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Soil Erosion

—a local and national problem

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Soil Erosion

—a local and national problem

C. G. Bates and O. R. Zeasman¹

THE EROSION of soils through the action of rain water and that from melting snow is almost universal in its occurrence. The gradual erosion and levelling of any country is inevitable, being a process which has gone on as long as there has been free water on the face of the earth. Nevertheless, this process is an extremely slow one where the landscape is naturally well covered by vegetation, and is greatly speeded by every mechanical disturbance of the earth's surfaces resulting from man's activities; and under certain conditions becomes needlessly destructive. The loss of fertile surface soil from the farms of the country alone represents an enormous economic loss, so that the problem becomes a "conservation" problem of the

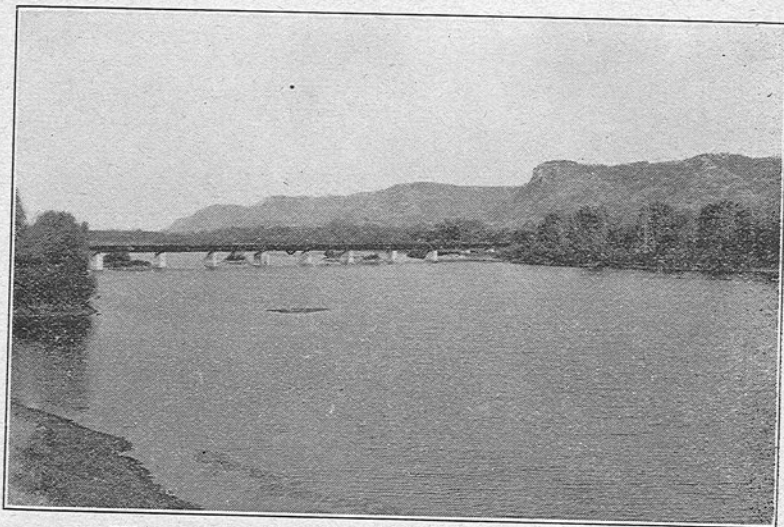


FIG. 1.—"THE FATHER OF WATERS" IN PEACEFUL MOOD.

(As seen from the Interstate Bridge at Winona.) The Wisconsin bluffs on the right give a clear conception of the most rugged portion of the territory considered in this bulletin. The steep slopes are in no small degree responsible for the silt problem of the Mississippi.

¹The authors express grateful acknowledgement of technical suggestions for this study received from various members of the staffs of the University of Wisconsin and of the Lake States Forest Experiment Station. It is also desired to express appreciation of the work of a number of assistants employed on the study, without which it would have been impossible to accumulate and present the most important new facts given in this bulletin. Among these, H. C. Moser, L. A. Holmberg, H. Bruhn and W. R. Anderson deserve special mention.

first magnitude. But this is only one of the injuries which results when water runs off the surface instead of soaking into the ground as it would under more natural or more controlled conditions. One of the greatest of these additional injuries is represented by the losses and hardships created by floods on the small and large rivers of the country. The 1927 flood on the lower Mississippi River has done more, perhaps, to attract attention to the seriousness of the erosion problem, than any other occurrence or series of events. Despite the fact that one even larger flood on the Mississippi is known to have occurred before the Mississippi Valley was largely placed under cultivation, those who have studied the matter seriously see a direct connection between the occurrence of large, damaging floods, and the occurrence of erosion on the individual farms of the Mississippi Valley. This relationship, it is hoped, will be brought out clearly in the course of the following discussion.

Why should forests be brought into this discussion, or erosion treated primarily as a forestry problem? Simply because forests represent a more natural condition of the land under which erosion does not occur to any appreciable degree. This is true of the virgin forest; it may be realized to almost as full an extent in the case of



FIG. 2.—SOUTHWESTERN WISCONSIN HILLS WERE NATURALLY FORESTED FROM TOP TO BOTTOM.

This deposit of limestone fragments at the lower level is the result of cultivation on the table-land above the present narrow belt of timber. Here is the beginning of a community problem.



FIG. 3.—SHEET EROSION WASTEFUL.

Sheet erosion means not only the loss of the most valuable organic elements of the soil which lie near the surface and affect greatly its water-absorbing capacity and tilth, but also the equivalent of many dollars worth of soluble plant foods per acre.

well-managed commercial forest provided the forest floor conditions are allowed to develop naturally, being undisturbed by fire or excessive grazing or trampling. The region discussed in this bulletin is essentially, from its river bottoms to the tops of its table-lands, hardwood forest land, and even soils long cultivated would return, through a brush stage, to hardwood forests were nature given a free hand. It should be evident, therefore, that it would be a simple and inexpensive matter to attain a much greater degree of protection from erosion than now exists, by allowing the natural forest to regain its foothold on many of the steeper slopes, where the most destructive erosion originates, later eating its way back into the more level fields. In some cases it would considerably complicate the management of a farm to permit this to occur; in others it could be done with actual benefit of the farm as a whole; in still other cases the amount of erosion occurring, and causing damage to a number of farms, to roads, and to the community as a whole, is so great as to raise the question whether the public interests do not demand that portions of the land be devoted to timber-growing rather than to farming. Such "key" situations are, fortunately, so few that they would have no appreciable effect on the farming community as a whole.

It was because of the possible service which forests might render, along with engineering works and better methods of land management, toward the decreasing of erosion on farms and of its far-reaching effects beyond them, that the University of Wisconsin and the Forest Service, United States Department of Agriculture decided upon a joint study of erosion in southwestern Wisconsin. If this cooperation between state and federal forces does no more than to widen the scope of the investigation and to show that Wisconsin's erosion problem is not purely one of local interest, it will have served a useful purpose. But still another purpose is served by bringing into the discussion, in addition to the skill of the engineer, what may be called the "naturalistic" point-of-view of the forester, which means, in this

case, merely a proper recognition of the importance of the natural balance between vegetation and soil.

The Full Significance of Soil Erosion

The process of erosion is not one which begins and ends with the removal of the soil from the surfaces of fields. In order to appreciate the importance to the farmer and the economic loss to the nation through unnecessary run-off of the water of rain and melting snow, it is desirable to consider all of the phenomena attending run-off and erosion which could not occur if the water percolated entirely into the ground and reached the streams only gradually. Therefore, these are listed with the briefest possible explanation of each, as many of them will be frequently referred to hereafter:

1. Water is lost to ground storage which would later be used by growing crops. The quick drying-out of hard-packed pastures is significant of the importance of this loss where the proportion of run-off is large. Rains which fall rapidly and wet thoroughly the receptive soils, often leave packed soils wetted only to a depth of 2 or 3 inches.
2. Soluble plant foods are carried away in the water which would otherwise be carried into the deeper soils and remain, at least

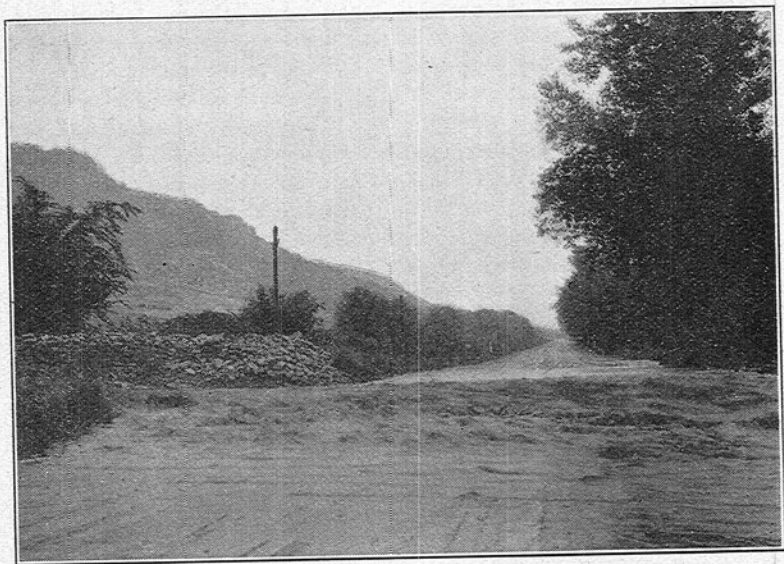


FIG. 4.—THE SAME "LIMESTONE RUN" SHOWN IN FIGURE 2.

When water runs off from cultivated areas at this rate, within an hour of the beginning of a rain, it means at least that the fields are being robbed of moisture which would grow crops.



FIG. 5.—A FIELD RUINED BY GULLYING

Gullying into the deep alluvial soil of this beautiful field has not only bodily removed acreage, but has rendered the remaining area almost useless by dividing it into small units and by draining it excessively. It can not even be used for pasture with entire safety, since some of the branches are 40-50 feet deep.

in part, within reach of the roots of crop plants. Bennett² estimates this loss to be several times as great as the present purchases and use of fertilizers.

3. The light organic matter (humus) which so greatly affects its tilth, its moisture-holding capacity, and its fertility, is most readily removed from the surface layer of the soil together with the clay and other finer elements which are also important to fertility and moisture-holding. As deeper fingering and gully-ing occur, the entire surface layer may go with the water, so that eventually a new soil must be formed from the unfertile sub-soil materials. As this process proceeds, the severity of run-off and erosion increases, so that eventually a field may become entirely unworkable. Even with the addition of vast quantities of organic matter, the restoration of such soils can hardly be accomplished in one man's life.
4. The cutting of deep gullies divides fields into smaller and smaller units, increasing the labor and cost for their cultivation. These gullies moreover, invariably form in the depressions where both the finest and moistest soil of the field has lain, so that the loss of productive capacity is greater than the loss of arable acreage. The loss of the most fertile bottom lands through bank-cutting is equally serious.

² Bennett, H. H. and Chapline, W. R. 1928. Soil Erosion a National Menace. U. S. Department Agriculture. Circular 33.

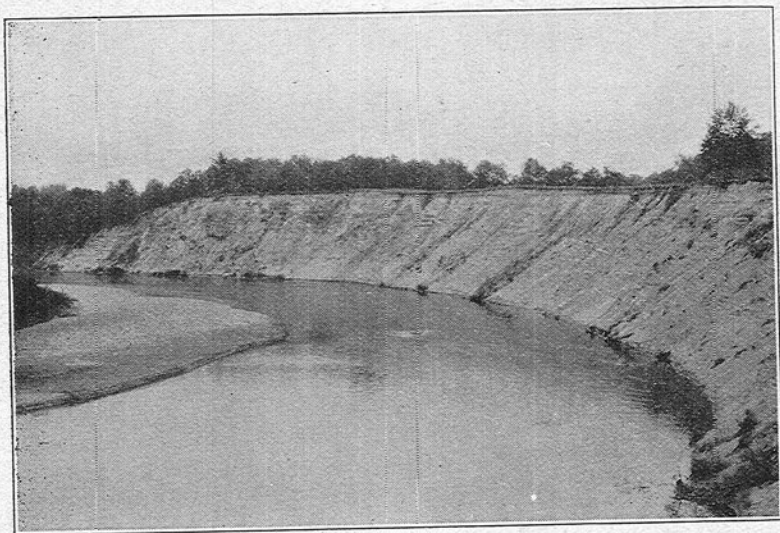


FIG. 6.—BANK CUTTING BY PERMANENT STREAMS (Black River)

Overloading with water from innumerable sources, causes great losses in the most tillable terrace soils. This sandy sub-soil cuts especially rapidly. Frequently farm buildings are undermined and destroyed by bank erosion.

5. Both gullying and bank-cutting tend to drain the adjacent ground of its sub-soil moisture, causing fields to dry out much more rapidly near gullies than elsewhere.
6. The increased quantity of water which reaches the regular stream channels causes both large and small streams to overflow their banks, flooding the bottom lands, killing crops directly, and often rendering the richest fields very precarious for use except as wild haylands. In addition, the direct damages by high waters to roads, bridges, and other improvements are so obvious to everyone that they need hardly be mentioned. But if we were to stop to count the total cost, for a single year, it would be appalling.
7. Finally, all of the soil material, as well as floating debris, carried from farms must be deposited somewhere. Often this damages the low-lying fields of a nearby farm, but it is still more a matter which affects the larger streams and valleys, and in the case of the Mississippi has become a problem which must be solved by the entire nation and by Federal expenditures which affect every citizen.

In the case of the Mississippi River, only the finest of the soil material is carried steadily into the Gulf of Mexico or deposited on the bottomlands of the lower river course when it overflows its

banks and dikes. The remainder is constantly building up the level of the river-bed itself, and by so doing is making perpetual, and almost impossible, the task of keeping the river within defined banks.

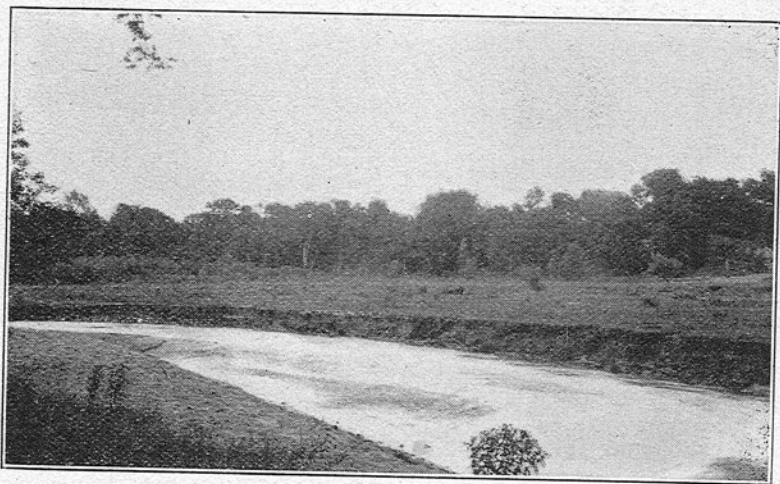


FIG. 7.—ONLY A SANDY BROOK

Mill Creek, Buffalo County, Wisconsin, is normally only a clear, sandy brook.

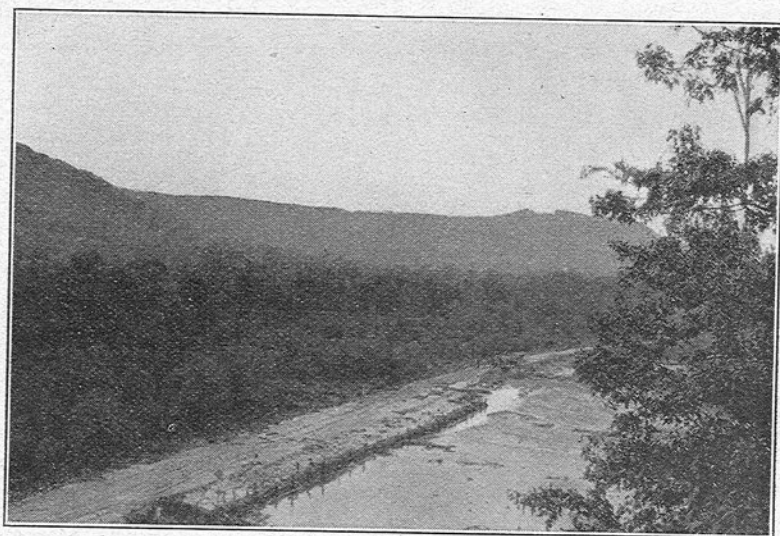


FIG. 8.—AT FLOOD TIME

Mill Creek, because of contributions of water from farm lands, not only overflows its bottomland once or twice each year, but floods this highway despite the fact that it has been raised 7 or 8 feet in recent years.

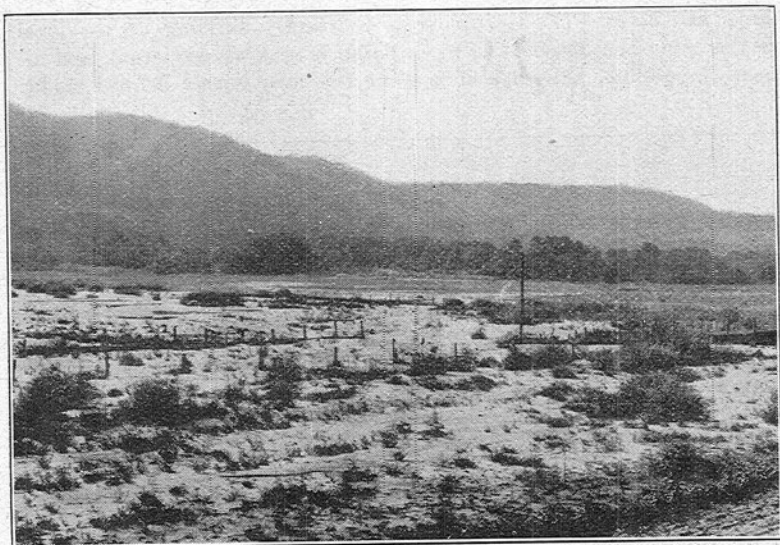


FIG. 9—ONLY THREE-FOURTHS OF VOLUME ERODED

This forty-acre deposit from a single large gully, covering valuable bottomland with rocks, gravel and sand to an average depth of 5 feet, represents only three-fourths of the volume eroded. The other fourth, 100,000 cubic yards, passed on into Buffalo River and thence into the Mississippi.

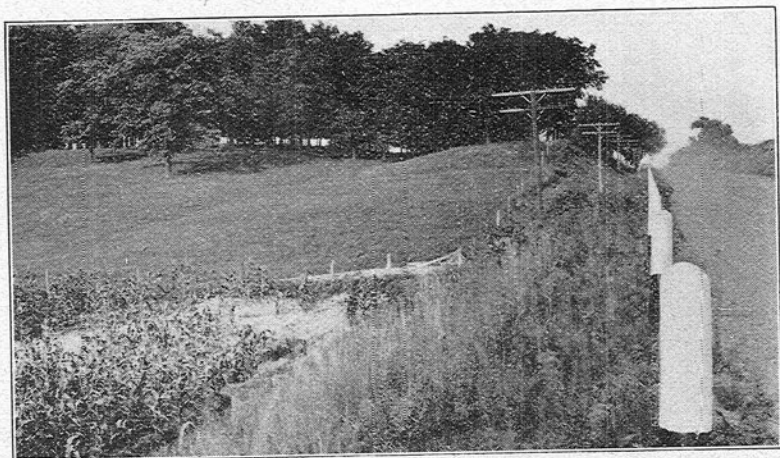


FIG. 10.—HIGHWAYS OFTEN CAUSE EROSION

Highways, while often the victims of erosion and floods, are also often the cause of erosion. The sand covering on the cornfield at the left is solely the result of run-off from the roadway and of cutting of the road ditch.

