Special Bulletin 171 August 1935

SOIL EROSION CONTROL

BY ENGINEERING METHODS

By
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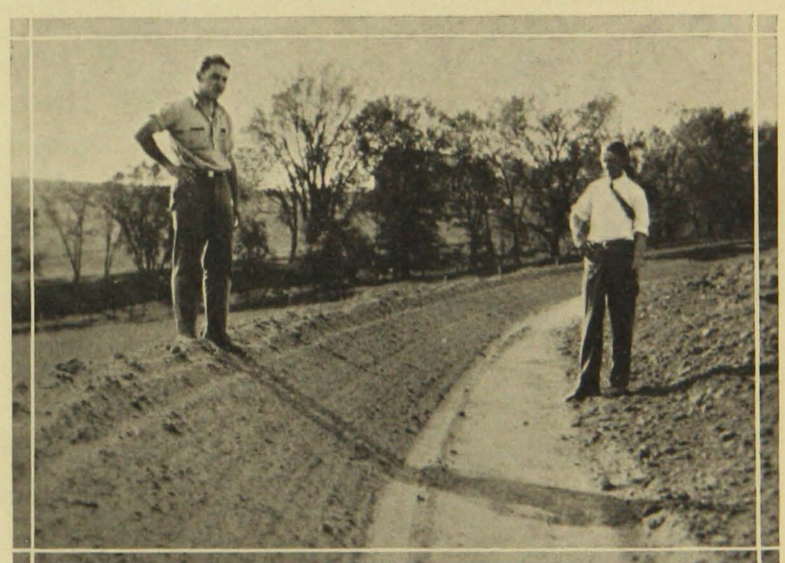
DIVISION OF AGRICULTURAL ENGINEERING
AGRICULTURAL EXPERIMENT STATION



A finished Mangum terrace eighteen inches high.

UNIVERSITY OF MINNESOTA
AGRICULTURAL EXTENSION DIVISION

Published in furtherance of Agricultural Extension, Acts of May 8 and June 30, 1914. W. C. Coffey, Acting Director, Agricultural Extension Division, Department of Agriculture, University of Minnesota, co-operating with U. S. Department of Agriculture. 8-35-10M

SUMMARY

Terracing is the ultimate and most effective method of controlling erosion on cultivated fields.

A combination of terracing and contour or strip farming reduces the soil losses to a negligible amount.

No part of a terrace gradient should exceed 0.4 foot in 100 feet and the total length of a terrace should never exceed 2,000 feet. Flatter grades and shorter lengths are much better.

None of the terrace slopes should ever be steeper than one foot vertical rise to four feet horizontal run.

The top terrace should always be constructed first, and the others in consecutive order, down the slope.

The provision of suitable outlets for terraces is very important. Artificial outlets are usually more satisfactory than natural channels as they can be so constructed as to prevent channel erosion.

The essential steps in gully control in order of importance are, stopping head growth, prevention of floor scouring and side erosion, and filling of the gully.

A diversion ditch above the head of the gully will often stop head growth; otherwise an engineering structure at the gully head is essential. The best type of structure is an open flume or a masonry dam with crest weir and basal apron.

Reduction of the gully floor gradient to two feet or less per 100 feet is essential. This is best done by check dams of brush, stone, or concrete laid across the gully floor at stated intervals.

To enable filling of the gully, a soil-saving dam at the outlet is essential to retain the silt and let the water by. Such dams may be made of earth, concrete or masonry.

INTRODUCTION

The final effective solution of the soil erosion problem even on a single farm requires employment of engineering practices and, in many cases, the services of a trained agricultural engineer. To present these engineering phases in a form that will enable the farmer and the rural engineer to co-operate effectively in soil erosion control activities is the purpose of this bulletin which should be used in conjunction with Special Bulletin 170, "Soil Erosion Control in Farm Operation."

Sheet erosion is a much more serious phase of the problem than is gullying. Usually, gullying is simply a more advanced stage and, in most cases, is the ultimate outgrowth of uncontrolled sheet erosion.

CONTROL OF SHEET EROSION

Soil erosion cannot be completely stopped, but the soil and water losses can be greatly reduced by changing some of our common farming practices. Sheet erosion, particularly, can be greatly checked by increasing the absorptive capacity of the soil. This may be accomplished by deep tillage, by tile drainage, and by increasing the organic matter through abundant use of barnyard manure. Other good farming practices that aid in controlling erosion include taking steep slopes out of cultivation, avoiding over-pasturing and burning of pastures and woodlots, crop rotations, contour farming, and strip farming. These matters are discussed in Special Bulletin 170.

Terracing.—Terracing is the ultimate and most effective method of controlling erosion on cultivated fields. It serves a double purpose as it checks washing of the soil by preventing the rapid movement of water over the surface and it helps to protect against drouth by holding the water on the slopes, thus giving the soil a chance to absorb more of it. Consequently there is a substantial increase in crop yields on terraced lands. A combination of terracing and contour or strip farming reduces the soil losses to a negligible amount. (See Fig. 1.)

Fig. 1. Terracing With Strip Cropping
The corn strip is uniform throughout. The grass strip fills the balance, thus avoiding point rows.

Best types of terraces.—There are many types of terraces but the Mangum terrace, named after the man who originated it, is best suited to Minnesota conditions. It consists of a broad ridge of earth 15 to 24 inches high, thrown up across the slope approximately along the contour (see Fig. 2) but having, in the direction of its length, a varying rate of fall sufficient to carry the water **slowly** to an outlet channel at the end.

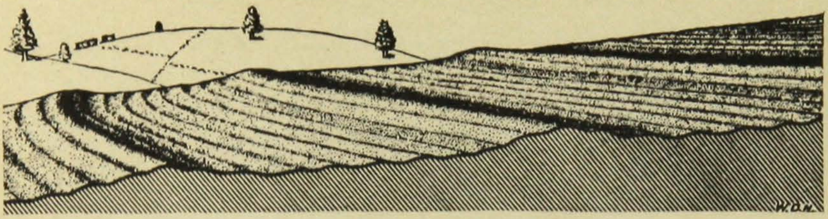


Fig. 2. Mangum Terraces on a Fairly Steep Slope, Showing How One Blends Into the Other Next Below It, Making the Field a Succession of Terraces (From U.S.D.A. Farmers Bull. 1669)

Table 1
Proper Vertical Interval Between Mangum Terraces and Feet of Terrace per Acre

Slope of land in feet per 100 feet	Vertical distance or drop between terraces in feet*	Linear feet of terrace per acre
1	2.00	220
2	2.75	320
4	3.40	515
6	4.00	655
8	4.75	745
10	5.50	795
12	6.30	830
14	7.10	860

* Where the soil is extremely susceptible to erosion, so that washing is likely to occur between the terraces, the vertical distances given should be decreased by one-half foot. On the other hand, if the soil contains considerable humus and is capable of absorbing a large part of the rainfall so that it is not easily eroded, the vertical distance may safely be increased one-half foot.

LOCATING TERRACES

The proper location of terraces is governed by the character of the soil and by the natural slope of the land. Table 1 gives the proper vertical spacing of terraces for different degrees of slope. The proper vertical distance from the top of the hill for the first terrace is the same as the proper vertical interval between successive terraces for the same rate of natural slope. Once the rate of natural slope is determined, therefore, the proper distance from the top of the hill to the first terrace can also be taken from Table 1.

Unless the natural slope is very uniform for a considerable distance down the hill, the rate of slope from the last preceding terrace should be determined in each case before locating the next one. If the rate of natural slope varies considerably along the terrace, the steeper part should govern the vertical interval. However, in no case should the distance between terraces exceed 200 feet.

