarded, the calculations being based on flow calculated from pitot tube velocities (15·2 c.f.s).

(2) Hydraulic Computations

Hydraulic computations were based on Manning's formula:—

$$V = \frac{1{\cdot}486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \dots\dots\dots\dots (1),$$

where

V = mean velocity in feet per second = Q/A
Q = discharge in cubic feet per second
A = cross-sectional area of flow in square feet
R = hydraulic radius in feet = A/p
p = wetted perimeter in feet
S = hydraulic gradient or slope of the specific energy line in feet per foot
n = coefficient of retardance.

Computations were made for a 20-ft reach between Station 2 and Station 4.

For calculation of cross sectional area (A), measurements made from the piano wire stretched across at each measuring station were plotted. Scale was 2 in. to the foot. Plotting of channel bottom readings and water surface readings and joining of the plotted points gave an outline of the cross-section of water flowing. Measurement of the area was made with a planimeter. Areas at the beginning and end of the reach were averaged to compute average area for the reach.

Mean velocity (V) was computed by dividing discharge by the average of the end cross-sectional areas.

Wetted perimeter (p) was measured from the cross-sectional drawing. Average wetted perimeter for the reach was computed by averaging the values for the beginning and end of the reach.

Hydraulic radius (R) was computed as the quotient of average area of cross-section in square feet and average wetted perimeter in feet.

The slope of the energy line (S) was determined by a method described by Scobey (1939). The formula used was:—

$$S = \frac{(Z_1 + h_1) - (Z_2 + h_2)}{L}$$

$$= \frac{\left\{Z_1 + \frac{v_1^2}{2g}\right\} - \left\{Z_2 + \frac{v_2^2}{2g}\right\}}{L}$$

where

S = slope of the energy line

Z_1 = elevation of the water surface above datum at the beginning of the reach

Z_2 = elevation of the water surface above datum at the end of the reach

v_1 = average velocity in the cross-section at the beginning of the reach

v_2 = average velocity in the cross-section at the end of the reach

g = the gravitational constant = 32·2 in English measures

L = Length of the reach in feet, measured along the bed slope.

With R, v and S determined, these were then substituted in formula (1) to solve for Manning's "n".

Computation of the product of mean velocity and hydraulic radius (VR) was made by multiplying the mean velocity for the reach by the hydraulic radius for the reach.

V. RESULTS AND DISCUSSION

Experimental results set out in Table 1 cover condition of vegetation at each test, the amount of water flowing, cross-sectional area, mean velocity, hydraulic radius, effective slope, calculated Manning's "n", the product VR and Stillwater retardance rating. Additional information covering top width of the flow section, width of complete submergence, centre depth, maximum surface velocity and the ratio of mean velocity in a vertical section to the surface velocities is also given in this table.

In Figure 1 the experimental values of Manning's coefficient "n" are plotted against the product VR for each test flow, against a background of the five n-VR curves developed at Stillwater. It will be noted that for Tests 1, 2, 5 and 6 (long kikuyu grass), the plotted points lie on or near curve B. For Tests 3 and 4 (kikuyu grass grazed short), they lie between curves C and D.

There was no measurable difference in cross-section as a result of any of the test flows. This was borne out by visual observation during tests. The old kikuyu grass lining appeared to give complete protection and the water passing through the channel was quite clear. The complete protection from erosion was expected, but this was not the main object of the study, which was to classify the vegetal retardance of kikuyu grass. The vegetative conditions tested fall into two main categories: long kikuyu grass in Tests 1, 2, 5 and 6 and short-grazed kikuyu grass in Tests 3 and 4. All stands would be regarded as thick.

TABLE 1

EXPERIMENTAL CONDITIONS AND RESULTS FOR CHANNEL LINED WITH KIKUYU GRASS

Test No.	Date of Testing	Duration of Flow (min)	Condition of Lining	No. of Stems per sq. ft.	Average Length of Stems (ft)	Discharge (cu. ft./sec)	Area of Section, A (sq. ft.)	Mean Velocity, V (ft/sec)	Wetted Perimeter, p (ft)	Hydraulic radius, R (ft)	Effective slope, S (ft/ft)	Top Width (ft)	Width of Shingling or Complete Submergence (ft)	Centre Depth (ft)	Maximum Surface Velocity (ft/sec)	Ratio Mean Velocity Vertical/Surface Velocity	Manning's Coefficient of Roughness, n	Value of VR	Stillwater Retardance Rating
1	17.iii.60	15	Green ..	104	1·3	2·55	4·15	0·615	8·76	0·473	0·048	8·5	1·8	0·83	—	—	0·322	0·291	B
2	12.vii.60	20	Leaves frosted	176	1·8	15·18	6·48	2·342	10·49	0·618	0·054	10·1	4·7	1·12	6·0	0·60	0·107	1·447	B
3	26.vii.61	8	Green, grazed short	188	0·3	4·15	2·18	1·906	5·98	0·364	0·047	5·8	3·8	0·57	4·9	0·63	0·086	0·694	C–D
4	26.vii.61	7	Green grazed, short	188	0·3	8·25	2·98	2·769	6·86	0·435	0·048	6·6	4·7	0·74	6·2	0·66	0·067	1·203	C–D
5	25.x.61	10	Green ..	252	2·2	2·99	5·04	0·593	9·11	0·554	0·049	8·9	2·6	0·98	3·9	0·29	0·373	0·329	A–B
6	25.x.61	10	Green ..	252	2·2	6·19	5·97	1·037	9·94	0·601	0·049	9·6	3·7	1·07	6·7	0·34	0·226	0·623	B