To deny this, or to minimize its importance as many engineers are inclined to do, is to shut one's eyes to the most important single factor

in a problem which affects the prosperity of the entire country. Every large river and many a small one is building land near its mouth. The load carried by the Mississippi and which tends to be deposited where the river loses its gradient, can be made enormous, and beyond the capacity of even this rich nation to cope with, or it can be materially reduced, perhaps to the point where a large proportion of it will be carried into the sea. Soil erosion in Wisconsin, and in every other state in the Mississippi drainage area, is intimately related to the problem which the nation is at present seeking to solve through the building of higher and higher levees and dams. The problems will be solved at least partially by the farmers of Wisconsin and other states through self-interest in the damage done by erosion at its source, but they should realize that every step taken to save their own farms from destruction is a step toward the ending of the great problem of the Mississippi floods.

The time to extinguish a fire is when it starts, not when it has reduced a building to ashes: likewise, the time and place for actually "controlling" the Mississippi River is through "extinguishing" the thousands of needless small floods at its thousands of sources, and by so doing largely eliminating the silting of the river. When the river has been freed as much as possible of its load of fertile agricultural soil, through which it is steadily impoverishing the greatest farming valley in the world, then the handling of the normal and unavoidable high-water stages of the river will be within human power.

From this brief resumé of the situation, it must be seen that soil erosion is an economic menace of the greatest importance; that it affects directly or indirectly the welfare of every citizen; that it may, therefore, justify invoking the police power of the states and the regulatory power of the Union. But before these steps are considered unavoidable, intelligent selfishness should direct that the individual, community, state, and nation pool their efforts in a cooperative way, each recognizing its responsibility to deal with those phases of the problem which affect the individual or collective interests.

II. THE REGION STUDIED

THE REGION in which a special study of the erosion problem has been carried on during 1929, embraces three counties in the unglaciated section of southwestern Wisconsin, and to a very small extent the Minnesota territory adjacent, in the vicinity of Winona. The map, Fig. 23, shows the territory in which work was done, as well as the other territory which may possibly, by its topography, influence the rainfall within the critical area.

Of the three Wisconsin counties, one, Buffalo, is strictly a river county, extending from the lower reaches of the Chippewa River on the north to the mouth of the Trempealeau River on the south, and

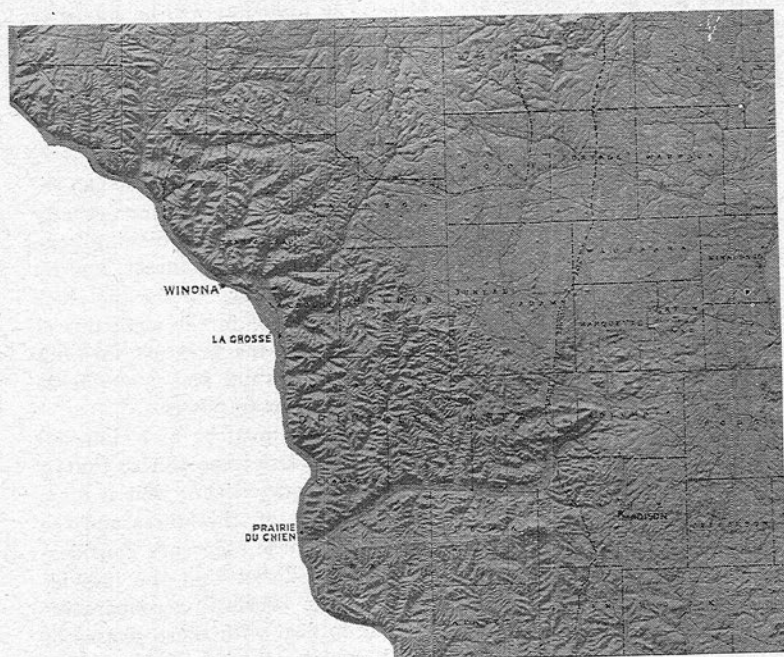


FIG. 11.—RELIEF MAP OF SOUTHWESTERN WISCONSIN

Showing the ruggedness of the territory in which erosion is most severe, as contrasted with the flat, central sandy area. Minnesota areas also studied were in the vicinity of Winona.

including much of the drainage of Buffalo (Beef) River. Trempealeau County lies to the east of Buffalo, touching the Mississippi between the mouths of the Trempealeau and Black Rivers and including portions of the drainages of each. Jackson County is an "interior" territory including quite a large portion of the drainage of Black River.

In addition to the intensive study in these areas, much work in the trial of control measures for erosion was done in La Crosse, Vernon, Crawford, and Monroe counties, the first three of which are bounded on the west by the Mississippi, and the last being on the La Crosse and Black river drainages.

Topography

The entire southwestern portion of Wisconsin, a large area adjacent in Minnesota, a small corner of northeastern Iowa, and a similar area of northwestern Illinois, comprise the "unglaciated region" which is so distinct in most of its characters from the surrounding territory which has been worked over and ground down by one or more glaciers. Originally this entire area was a nearly level lake bed, during which period successive layers of sandstone and limestone were laid down horizontally, the topmost of which lay at least 600 feet above the present level of the Mississippi, or say 1,200 feet above sea level. This plain has been cut down, by the present streams so that the topmost level is now represented only by the highest land between the streams, yet there is so much of this of about the same height that when one is

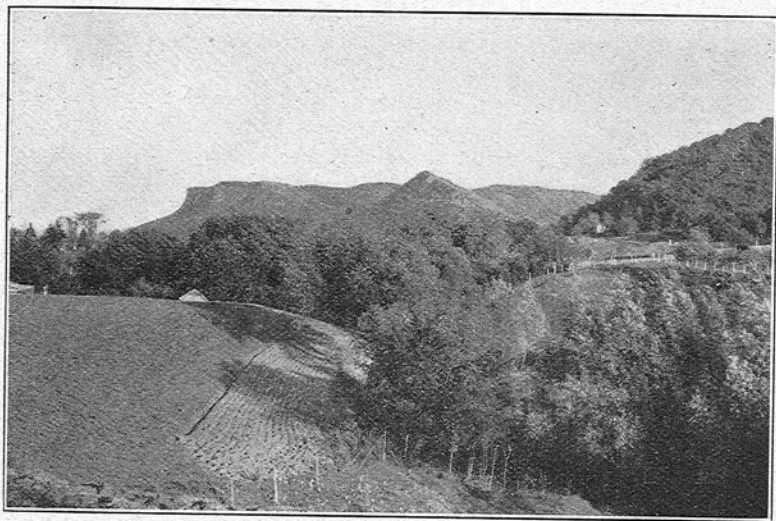


FIG. 12.—BLUFFS WHICH WALL IN THE MISSISSIPPI ON THE WEST BANK
They extend as far south as northeastern Iowa, and are of about the same height and character as those of southwestern Wisconsin.

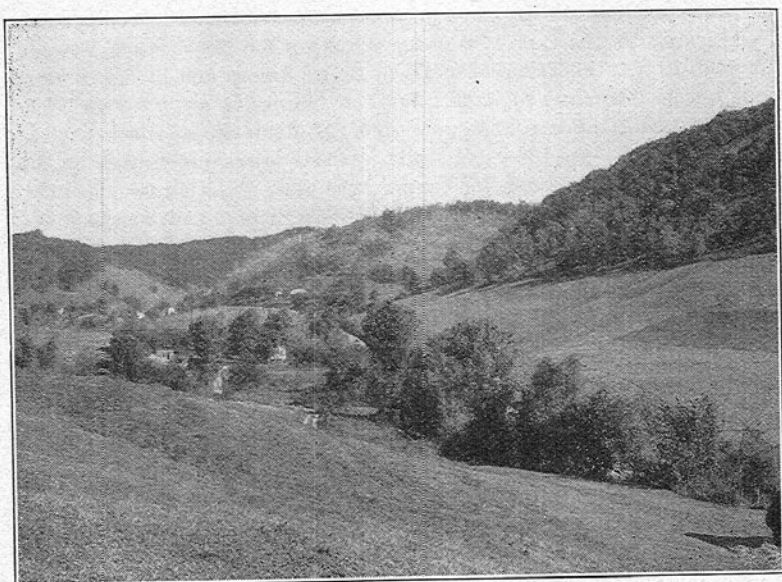


FIG. 13.—AN INTERIOR VALLEY IN SOUTHERN BUFFALO COUNTY, WISCONSIN

These steep fields are typical of many farms in this region. Land lying at a slope of 40 per cent is here being cultivated, while the wooded pasture above reaches the very steep gradient of 60 per cent.

on a high point, and looks across the country, it gives the appearance of a great plain, deeply dissected by the larger valleys, much less so by those of the smaller streams. This plain we shall hereafter speak of as the "table-land."

The Mississippi has cut more deeply than the smaller streams into this great mass of sedimentary formations, and the most rugged topography is found in its vicinity. (See Figure 11) The smaller streams must, of course, cut to practically the same depth to reach the Mississippi, and near their mouths are in some cases also in deep, steep-walled valleys, but toward their heads they rise nearer to the level of the plain, and, of course, the topography has much less relief. Near the Mississippi it is not uncommon to see bluffs rising 500 to 600 feet above the river in a distance of one-fourth to one-half mile.

Another feature of the topography of this deeply-dissected region is the existence along most of the length of the larger streams, and the lower portions of their smaller branches, of terraces which represent the water deposits of past ages in old valleys when the streams were, possibly, carrying greater volumes of water and were wider than at present. These terraces or benches are of interest in the present study because their soil is much more erodable than the other soils of the region, while at the same time they comprise the most attractive areas for farming with the possible exception of the best table-lands.

Soils

Aside from the river-deposited or "alluvial" soils of the region, just mentioned, and which are, of course, of limited extent, there are two general types. These are the "residual" soils derived from the sandstones and limestones which have been weathered down during the long eroding process, and the loess soils. The former, except for their movement, perhaps, from the face of a bluff to the foot of the slope below, are largely left where they were formed. In other words the residual soils are those derived from the "country rock" or local soil-building materials. They vary somewhat in texture according to the proportion of the finer materials which have been washed out, and also according to the proportions of the different limestone and sandstone elements which entered into the mixture. They are generally more porous soils than the following, and occasionally quite sandy, as where the plain has been cut down to such an extent that only sandstones can contribute to the present or recent soil formation. Thus the areas of "Boone" fine sand and fine sandy loam are largely derived from the sandstone, while many of the steep, rocky slopes are made up largely of limestone material which frequently forms rather

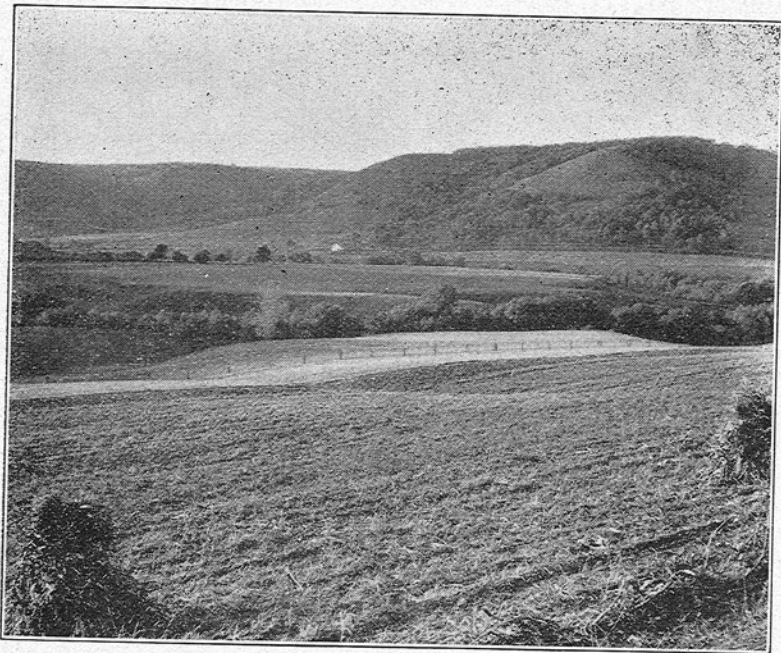


FIG. 14.—VALLEY IN MISSISSIPPI REGION

This valley in the unglaciated region has the high enclosing hills typical of the territory close to the Mississippi, and has a very large area of the level and tillable terrace or river-bench fields, which are often subject to deep gullyng.

stiff soil masses despite the large and small rock fragments which may be included.

The loess soils of the region are those which have been blown in from some distant source³ and have fallen as a blanket over the entire region, varying in depth like all wind-formed drifts, from place to place. Because of present prevailing winds, and perhaps also those prevailing when this deposition was taking place, slopes exposed to the west usually have a very thin covering of loess soil, if any, while those exposed to the east have the heaviest. In the deepest places the loess deposit may readily be 20 feet or more in depth, but over the high plain, and probably for the region as a whole, it is likely to average 3 or 4 feet in depth. The loess soils are fine and very uniform in texture, do not absorb water so readily as most of the sandy or stony residual soils of the region, and are further subject to deep erosion because of their vertical fissuring, or one might say, because of the lack of definite horizontal stratification, which usually gives layers of high resistance.

Climate

The region under discussion is, from the standpoint of temperatures, within but closely bordering the northern limit of the corn-belt, having mean summer temperatures for the four months, June to September, of from 65° in Eau Claire and Monroe counties, to 69° in central Crawford County, and of course, higher in the Illinois and Iowa territory. The growing season is from 130 to 160 days in length.

The rainfall is, in general, from 30 to 33 inches a year, with the heaviest precipitation in the months, May to September. The "highlands" in the region under discussion probably receive a little more rainfall than the lowlands along the Mississippi River, Whitson and Baker⁴ estimating from the records of 1897-1909 that in this region an increase of elevation of 100 feet produces nearly an inch additional rainfall per year. (For local records see discussion of the rainfall factor under Causes of Erosion) Miller,⁵ from the records for 30 years shows a high spot, reaching 34 inches annual precipitation, in the more elevated region east of Prairie du Chien, the same locality having two more inches of precipitation in the warmer half of the year, than the adjacent Mississippi bottom.

There is, moreover, a very considerable snowfall, and with mean January temperatures of from 12° to 16°, not a little of it commonly

³ The picture seems simpler to the layman, and more closely related to the movement of soil by wind which is going on at the present time, if it be assumed that the loess or wind-deposited soils of this region are merely the finer material from the residual soils, capable of being moved by wind. The principal reason for assuming a distant source is the fact that their lime content is higher than could be expected were the material derived from the local soils and rocks.

⁴ Whitson, A. R., and Baker, O. E. 1912. The Climate of Wisconsin and its relation to agriculture. Wisconsin Agricultural Experiment Station Bulletin 223.

⁵ Miller, Eric. 1929. Rainfall maps of Wisconsin and adjoining states. Repr. Trans. Wisconsin Academy Sciences, Arts, and Letters. Vol. XXIV.

accumulates to melt and run-off during the "big thaw" of the spring, which may and quite often does occur as early as February, and sometimes as late as April. This possibility of accumulation and heavy run-off over deeply frozen ground, together with the heaving and loosening action of ground-freezing, is a considerable item in creating erosion liability, to which more southerly regions are not subject.

III. THE CAUSES OF EROSION

BEFORE CONSIDERING even in a broad way, the seriousness of the erosion problem in the farming regions of Wisconsin, it will be well to build up a better understanding of the erosion process itself by considering separately the many factors which cause and control it. References to individual causes in the later discussion will then be less puzzling to those who have not considered all aspects of the subject. But to begin with, it is desirable to agree on the use of oft-repeated terms.

The term erosion, as used in this bulletin, means the loosening and removal of soil from its previous resting-place by the action of water. The study does not deal at all with a similar process sometimes carried on by wind action. The term **run-off** means the movement of water over any ground surface, in distinction from the water which percolates into the ground and which may reach a permanent stream in the form of seepage or springs. Run-off may occur without appreciable erosion, but erosion never occurs without run-off. This is true even of that form of erosion which we shall term **bank-cutting**, and which may occur along the channel of a permanent stream, for practically all bank-cutting and changes in the channels of streams occur when the streams are swollen with run-off water and its load of silt. This term, **silt**, is commonly and will here be used to mean any of the solid soil material being carried by run-off water or by a stream although, in its technical sense, the word **silt** refers only to very fine soil material.

Erosion has four distinct forms, as well as intermediate ones. **Sheet erosion** is the process going on when a smooth, even surface is washed by rain. The process is best exemplified on a road surface or hard-packed smooth pasture, since the loose soil of a field seldom cuts evenly. Sheet erosion generally removes only the finest, lightest, and most valuable part of the soil, since the water is of such small volume at any point that it has little mechanical power.