Since the terraces must be placed closer together as the slope becomes steeper, the number of feet of terrace per acre increases with the slope as given in Table 1.

GRADIENTS FOR TERRACES

For terraces much longer than 300 feet the rate of fall should increase from the top toward the outlet about as shown in Table 2. Where the length does not exceed 300 feet, a uniform rate of grade of 0.15 to 0.20 per cent gives best results.

Table 2
Rate of Fall for Terraces, Beginning at the Upper End

Length of terrace, feet	Drop in terrace in feet per 100 feet of length
0 to 300	0.10
300 to 600	0.15
600 to 900	0.20
900 to 1,200	0.30
1,200 to 1,500	0.40

LENGTH OF TERRACES

For best results terraces should not be more than 1,200 feet long. Shorter ones are much better. In extreme cases an occasional terrace up to 2,000 feet is permissible. In terraces appreciably longer than 1,500 feet it will be best to make the variable gradient intervals each approximately one-fifth of the total length of the terrace, rather than to make the outlet interval with the heaviest rate of grade absorb all the extra length. (For example, in a 2,000-foot terrace, the grade intervals would be 400 feet long and the rates of grade for successive intervals from the top toward the outlet, as in Table 2.) **In no case should a rate of grade greater than 0.40 feet in 100 feet be used on terraces.**

If outlets can be made available at both sides of a long field it is better to divide the terrace gradient at the center of the field, at the top, and run the two halves down to outlets at opposite sides of the field.

WIDTH OF TERRACES

On natural slopes up to 14 feet in 100, terraces constructed as shown in Figure 3 will have a horizontal width of base of 40 feet, from the top of the cut slope on the upper side to the toe of the fill on the lower side. "Wide terraces are the more desirable from the standpoint of crossing them with farm machinery. The width may be increased each year by throwing the soil to the center of the terrace in plowing until, on moderate slopes, the lower edge of one terrace meets the upper edge of the next below, and the whole field, as often happens, becomes a series of terraces."[1] (See Fig. 2.)

[1] From U.S.D.A. Farmers' Bulletin 1669.

HEIGHT OF TERRACES

In southeastern Minnesota the lowest satisfactory theoretical height of terraces, from the bottom of the ditch to the crown of the fill, when completed, is 15 inches or 1.25 feet if constructed as shown in Figure 3.

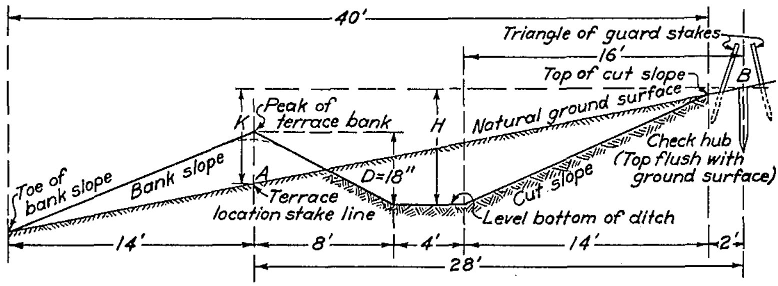


Fig. 3. Cross-section of a Terrace Suitable for General Use

The terrace banks, when first graded, should be built up to a height of about 18 inches above the ditch bottom as shown by the intersection of the slope lines in Figure 3. For the rainfall conditions of this region, terraces thus constructed, 18 inches high, and for vertical spacings and maximum approved lengths given herein, will have a theoretical factor of safety of about 7 to 10 when first constructed. This allows about 3 inches for rounding-off the top and 3 additional inches for settlement, still leaving the firm, settled terrace 12 inches high. This final height of 12 inches will still have a maximum factor of safety, in most cases, well above 5 and will still allow for some silting which is bound to occur even when the terrace is protected by grass cover. If carefully built and maintained, and inspected after heavy storms, such a terrace will last a long time and is in little danger of being overtopped by anything short of a cloudburst. It is not good economy to build terraces less than 12 inches high when thoroly packed and settled. Nor should they be built higher than is necessary for adequate carrying capacity as the extra height increases both the cost and the difficulty of farming operations.

FINISHED SLOPES ON TERRACES

For best results the finished slope, either of the ditch or of the terrace bank, should never be steeper than one foot vertical rise to four feet horizontal run, as this is about the steepest slope over which the field machinery can be operated successfully. The flatter these slopes can be made at reasonable cost, the greater the ease of field operation and the less the liability of serious erosion.

A LEVEL NECESSARY FOR TERRACING

A farm level and the knowledge of how to use it are necessary for laying out terraces. The principle of leveling is simple and easily mastered. A simple method of leveling is outlined in Circular 36 of the University of Minnesota Agricultural Extension Division, which also shows a practical home-made level. A commercially-made farm level and rod giving good satisfaction and widely used in terracing work may be obtained for about $25.

STAKING AND CHECKING CONSTRUCTION OF TERRACES

Great accuracy of linear measurement along the terraces is not essential. The rodman can pace off along the contour the intervals wanted between stakes. In general a stake should be set, at the proper grade, every 50 feet of length, and on sharp turns of the contour much closer.

It will be found best, where at all possible, to set up the level in a position where the whole of any given terrace can be set from it without having to turn. **However, where turns must be taken, the same care and accuracy should be exercised in reading on turning points as in other classes of leveling work. Such readings should be taken to the nearest 0.01 of a foot.**

It is not necessary to carry a regular and complete set of elevations down the field thus bringing all terraces under a given datum, but to do this will prove convenient in checking construction and in making possible future additions; hence it is recommended as is also the setting of one convenient and permanent bench mark relative to each field. As a rule, however, there would be no advantage in carrying the same datum from field to field, even in the same community.

Twice the difference between two level readings 50 feet apart directly up and down the slope will give the slope of the land per 100 feet. (On steep slopes it will usually be impossible from a single position of the level to take two readings a full 100 feet apart, directly up and down the slope.)

The vertical drop from the top of the hill to the first terrace, or from one terrace to the next, is then measured with the level, to determine a starting point in each case. From this point the line of the terrace may be run out each way, the rodman stepping off a succession of 50-foot distances approximately along the contour. At each 50-foot point on the given terrace line the levelman will take a reading and move the rodman straight up or down the slope at right angles to the line of the terrace until the reading shows just half the desired rise or fall per 100 feet, according as the terrace line is being run up or down grade. For example, if the rate of fall for the section being laid out is 0.30 of a foot per 100 feet, and, at a given point, the proper grade rod reading is 4.50, at the next point, 50 feet away, the grade rod reading will be 4.65 (4.7), if the line is being run down grade (toward the outlet), or 4.35 (4.4), if up grade (away from the outlet), the change in grade for 50 feet in length along a 0.30 per cent grade being 0.15 feet. At the next point the proper reading will be 4.80 or 4.20 according as the terrace is being run down or up grade. Readings of the rod held on the ground should be read only to the 0.1 of a foot nearest to the proper grade rod reading. In the example the numbers in parentheses are these readings to the nearest 0.1 of a foot. At each point found as above described, a stake should be set with the number or letter of the terrace marked upon it for the guidance of the man plowing out the terrace. For example, if the top terrace is marked "A" all stakes on it should be so marked, all on the second one "B", all on the third "C", etc. On rough or rounding hillsides it may be necessary in places to set stakes every 25 feet.

In staking the terrace line across draws or small gullies it is necessary to avoid too sharp turns in the terrace by dropping below the established grade line and setting a stake in the bottom of the gully as at the point of the vertical arrow, Figure 4, with the necessary fill marked on its face.