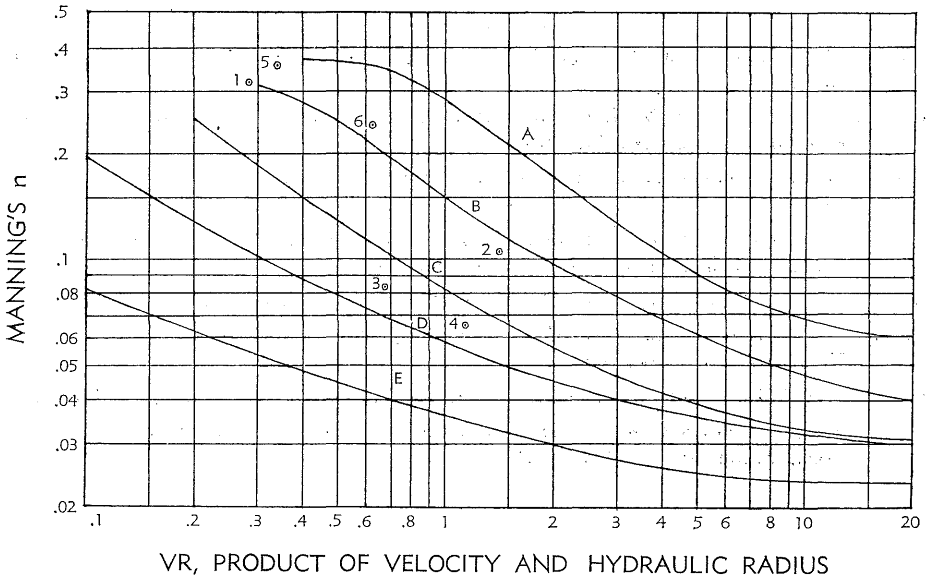

Fig. 5.—Experimental results for kikuyu grass channel in relation to retardance curves developed by Stillwater Outdoor Hydraulic Laboratory. Figures beside plotted points show test numbers for present tests.

Results are generally confined to the lower and mid values of VR and consequent high values of n. The quantity of water available and the size and slope of the test channel prevented the obtaining of high VR values where a bigger percentage of the grass would be shingled and values of n would be lower.

If kikuyu grass does follow the Stillwater retardance curves—and this is quite probable in view of the claimed general applicability of the curves to a wide variety of vegetation—then from the results obtained it is concluded that Retardance C is an appropriate curve for a thick stand of kikuyu grass grazed heavily and Retardance B is appropriate for a thick stand allowed to grow long and rank. Thinner stands would fall on a lower retardance curve in each case.

Further work to check the applicability of these curves over the full range of n-VR relationships is called for, but in the meantime use of the appropriate Stillwater retardance curve as indicated by the tests is justified and will give better results than the use of a fixed value of Manning's "n", which does not take into account the change in retardance as the grass is bent over by high-velocity flows.

VI. ACKNOWLEDGEMENTS

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REFERENCES

COX, M. B. (1942).—Tests on vegetated waterways. Tech. Bull. Okla. Agric. Exp. Sta. No. T-15.

COX, M. B., and PALMER, V. J. (1948).—Results of tests on vegetated waterways. Misc. Pub. Okla. Agric. Exp. Sta. No. 12.

PALMER, V. J. (1945).—A method for designing vegetated waterways. *Agric. Engng* 26:516-20.

REE, W. O., and PALMER, V. J. (1949).—Flow of water in channels protected by vegetative linings. Tech. Bull. U.S. Dep. Agric. No. 967.

RUSSELL, G. E. (1954).—"Hydraulics." (Henry Holt and Co.:New York).

SCOBEY, F. C. (1939).—The flow of water in irrigation and similar canals. Tech. Bull. U.S. Dep. Agric. No. 652.

SMITH, D. D. (1946).—Bluegrass terrace outlet channel design. *Agric. Engng* 27:125-30.

ANON. (1947).—Handbook of channel design for soil and water conservation. U.S. Soil Conservation Service SCS-TP-61.

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