Fingering, often called "shoe-string gullying", is the process which quickly follows sheet erosion especially when the soil is loose. The term implies the formation of tiny gullies (as, for example, in each furrow of a freshly cultivated cornfield) which converge toward the lowest point of the field, and through this concentration the water acquires greater and greater cutting and carrying power. When this process attains sufficient magnitude so that the channels for the water are not readily changed or obliterated, the process is called **gullying**. Gullying may go to any depth or extent that the conformation of the ground, the fall to a permanent channel, or the character of the substratum will permit. Gullies 100 feet in depth are not uncommon and in fact, have no definite limits. When gullies cease to extend their width or depth, and their walls in consequence recede to a slope which

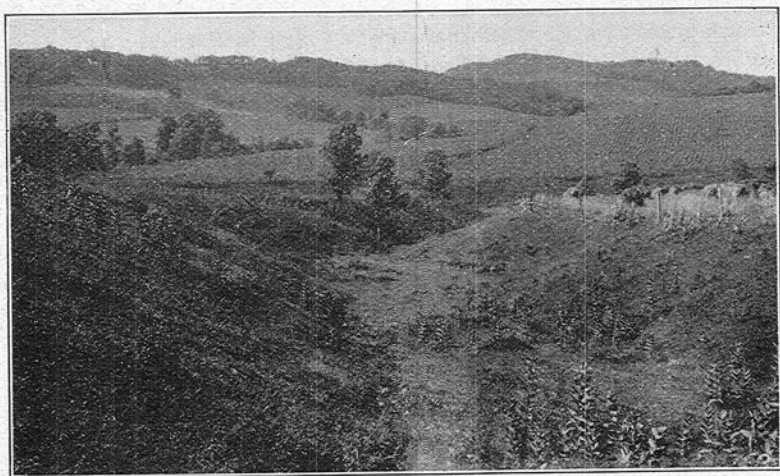


FIG. 15.—A "HEALED GULLY" IN SOUTHERN TREMPLEAU COUNTY

Probably due to a diversion of waters at its head, this gully has become thoroughly sodded over with walls standing at a gradient of 50 per cent and bottom sloping 12 per cent. So great has been the change in its stability that it now tolerates sheep grazing with no apparent tendency to break out afresh.

is more or less permanent, they are said to be "healing," a process invariably accompanied by the establishment of vegetation. A gulch is a healed gully, that is, it is a course for the drainage of temporary waters which is fully under the control of a vegetative cover, not appreciably changing its size or shape, and, therefore, temporarily inactive so far as the erosion process is concerned.

Bank-cutting is another and final form of erosion which, as already stated, may occur even in permanent streams. The term may be considered to apply to the entire process by which the course or position of a stream is changed. Bank-cutting on one side of a stream is often accompanied by the formation of sand-bars, and eventually by land-forming at another point, but the great inconveniences usually caused by such changes are obvious. It should be realized that inevitably the finest of the soil material is carried a great distance by the stream before being deposited, and the land-owner who is robbed of good bottomland is seldom compensated in kind. The formation of rich fields on the Mississippi bottoms of Louisiana, by material carried away from the fields and creek-bottom pastures of Wisconsin, is not a source of much satisfaction or compensation to the Wisconsin farmer.

It should be obvious to anyone that the only basic requirements for soil erosion are soil and water, for it is impossible for water even to move off perfectly flat land⁶ without carrying some of the finer soil ingredients in suspension. The broader major causes of erosion may,

⁶ For example, it is shown in a recent Texas bulletin (Factors Influencing Soil Erosion, by Conner, Dickson and Scoates, Bull. 411, Texas Agric. Exp. Sta. 1930) that a sample area with a clay loam soil, classified as "level" eroded at the rate of 8583 pounds per acre per year (3-year average), while with 1% slope this rate was doubled, and with 2% to 3% slope the rate was trebled. The above quantity represents a layer 1/35 inch deep from the entire area.

therefore, be generally described as the topography, soil, and rainfall of the region. However, some of the minor causes are often quite as directly responsible for serious destruction. It is, then, impossible and unnecessary to draw any sharp distinction between major and minor, direct and indirect causes of erosion. Any factor which tends to augment it, to increase the rate of erosion, should properly be discussed as a direct cause.

It is a fatalistic view to assume that a combination of factors causing destructive erosion may occur at almost any place or time and that such combinations can not be guarded against. True, erosion never can be entirely prevented by man's activities and precautions, yet the main symptoms are generally recognizable, and even the possibility of a rain of unheard-of proportions can be provided against, and its effects nullified by proper engineering works prepared in advance, if "the game is worth the candle". In other words, the causes of erosion are all definite and not in any sense "mysterious".

Erosion Influenced by the Type of Soil

Erodibility of General Soil Types:

Both surface erosion and deep gulying are considerably influenced by the type of soil, although a given soil type may not behave consistently under all conditions and no type of soil is entirely safe from erosion. Thus, sandy porous soils are in general least subject to gradual wearing-down by water action, since they are capable of absorbing a great amount of water in ordinary rains. On the other hand, if the rate of rainfall becomes so great they are fully saturated, or if percolation is prevented by frost, or by even thin strata of clay, the very lack of "binding" qualities in the sandy soils permits them to be moved at a very rapid rate. Again, however, the coarseness of the material may cause it to be deposited before it has been carried any great distance.

Very heavy clay soils are more subject to gradual wearing down by water. However, in such soils the very strong cohesion between the particles offers great resistance to loosening. Given a clay soil saturated and softened by long exposure to water, as in the spring melting period or after a long drizzling rain, the surface layer may be expected to move off readily with surface run-off of any amount: yet it is surprising how thin a layer will be affected, since the deeper soil offers greater resistance.

It becomes apparent, therefore, that the soils most likely to be eroded rapidly and steadily are in the intermediate class which the layman calls "loams", a clayey-sand being perhaps the worst of all. These are sufficiently loose and porous to absorb and hold a large volume of water; at the same time they contain sufficient of the finer elements to make them easily "fluxed" if we may use this term to denote a soil in a plastic or semi-liquid condition. With support remov-

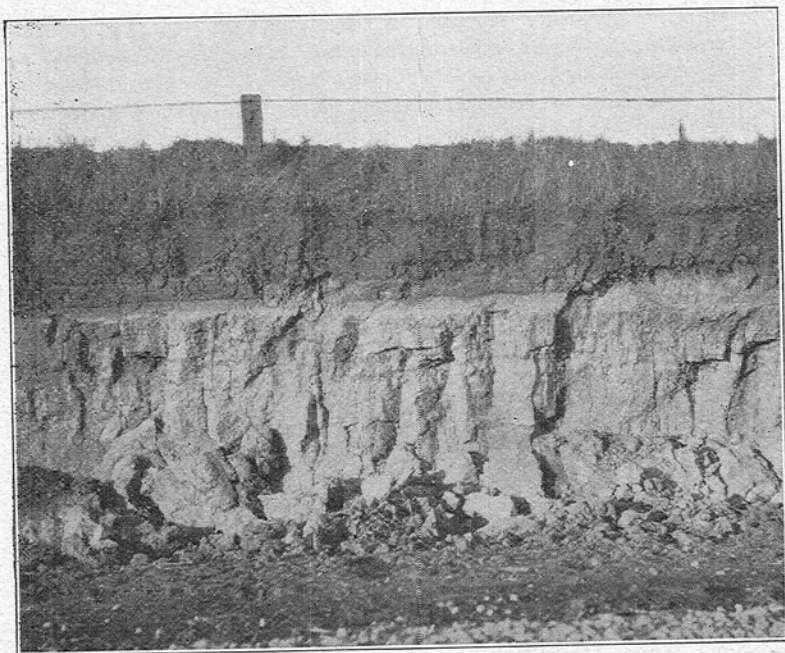


FIG. 16.—LOESS TENDS TO FRACTURE IN VERTICAL LINES

The tendency for loess or wind-deposited soil to fracture in vertical lines is an important factor in its rapid erosion, especially on the banks of gullies or streams where it may be undermined. This may be due to the lack of horizontal layering, but some investigations have indicated that the soil particles, some of which are elongated, have actually settled into place with their long axes vertical.

ed on one side, as in deep gullying, such soils become soggy with water and tend to slough off in great masses. This is particularly true of the loamy or clayey soils of wind-blown origin, termed "loesses" and even of some "joint clays", because these soils tend, even when dry, to cleave in vertical lines rather than horizontal lines. On the other hand, good loams are generally helped and in a sense protected, at least from surface erosion, by a good humus layer on top.

Effect of Humus:

Humus in any soil tends to prevent or at least decrease erosion, and it is because of the loss of humus that fields which have been continuously farmed for years, and have become poor in the productive sense, tend to erode more and more easily as time goes on. Humus seems to aid in retarding erosion in two ways. It undoubtedly always helps percolation by maintaining the porosity of the soil, and to the extent that it reduces run-off in this way it reduces the danger of erosion. Undigested, fibrous humus often appears to have a further value in acting as a mechanical obstruction. Its pres-

ence, for instance, in a very fine clay soil may have an effect equivalent to that of material coarse enough to be seen, as when straw is mixed into the soil. Fully digested humus, also, may be credited with acting as a binder between coarse soil particles, much as does clay. The organic matter which is not mixed into the soil, however, is itself easily washed away, since it floats more readily than the mineral particles, particularly more than the coarser sandy ingredients of the soil. Thus, without doubt, the main effect of a good humus layer on the top of a soil must be in keeping the soil porous.

Lowdermilk⁷ has recently shown most convincingly how humus, either in a forest or as it is mixed in the soils in fields may keep a soil "porous." Anyone who has ever worked with cement or plaster knows the meaning of the word "puddled". The farmer sometimes applies this term to the smooth, packed surface which is left at the bottom of the furrow if the plow is drawn through a sticky soil when it is too wet. The gardener knows that the soil is puddled if stirred while too wet. Rain falling on any soil which contains the slightest amount of clay tends to "puddle" these fine ingredients in a thin layer on the surface. Once this layer is formed, it keeps water from entering the soil almost as effectually as though the soil were a pure clay. Humus on and in the surface layer keeps the clay particles from forming their continuous film. Thus Lowdermilk found that a soil covered by

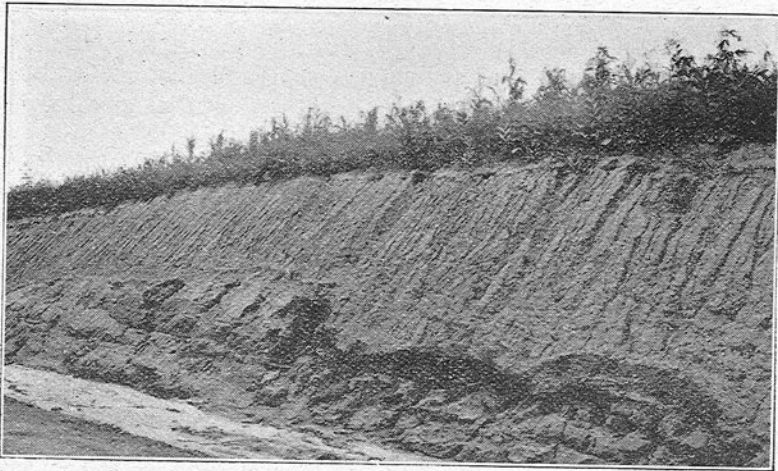


FIG. 17.—A FEW RAINS CUT VERTICAL GULLIES

On this cut-bank of a roadway, left smooth a month before this picture was taken, a few hard rains have readily cut vertical gullies in the top layer of loess soil, while the substratum of sand and gravel in horizontal layers has resisted the direct cutting, but has been undermined. This bank, 1200 feet long, eroded at the average rate of one cubic yard per day during the first month after the new road was finished.

⁷ Lowdermilk, W. C. "Influence of Forest Litter on Run-off, Percolation and Erosion." *Journal of Forestry* Vol. XXVIII, No. 4, April 1930.

a layer of humus could keep on absorbing rain at a rapid rate hour after hour, and the water kept moving steadily into the deeper soil, which seemed to have unlimited capacity.

Effect of Stones:

In somewhat the same way gravel or stones in the soil, and especially those near the surface, tend to keep the soil open and porous and also offer a mechanical obstruction to erosion, because they are themselves moved with difficulty. Lying on the surface, they probably act in a gross way to break up the clay films which might form through the "puddling" action of rain, just as do the finer particles of humus. At any rate it is always noticeable that a stony soil absorbs water much more readily than an equally heavy soil free from stones. Probably the greatest importance of gravel and stones, in connection with erosion, however, is to be attached to their ability to resist the cutting power of water, both on the surface of soils and on banks where the process has already gone far enough to uncover the subsoil. It is true that all of the finer material may be washed away from around the stones, yet when these are left in sufficient abundance to form a complete covering of the slope, the cutting process quickly comes to a standstill. The value of a stone "rip-rap" surface to protect cutting river banks is too well known to need any explanation. This is the function which we see served when a stony soil is washed down until only the stones remain on the surface.

Effect of Sandy Sub-soils:

Contrarily, beds of sand and fine gravel once they are attacked by a sufficient volume of water to move such coarse material, give way at a surprising rate, and such beds in the deep sub-soil are often responsible for the very rapid progress of deep gullies. Assume that by a relatively slow process a gully has worked down to a layer of coarse sand, a foot thick, lying ten feet below the surface. Under this sand bed there are additional layers of stiff clay. Now, the water coming into the head of this gully, and falling ten feet, is so concentrated that it can immediately dig a deep round hole in the sand, at the same time carrying the loosened material down the gully, where it adds to the cutting power of the water as it moves along. Soon it is found that the sand bed is being eaten away far under the stiff soil which lies above it. In other words, the stiff material which has resisted fairly well the direct cutting action of the water is undermined, and a large block of it soon caves off, falling where the waterfall can quickly cut it apart and move it away. This undercutting in the sand layer, therefore, speeds up the whole process, and it is not uncommon to find that as the head of the gully moves farther and farther back into the field of good soil, the bottom level of the gully is maintained at the level of the sand stratum. This could never happen if the same volume of water, without the great fall, were simply moving over the bed of

sand. It is obvious that protection must be sought by checking the force of the falling water, a subject which will be treated more explicitly in a later chapter. It is merely desired to emphasize at this point that when gullies have once started, and water-falls are produced, the ability of the given volume of water to cut material away has been magnified many times. Under such conditions the coarsest material can be moved, and we find that the cohesive power of shales, clays, and similar fine materials offers greater resistance to movement than the mere weight of sand or gravel particles which are not bound together.

Loose Materials Hasten Erosion:

Altogether, it is unsafe to say that one type of soil is potentially more unstable or dangerous from the erosion standpoint than another, without knowing all of the other conditions. However, it is possible to generalize to the extent of saying that, while stiff clay soils are eroded at the surface more readily, and by smaller quantities of water than are sandy soils, they continue, due to the materials which bind them solidly together, to be acted upon more superficially under nearly all conditions; while sandy soils are less easily set in motion, but once the volume and power of the water are sufficient to carry the coarser material, they move much more rapidly, and in larger masses.

It has been mentioned above that when the sand is set in motion down the bed of the hypothetical gully, while it reduces the velocity of the stream it probably adds to the macerating, cutting, and abrasive power of the water itself. It is obvious that when a small stone is thrown against the bank as it moves along in the water it is likely to loosen more material than would a similar volume or weight of fine material being carried by the stream. In other words, where thousands of strokes of a claw-hammer would be necessary to split a large rock, only a few blows of a heavy maul are required. Here again, the type of soil enters into the erosion problem; erosion once given a good start in coarse sandy material is likely to work with surprising swiftness because of this new cutting power which is given to the stream. But it is difficult to conceive of a stream being so heavily laden with clay that the cutting power of the water would be materially increased, although the mere increase in volume caused by the soil load, would have its effect.

Topography and Slope of Ground Important Factors in Erosion

Unglaciaded Region More Dissected:

If, broadly speaking, erosion is far less striking and serious in the glaciaded portion of Wisconsin than in the unglaciaded southwestern section, the difference may be ascribed to the difference in topography more than to any consistent difference in the kinds of soils involved, although, as has been pointed out, the wind-blown loess soils of the

southwestern region seem more subject to the gullying process than do the mixed soils of the glaciated region.

The larger portion of Wisconsin (glaciated) is a region of low relief, or as commonly said, is "a gently rolling country." Its surface has been more largely and recently affected by the levelling action of ice sheets than by the action of large and small surface streams forming definite drainage systems and molding these to suit that run-off which must be disposed of. As a result, small undrained "pot holes" or pockets on the higher ground, and extensive swamps in the lower ground are relatively more common in eastern Wisconsin, and the entire process of surface run-off is retarded and decreased. The gravel component of most glacial sub-soils helps in the same direction.

In contrast, the streams of southwestern Wisconsin have been for long ages cutting their definite channels down through the high plain of sandstone and limestone rocks which originally lay everywhere about 600 feet above the present level of the Mississippi River. Most of the streams have reasonably gradual falls, from their distant heads on this high plain, to the river level, but much of the old plain still remains close to the Mississippi, which means that the streams near their outlets are in valleys 400 to 500 feet deep. Especially on both sides of the Mississippi itself, the walls of the valleys are decidedly

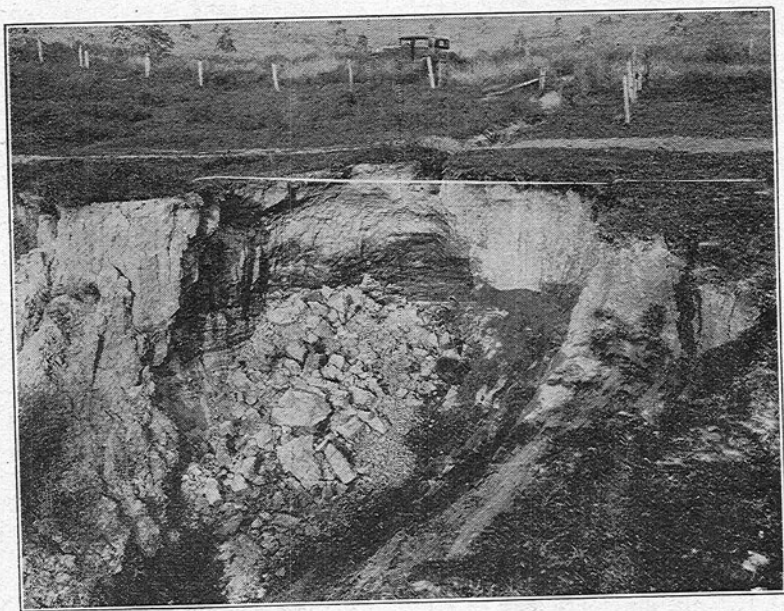


FIG. 18.—THIS GULLY HEAD ADVANCED 10 FEET IN THREE MONTHS
A stream of water falling a few feet on a sandy layer in the sub-soil cuts it away rapidly and the better surface material is then undermined and caves away.