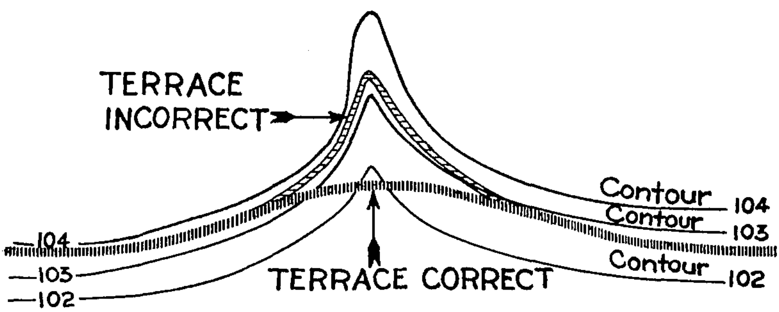


Fig. 4. Correct Location of a Terrace Across a Small Gully or Ravine (Courtesy of the Austin-Western Co.)

As each line stake is set (Position A in Figure 3) drive a hub stake with firm, square-sawed top solidly into and flush with the surface of the ground, 28 feet up hill from the line stake at right angles to the terrace line. (Position B in Figure 3.) This hub stake should be protected from disturbance during construction by a tripod of stakes driven around it as shown in the figure.

Take a level reading on the top of this hub stake. The difference between this reading and that on the ground at the line stake should be recorded in the notes opposite the proper station number. This difference is the value K in the figure and in column 2, Table 3.

In column 3 of Table 3, or from the chart in Figure 5, opposite the value of K, just determined, will be found the vertical distance, H, from the top of the hub to the bottom of the finished ditch. When the grading is ready for testing, place one end of a 16-foot straight-edge, equipped with a small level, on top of the hub stake, the other end extending out over the bottom of the ditch. Holding the straight-edge level, measure the distance from its under edge to the bottom of the ditch.

Table 3
For Use in Laying Out and Checking Construction of Terraces

Natural slope across terrace line	Vertical distance, K, between A and B in Figure 3	Vertical distance, H, from bottom of ditch to B in Figure 3	Vertical spacing between terraces
Feet per 100 feet	Feet	Feet	Feet
2	0.56	1.07	2.75
3	0.84	1.29	3.00
4	1.12	1.51	3.50
5	1.40	1.73	3.75
6	1.68	1.95	4.00
8	2.24	2.39	4.75
10	2.80	2.83	5.50
12	3.36	3.27	6.25
14	3.92	3.71	7.00

If this value is less than the value of H just found the ditch is still too high by the amount of the difference. If it is more the ditch is already too deep by the amount of the difference.

Check the top of the ridge by leveling in a similar manner from the point just tested in the bottom of the finished ditch up to the straight-edge held level on the top of the ridge opposite. If this value is less than 18 inches the ridge is low by the amount of the difference; if greater, the ridge is high by the amount of the difference.

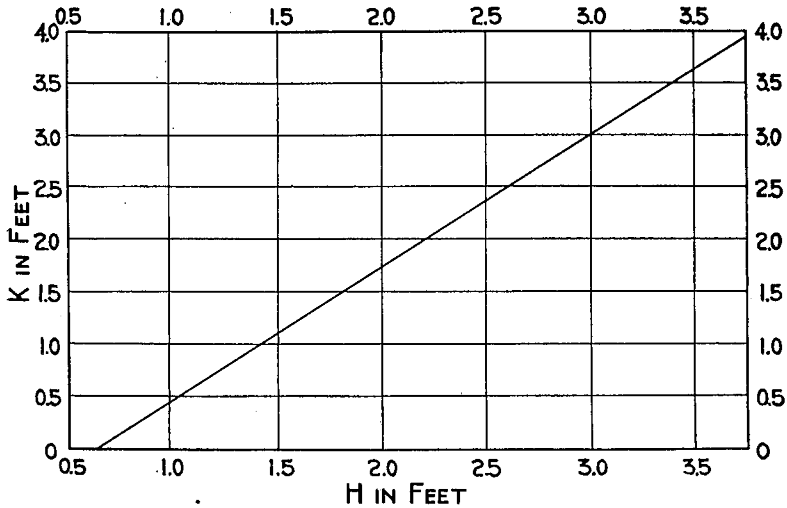


Fig. 5. Relation between K and H from Table 3

Illustrative example.—At a given station assume that the level reading on the rod at the line stake is 6.44 and that the reading on the corresponding hub stake is 4.20. Then $K = 6.44 - 4.20$ or 2.24. The corresponding value of H is 2.39. Next suppose the distance from the straight-edge to the bottom of the ditch, **as dug,** is 2.19. The ditch is then still high by an amount $2.39 - 2.19$ or 0.20.

At the same time and point, if the straight-edge held on top of the ridge is 1.05 above the point in the ditch just tested, the ridge is low by an amount $1.50 - 0.20 - 1.05$ or 0.25.

If the value of K found lies between two tabular values, the corresponding value of H may be found by proportion. Thus, if K as found is 2.20, H is 2.36.

In the manner described every point of the grading where a stake was originally set may be quickly tested and brought to correct grade.

Table 4
Sample of Notes To Be Taken in Staking Out a Terrace Similar to That Shown in Figure 18

Station number*	Natural slope, per cent	Vertical interval between terraces, feet	Rate of grade, per cent	Rod reading at line stake (Point A)	Rod reading on hub (Point B)	K	H
				Feet	Feet	Feet	Feet
4	8	4.75		4.1	1.86	2.24	2.39
+50				4.0	1.74	2.26	2.40
5				3.9	1.67	2.23	2.38
+50				3.8	1.55	2.25	2.40
6			−0.15 x −0.20	3.7	1.43	2.27	2.41
+50				3.62	1.40	2.22	2.36
7				3.55	1.30	2.25	2.40
+50				3.47	1.25	2.22	2.36
8	8	4.75		3.4	1.13	2.27	2.41

* Station numbers run from outlet up grade.

A good pine board 1″×4″×16′ makes a very serviceable straight-edge when trued up with a jointer plane from time to time. **Always measure from the bottom edge of the straight-edge.**

Table 4 is a sample page of notes that should be taken in laying out and providing for checking the construction of a 1,200-foot terrace.

CONSTRUCTION OF THE TERRACES

Order of construction.—The top terrace should always be constructed first, and the others in consecutive order, down the slope. If it should rain before the job is completed the top terrace could take care of the water falling on the slope above it, and any succeeding terrace all the water falling on the slope between it and the next terrace higher up. But if a lower terrace were constructed first, or if one or more terraces were temporarily omitted in the order of construction, the water would be apt to pile up behind the lower terrace far in excess of its capacity. In this case it would be washed out with all below it, thus causing greater damage than would unchecked erosion on an unterraced field.

Marking out the terraces.—The first step in construction must be to run a simple plow furrow along the stake line on each terrace. This marks the line continuously and more clearly than it is marked by the stakes. It is difficult for one to follow an irregular line of stakes while operating a grader, but he can readily follow a continuous furrow.

Grading the terraces.—This furrow marks the **center line of the embankment of the terrace.** The earth obtained from the first cut of the grader should be moved to just below the furrow. The material from succeeding cuts should be moved over against that from the first one.

In constructing the terraces across draws or shallow ravines it will be necessary to **build the embankment of the terrace higher to offset the drop in the surface, and heavier to prevent cutting from the impact of the water flowing down the draw.**

Any high spots in the ditch grade, or any low spots in the embankment revealed by the check discussed on page 9 must be remedied by reworking with the grader, with a team and scraper, or by hand. Then the work should be rechecked with the level and any defective places still remaining should be rectified. Only in this way can proper functioning be assured and overtopping during freshets be guarded against.