FIG. 19.—TERRACE SOILS READILY UNDERMINED

Terrace soils, especially when the substrata are very sandy, are readily undermined and "slough-off" at a rapid rate, due to lack of cohesion in the materials. In this case the "angle of repose" of the gully walls is quite largely determined by the "running" of the dry sand, while the surface layer of heavier soil stands almost vertically.

steep. It seems probable that the water which must drop off of the high table land near the Mississippi has a greater opportunity to accomplish destructive erosion than the run-off of any other part of the state, simply because of the steepness and height of the slopes. Both because of this opportunity, and because whatever soil is eroded has every chance of being carried into the Mississippi, the bluffs of the river and of the lower reaches of the side streams comprise a "key" situation for the occurrence and treatment of the erosion problem, probably important enough from the standpoint of river control to be considered a public responsibility.

River Terraces Readily Eroded:

Both the Mississippi and many of the larger tributaries in southwestern Wisconsin have, unquestionably, in times past, flowed at higher levels than they now do and in most cases have occupied wider valleys than the present river-bottoms subject to periodic overflow. These old river beds were, like the present river bottoms, built up of layer upon layer of sand and silt carried by the streams and deposited by subsiding waters. As the entire drainage system has lowered itself, these river deposits are, of course, left as "terraces" or benches standing from 20 to nearly 100 feet above present stream levels. Such benches, both because of their flatness and their mixed alluvial (water-borne) soils, are in practically all regions considered the most choice of farm lands. Nevertheless, it is their cultivation which creates one of the greatest of the erosion problems, because as has been described

in the discussion of soil types, such alluvial soils, usually containing beds of loose sand at one level or another, are most easily gullied.

In addition, the topographic position of these terraces requires often that they carry and dispose of much water from the residual slopes which lie above them. Moreover, they are often, at their lower edges, subject to cutting by the larger streams, and the custom of building highways on their "shoulders" or along the stream bottoms subjects them to still further dangers, as will be brought out later.

Under other conditions than those just mentioned, the situation of land may give it protection against such injury. Thus, the high table lands 500 to 600 feet above the river in this region, are obviously protected from erosion first by their flat character, and secondly by the fact that there is no higher-lying ground which can possibly contribute run-off to them. The situation of the table-land farmer in this region is indeed fortunate. Not so fortunate is the owner of a bottom-land farm, nor one who controls the intermediate slopes subject to the run-off from the table-land fields. This interdependence of neighboring farms for their very safety makes the erosion problem a communal rather than a strictly individual affair.

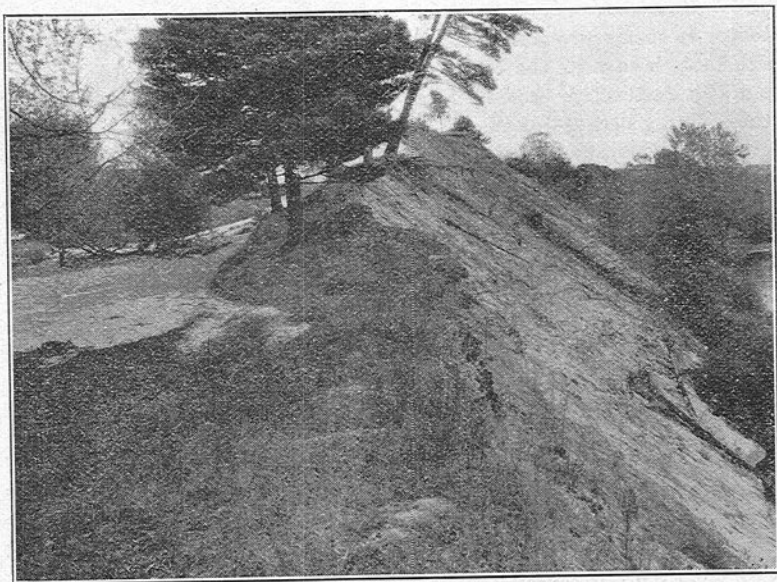


FIG. 20.—BANK CUTTING BY BLACK RIVER

This cutting has here created a precarious situation which will result in deep gullying unless steps are taken to hold back the river by effective bank protection. The gulch on the left runs parallel with the river and 30 feet above it at this point. Only a few more feet of ground need to be cut away (foreground of picture) to permit the side-stream to drop directly into the river. (see also Figures 6 and 27).

Steep Slopes Cause Rapid Run-off:

If the dependence of erosion to some extent on the topographic position of the individual parcel of land is somewhat complicated, the influence of steepness or "gradient" of fields, pastures, and wooded slopes upon erosion is direct and fairly simple. That is, it should be apparent that the steeper the ground, the more likely is a portion of the rainfall to run off superficially rather than to be absorbed into the soil, and, of course, the faster will any run-off flow. Outside of a small group of engineers, most people, however, probably do not realize that the ability of a stream of water, of any given size, to carry away soil and to cut its way into the soil, increases very much faster than the slope of the ground and the speed of flow increase. Thus we should logically expect a stream, however large, to make its way down a 40 per cent slope faster than it would down a 20 per cent slope: the actual cutting and carrying-power of the swifter stream, however, would be many times as great as that of the more sluggish one, according to the formulae which are generally accepted. Similarly a stream of water which has a sheer fall of twelve feet has a cutting power where it strikes the bottom, several times as great as that of the same stream falling only four feet. It is for this reason that so much effort is justified, in any form of erosion control, to eliminate direct, cutting water-falls in the eroding channels, and to reduce the speed of run-off.

It should, however, be realized that while steepness of slope in general affects very directly the rate of and probable damage from surface erosion, it has a much less direct effect upon deep gullying. True, a steep slope or a sharp "drop-off" is nearly always necessary to begin the formation of a deep gully, but once it is started the fact that the ground into which it is eating its way is flat, or nearly so, has little or no effect, the controlling factor then being merely the quantity of water which may be brought from this ground to the head or "drop" of the gully as affected by the topography on both sides.

The Limitations of Slope Steepness:

In connection with the question of slope gradient it may be desirable to introduce two technical terms which will be employed somewhat in the later discussions, and whose definition will further clarify the problem of moving soil. These terms are **angle of repose** and **stabilization**.

When it is said that a given piece of ground is "at its angle of repose" it is implied that it lies at a sufficiently gentle slope so that it will not be affected, en masse, by existing conditions, although it will never be safe from surface washing, as has already been pointed out. To make the matter clearer, let us consider the case of clean, moderately sharp sand. When such sand is perfectly dry, it will stand at an angle of about 60 per cent; beyond this angle material rolls down until the gradient is re-established, or in other words, 60 per cent is

the slope of the "angle of repose" of dry sand. As is well known, moist sand can be piled at a considerably steeper angle than this, since a little moisture gives the sand particles some cohesion. But, add enough moisture to saturate the sand, and it again "runs" very freely; it will not come to rest until it has settled down to an angle of about 10 per cent. This angle is still lower if water is flowing over the sand, under which condition the angle of repose⁸ may be only 1 or 2 per cent. It is thus seen that a given material has different angles of repose according to the amount of water that may be present to move it.

But it is evident that different types of soil material respond quite differently to moisture and to moving water. Thus clay banks showing horizontal stratification will often stand vertically so long as dry, and in the naturally compacted state must be thoroughly saturated before they will slough off in masses. Loess soil with its vertical "grain" is not so good in the latter respect. While, also, water may flow over firm clay beds without cutting them rapidly, yet once clay has been picked up by a stream it settles only very slowly and usually in a practically horizontal plane. Thus gullies in clay usually have steeper walls and flatter bottoms than those in sandy material.

It is probable that even a superficial study of different soil types, their physical properties, and their behavior under the influence of water, gives one a saner conception of how and why gullies form than any other line of investigation.

When considering the steepness of the bottom of a gully we think of a stream of water, and an angle of 3 per cent to 8 per cent, depending on the size of the stream: when thinking of the side walls of a gully or the slopes of a road "cut" we conceive small trickles of water here and there, the soil mass as a whole not covered by water, although saturated occasionally. In this case the angle is determined largely by the ease with which the saturated material parts from neighboring material and sloughs off. Such an angle may be from 20 per cent for sand to 50 per cent for clay, or even slightly higher. This angle is slightly greater than that of a road, railroad, or dam fill, for the reason that the filled material does not "hang together" as strongly as material which has for ages been compressed in the subsoil. In other words, natural cohesion of the soil particles and amount of water acting on them, largely determine erosion phenomena.

Stabilization Process:

When, because of the cessation of water action on the surface, or the cessation of cutting and removal of material at the foot of a bank

⁸ Strictly speaking, we should use the term "angle of compensation" rather than angle of repose, where there is an active moving force, such as running water, to disturb the soil. This longer term implies a balance between the force of gravity and the cohesive power of the soil, tending to hold it in place, opposed to and exactly balanced by the moving force of the water. The discussion will probably be as understandable, however, if we adhere to the simpler term implying "rest."



FIG. 21.—AN IMPORTANT SOURCE OF DIRECT EROSION

This somewhat common view along our modern highways illustrates not only the principle of instability of soil material, but also an important source of direct erosion and for the formation of gullies, which may readily be started by the "waterfalls" created at any of the numerous gulches. The "fill" on the right is, of course, least stable of all, and deserves every help in acquiring a protective mantle of vegetation.

of earth, or as a result of quick growth of vegetation and the binding power of the roots, the bank of a gully has settled until it is no longer in danger of sloughing when the earth becomes saturated, it is said that the "stabilization" process has set in, or the bank is "stabilized". This may be only a temporary condition since it is obviously dependent on factors outside the soil itself, which factors may change at any time, but it is at least always a hopeful sign in dealing with gullies. At this stage we like to say that the gully, like a deep wound, is "healing".

A vertical clay wall, or even a rocky cliff, no matter how unchanging it may appear to be, can never be said to be "stabilized" because in that position it remains most of the time too dry for vegetation to become established on it. It will wear away, if only by slow surface washing, until its surface is flat enough to absorb moisture and to grow a cover of vegetation. Thus, in a word, complete stabilization can never be said to exist until the soil surface is thoroughly covered by vegetation, in which condition considerable variations in the water factors may occur without affecting it appreciably. Any condition short of this, however, is a source of danger if concentration of water occurs either through change in land management or unusual rainfall. It therefore follows that, after reducing to a moderate slope, artificial cuts and banks can be stabilized most quickly by sodding or encouraging vegetation of any kind.

Stability of Slopes Easily Destroyed:

It can not be emphasized too strongly that when the foot of a fully stabilized slope is cut away, either by a rampageous stream, a stream finding a new channel, or by cutting such as is done in making roads, the entire slope above the cut is placed in an unstable condition, and will remain so until the original gradient has been reestablished or nearly so, by the removal of a rectangular or wedge-shaped slice of the soil mass. This, in fact, is the key to erosion on a large scale, for practically no gullies, involving large masses of soil, are started except by a disturbance at, and a cutting away of the foot of a soil mass.

If the soil mass above the cut already lies at about the maximum angle of repose for that class of material, then the sloughing-off action will probably be immediate and complete, until the original angle is reestablished for the entire slope. Suppose, however, that the cut is made at the edge of a gently sloping field, instead of the foot of a steep wooded slope. The soil of the field probably lies at a lower angle than the angle of repose of that class of soil, but is in no true sense "stabilized" for it must be remembered that soil in cultivation has very little to bind it together. If now, the cut bank, perhaps only a few feet high, is sloped back so that it stands at about the same angle as the wooded slopes nearby, and if immediate measures are taken to cover this cut face with vegetation, then we may have a stabilized condition corresponding not to the conditions of the field soil, but to those of nature.

But if, instead of this precaution, the bank is left untreated, the field is plowed close to its edge, and the water from the field is allowed to flow over the bank, then an entirely different situation is created, and a gully is very likely to be formed which will cut back into the field, its bottom having the same angle as that of the field slope, or even a lower angle since there will be a greater concentration of water here than on the surface of the field. If this gully meets a resistant subsoil (clay) it may stop and heal, without going very far; if it finds a sandy subsoil even less resistant than the plowed soil of the field, it may "dig itself in" deeper and deeper as it gets into higher ground.

Soil Disturbance Most Potent Factor in Erosion

Natural Erosion Cycles:

As has just been pointed out, soils in their natural condition, with a cover of forest, shrubs, or even good native sod, except on very steep slopes, never erode at an appreciable or damaging rate. About the only material carried away by rains severe enough to cause surface runoff, is some light organic matter which is soon replaced by the leaves of the vegetation itself. On flatter ground there is actually a constant increase in such material, while on the steeper slopes there is a con-

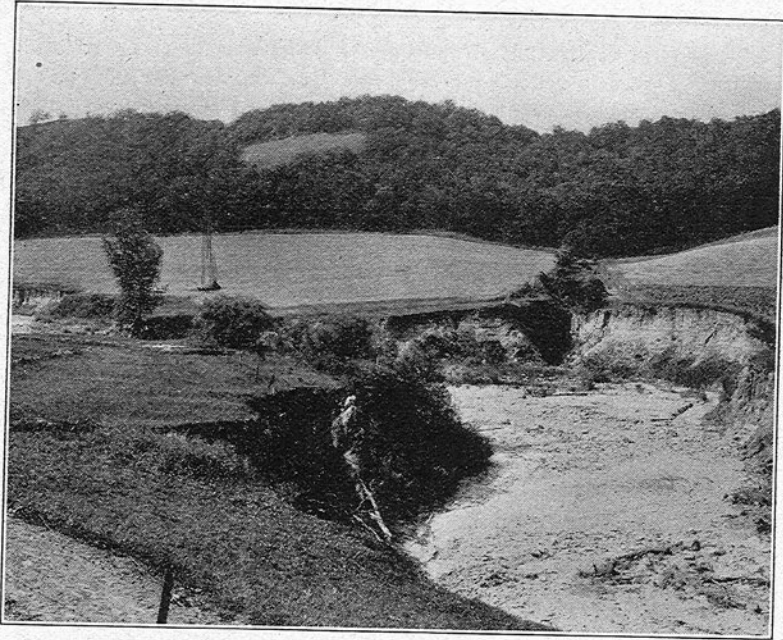


FIG. 22.—COMMON FORM OF BANK CUTTING WHICH IS EATING INTO VALUABLE FIELD SOILS

The overloading of this temporary stream is due largely to run-off from fields on the table-land, but also to two miles of hard-surfaced roadway which parallels the stream. A few years ago this was a harmless, shallow drain.

stant removal, but the humus content of the surface soil remains at about the same low level year after year.

It is undoubtedly true that, in the ages before man's activities, soil disturbances so great as to initiate periods of very active erosion and gulying occurred at intervals, following cycles of heavy rainfall. It may readily be conceived that the streams which were steadily cutting their way down in their present valleys, during periods of high water cut into the banks of the terraces which they had deposited previously. Whenever this occurred, some gulying doubtless resulted on the side of the stream where a "raw" bank had been created, for such cutting increases the gradient of every side stream. This gulying of the terraces would continue until the gradient had been reestablished at the original "angle of repose" by increasing the total length of the side stream or gulch, and thus the process might be carried a long way back from the stream whose action started it.

But if we can note at the present time an unusual and alarming amount of erosion, brought about only to a slight extent by what is called a "cycle of wet years," the change must certainly be ascribed primarily and directly to disturbances of the soil resulting from man's activities.

Cultivation:

A general realization of the danger which lies in the cultivation of steep slopes is reflected in the fact that the farmer who is not driven to desperate measures to obtain sufficient tillable land leaves the upper and steeper portions of his slopes either in pasture or woods. This is a precaution which has, perhaps, more to do with the general control of erosion than any other single thing, yet in many instances slopes entirely too steep to be cultivated safely are today being cleared for additional field, whereas, except for exigencies faced by the individual farmer the tendency should and would be in the opposite direction for economic reasons.

Cultivation of the soil is a "disturbance" but since it is intended to go into the various phases of cultivation and land use in a later chapter, the present discussion will be confined to some forms of soil disturbances which are more localized, which are less necessary, and which can be almost wholly avoided by sane engineering methods.

Overloading of Streams:

As stream bank cutting is probably the original and most natural of causes for the initiation of gulying, so must stream-bank cutting and stream channel changes which result from artificial causes be given first importance in the list of preventable causes. In using the term "artificial causes" there is implied any action upon the natural flow of a stream which results from human interference. Thus, the mere increasing of the flow of a stream, through diverting to it surface run-off which would not otherwise reach it, is an artificial cause for bank-cutting by the stream at some point lower on its course.

A most unfortunate aspect of the situation is that, particularly in towns, tremendous additions are made to the flow of streams from sanitary sewers, storm sewers, and direct run-off from streets and yards. Any living stream is a "sewer" which may be used to carry away anything which we do not want about. Not the slightest thought is given to the fact that the stream, in its natural existence, has provided itself with a channel of a certain maximum storm capacity, and that if this capacity is exceeded the stream is certainly going to leave its banks and overflow land, or is going to cut and widen its banks and do almost an equal amount of damage in another way. Much of this excess loading of streams during storms could be prevented by dams which would temporarily impound the water and release it when the normal flood had subsided, or by emptying it into naturel pockets.

Changing of Channels:

Changing the channels of streams is another very potent factor in causing them to cut their banks and start gulying. When this is done intentionally with the purpose of shortening and straightening the channel, it is usually beneficial at the point where the change is

made, although it may result in a higher and quicker flood of water at points below. It is more often when a stream is partially diverted by a road, or some other necessary "fill" that the new channel offered to it proves inadequate for the flood discharges, and must be widened and enlarged by the stream itself, often affecting much land on either side. This process by which the cutting of a bank may initiate gully-ing has already been described, so that we need not repeat at this point. The reader is referred particularly to Figure 20 as a striking illustration of how the process proceeds.

Excavations and Road Construction

Still more often, while a nearby stream may be indirectly affected, man's activities result directly in the creation of cut banks, resembling in every way those created by streams, and setting up a new and entirely artificial system of drainage for the land lying above. It can not be repeated too often that every such cut made in road-building, railroad development, and for other purposes such as gravel-pit excavations, is a trigger by which the forces which cause gullying may be released, especially if the opportunity is created for the formation of waterfalls of any magnitude whatever.

Figure 21 illustrates clearly the principle. The high cut faces along this roadway will themselves erode, with perhaps no more serious damage than the frequent filling of the drainage ditch on the upper side of the road, and some small contributions of silt to the adjacent streams. Eventually they will cover with vegetation and the process will then proceed at a less noticeable rate. The fill on the right of the road will make even larger contributions of silt to the adjacent river and will never be entirely stabilized. But each of the cuts across a natural gulch contains the ingredients of what will probably be a very active gully within two or three years. Waterfalls from 4 to 10 feet high have been created which, unless very high resistance is met in the form of roots and stones, will eat their way back into the higher ground at a rapid rate. Apart from the damage to the adjacent pastured woodland, the cost of removing this eroded material from the roadway will, in a few years, amount to as much as the engineering work necessary entirely to prevent it. Small dams which would give support to the ground and at the same time let the water over these falls without opportunity for cutting, or even a masonry-lined trough or trough-like steps to carry the water over the drop, would almost entirely destroy its injurious power. But the road engineer interests himself only in building a foundation for pavement, and in making ditches and channels which will keep the roadway itself from being flooded at the lowest possible initial cost. The enormous cost of later maintenance work is seldom, if ever, given due consideration when construction plans are made.

In a situation such as has just been illustrated, the run-off water from the roadway itself and from the bare soil surfaces which are

necessarily created in connection with it, is a very considerable item. Usually most of this water is concentrated in ditches on the upper side of the road, and in such ditches is taken to the nearest low point before being conducted under the road through a culvert. In this process the water usually cuts the road ditch and shoulders and collects an extraordinarily heavy load of silt, which adds greatly to the difficulty of disposing of it properly. Diverted into a regular stream channel it is sufficiently a nuisance, but allowed to spread upon fields it is even more injurious. Admitting that roadways must be fully drained, much more attention should be given by engineers to the disposal of the drainage water. The lining of road ditches with stones or concrete tends to reduce the combined volume of water and mud to be disposed of, rubble even permitting some percolation. Cut sod placed in ditches has even greater possibilities, provided the grade of the ditch is small and that washed-in material does not require frequent opening of the ditch with a grader or ditching machine.

These few illustrations should serve to show that much of the erosion which is so commonly seen at the present time is due to man's activities and is largely preventable. To prevent it, it is largely necessary that those who deal with the disposal of necessary run-off water should be taught to feel that natural water channels are not legitimate dumping places for anything that can be led to them. If this principle is recognized, most of the abuses will be automatically corrected.

Amount and Rate of Rainfall Directly Affect Erosion

Statistics are not needed to convince even the most casual observer that heavy and rapid downpours are much more likely to cause erosion than equal quantities of rain falling over longer periods. This is so generally fixed in the lay mind that the language has been fitted to express the relationship. Thus, a slow, steady rain is commonly called a "ground-soaker" while a dashing rain is in many localities referred to as a "gully-washer."

This means, of course, merely that any given type of soil can receive and absorb rainfall up to a certain rate, depending a good deal on its condition of tilth at the time, and to some extent on the time and amount of other recent rains. Once this rate of fall is exceeded, some of the water must run off, even though the soil continue to absorb at its maximum rate. The greater the rate, and the greater the impact of the rain on the soil (the "puddling" effect on clay already mentioned probably enters the picture here) the greater the proportion of the rain which must run off the surface. Although different regions may vary somewhat in the severity of their rainstorms, or at least in the frequency of hard, dashing rains, it seems to the writers probable that some rains are likely to occur in almost any region which may run off of bare soils to the extent of 75 or 80

per cent of the whole, while the quiet rains, though of large amount, cause no run-off at all.

It is thus evident that it is not quantity of rainfall which is particularly important in the study of erosion, but rate of rainfall. Because of this it is very difficult to obtain statistics for different regions which give a good basis for comparing them as regards the rainfall factor in erosion. True, the greater the rainfall in the summer months, the more likely are there to be individual storms of violence, yet such a rule can not be blindly followed when consulting the numerous rainfall records which show only total quantity by 24-hour periods, as it may be entirely misleading in individual instances. Neither do the few Weather Bureau records showing intensity of rainfall help very greatly. A minute-by-minute record at La Crosse, to use an example applicable to southwestern Wisconsin, may give a very good basis for comparing the number of "excessive" rains of southwestern Wisconsin, or at least of the Mississippi Valley proper, with those of some other region, but it tells us nothing with certainty, as to what may have occurred at a point 50 miles away at the same time, since the rains of greatest severity are often the most narrowly localized. Thus, the fact that La Crosse may have recorded an unusual number of severe rains in the summer of 1928 does not prove that Buffalo County was so afflicted, but the fact that several records for Buffalo County show very heavy rainfall by individual days and months in the same season leads one strongly to suspect that violent rains were frequent in the eroding territory.

On the other hand, over a long period of years, there apparently is not a great deal of difference in the number of hard rains visiting different localities in different parts of the country. Assuming this to be true, Ramser⁹ cites data compiled by the U. S. Weather Bureau from 19 stations throughout the United States having timed records of rainfall. This compilation shows, for example, that a rain of one inch lasting 30 minutes is likely to occur in the Mississippi Valley or eastern United States once every two years, while a fall of 2 inches in a similar period is likely to occur only once in 50 years. Rainfall of one-half inch in five minutes is likely to occur as often as once in 10 years, but a rate of fall for five minutes, much greater than this, becomes extremely rare. According to this average table, some of the rates of rainfall noted in southwestern Wisconsin during 1929 were in the class of "very rare" or unusual. For example, 1.50 inches falling in 26 minutes such as occurred at Winona, Minnesota, on July 23, can be expected only about once in 12 years. La Crosse, Wisconsin, recorded a very similar rain on June 10, 1929. The following record for three stations in southwestern Wisconsin and two on the opposite west bank of the Mississippi River, is

⁹ Ramser, C. E., 1927. Run-off from small agricultural areas. *Journal of Agricultural Research*, U. S. Department of Agriculture 34: No. 9, May 1.

TABLE I.—MONTHLY AND SEASONAL PRECIPITATION IN INCHES
With number days having 1 inch or more of rain shown in parentheses
 Hatfield, Wisconsin

Year	Nov.*- March	April	May	June	July	August	September	October	May to October
1915	—	.60 (0)	5.62 (1)	5.44 (3)	3.85 (0)	4.46 (1)	3.80 (0)	1.56 (0)	24.73 (5)
1916	7.05	3.09 (1)	4.80 (2)	4.92 (1)	1.20 (0)	1.98 (1)	4.11 (0)	2.77 (0)	19.78 (4)
1917	6.35	3.08 (0)	2.59 (1)	4.46 (1)	2.91 (0)	4.23 (1)	2.06 (0)	2.18 (0)	18.43 (3)
1918	3.62	1.93 (0)	10.57 (4)	2.25 (0)	2.21 (0)	2.47 (0)	1.84 (1)	1.89 (0)	21.23 (5)
1919	5.63	3.04 (0)	2.69 (0)	7.96 (3)	5.35 (2)	2.42 (0)	3.53 (1)	2.84 (1)	24.79 (7)
1920	6.85	1.87 (0)	3.36 (1)	4.93 (1)	1.55 (0)	2.40 (0)	.75 (0)	2.10 (1)	15.09 (3)
1921	6.12	4.41 (1)	3.21 (0)	2.37 (1)	5.60 (4)	2.58 (1)	3.42 (1)	1.39 (0)	18.57 (7)
1922	6.71	3.83 (2)	3.32 (0)	5.39 (1)	3.02 (0)	1.20 (0)	3.25 (0)	.53 (0)	16.71 (1)
1923	7.99	2.60 (0)	2.43 (1)	5.06 (1)	2.65 (0)	3.68 (1)	3.34 (0)	.49 (0)	17.65 (3)
1924	6.21	3.04 (0)	2.39 (1)	4.97 (2)	2.66 (0)	7.09 (2)	4.20 (2)	.35 (0)	21.66 (7)
1925	3.83	2.57 (1)	.57 (0)	8.36 (4)	5.89 (2)	1.95 (1)	5.56 (2)	1.20 (0)	23.53 (9)
1926	7.47	1.86 (1)	3.84 (1)	3.04 (1)	3.78 (0)	4.90 (1)	6.26 (1)	2.33 (0)	24.15 (4)
1927	6.13	2.00 (0)	3.11 (1)	2.27 (0)	4.09 (1)	1.70 (0)	6.67 (2)	3.36 (1)	21.20 (5)
1928	5.71	2.61 (0)	1.89 (1)	4.35 (1)	6.71 (4)	7.86 (3)	6.22 (2)	5.10 (2)	32.13 (13)
1929	4.94	3.14 (1)	2.52 (0)	2.48 (0)	2.39 (0)	2.61 (1)	3.50 (1)	1.23 (0)	14.73 (2)

*Beginning in the calendar year preceding the year indicated.
 Data from the U. S. Weather Bureau "Climatological Data."

TABLE II.—MONTHLY AND SEASONAL PRECIPITATION IN INCHES
With number days having 1 inch or more of rain shown in parentheses
 La Crosse, Wisconsin

Year	Nov.*- March	April	May	June	July	August	September	October	May to October
1915	—	.86 (0)	5.23 (0)	3.91 (2)	5.28 (3)	3.83 (1)	5.55 (2)	1.81 (0)	25.61 (8)
1916	8.18	3.01 (1)	3.17 (0)	4.30 (0)	3.02 (1)	4.45 (1)	4.75 (1)	2.69 (0)	22.38 (3)
1917	6.99	3.35 (0)	3.14 (1)	5.79 (2)	6.94 (2)	2.51 (1)	3.36 (1)	2.64 (0)	24.38 (7)
1918	5.27	1.70 (0)	6.55 (2)	3.46 (0)	4.80 (2)	2.84 (1)	1.36 (0)	1.57 (1)	20.58 (6)
1919	7.36	3.41 (0)	2.34 (0)	6.52 (1)	2.55 (0)	1.39 (0)	2.35 (1)	3.20 (1)	18.35 (3)
1920	8.46	3.45 (2)	1.86 (0)	8.14 (3)	1.05 (0)	2.25 (0)	.81 (0)	2.56 (1)	16.67 (4)
1921	7.27	3.37 (0)	5.96 (2)	2.31 (0)	2.36 (0)	1.26 (0)	6.09 (2)	1.41 (0)	19.39 (4)
1922	9.74	3.86 (1)	4.86 (1)	3.30 (0)	2.08 (0)	3.43 (0)	2.34 (0)	1.20 (0)	17.21 (1)
1923	8.00	1.69 (0)	1.53 (1)	4.86 (2)	.62 (0)	2.30 (0)	4.00 (2)	.70 (0)	14.01 (5)
1924	6.99	2.24 (0)	1.75 (0)	6.04 (2)	1.94 (0)	9.25 (3)	3.58 (0)	.75 (0)	23.31 (5)
1925	4.93	1.39 (0)	.84 (0)	6.81 (2)	5.83 (2)	1.40 (0)	7.15 (2)	1.73 (0)	23.76 (6)
1926	7.01	1.81 (1)	3.31 (0)	1.74 (0)	5.19 (2)	3.05 (2)	4.92 (1)	1.73 (0)	19.94 (5)
1927	6.02	1.99 (0)	4.59 (1)	2.46 (0)	3.74 (1)	3.03 (1)	5.71 (2)	2.78 (1)	22.31 (6)
1928	8.62	2.41 (0)	2.99 (1)	3.25 (0)	6.14 (3)	8.69 (4)	4.73 (2)	3.06 (2)	28.86 (12)
1929	9.19	3.56 (1)	3.39 (0)	3.63 (1)	2.59 (1)	1.79 (0)	4.33 (0)	1.73 (0)	17.46 (2)

Data from the U. S. Weather Bureau "Climatological Data."
 *Beginning in the calendar year preceding the year indicated.

TABLE III.—MONTHLY AND SEASONAL PRECIPITATION IN INCHES
With number days having 1 inch or more of rain shown in parentheses
Mondovi, Wisconsin

Year	Nov.*- March	April	May	June	July	August	September	October	May to October
1915	—	.98 (0)	—	—	—	—	—	—	—
1916	6.11	2.02 (0)	5.80 (2)	6.10 (3)	.71 (0)	1.35 (0)	3.15 (0)	1.31 (0)	18.42 (5)
1917	7.20	2.55 (0)	4.06 (1)	3.67 (1)	2.33 (0)	3.22 (1)	2.79 (0)	3.98 (0)	20.05 (3)
1918	5.13	1.05 (0)	5.49 (3)	3.19 (2)	1.93 (0)	4.19 (1)	2.68 (1)	2.88 (1)	20.36 (8)
1919	8.92	3.31 (1)	1.80 (0)	6.02 (2)	3.95 (1)	2.77 (1)	—	—	—
1920	—	2.72 (1)	4.37 (1)	10.44 (4)	1.03 (0)	1.09 (0)	1.07 (0)	—	—
1921	10.23	4.06 (1)	5.79 (2)	7.50 (2)	2.84 (0)	3.57 (1)	3.39 (0)	2.45 (1)	20.45 (6)
1922	11.05	3.84 (2)	5.94 (2)	7.61 (3)	5.67 (2)	1.85 (0)	4.00 (2)	1.11 (0)	24.20 (5)
1923	5.57	2.18 (1)	3.41 (2)	7.55 (4)	2.38 (1)	4.43 (2)	3.77 (0)	2.13 (1)	27.20 (10)
1924	7.49	5.02 (1)	1.86 (0)	3.28 (1)	2.54 (1)	5.96 (3)	4.92 (2)	.91 (0)	22.45 (9)
1925	4.98	1.55 (0)	1.55 (0)	11.08 (5)	5.45 (1)	1.42 (1)	5.43 (2)	1.18 (0)	19.74 (7)
1926	9.88	2.09 (1)	3.35 (1)	2.38 (0)	9.74 (4)	3.36 (1)	7.90 (2)	1.19 (0)	26.12 (9)
1927	10.25	1.67 (0)	4.88 (1)	2.75 (1)	2.59 (0)	.70 (0)	5.88 (2)	1.74 (0)	28.47 (8)
1928	9.12	4.33 (1)	2.20 (0)	5.08 (3)	4.87 (2)	8.41 (3)	4.81 (2)	4.41 (2)	21.21 (6)
1929	4.70	4.38 (2)	2.04 (0)	2.61 (0)	3.73 (1)	1.16 (0)	5.12 (1)	2.71 (0)	28.08 (10)
								1.43 (0)	16.09 (2)

*Beginning in the calendar year preceding the year indicated.
 Data from the U. S. Weather Bureau "Climatological Data."

TABLE IV.—MONTHLY AND SEASONAL PRECIPITATION IN INCHES
With number days having 1 inch or more of rain shown in parentheses
Reads Landing, Minnesota

Year	Nov.*- March	April	May	June	July	August	September	October	May to October
1915	1.92	1.13 (0)	5.50 (1)	4.72 (1)	4.92 (0)	5.27 (3)	3.21 (1)	2.81 (0)	26.43 (6)
1916	4.30	4.46 (1)	5.35 (1)	4.21 (0)	1.89 (0)	1.03 (1)	2.90 (0)	1.48 (0)	16.86 (2)
1917	4.44	1.94 (0)	4.74 (2)	4.02 (1)	3.65 (1)	3.88 (0)	2.54 (0)	2.29 (0)	21.12 (4)
1918	1.46	.61 (0)	3.97 (1)	4.10 (2)	1.38 (0)	2.73 (0)	1.47 (0)	2.01 (0)	15.66 (3)
1919	3.38	2.71 (1)	1.10 (0)	6.33 (2)	5.43 (2)	1.98 (0)	2.67 (0)	1.75 (0)	19.26 (4)
1920	4.67	2.46 (1)	4.96 (2)	8.64 (2)	.95 (0)	3.14 (1)	1.15 (0)	.73 (0)	19.57 (5)
1921	—	2.65 (0)	6.85 (2)	2.59 (1)	4.28 (2)	.67 (0)	3.26 (1)	.73 (0)	18.38 (6)
1922	—	1.81 (0)	3.98 (0)	2.26 (0)	3.85 (3)	2.13 (1)	2.44 (0)	1.59 (0)	16.25 (4)
1923	—	.97 (0)	1.12 (0)	6.86 (3)	1.41 (0)	3.52 (0)	7.09 (1)	1.24 (0)	21.24 (4)
1924	—	3.77 (0)	1.61 (0)	5.05 (2)	4.88 (1)	7.20 (2)	6.93 (3)	1.60 (0)	27.27 (8)
1925	—	2.47 (0)	1.57 (0)	8.28 (2)	5.53 (1)	.82 (0)	6.58 (2)	1.83 (0)	24.61 (5)
1926	—	1.40 (0)	2.46 (0)	3.07 (1)	2.89 (0)	3.00 (1)	7.40 (2)	1.78 (0)	20.60 (4)
1927	—	2.46 (0)	2.71 (0)	5.30 (1)	1.75 (0)	2.50 (0)	6.53 (2)	2.53 (0)	21.32 (3)
1928	—	2.50 (0)	1.98 (1)	5.02 (1)	3.91 (1)	11.79 (4)	6.02 (2)	2.73 (1)	31.45 (10)
1929	—	3.72 (1)	3.41 (0)	3.81 (1)	4.61 (2)	2.18 (1)	4.12 (1)	1.12 (0)	19.25 (5)

*Beginning in the calendar year preceding the year indicated.
 Data from the U. S. Weather Bureau "Climatological Data."