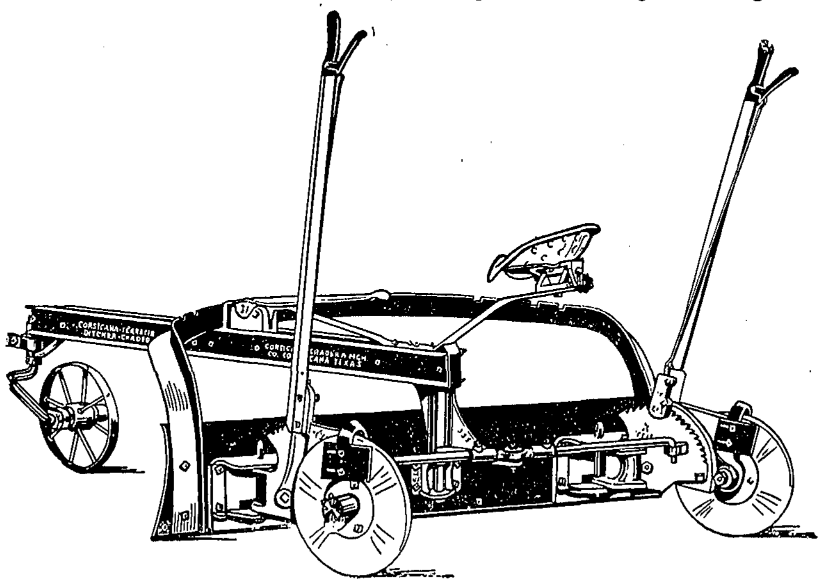


Fig. 6. A Small Terracing Machine Much Used with Satisfactory Results

Terracing equipment.—If economy of time is no object, good terraces can be built with a small road- or terracer-grader (see Fig. 6) or even with a steel or plank drag fitted with a steel cutting edge; but the best type of grader from the standpoint, both of good work and economy of time, is a large size terracer-grader. The distinguishing feature of the terracer-grader is an extra high blade curved to about 1/6 to 1/4 of a full circumference and widely and easily adjustable both in tip and lateral angle (see Figs. 7 and 8). Such a grader blade rolls rather than pushes the earth ahead of it. Furthermore, it not only requires relatively less power to draw it, but it also puts the earth more nearly where it is wanted with each round of the grader. A well-built terrace can be constructed with this type of equipment in 8 to 10 rounds. Several commercial concerns make this type.

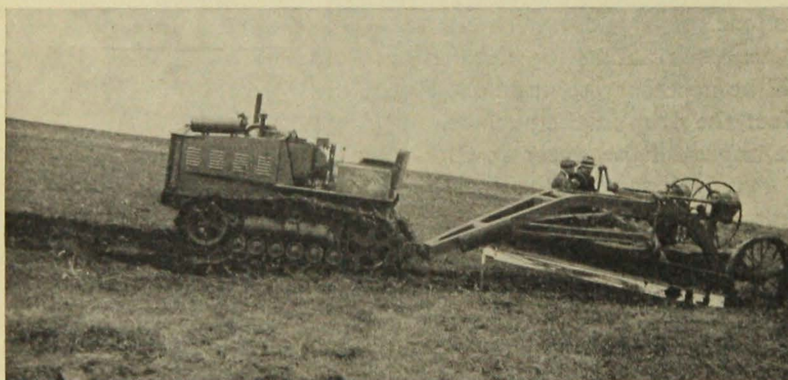


Fig. 7. Terracer-Grader with 10-foot Blade and Drawn by Tracklaying Tractor

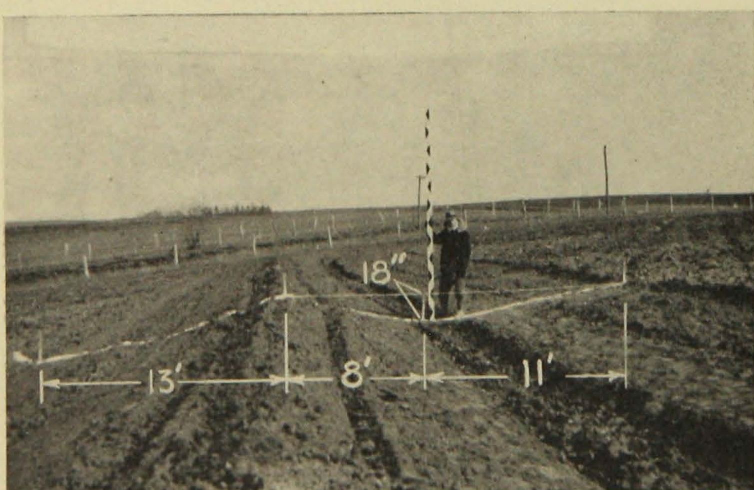


Fig. 8. Terrace Built in Eight Rounds in Fillmore County, Minnesota, With the Equipment Shown in Figure 7 (Courtesy U.S.D.A. Soil Conservation Service)

In 1934 two new terracing machines were developed that can be operated by a medium-size tractor (two-bottom plow size). The Iowa terracer, developed at Iowa State College, is an 18-inch single-bottom tractor plow with a shortened moldboard and rotor driven by the power take-off. The rotor, running at a speed of 1,060 r.p.m., throws the soil into a ridge. A well-built terrace can be constructed in 25 to 30 trips. (See Figs. 9 and 10.)

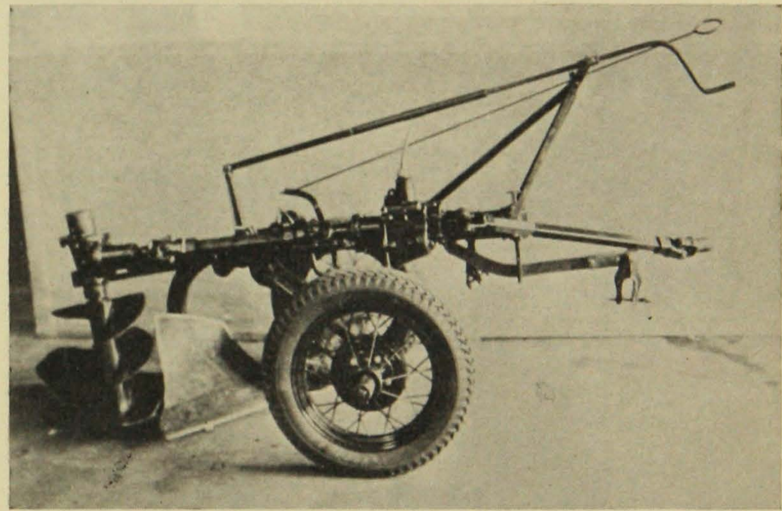


Fig. 9. The Iowa Terracer
(Courtesy Agricultural Engineering Department, Iowa State College)

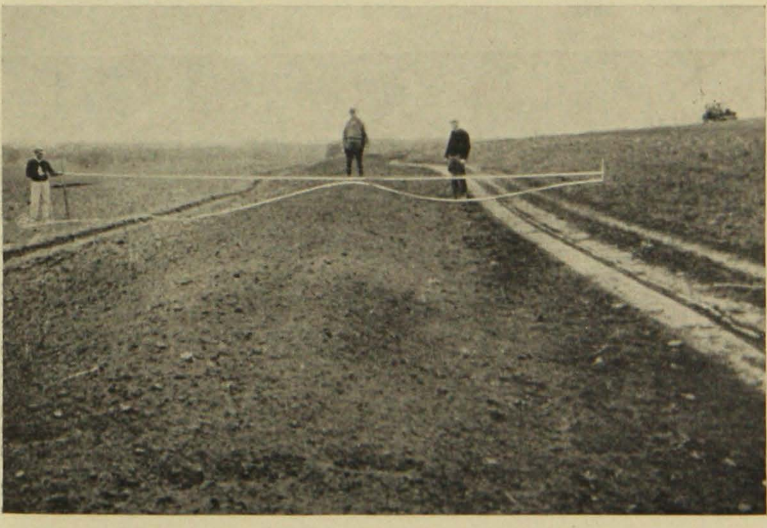


Fig. 10. Terrace Built by the Iowa Terracer
(Courtesy Agricultural Engineering Department, Iowa State College)

The Missouri terracer, developed at the Missouri Experiment Station, is an elevating grader type. A 26-inch disk plow cuts and delivers the soil onto a rubber carrier-belt which delivers it to the terrace ridge. Satisfactory terraces can be built in 12 to 14 trips. (See Figs. 11 and 12.)