TABLE V.—MONTHLY AND SEASONAL PRECIPITATION IN INCHES
With number days having 1 inch or more of rain shown in parentheses
 Winona, Minnesota

Year	Nov.*- March	April	May	June	July	August	September	October	May to October
1915	5.23	1.91 (0)	6.84 (3)	4.09 (1)	2.85 (0)	3.46 (1)	5.28 (2)	1.41 (0)	23.93 (7)
1916	6.88	5.23 (1)	5.61 (2)	3.75 (0)	3.04 (1)	3.80 (1)	5.10 (0)	2.49 (0)	23.79 (4)
1917	6.73	4.66 (1)	3.13 (0)	5.45 (2)	4.28 (1)	2.16 (0)	1.63 (0)	3.48 (0)	20.13 (3)
1918	4.27	1.69 (0)	5.95 (2)	3.29 (0)	2.53 (0)	2.18 (0)	2.21 (0)	2.49 (1)	18.65 (3)
1919	8.26	3.11 (0)	1.46 (0)	5.59 (1)	4.84 (2)	—	3.82 (0)	2.82 (1)	—
1920	6.77	2.48 (0)	2.51 (0)	9.18 (4)	4.11 (2)	3.36 (0)	1.28 (0)	2.75 (0)	23.19 (6)
1921	8.40	3.41 (1)	—	3.58 (1)	3.77 (1)	3.41 (1)	4.43 (1)	—	—
1922	6.62	3.59 (2)	4.63 (0)	2.88 (1)	5.18 (1)	3.32 (2)	3.69 (1)	1.22 (0)	20.92 (5)
1923	8.15	1.79 (0)	1.48 (0)	5.15 (3)	1.14 (0)	3.27 (1)	4.13 (1)	.70 (0)	15.87 (5)
1924	6.74	2.59 (0)	1.78 (0)	5.33 (1)	2.93 (0)	8.41 (2)	4.48 (2)	1.28 (0)	24.21 (5)
1925	6.23	1.44 (0)	1.91 (0)	10.79 (5)	6.95 (2)	1.27 (0)	7.17 (2)	2.72 (0)	30.81 (9)
1926	7.50	1.62 (1)	3.76 (0)	1.91 (0)	4.43 (1)	3.53 (2)	6.35 (1)	2.41 (0)	22.39 (4)
1927	6.17	1.47 (0)	—	—	—	—	4.03 (0)	2.00 (1)	—
1928	6.25	—	2.03 (0)	3.64 (0)	4.41 (1)	8.40 (2)	2.66 (1)	4.10 (1)	25.24 (5)
1929	9.81	4.46 (1)	—	2.43 (0)	2.00 (0)	—	3.71 (0)	.92 (0)	—

*Beginning in the calendar year preceding the year indicated.
 Data from the U. S. Weather Bureau "Climatological Data."

TABLE VI.—AVERAGE PRECIPITATION FOR FIVE STATIONS^a
Monthly and Total Quantities, in Inches

Year	Nov.*- March	April	Number days 1" or plus	May	June	July	August	Sept.	Oct.	Total May- October	Number days 1" or plus	Total Nov.- Oct.
1915	—	1.10	.0	5.80a	4.54a	4.22a	4.25a	4.46a	1.90a	25.17	6.5a	—
1916	6.50	3.56	.8	4.95	4.66	1.97	2.52	4.00	2.15	20.25	3.6	30.31
1917	6.34	3.12	.2	3.53	4.68	4.02	3.20	2.48	2.91	20.82	4.0	30.28
1918	3.95	1.40	.0	6.51	3.26	2.57	2.88	1.91	2.17	19.30	5.0	24.65
1919	6.71	3.12	.4	1.88	6.48	4.42	2.14a	3.09a	2.65a	20.66	4.7a	30.49
1920	6.69a	2.60	.8	3.41	8.27	1.74	2.45	1.01	2.12	19.00	4.8	28.28
1921	8.00a	3.58	.6	5.45a	3.67	3.77	2.50	4.12	1.16a	20.47	5.5a	32.05
1922	8.53a	3.39	1.4	4.55	4.29	3.96	2.39	3.14	1.33	19.66	4.2	31.58
1923	7.43a	1.85	.2	1.99	5.90	1.64	3.44	4.47	0.81	18.25	5.2	27.53
1924	6.86a	3.33	.2	1.88	4.93	2.99	7.58	4.82	1.03	23.23	6.4	33.42
1925	4.99a	1.88	.2	1.29	9.06	5.93	1.37	6.38	1.73	25.76	7.9	32.63
1926	7.96a	1.76	.2	3.34	2.43	5.21	3.57	6.57	2.00	23.12	5.0	32.84
1927	7.14a	1.92	.0	3.82a	3.20a	3.04a	1.98a	5.76	3.02	20.82	5.0a	29.88
1928	7.42a	2.88a	.2	2.22	4.27	5.21	9.03	4.89	3.54	29.16	10.0	34.46
1929	7.16a	3.85	.2	2.84a	2.99	3.06	1.94a	4.16	1.29	16.28	2.8a	27.29
Av.	6.83	2.56		3.56	4.84	3.58	3.42	4.08	1.99	21.48	5.37	30.87
Norm.	6.45	2.37		4.12	4.54	3.63	3.44	3.63	2.49	21.85		30.67

*Beginning in the calendar year preceding the year indicated.
 Data from the U. S. Weather Bureau "Climatological Data".
^aIndicates one or more stations not included in average.

inserted solely for the purpose of comparing years, so far as we can with the type of records available. The year 1921 was, at most of the stations, a worse one than 1922, with many severe washing rains, and in both 1921 and 1922 there was apparently opportunity for much damage from large snow accumulations in the spring. In agreement with the opinion held by many local residents, the summers of 1924 and 1925, particularly the latter, were severe, but 1928 was probably much the worst of all.

These records are presented both in the usual form, showing the total amounts by months which can be compared with the 15-year averages for the same months; and to show also the number of days in which the rainfall for 24 hours was one inch or more. It is true that this latter measure does not include all of the rains which fall rapidly enough to do severe washing; also that an inch or more in 24 hours may fall gently enough to do little harm. However, according to the careful observations made in the summer of 1929, severe rains in this region are quite likely to amount to as much as an inch, falling within a period of an hour or two.

The remainder of the record, five months of each winter period, is assembled in a form to be suggestive of the possible accumulation of snow and ice, and the possible damage from the melting of this accumulation in the spring. Obviously the actual damage must vary greatly according to the rate at which the melting occurred in different years, on which there is no statistical information.

It is possible, with this record for southwestern Wisconsin, to relate a period or "cycle" of rather unusual rainfall to the beginning of a good deal of gullying. Thus a good deal of "hearsay evidence" indicates that many of the larger gullies in Jackson County became very active "about 1916," while in Buffalo County, 1921 and 1922 are more frequently pointed to as the "cause of most of it." In any event it is evident that the danger of gullying is much greater in some years and groups of years than in others.

Once this gullying has been started, the return to normal or sub-normal rainfall years does not necessarily mean its cessation, for even an occasional severe rain will continue the process until the easily-gullied land has been dissected, provided there is no human interference. On the other hand, such is the nature of the stabilization process, in which weed, grass, shrub, and tree growth play an important part, that it is conceivable that the sides, or even the head of a gully may "heal" most readily in a season with abundant rainfall for vegetative growth, yet with few storms to cause run-off. Such conditions we would naturally associate with a year which had a somewhat cool summer, just as we associate "gully-washing" rains with days of intolerable heat.

As regards the effect of the total quantity of precipitation on the occurrence of destructive erosion, it appears at first thought that

character of the rains, are the same, it is to be expected that increased rainfall will result in increased erosion.

The fact that southwestern Wisconsin receives a little more precipitation, on the average, than any of the surrounding territory, may account for the prevalence of erosion there, although the different topography offers as good an explanation. In fact, however, there seems to be a good deal of variation within the region itself, and the data collected during the summer of 1929, the regular weather stations being entirely too scattered to furnish the information, tend to show that the two areas of highest concentration of gullying, on the Black and Buffalo Rivers, are also areas which receive the most severe summer rains.

Figure 23 illustrates what actually occurred in the period from July to October, 1929, within a radius of about 50 miles northward and eastward of Winona, Minnesota. Within this territory, regular weather records were obtained at Winona and Reads Landing on the west bank of the Mississippi, and at Mondovi and Blair, Wisconsin, the former near the head of Buffalo River and the latter on the Trempealeau River. In addition to these, special observations were made at ten points within the territory bounded by these stations, forming a series north from Winona, and another one eastward, as already implied.

With a few interpolations for periods in the four months when individual gauges were not observed, it is found that within this territory the lowest recorded precipitation was 7.8 inches and the highest 12.6 inches. At Winona, on the bank of the Mississippi, more or less sheltered by high hills on the west, the official record of 9.2 inches for this period is appreciably exceeded by 10.1 inches in the edge of the hills about 3 miles west of town. Crossing the river to the east, along the edge of the large delta of the Trempealeau, a somewhat drier area is found with only 8.2 inches. The amount is only slightly greater (8.8 inches) immediately east of Galesville and 17 miles east of Winona. At this point, however, the higher hills begin, and there immediately begins an increase in precipitation, giving a total of 11.3 inches about 10 miles east of Galesville, and 12.6 inches 3 miles east of North Bend, which was the highest and most easterly point reached. At Blair, which is some 20 miles north of North Bend, in a valley surrounded by high hilly country, the total was less, 10.6 inches.

This sharp rise to the east of Galesville is accounted for first by the greater elevation of the ground, and secondly by considering the great swampy area at the mouth of the Trempealeau, and the nearly contiguous delta of the Black River (as well as all of the Mississippi bottomland) as an area which not only because of its flatness does not induce precipitation, but also may add very appreciable moisture to the air currents passing over it. It is not worth while to go into this

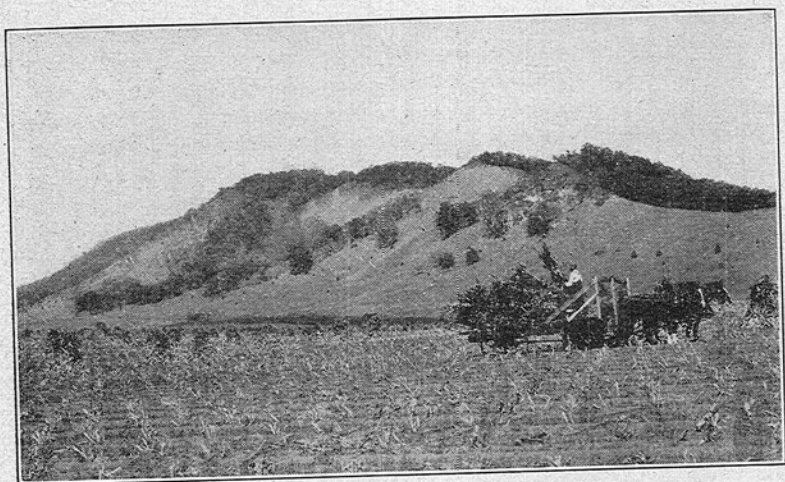


FIG. 24.—AN AREA WHICH RECEIVES LESS THAN AVERAGE RAINFALL

The paucity of the vegetation on the river bluffs south of Cochrane suggests an area which receives less than the average precipitation, as the records for 1929 indicated to be the case.

matter extensively in this bulletin, except as it gives a theoretical basis for assuming that the precipitation differences noted in the single season of 1929 may be more or less regular differences for the summer. It is merely, on a small scale, the same thing which happens in the entire Mississippi drainage, for the waters of the river are no more than dumped into the Gulf of Mexico than they are picked up by warm currents and brought back to water the Mississippi valley, according to the general accepted opinion of meteorologists.

North and northwest from Winona on the Wisconsin side of the river, there are found (for the four months of 1929) similar local differences. The driest point for the entire period (7.8 inches) was on the edge of the river bottom about three miles south of Fountain City. Almost equally dry was a point on the east side of the Wau-
mandee valley about two miles north of Fountain City, where air currents from the west may cross quite a wide area of bottom-land before striking any elevated ground. During July and August the dearth of rain, during several storms, seemed most striking at a point two to three miles south of Cochrane, and the arid appearance of the river bluffs at this point (see Figure 24) testify to the probability of this. However, no record was obtained here until the later part of the season, when only a slight shortage was noted, so that this locality can not be classified with certainty. From this point northward the precipitation on the bluffs along the river, and at all points in the Buffalo River valley, appears to increase markedly. Thus, a point 7 miles north of Alma, gave a total of 11.46 inches for the four months,

Reads Landing 12.03 inches, and Mondovi, 20 miles farther north, 11.34 inches.

Since these differences were not due to one or two rains, but were rather the rule, at least in July and August, it seems evident that at least the lower two-thirds of the Buffalo River valley is in the path of most of the heavy and violent summer rains. Another season, of course, might show this locality to be short of water. In logical explanation of such a rainfall distribution as the normal occurrence, however, may be mentioned the width of the Mississippi bottom at the mouth of the Chippewa, and the comparatively broad expanse of Lake Pepin, both to the west of the area in question, while to the southwest, opposite the mouth of the Buffalo, are the broad open valleys of the Zumbro and Whitewater rivers on the Minnesota side. The opinion is ventured that these low areas not only receive less precipitation than the surrounding hills, but also put considerable moisture into the eastward-moving air currents, and that when these currents strike the high hills on the Wisconsin side they precipitate heavily. On the other hand, the relatively high precipitation at Reads Landing, during 1929, and most of the summers since 1915, is inconsistent with this, unless we assume air currents moving down the river to strike some local promontory in that immediate vicinity.

Both because of its practical bearing on the treatment of the erosion problem and its scientific interest, this question of the local distribution of rainfall deserves further attention. Is it directly a result of actual elevation of the immediate and surrounding ground, or



FIG. 25.—FROST AND SNOW WATER POWERFUL IN EROSION

Frost and snow-water combined are powerful factors in advancing the erosion of gullies in southwestern Wisconsin. Note the large blocks of earth sloughed-off the banks, to be melted away by later rains. Fortunately this gully is now dammed. See Figure 44.

do the storms tend to follow certain paths? Should the exceptionally heavy rains of the Buffalo River valley be found to be of regular occurrence year after year, for example, the erosion problem of that valley must be looked upon and treated as one due in part to the character of the rains rather than to soil or topographic peculiarities entirely. This may lead to a different method of treatment than would otherwise be the case, and a different point-of-view when transferring erosion-control practice from that valley to another where there was less severe rainfall to cope with.

Frost Action and Snow Melting Create Special Erosion Problems

While severe or excessive rains in summer produce the more spectacular floods of short duration, there is scarcely any doubt that a large part of both the sheet erosion and the gullyng is accomplished by the water which runs off from melting snow, in a region like southwestern Wisconsin where considerable snow lies on the ground through the winter and heavy falls of rain and snow may come during the spring months. While the run-off from melting snow is rarely in such volume as that which characterizes hard summer rains, its persistence day after day, with opportunity for the complete saturation of the surface of the soil, gives it opportunity to do heavy moving. The fact that the deeper soil may be largely frozen while this surface run-off is occurring is not a deterrent to the surface damage, while the heaving and loosening action when the frost gives up its hold is a large factor in causing "sloughing" of the walls of gullies, and greatly hastens the gullyng process. Probably the worst damage is done in years when the melting occurs rather late, with most of the frost already out of the ground.

While we can only assume in a general way that heavy snowfall through the winter months will cause large volumes of water to run off in the spring (since there may or may not be thaws before the main melting period arrives) it is worth noting again, as in the preceding discussion, the fact that the spring seasons of 1921 and 1922, believed by local residents to have been especially bad seasons for the starting of erosion, show much greater opportunities for the accumulation of snow and for heavy melting run-off than any other years in the 15 recorded, having 8 inches or more of precipitation from November to March against a normal for all five stations of 6.45 inches. The year 1926 comes next in order, with 1923 and 1928 about equal to each other but a little lower in the scale. It is noteworthy that the different stations are not at all consistent in this respect, and since such records are subject to a good deal of error, the average for the five stations is most acceptable (Reads Landing however, has no winter records after 1919-1920).

IV. EXTENT OF EROSION IN WISCONSIN

AS HAS ALREADY been indicated, the study of erosion during the summer of 1929 was largely confined to three counties in southwestern Wisconsin, for the reason that here could be found a greater number of examples of destructive erosion than anywhere else, with the best opportunity to relate cause and effect through numerous observations. Since Buffalo and Jackson counties contain the two areas of highest gully concentration perhaps to be found in the entire State, it will be well to cite some data for the purpose of showing how destructive erosion can be. No claim is made that these figures represent any "average" whatever. On the contrary they were taken from the worst areas that could be found. They do, nevertheless, represent what might happen in almost any part of the non-glaciated section of Wisconsin and in the similar regions of southeastern Minnesota and northeastern Iowa, in the vicinity of the larger streams, where there are river terraces to be destroyed. Not only are such developments possible throughout the region, but they are entirely probable as lands continue to be worked without any special preventive measures being taken.

Rate of Growth of Gullies

The growth and spreading of deep gullies, like the erosion process in general, is, of course, very much dependent on the conditions of soil, rainfall, watershed area, etc. Since deep gullies invariably start on low ground, as for example the lower edge of a stream terrace, and work back into the deeper deposits, sometimes gaining in depth as they go into higher ground, the depth of material which they have to work in is of considerable importance in determining their rate of progress. Thus a vertical wall five or six feet high may stand for considerable time without caving, but one 20 or 50 feet high has less chance of standing up if it becomes undercut and is then, perhaps loosened by frost action. For this reason a gully which is not very menacing when it first starts, having only a few feet of drop at its head, becomes more and more active as it works back into greater depths of loose material, until finally it is stopped by the decreasing size of the watershed which supplies the water, and by encountering more resistant material such as rocky residual soils. All this is particularly true of gullies in the loose material which has been deposited by streams, in horizontal strata, and usually with more or less frequent layers of sand. The presence of a more resistant layer of clay often determines the bottom level of the gully, while the sand above it will undercut through the "waterfall" action at the head, leaving great masses of material unsupported. Such gullies have been known to progress, at one or more of their heads, at the rate of about 200 feet each year.