Fig. 11. The Missouri Terracer
(Courtesy of the Missouri Station and "Agricultural Engineering")

Since neither the Iowa nor the Missouri terracers are reversible, terraces made with them must be built from both sides or the return trip made without working. Borrowing material from below the terrace banks, as when building from both sides, is not the best construction.

Fig. 12. Terrace Built by the Missouri Terracer
(Courtesy of the Missouri Station and "Agricultural Engineering")

TERRACE OUTLETS AND PROTECTION WORKS

The provision of suitable outlets for terraces is extremely important. Altho natural channels, drainage ditches, and road ditches may be so used if located convenient to the terraced field, artificial outlets as shown in Figure 13 are usually more satisfactory as they can be so constructed as to prevent channel erosion. Whenever possible the outlet channel should be constructed without any drop between it and the terrace.

The outlet channel should be sodded and, on slopes steeper than 2 per cent, treated plank erosion checks (see Fig. 13), with the upper edge of the plank set flush with the channel bottom, should be located at intervals as given in Table 5. Where sod is difficult to establish, the checks should be set closer than called for in the table. These checks

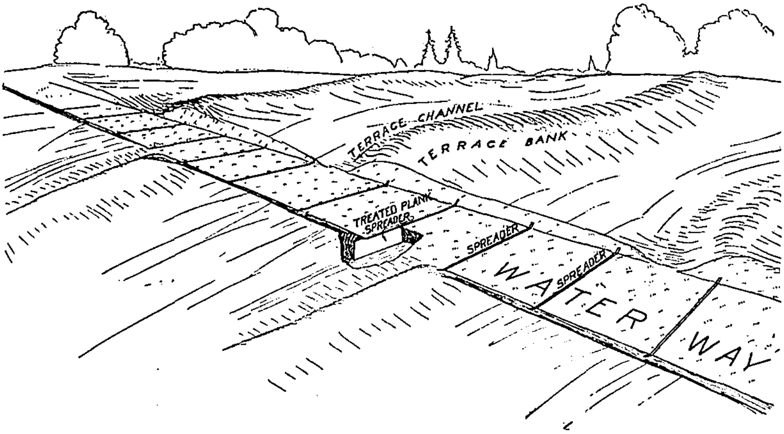


Fig. 13. Terrace Outlet Channel Showing Treated Plank Erosion Checks

should be set level to keep the water spread at a uniform depth across the channel bottom. In place of plank checks, strips of poultry netting laid flat and securely fastened down may be used to hold the sod in place until it is firmly rooted.

Table 5
Suggested Vertical and Horizontal Distances between Erosion Checks in Terrace Outlets

Slope of land in feet per 100 feet	Distance between erosion checks	
	Horizontal distance, feet	Vertical distance, feet
1	200	2.0
2	85	1.7
3	50	1.5
4	35	1.4
6	22	1.3
8	15	1.2
10	11	1.1

Since the eroding power of the water increases rapidly with its rate of movement, it should be conducted off the field at a low velocity. The velocity of the water is governed by two factors, the slope of the land, and the depth of flow. By decreasing the depth of flow on the steeper slopes, as by widening the channel, the velocity can be reduced. Figure 14 gives the maximum flow depth recommended for slopes up to 10 per cent while Figure 15 gives the required bottom width of outlet channel to handle a run-off of 100 cubic feet per second for slopes up to 10 per cent. The terrace outlets should be constructed to carry at least 3.5 cubic feet per second for each acre drained.

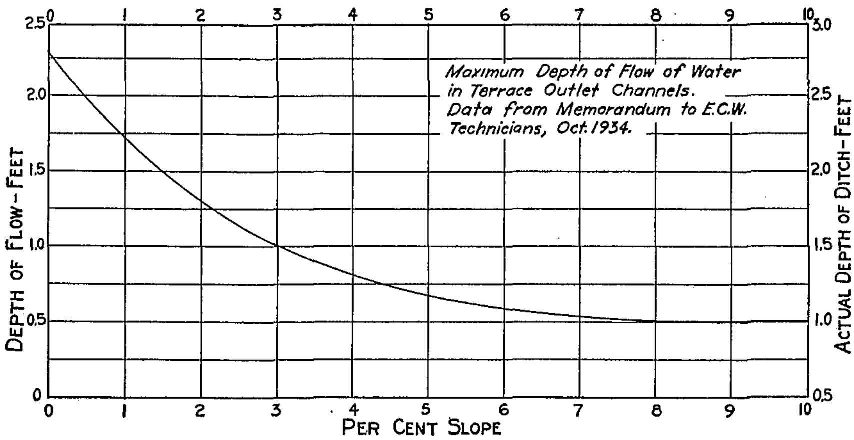


Fig. 14. Flow Depth for Terrace Outlet Channel

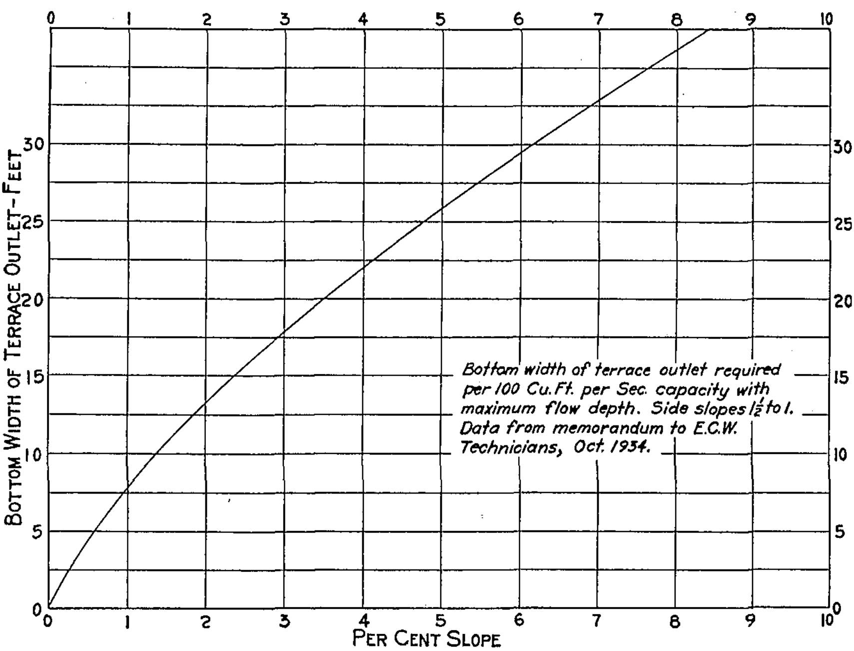


Fig. 15. Bottom Widths of Terrace Outlet Channels for a Capacity of 100 Second Feet

Illustrative example for design of terrace outlet channel.—To determine the size of terrace outlet required on a 6 per cent slope, proceed as follows to drain 12 acres. From Figure 14 the maximum depth at which the water can flow without causing erosion is 0.6 foot. For safety, the actual depth of the channel should be 0.5 foot deeper or 1.1 feet deep. The amount of water to be carried will be 12 times 3.5 or 42 cubic feet per second. Therefore, by Figure 15, the bottom width of channel would be 42/100 of the size given for a 6 per cent slope, or 42/100 × 30 or 12.6 feet. In case it was necessary for a channel on a 6 per cent slope to carry 130 cubic feet per second, the bottom width required would be 130/100 × 30 or 39 feet. As a general rule it is more desirable to have numerous small outlets than a few large ones.