Gullies in more uniform material, such as loessal soils, usually do not become so deep because their bottoms tend to slope more nearly with the level of the ground into which they are cutting and are more likely to rise by successive steps. There are no weak lines formed by sandy horizontal strata, to which the water falling at the head tends to cut at all stages. Under-cutting of the vertical walls at the heads is not so common, but the fact that this class of material tends to cleave in vertical planes nevertheless keeps the walls perpendicular. In consequence, even though such gullies may appear as threatening as those in terrace soils, the gullies in more resistant soils do not make such rapid progress.

The few observations on the actual rate of cutting-back of gullies, which have been made in this study, by marking the location of the heads (mostly about July 1, 1929) do not give statistical information of much value because they have so far covered only a nearly normal summer and a spring melting period when the quantity of snow water was very small. Such observations must be continued over a number of years to give comparative data for different soils and situations. The most rapid progress made by any of the marked gullies was a

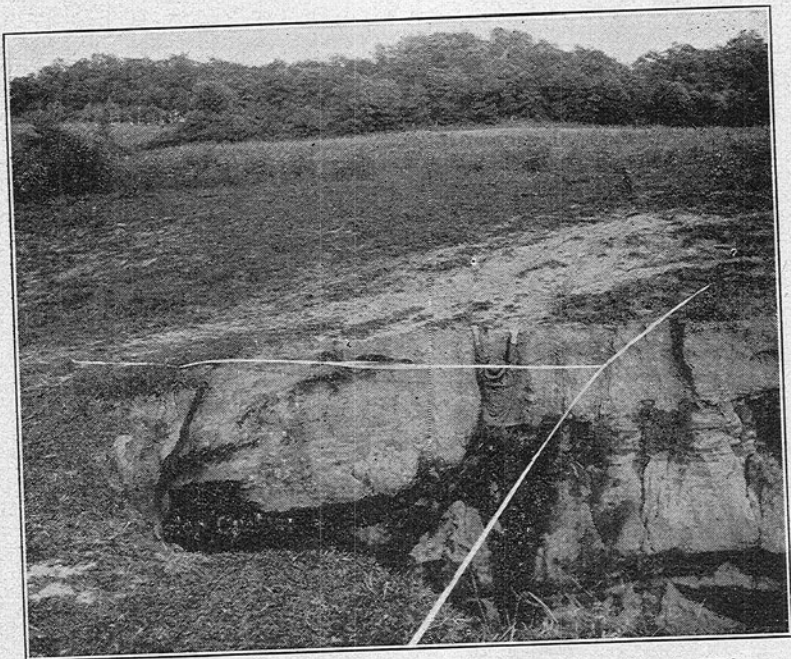


FIG. 26.—THIS GULLY HEAD ADVANCED 14 FEET IN TWO MONTHS
When gullies become 20 feet or more in depth, and there are sandy layers in the sub-soil, they cut back very rapidly through under-cutting and caving of the more resistant surface layers. As indicated by the tape, this gully-head advanced 14 feet during three months of 1929.

horizontal distance of 14 feet for the three months July-September. (See Figure 26) Some of the gullies in more resistant soils did not make any measurable progress during this same period, other than surface washing of the exposed faces. However, nearly as much soil may be carried away at such times as during the spring, when the action of frost and water together causes the most active caving of banks. This latter process leaves many huge masses of earth to be "melted" and carried away by the action of later rains, a much less spectacular process but none the less important.

Rate of Erosion in Areas of Active Gullying

In Buffalo County an area of about 75 square miles, containing most of the river terrace land along many miles of the Buffalo River and some of that on tributary streams, was intensively combed to determine the number and extent of the gullies at present active. A total of 170 such gullies were individually mapped, and the length, width, and depth of each recorded. These gullies had in 1929 a total length of 18 miles, or an average of 559 feet. They covered a total area of 138 acres or an average per gully of four-fifths acre. The volume of soil which has been removed from them is 3,247,000 cubic yards or an average per gully of 19,100 cubic yards. If we assume that on the average these gullies have been active for ten years—seemingly a fair assumption if it be conceded that a large proportion of them began to be active in 1921 and 1922, or 1924 and 1925, during seasons of unusually heavy rainfall—then it means that approximately 300,000 cubic yards of soil are being removed annually from this small area (roughly 400,000 tons). This volume is sufficient to fill the channel of Buffalo River for a distance of over three miles every year.

This figure of 300,000 cubic yards, however, can not be directly used to indicate the load which is thrown into Buffalo River. Measurement of the "fans" formed on the river-bottom at the mouths of some of the largest gullies indicate that 75 per cent¹⁰ to nearly 90 per cent of the volume of the material may be too coarse to be carried across the flats and into the river. It is probably less in many cases where gullies empty more directly. It would, therefore, be unsafe to assume that more than 100,000 cubic yards per annum of the gully material from this area of 75 square miles was in the form of silt actually carried away by Buffalo River, except at times of unusually high water when the fans are cut away. However, in attempting to arrive at an erosion figure for the entire Buffalo River watershed of

¹⁰ Thus, Slab-fence Gully total erosion 416,835 cubic yards; area of delta, 40.8 acres; average depth 4.9 feet; volume in delta 319,576 cubic yards.

Gilkey Creek, total recent erosion 263,000 cubic yards; area of delta 28.3 acres, average depth 5 feet, volume 228,000 cubic yards. The figure for the total erosion in this case makes no allowance for cutting along a considerable length of main stream channel below the present active gullies, either now or when the most active cutting may have been in these lower reaches.

roughly 360 square miles, it is impossible greatly to reduce the rate per square mile because even the above figure of 300,000 cubic yards makes no allowance for the prevalent surface erosion. Considering that something over 100 square miles in this watershed is cultivated, it is estimated that the total erosion, possibly in the long run becoming a load on Buffalo River, must be between one-half and one million cubic yards as an annual average.

This figure can be checked only in a suggestive way by considering the stream silt loads observed during the summer of 1929, because it is evident to anyone that a higher percentage of silt, and sometimes a large proportion of the entire annual load, is carried by the high waters of a few weeks' duration. The average of seventeen observations on Buffalo River, under low-water conditions, showed a load in the water of about 383 parts per million (by weight), while a single additional record immediately after a heavy rain gave 48,890 p.p.m. bringing the arithmetic average up to 3,078 p.p.m. The inclusion of this high figure still gives a conservative annual mean, since it assumes that high-water conditions prevail only $\frac{1}{4}$ s of the year. No allowance is made for movement of the "bed load," which in a stream like the Buffalo is doubtless a heavy one. Assuming that the run-off per square mile is about the same as that of adjacent streams for which there are government records, it should be about 288 second-feet at the mouth of Buffalo River. This means that in a year's time the stream carries to the Mississippi about 827,000 cubic yards of silt.

The last-named figures are believed to be on the conservative side and may be taken to indicate that the estimate of total erosion is a very moderate one. It must be remembered, however, that whatever the actual amount of sheet erosion, this consists largely of fine material which will be carried into Buffalo River much more largely than the sub-soil material cut from gullies.

There is no large area on the Black River where gullying is so prevalent as on Buffalo River, but the deep and wide terrace of the former gives opportunity for some gullies of enormous size, mostly concentrated in one locality. Thus, a single one of these has, mostly since 1916, dumped slightly more than a million cubic yards of coarse and fine material directly into Black River. An examination of eight square miles of the drainage brought to light thirty-one active gullies (including the above) with a total length of nearly 8 miles (average per gully 1,300 feet) an area of 103 acres (average 3.3 acres) and a volume of 3,843,661 cubic yards, average 123,989 yards per gully. Assuming again an average period of activity of 10 years for these present gullies, their contribution to the river has been 384,000 cubic yards per year, much less reduced in this case by river-bottom deposits, since many of the gullies empty directly into the main stream,

which is depositing the coarser material on a delta of about 75 square miles area, where it reaches the Mississippi River bottom.

The silt observations for Black River, fifteen in all, include no records when the river was especially high or muddy, and, therefore, show an average silt load of only 432 p.p.m. The silt observations were made where the stream has become a little sluggish and drops much of its silt load, in ordinary stages, to be picked up again during high-water stages, which are not at all represented in our observations.

Even on the very low basis of 432 parts per million, however, the total silt load of the Black River, with its drainage of 2920 square miles and its discharge of 0.72 second-feet per square mile, is seen to be 848,448 cubic yards per year. Actually it is probably several times this amount. The eight square miles of active erosion area which have been mapped appear to be contributing, per square mile, about 165 times as much to the river as the average area of the watershed. A high ratio is to be expected because the upper portion of the Black River watershed is rolling, or flat, and sandy, and therefore contributes very little silt to the stream, and because dams along the middle reaches of the stream are retaining the silt from the upper watershed. However, even considering these facts it would not be surprising to find that when high-water stages are included, Black River's annual silt-load amounts to 5 million cubic yards.

It is seen from the reservations that have to be made in using the scant data of silt load for the larger streams, mostly obtained at low-water or ordinary summer stages, that a better idea of the total quantity of erosion in southwestern Wisconsin would probably be obtained by considering the load of smaller streams which, during the period of observations in 1929, were mostly subjected to one or more sudden rises resulting from heavy rains. Comparing the average silt load of Mill Creek, Kainmuler Creek and Gilmore Creek with those of the larger streams arising mainly from similar areas (Table VII), it becomes obvious that a large proportion of the loads which arise from the erosion of land surfaces are dropped when they reach the larger and slower-moving streams. It can not be conceded, however, that these loads cease to be a problem of stream-flow, or cease to be a menace to the Mississippi when they are once dropped. Much of the coarse material carried in suspension by the smaller streams (and therefore included in these measurements) becomes the so-called "bed load" of the larger streams, which it is almost impossible to measure, or even to estimate with any hope of accuracy, so many are the factors which affect its movement. Other portions are deposited as sandbars within the channels of the larger streams, or upon their overflow lands or within the deltas at their outlets. Practically none of this deposit is permanent. It may be picked up and moved into the Mississippi by a flood of the same magnitude, or even one of less mag-

nitude than the one which carried it to its temporary resting place. Certainly, almost everyone has the knowledge that exceptionally high floods set in motion great masses of such material and entirely change

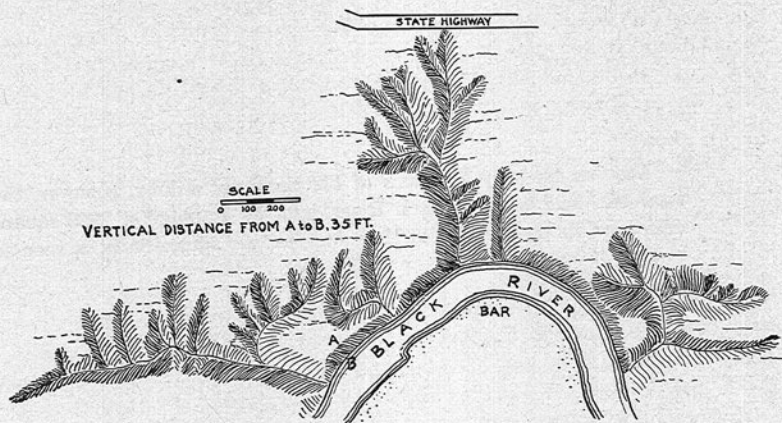


FIG. 27.—GULLIES EATING INTO BLACK RIVER TERRACE

A system of gullies eating their way into the terrace of Black River, within its most active area. Total volume removed in recent years, 775,000 cubic yards. The shifting of the river was probably responsible for "setting-off" this gullying, by causing slight waterfalls in the side gulches.

TABLE VII.—SILT LOADS CARRIED BY STREAMS
JULY TO OCTOBER, 1929
(in parts per million by dry weight)^a

Stream	Location	Number times sampled	Maxi- mum p.p.m.	Arithmetic Average p.p.m.
Mill Creek, active tributary of Buffalo River	Highway 37 crossing Mostly at Pine Creek. Some near mouth	16	55,970 ^b	5,301
Buffalo River	Highway 35 crossing	18	48,890 ^b	3,078
Waumandee Creek (direct into Mississippi River)	Highway 35 crossing	24	3,920	631
Kainmuler Creek (trib- utary Waumandee from sandy area)	Near mouth	14	48,760 ^b	4,769
Trempealeau River (west limb)	Highway 54 crossing	19	7,110	768
Beaver Creek, below dam	Galesville, Wis.	16	150	94
Black River	Highway 35-53 crossing	15	4,820	432
Gilmore Creek (Minnesota)	Before reaching Mississippi River bottom	8	11,270 ^b	2,409
Zumbro River (Minnesota)	Near Kellogg	4	580	260
Whitewater River (Minnesota)	Near Weaver	4	350	195
Average all summer observations on large and small streams		138		1,926
Temporary ditch and gully waters		10	209,880	57,290

^aIn converting to volume, or yardage, the silt has generally been considered as one-fourth heavier than water, making the converting factor 0.8. It varies, of course, from lighter than water to about 50% heavier for sand.

^bThese are the only samplings which can possibly be called "high water" conditions.

the environs of the small rivers. So far as known no one has ever attempted to estimate the total silt movement under such conditions, in the upper portion of the Mississippi drainage, or with reference to the conditions here discussed.

It is evident, then, that an estimate which gives a reasonable measure of the total erosion can not be far wrong in indicating the total load which will be brought to the Mississippi. This does not by any means indicate the amount of material which will be currently moved down the Mississippi, if it becomes largely bed load in the larger stream, for the bed-load capacity of the large stream is probably considerably less than that of all its tributaries, and it appears from the aggrading character of most of the streams in this region that they are taxed to their several capacities by the present rate of soil erosion.

The basis for such an estimate, in order to be kept very conservative, may be taken as 2,000 p.p.m., approximately the average of all of the observations on all streams in 1929, this being equivalent to about 8 feet of silt to be settled out of 5000 feet of water. There may be used the approximate figure of 10,000 square miles as defining the unglaciated region of southwestern Wisconsin, of fairly uniform character from the mouth of the Chippewa to below the mouth of the Wisconsin and including a narrow strip in southeastern Minnesota, next to the Mississippi, which is fully as critical from the erosion standpoint. The amount of water coming from this entire area is assumed to be 0.8 second-feet per square mile¹¹ or 8,000 second-feet in all. These basic figures give a total silt contribution to the Mississippi of 15 million cubic yards, which, of course, is equivalent to 1500 cubic yards annually from each square mile of the territory. The silt brought down by the Mississippi at its mouth is estimated by Bennett and Chapline¹² at about 317 cubic yards per square mile of watershed, and while this indicates that Wisconsin's contribution is very large and important, it is impossible properly to compare the two figures. Considering the large drainage areas of the Chippewa, Black and Wisconsin Rivers which do not enter into this estimate, it is probable that the total contribution to the Mississippi within this stretch is more nearly 25 million than 15 million cubic yards. The Chippewa is most widely known as a sand carrier, its enormous load apparently arising from the present rapid erosion of its ancient terrace rather than from unfavorable watershed conditions in general.

It is well to express the above-estimated erosion of 1500 cubic yards per square mile in terms of soil loss. If it be conceded, as the

¹¹ Water Supply Papers of the U. S. Geological Survey indicate this to be an approximate mean for the watersheds of the region.

¹² H. H. Bennett and W. R. Chapline "Soil Erosion a National Menace." U. S. Dept. of Agriculture, Circular 33, 1928. On page 17, the silt load of the Mississippi is given as 429 million tons or roughly 390 million cubic yards, the watershed of the Mississippi having a total area of 1,231,492 square miles.

observations for cultivated and forested or natural grass areas seem to show, that practically all of the soil erosion is from the cultivated areas, then the one-third of the entire area which is cultivated in southwestern counties of Wisconsin is losing soil at the rate of 4500 cubic yards per square mile, which is equivalent to a depth of approximately one inch every 20 years,¹³ of the most valuable surface material which geologists state can only be replaced or re-formed by natural processes in about 1000 years. Perhaps this loss could be better tolerated if it were evenly distributed, but the alarming fact of the situation is that parts of fields here and there are being eroded so deeply as to make them wholly useless.

Thus, while the average farmer in the region under discussion is losing only a little corner of a field here and there, and by dint of leaving sod strips, or by grading them over each year or two is keeping the smaller and shallower gullies from dividing his fields, several farms on which the larger gullies have been formed have been rendered almost valueless or so difficult to handle that they can not be made to pay in these times of close accounting. When a gully with a total length of over a mile and a surface area of 25 acres eats its way through the most fertile portion of a farm of less than 300 acres, it has not only rendered at least 50 acres worthless except for low-grade pasture, but it has made the working of the divided fields an additional burden which few farmers could attempt to carry. Thus, one by one, such farms will be given back to nature or become at best, woods and wild pastures.

The lesson which must be pointed out, of course, is that this tremendous economic loss to local communities could be prevented by a very small expense at the time when the gullies were first beginning to eat their way into the good fields. Thus a farm valued at \$30,000, completely lost in a period of 20 years, represents an annual loss of \$1500. Dams built at the cost of a single year's loss and made stable and permanent by a little later care, could undoubtedly have been made to prevent all of the rest of the loss. Nowhere could the "ounce of prevention" proverb be more applicable.

General Conditions Throughout the State

If we may judge the other farming regions of Wisconsin without actual surveys, but solely on the basis of the "muddiness" of their streams, the good soils of the State are all being removed at a rapid rate. That this is being done in the more insidious form of sheet erosion, without great immediate noticeable damage to the fields, cannot be denied, yet there are many examples in every part of the state where sheet erosion is proceeding so rapidly as to bare the light-

¹³ After exceptional rains, deposits from freshly plowed fields, equal to 1/15 inch at one time, have been noted.

colored sub-soil, or in other words much more rapidly than new fertile soil can possibly be formed even by the most generous application of organic fertilizers.

The economic loss which this represents is difficult to estimate, yet if we accept the estimates of Bennett and Chapline¹⁴ for the country as a whole, it would mean that the replacement of the soil ingredients, by the use of fertilizers, must cost the farmers of Wisconsin no less than five million dollars annually. At present Wisconsin farmers are expending about 1½ million dollars annually for commercial fertilizers, but the value of manure produced and used on farms is many times this amount. Even these extensive applications are apparently not keeping pace with the erosion losses.