Methods of protecting outlets.—If the drop from the mouth of the terrace to the bottom of the outlet channel is great enough to cause channel erosion, a flume of sod, rock, concrete, or galvanized iron is needed to conduct the water from the terrace level down to the outlet ditch. (See Fig. 16.) It is a good plan to keep terrace ends in tough permanent sod for a distance of 25 feet or more back from the outlets. They may also be protected from cutting back by means of the post and brush checks similar to those used in gully control.

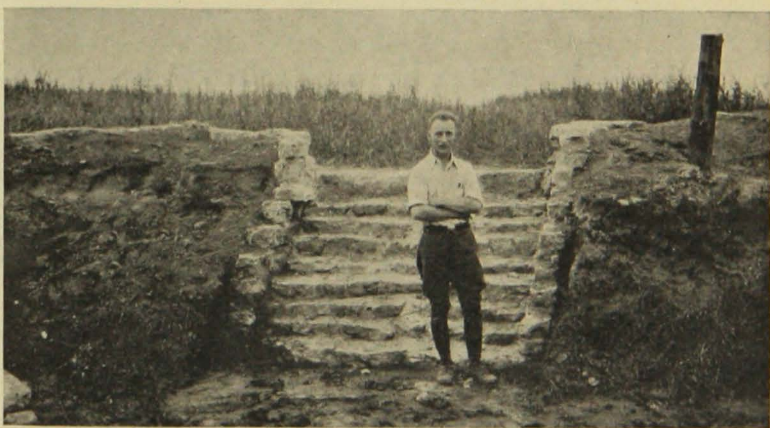


Fig. 16. An Effective Type of Terrace Outlet Built of Rubble Masonry

GULLY CONTROL AND ELIMINATION

Gully control and elimination involves three major steps, to be carried out in the order given: **Stopping head growth, prevention of floor scouring and side erosion, and filling or reclamation of the gully.** Wherever the gully has attained appreciable size, each of these three steps is essentially **an engineering problem.**

Stopping Head Erosion

Diversion ditches.—Frequently the logical first step in stopping head erosion is the construction of a diversion ditch that will collect the water above the head of the gully and carry it away slowly to a proper outlet, thus preventing it from falling over the head of the gully. If this ditch be long (1,000 feet and upwards) it should have a variable rate of grade increasing from the upper end toward the outlet according to the standard laid down for terrace gradients (see Table 2). In no case should it have a fall greater than 6 inches in 100 feet and usually a maximum rate of fall of 4 inches in 100 feet should be sufficient.

Head control structures.—Where it is impossible to prevent flow of water over the headwall of the gully it is necessary to provide some type of structure through which to drop the falling water to the floor of the gully without causing further trouble. Such a structure may be an open flume or a closed culvert, preferably the first, of wooden plank, galvanized sheet iron or concrete, or it may be a rubble masonry or concrete dam. Such a dam must be provided with a weir notch, apron and side walls to control and redirect the energy of the falling water. Such a dam of proper design is the most reliable type of head control works. However, it must be designed on hydraulic principles safely to withstand the pressure of the mud and water behind it and the weir notch in its crest must be of a size sufficient to carry the largest discharge of water from any flood. The dam should be extended well into the floor and walls of the gully to prevent undermining by seepage.

Tables 6, 7, and 8, in conjunction with Figure 17, give the essential values for approximate design of rubble masonry or mass concrete dams for ordinary gullies (4 to 10 feet deep). This type of dam, in its simple essentials, was found very effective in the soil erosion control work of the ECW in southeastern Minnesota; but the one-foot cross wall on the apron, the setting of the apron gradient steeper than and sunk below the gully floor gradient, and the turning of the side or buttress walls outward at right angles to the line of flow of the water into the natural walls of the gully, all as shown in Figure 17, have been found to be necessary additions to the design as originally used.

To insure sufficient capacity and strength to meet the demands of a given location the headworks should be designed by an engineer well grounded in structural and hydraulic theory and practice. While a farmer used to laying up rubble masonry may, himself, be able, guided by the plans in Figure 17 and the information in Tables 6, 7, and 8, to construct his own dams for gullies of moderate size, he is strongly advised not to do so. This is because there are many intricacies both of design and construction that must be exactly right to make the dam effective and safe and that require the services of men especially trained in construction works of this type.

Dams of the general design shown in Figure 17 may also be built of mass concrete if so desired, or their cost may be reduced by using

Table 6
Standard Dimensions for Rubble Masonry Dams Like Those Illustrated in Figure 17

Total height, H+h,* of dam	Thickness, B, at base of front batter	b	e
Feet	Feet	Inches	Feet
4	3.0	8	1.5
5	3.5	8	1.75
6	4.0	8	2.0
8	5.0	8	2.5
10	6.0	8	3.0
12	7.0	8	4.0

* h should be at least from 6 inches to 1 foot greater than d.

Table 7
Recommended Length of Apron and Location of One-Foot Cross Wall Across Apron for Different Amounts of Run-Off

Rate of run-off in cfs.	Distance D, in feet, of 1 foot cross wall from foot of dam for heights of dam to weir crest given in feet at heads of columns below				Recommended total length, L, in feet, of apron for heights of dam to weir crest given in feet at heads of columns below			
	4	6	8	10	4	6	8	10
50	2.0	2.5	3.0	3.0	10.0	12.0	14.5	16.5
100	3.0	4.0	4.5	5.0	11.0	13.0	16.0	18.0
150	3.0	4.0	4.5	5.0	12.0	14.5	17.0	19.5
200	3.0	4.0	4.5	5.0	13.0	15.5	18.5	21.0
250	4.0	4.5	5.5	6.0	14.0	17.0	20.0	22.5
300	4.0	5.0	6.0	6.5	14.5	18.0	21.0	24.0
350	4.5	5.5	6.3	7.0	15.5	19.0	22.5	25.5
400	4.5	5.5	6.5	7.0	16.5	20.5	24.0	27.0

Table 8
Dimensions of Weir Notches (Dimensions d and h in Fig. 17) for Rates of Run-off and Areas of Watershed Given Below

Rate of run-off in cfs.	Approximate areas of water-shed in acres for rainfall in inches per hour as given at heads of columns below			Theatretical depth, d, in feet, of water on weir crest for lengths of crest, C, in feet, as given at head of columns below					Recommended total depth, h, in feet, of weir notch for lengths of crest, C, in feet, as given at heads of columns below				
	2	3	4	5	10	15	20	25	5	10	15	20	25
50	63	38	27	2.06	1.30	1.00			2.50	2.00	1.50		
100	125	76	53		2.05	1.57	1.30			2.50	2.00	2.00	
150	188	114	80			2.06	1.70	1.46			2.50	2.30	2.00
200	250	152	106			2.49	2.06	1.77			3.00	2.50	2.30
250	313	190	133			2.89	2.39	2.06			3.50	3.00	2.50
300	375	228	159			3.27	2.70	2.32			4.00	3.50	3.00
350	438	266	186			3.62	2.99	2.57			4.50	3.50	3.00
400	500	303	213			3.96	3.27	2.81			5.00	4.50	3.50

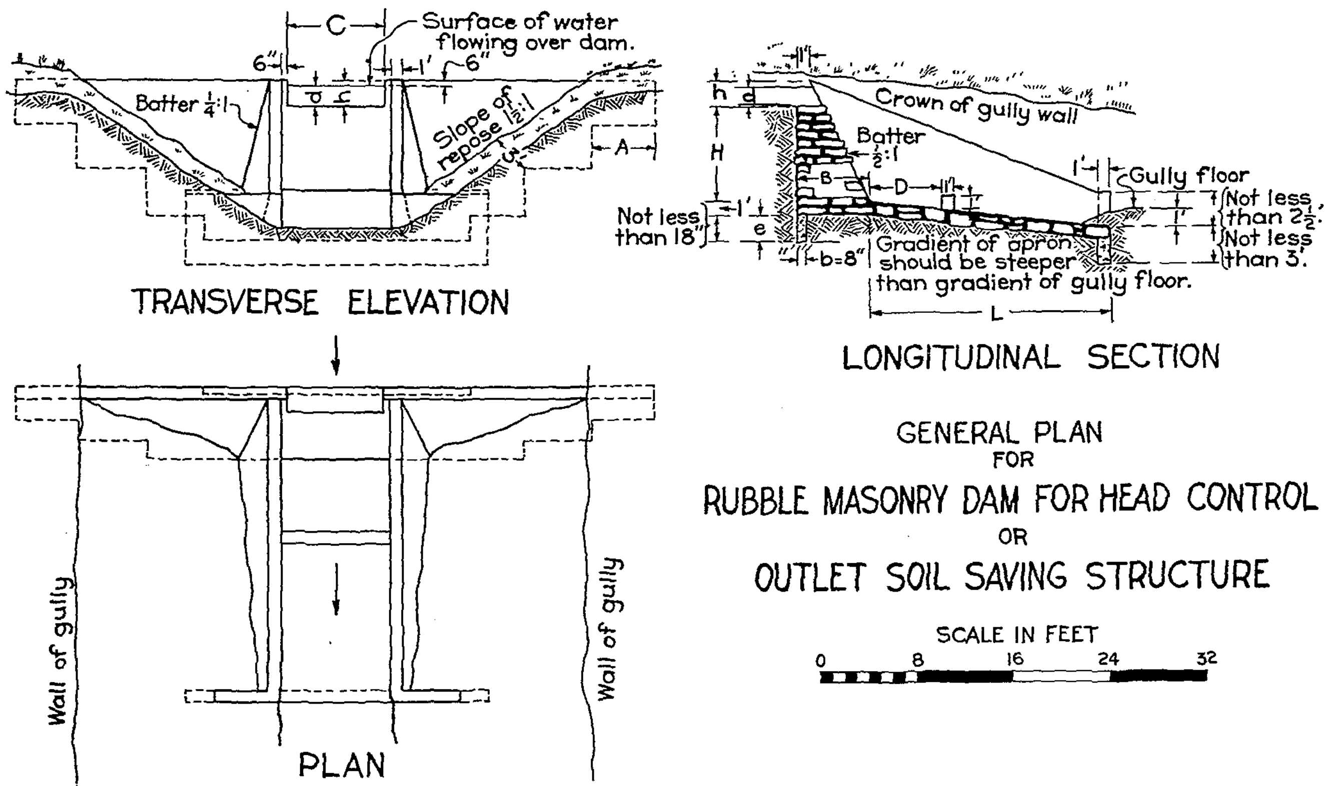


Fig. 17. Plan of Rubble Masonry Dam for Head Control of Gullies or for Use as a Soil-Saving Dam

reinforced concrete which calls for less material; but on account of the great reduction in weight of the structures a different design is then required to withstand failure by slipping.

Where the gully is very narrow at its head for the water that it must carry from heavy rainfall, Figure 18 shows a type of dam with a circular arc spillway especially suited to such a case. This type has also been used effectively by the ECW engineering staff in southeastern Minnesota.

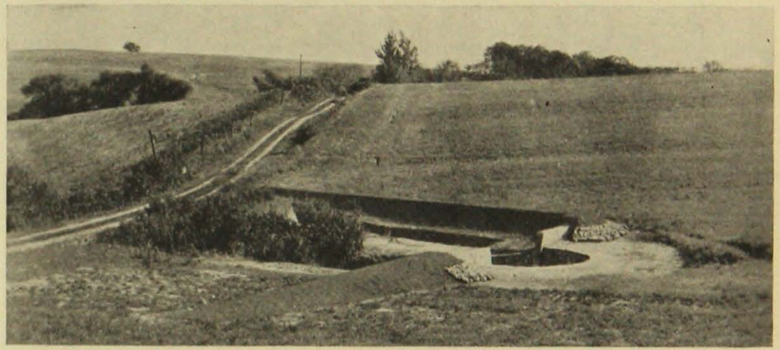


Fig. 18. A Circular Arc Spillway of Rubble Masonry for Head Control on Gullies (Courtesy of the State Administration of ECW)

General recommendations.—For guidance in effective use of simple masonry dams, similar in general to that shown in Figure 17, the following recommendations, based on both experience and laboratory tests, are offered.

1. Gully floors with gradients of 3 per cent or greater are usually unstable. Such require check dams at intervals that will stabilize the gradient at 2 per cent or less, and heavy, hand-placed riprap for a width of 6 to 8 feet is needed below each check and below the apron of the main dam with its surface lying within the new stabilized gradient. The crest of the first check dam below the main dam should be at practically the same elevation as that of the toe of the apron on the main dam.

2. The apron of the main dam should have a total length at least as great as that recommended in Table 7; its floor should be on a gradient steeper than that of the gully floor below it in all cases where the natural gradient of the gully floor exceeds 2 per cent; the submerging of the toe of the apron a foot below the gully floor is desirable; and the cut-off wall at the toe of the apron should extend at least 3 feet, vertically, below the toe.

3. There should always be a cross wall a foot high extending across the floor of the apron at right angles to the direction of water flow and at a distance from the foot of the dam as shown in Table 7 for each specific case.

Prevention of Floor Scouring and Side Erosion

Once the head growth is stopped, steps must next be taken to check the velocity of the water flowing through the gully, thus avoiding the deeper scouring of the gully floor and the undermining of its walls. This may be done by constructing check dams across the gully floor at frequent intervals for its entire length. Except at the outlet of the gully, it is usually sufficient to construct the check dams of loose rock, woven wire or posts and brush. They are cheap and easily built. (See Special Bulletin 170.) As soon as the first dams are filled to the top with eroded material, new ones should be built. Any ordinary gully can be quickly filled in this manner. Check dams should always be made lower at the center than at the edges so the water will not cut around them. Frequent low dams are more economical and less apt to wash out than few high ones. The dams should be so spaced that the new stabilized gradient between them, when once established, does not exceed 2 per cent. Brush dams give the best satisfaction when built of green brush with the leaves still on and the butts extending up stream. The butts should be well choked with old straw or hay. A loose brush pile in a gully is useless, as the silt-laden water will pass through without depositing any appreciable amount of soil. It is not advisable to put a straw stack in a gully, as the water is likely to cut around the stack and enlarge the gully.

Where the quantity of water to be taken care of is considerable, or its flow continuous, or when local availability of materials seems to justify it, these check dams may be built to best advantage of concrete or rubble masonry. In this case the general design of Figure 17, supplemented by Tables 6, 7, and 8 should be used, altho, the drop over check dams usually being small, the masonry apron just below the dam can usually be replaced by one of heavy, hand-placed riprap.

Filling or Reclamation of the Gulley

Soil-saving dams.—In any gully of appreciable size there should be one or more soil-saving dams of masonry or earth so constructed as to retain the silt burden but let the water by. At least one such dam at or near the mouth of the gully is necessary to its control and elimination.

The type of rubble masonry dam shown in Figure 17 and covered by Tables 6, 7, and 8 and the accompanying discussion under head control is also very effective for use as a soil-saving dam.

Soil-saving dams of earth must be provided with a vertical drop culvert with horizontal portion extending through the dam and provided with an outlet protection of concrete, all as shown in Figure 19, to let the water by and retain the silt burden above the dam. Ordinarily the culvert should be designed with a sufficient capacity to carry, with

Table 9*

Cross-Sectional Areas of Pipe or Conduit for Drop-Inlet, Soil-Saving Dams for Rolling Watersheds with Length Equal to About Twice the Width

Drainage area	With no spillway around or over dam: Very little storage above dam		With no spillway around or over dam: Storage above dam, surface area, ½ acre, at level of top of inlet pipe		With spillway having capacity about half that of pipe in column 2; storage, ½ acre at level of top of inlet pipe	
	4-foot drop	8-foot drop	4-foot drop	8-foot drop	4-foot drop	8-foot drop
Acres	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.
1	0.4	0.3	0.2	0.1	0.05	0.0
2	.7	.5	.35	.2	.1	.0
4	1.1	.8	.6	.3	.15	.0
6	1.5	1.1	.8	.5	.2	.0
8	1.9	1.4	1.1	.65	.25	.0
10	2.2	1.7	1.3	.8	.36	.0
15	3.0	2.3	2.0	1.2	.4	.1
20	3.8	2.8	2.7	1.7	.5	.2
25	4.5	3.4	3.4	2.2	1.1	.3
30	5.1	3.8	3.9	2.6	1.2	.5
35	5.8	4.3	4.5	3.1	1.5	.7
40	6.3	4.8	5.1	3.5	1.8	1.0
45	6.9	5.2	5.7	4.0	2.2	1.2
50	7.5	5.6	6.3	4.4	2.6	1.5
60	8.6	6.5	7.6	5.4	3.2	2.2
70	9.7	7.3	8.6	6.2	3.7	2.5
80	10.7	8.0	9.6	6.9	4.2	2.9
90	11.7	8.8	10.6	7.7	4.8	3.3
100	12.6	9.5	11.6	8.4	5.3	3.7
125	15.0	11.2	14.1	10.4	6.7	4.8
150	17.2	12.9	16.7	12.4	8.2	6.0
175	19.2	14.4	19.2	14.4	9.6	7.2
200	21.3	16.0	21.3	16.0	10.6	8.0
300	28.8	21.6	28.8	21.6	14.4	10.8
400	35.8	26.8	35.8	26.8	17.9	13.4
500	42.3	31.7	42.3	31.7	21.1	15.8
600	48.5	36.4	48.5	36.4	24.2	18.2
700	54.4	40.8	54.4	40.8	27.2	20.4
800	60.2	45.2	60.2	45.0	30.1	22.5
900	65.7	49.3	65.7	49.2	32.8	24.6
1,000	71.1	53.3	71.1	53.3	35.6	26.6

For very hilly watersheds increase above cross-sectional areas 25 per cent.
For square or fan-shaped watersheds increase above cross-sectional area 15 per cent.
For sizes of pipes corresponding to the above cross-sectional areas see Table 10.
* From U.S.D.A. Farmers' Bull. 1234.

Table 10*

Cross-Sectional Areas of Pipes of Standard Diameters for Use in Selecting Sizes Corresponding to Areas in Table 9

Diameter of pipe	Cross-sectional area of pipe	Diameter of pipe	Cross-sectional area of pipe	Diameter of pipe	Cross-sectional area of pipe
Inches	Sq. ft.	Inches	Sq. ft.	Inches	Sq. ft.
6	0.20	18	1.77	33	5.94
8	.35	21	2.41	36	7.07
10	.55	24	3.14	39	8.30
12	.79	27	3.98	42	9.62
15	1.23	30	4.91	45	11.04
				48	12.57

* From U.S.D.A. Farmers' Bull. 1234.

safety, the largest amount of water ever known to discharge through the gully, but a spillway of heavy well-established sod, or woven willow or concrete, should also be provided as an emergency measure to take

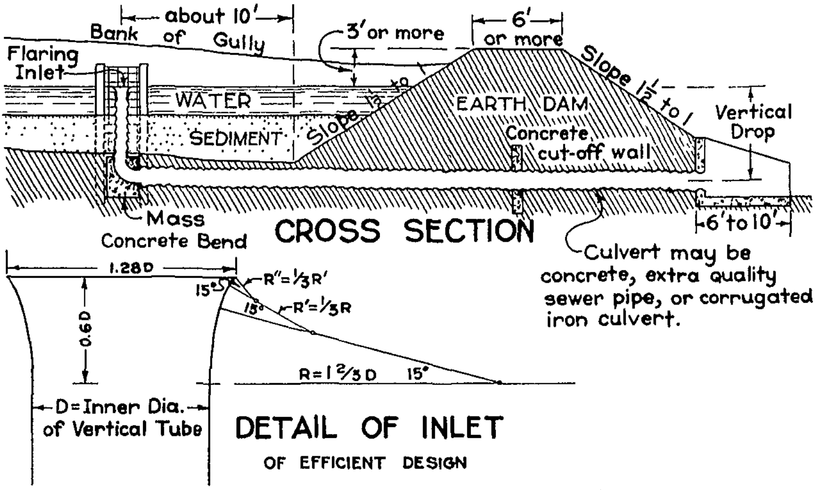


Fig. 19. Earth Soil-Saving Dam and Culvert with Vertical Drop Inlet (Adapted from U.S.D.A. Farmers' Bull. 1234)

care of exceptional rainstorms. Tables 9 and 10 serve for approximate design of culverts. For large installations and for steep, narrow watersheds, it will be well to have a special design worked out by a competent engineer. The culvert may be of high-quality reinforced concrete, or of corrugated iron culvert pipe, set in a concrete bend. Care should be taken to have the culvert set on a firm undisturbed bed of natural soil, and seepage collars should be provided every 12 to 15 feet of its length. The ends of the dam should be as high, at least, as the walls of the gully. To prevent undermining by seepage, the bed on which the earth dam is built should be thoroly cleared of all vegetable matter and every precaution should be taken to secure the tightest possible bond between the filled material and the natural bed.

ACKNOWLEDGMENTS

The authors wish to express their appreciation of the valuable and comprehensive aid obtained in the preparation of this bulletin from the following publications: Nebraska Extension Circular No. 123, "Soil Washing—the Cause and Methods of Prevention," by P. H. Stewart and I. D. Wood; U.S.D.A. Farmers' Bulletins 1234, "Gullies—How To Control and Reclaim Them," and 1669, "Farm Terracing," by C. E. Ramser, U.S.D.A. Bureau of Agricultural Engineering, and to the U.S.D.A. Soil Conservation Service for the cover-page picture.