V. RELATION OF LAND MANAGEMENT TO EROSION

FROM THE standpoint of the average farmer the erosion which arises directly from the use of his land for field, pasture, hay-land, or forest-growing is of first importance, because he can substantially reduce such erosion by a different use of the land or by different systems of cultivation. It is undoubtedly true that sheet erosion, or even the formation of small shallow gullies, can be very largely controlled by slight changes in the method of cropping or handling. As has been rather emphatically pointed out in the preceding discussion, deep gullying into fields is more often directly traceable to disturbances outside than to the treatment of the field itself. Even here, however, any change in the use or management of the land which will tend to reduce the amount of water going into gullies should facilitate their correction and control.

Because it was believed that a very large part of the loss of soil from farms could be corrected by the farmer himself, a special effort was made in the summer of 1929 to determine the relative amounts of run-off which come from fields in different states of cultivation, from pastures and from timber tracts. Once it is established whether the water which carries away the soil of a cultivated field arises largely on that field, or on the hayland, pasture or timberland, usually located on the steeper ground above, it will be possible to apply the corrective measures where they should be applied, and not to waste effort in useless treatments.

Prior to the Wisconsin study made in 1929 there was already available a considerable background of experience and observation, as well as a few well-executed experiments such as those of the Missouri

¹⁴ Bennett, H. H., and Chapline, W. R. 1928. Soil Erosion A National Menace. U. S. Department of Agriculture Circular 33. On page 2 these authors represent the value of chemicals removed annually from soils of the United States to be replaced by fertilizers at a cost of two billion dollars. Of this amount 10 per cent can be shown to be a "tangible yearly loss to the farmers." Wisconsin's share of this has been estimated as 1/40 of the whole, by the writers of this bulletin.

Agricultural Experiment Station.¹⁵ These should be reasonably applicable to the soil and climatic conditions of southwestern Wisconsin. The Missouri experiment dealt with long narrow strips of $\frac{1}{80}$ acre each, artificially demarked by strips of galvanized iron set on edge to keep the run-off from one strip separate from that of the next strip. The land had a slope of slightly less than 4 per cent.

For the six years from 1917 to 1923, these plots, whose surfaces were consistently treated in different ways, showed run-off of rainfall water, and erosion of soil in the quantities indicated below. During the six-year period the annual precipitation varied from 24 to 50 inches, with an average slightly under 36 inches. In most of the plots, the quantity of rainfall *absorbed* into the soil was very uniform from year to year, or in other words, an excess of rain produced an excess of run-off rather than greatly increased absorption.

TABLE VIII.—RESULTS OF DIFFERENT SOIL TREATMENTS
IN MISSOURI
Average or Totals for Six Years, 1917-23.

Plot number and description	Percentage of rainfall which ran off, average	Erosion, total number of pounds from $\frac{1}{80}$ acre
1. Not cultivated, weeds pulled	48.92	5195
2. Plowed 4 inches deep	31.26	6184
3. Plowed 8 inches deep	28.36	5355
4. Sod	11.55	42
5. Wheat each year	25.19	998
6. Corn, wheat and clover in rotation	14.14	343
7. Corn each year	27.38	2663

The most striking thing in these figures is the almost complete absence of run-off and erosion from the plot kept continuously in sod, principally of blue-grass, and which was never grazed. Because not grazed it was, probably, in soil and cover conditions more comparable to hayland than to pasture. Likewise, the rotated field gave very low run-off and erosion, two-thirds of the entire amount of erosion occurring in the years when only corn occupied the ground, while the second year for the clover, which was seeded with the wheat, showed high absorption and negligible erosion. The wheat and corn crops repeated each year had very little effect on run-off (comparing with ground plowed only) but did reduce erosion by 80 and 50 per cent respectively.

Observations Made Under Wisconsin Conditions

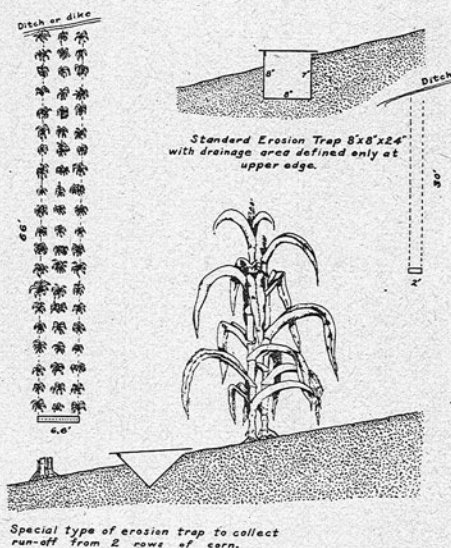
In order to have data comparable in nature to the above but taken directly from the farms and fields of southwestern Wisconsin, and particularly to bring out the part played by the wooded area of the

¹⁵ University of Missouri Agricultural Experiment Station, Research Bulletin 63, 1923. "Erosion and Surface Run-off under Different Soil Conditions."

well-balanced farm, about forty (40) so-called "erosion traps" were operated during the summer of 1929. The "catch" of these traps was measured after each rain, or at least at 24-hour intervals when rains were in progress. Instead of attempting to obtain precisely limited run-off areas, it was thought best to deal with conditions as they occurred in the fields, without disturbing the natural flow of the surface run-off by any artificial barriers, since a slight diversion of the surface flow may cause it to erode the soil more than would otherwise be the case. Thus, in effect, when a trap was set in a grain-field or pasture it amounted to little more than an excavation into which the water reaching that point would naturally flow. Within this excavation a galvanized iron tank was so placed as to catch the water and hold it until measured. Similarly, the silt carried by the water was measured after it had settled in the tank. A small amount of erosion from just above the "lip" of the traps occurred when they were first set, the reason for which will be seen by reference to Figure 28, but this was not noticeable after one or two rains had washed down the loosened soil. The traps were 24 inches long, that is, took in a section of the ground 24 inches wide, and were 7 inches deep below the lip and 8 inches wide. They were covered by flat sheet iron covers tilted so as to take the direct rainfall to the down-hill side. These dimensions gave rather small capacity, insufficient for the larger amounts of run-off. In a number of cases it was possible, therefore, to record only that the trap had been filled to overflowing, without knowing how much. However, as will be seen from the data, this actual amount is

FIG. 28.—METHOD OF PLACING TRAPS TO CATCH THE RUN-OFF FROM FIELDS AND PASTURES

This is done without interfering with the natural direction of its flow or concentrating it in any channel. The longer traps were designed to fit the natural channels which form in cornfields.



not so important as the point, in terms of rainfall, at which the run-off began to be appreciable. In short, the measurements were intended to be of a qualitative rather than an exact quantitative nature.

In most cases the drainage area to one of these traps was limited, either by natural boundaries or by means of a cross-ditch a short distance above, to a section of the field two feet wide by twenty or thirty feet long, the purpose being to see how much run-off found its origin at that particular section of the field, and not how much it received from land lying higher up the slope. In the case of cornfields, it was thought best to employ somewhat larger traps, whose length was sufficient (6.6 feet) to cover two of the spaces between rows of corn. This was necessary because the cultivation of corn usually leaves shallow furrows which definitely collect the entire drainage between each pair of rows. In case the last cultivation had been across the line of natural drainage, the contour furrows were not disturbed within the space between the outside corn rows, but they were blocked off by small dikes so that only the water collecting in the two-row strip could fill them and eventually overflow into the next furrow below. The strips in cornfields were blocked off 66 feet from the traps, so that the area included was approximately 1-100 acre. Since the long, trough-like traps employed here were of even smaller relative capac-

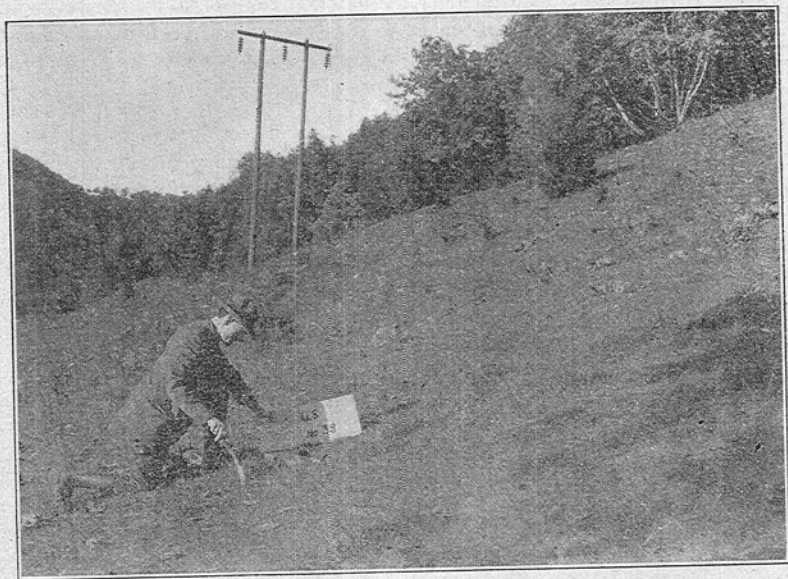


FIG. 29.—EROSION TRAP IN NATURAL SOD

Twenty-four-inch rectangular erosion trap in natural sod on steep slope of Mississippi River bluffs. The "lip" of the trap on the up-hill side, is inserted horizontally about an inch below the surface of the ground. There is nothing to divert the water from or toward the trap except a shallow diversion ditch about 20 feet up the slope. Only the run-off from the area immediately above the trap is obtained.

ity than the 24-inch rectangular traps, they were arranged to overflow, when filled, into pits where the excess volume of water could be roughly estimated.

The results obtained in these measurements, despite their approximate and qualitative character, are decidedly clear-cut and show much greater differences between different conditions of soil and cultivation than were anticipated. One difficulty in making full use of the data arises from the fact that, while the total rainfall was measured at each trap, only a very general idea of the intensity of different rains could be obtained. Only one tipping-bucket rain-gauge for measuring this was available, and the measurements at this one point would not necessarily apply elsewhere. However, these records, and the notes made wherever the observers happened to be, indicated that almost without exception the rains in July and August were of great intensity, even though small in amount, and whether falling in the afternoon, or quite as commonly in the early morning hours. Those occurring after the middle of September and in October were generally of a much slower character and produced very little run-off anywhere. Thus, if only the summer rains are employed, there is a fairly high intensity of rainfall throughout, and fairly consistent results in the form of run-off, that is, run-off consistent in quantity with the total amount of precipitation recorded in single rains.

For the sake of clearness it may be said that the maximum capacity of the rectangular traps, a depth of seven inches of water, represents a run-off of only about one-sixth of an inch from a drainage area of sixty square feet or nearly one-fourth inch from an area of forty square feet. Therefore, if the trap was filled by a rain of one inch, it means about sixteen per cent run-off from the larger area, or twenty-three per cent from the smaller. The most important points of the trap records are summarized in Table IX.

Run-off from Different Cover Conditions in the Hills near Winona

The data for Traps 5, 6, 7 and 8 are presented first, because these four were all subjected to the same rains and the first and last numbers were only about one-fourth mile apart with about 200 feet difference in elevation. They were located on the partly loessal and partly residual soils in the hills near Winona, Minnesota. Beginning with Number 5, there are represented in the order of the numbers a fallow table-land field, hayland, forest, and pasture.

The field had been in hay until the preceding fall when it was plowed, and by August had developed only a light cover of grass and weeds. It occupied the top of a ridge but at the trap had a slope of about 18 per cent to the east. Below this, the slope broke more sharply. Trap 6 was placed in the upper ridge of the undisturbed hayland as near as possible to the fallow land, with a slope of 21 per cent. The hayland is mowed but once a year and consequently had a mat of old

TABLE IX.—SUMMARY OF EROSION TRAP RECORDS

Locality and soil	Use of land	Slope percent	Trap number	Period of observations (1929)	Size of rains which filled trap		Depth of rain required to start run-off	Highest Ratio Run-off to Rain				General measure of silt collected	
					Rain	Depth in trap		Run-off ratio to rain	Based on run-off area of				
Bluff land near Winona Loess and residual limestone soils.	Fallow after hay	18	5	9/17-8/8	1.15,	Inches 1.34,	.70	Inches .28	Inches 0.70	Inches 7.0	Percent 33	Sq. Ft. 40	1/2 inch mud, 7/23
	Hay, cut yearly	21	6	9/17-8/8		none	.20	1.34	6.2	15	40	Traces organic matter	
	Forest, young	45	7	9/17-8/13		none	.50	1.22	1.3	4	40	Water discolored	
	Pasture, cropped moderately	35	8	9/17-8/13	1.17,	1.20,	0.70	.15	0.70	7.0	33	40	Traces silt & humus
	Pasture, bare point	31	26	7/6-10/30	1.21,	1.09,	1.70 ¹⁾	.20	0.60	4.8	27	40	1/8 inch fine silt 7/23
	Pasture, depression	32	27	7/6-10/30	1.21			.30	1.09	5.4	17	40	Organic silt only
	Woodland, pastured	38	28	7/6-10/30	1.21			.50	1.21	7.0	13	60 ⁸⁾	Organic silt only,
	Rocky, natural grass	52	29	7/6-10/30	1.21			.50	1.21	7.0	13	60 ⁸⁾	Organic silt only,
	Average										19		trace mud 8/13.
	Galesville district, Loess soil	Pasture, closely cropped	27	1	9/19-7/13 & 8/23-10/30	0.58	1.43		.15	0.36	5.0	37	50
Pasture, moderately cropped		10	4	9/20-10/30		none		.25	0.57	3.5	14	60 ⁸⁾	Water nearly clear
Oats, bare soil		17	15	7/3-10/30	0.59	0.66	0.72	.10	0.46	7.0	48	42	1 1/2 inch clay, 7/13
Oats, good soil		10	3	9/20-10/30	1.28	0.46	1.25	.60	0.31	0.2	1.7	50 ⁸⁾	Traces only
Corn, furrow with slope		9	32	7/13-10/30	0.75	0.26	0.72	.20	0.26	11.42 ²⁾	44	132 ²⁾	1/4 inch mud twice ²⁾
					1.06	1.92							
Corn, furrows across slope		17	33	7/13-10/30		0.85		.30	0.85	5.8	7	132 ²⁾	Traces fine mud
Pasture, sandy		55	34	7/13-10/30		1.30		.20	0.54	4.0	12	80 ³⁾	Traces sand; mostly clear
Dense forest		42	2	9/15-10/30		none		.70	1.25	.12	0.2	60	Traces organic matter
Dense forest		38	13	7/3-10/30		none		.40	0.59	.6	2	60 ³⁾	Traces organic matter
Open, grassy woods	13	14	7/3-10/30		none		.30	0.59	1.2	3	80 ³⁾	Traces organic matter	
Average										17			
North Bend district Residual or terrace soils	Grassy oak timber	40	16	7/7-9/30		none		1.40	0.69	5.5	21 ⁴⁾	50 ⁸⁾	Traces sand until moved 4)
	Corn	17	17	7/7-9/30	0.97,	0.69,	0.54	.18	0.22	7.0	61	70	4 inches sand 7/13, 1 inch or more several times
					0.31,	0.79,	1.69,						
	Pasture, closely cropped	16	18	7/7-9/25	0.65,	1.82,	0.22	.30	0.34	6.0	53 ¹⁰⁾	44	Traces sand
Average					0.97,	0.79,	1.69				45		

Mississippi bluffs Residual lime and sand	Natural pasture, close grazing	33	31	$\frac{7}{16}-\frac{1}{80}$	none								
	Nat'l pasture, mod. grazing	35	38	$\frac{9}{16}-\frac{1}{80}$	none	.30	0.40	3.1	10	100	Traces, mostly humus		
	Cornfield, hand cult.	28	36	$\frac{7}{25}-\frac{1}{80}$	0.73	.50	0.61	0.8	45)	40	Traces, mostly humus		
	Forest, heavy	52	30	$\frac{7}{16}-\frac{1}{80}$	none	.30	0.73	7.0	21	60	2½ inches mud, 8/7		
	Average					.60	0.61	.05	0.4 9	306)	Leaf humus only		
Buffalo River Terrace alluvium Residual at higher points	Corn, furrows across slope	14	35	$\frac{7}{16}-\frac{1}{80}$	none	.50	0.69	1.5	2	132	.02 inch fine silt, 9/25		
	Oats, poor soil	7	19	$\frac{7}{2}-\frac{1}{80}$	1.19, 0.97,	0.34, 1.06	1.33 0.96	.30	0.34	7.0	27	1007) ¼ inch mud, 7/3, less several times later	
	Hay, packed soil	10	20	$\frac{7}{2}-\frac{1}{80}$	1.33,	0.97,	1.06	.55	0.97	7.0	19	508) Trace silt, 7/8	
	Hay, packed soil	15	21	$\frac{7}{2}-\frac{1}{80}$	1.33,	0.97,	1.06	.55	0.97	7.0	19	508) Trace silt, 7/3, 7/6	
	Edge of hay-field (forest)	?	22	$\frac{7}{2}-\frac{1}{80}$	none	.60	1.06	1.1	3	508)	No erosion, clear water		
	Forest, good	49	23	$\frac{7}{2}-\frac{1}{80}$	none	.50	0.69	0.5	2	508)	No erosion, clear water		
	Forest, good	30	24	$\frac{7}{2}-\frac{1}{80}$	none	.50	0.69	0.5	2	508)	No erosion, clear water		
	Average									11			
	Waumandee Creek sand8)	Pasture, natural	26	25	$\frac{7}{8}-25$, $\frac{8}{25}-\frac{1}{80}$	none	.40	0.51	1.3	8	40	No erosion	
		Open oak woods	18	9	$\frac{6}{17}-\frac{1}{80}$	none	.20	0.44	.2	1	508)	Traces organic matter	
Corn, furrows with slope		19	10	$\frac{6}{18}-\frac{1}{80}$	0.73	.30	0.34	6.5	199)	1322)	½ inch sand 6/28, also 8/9		
Oats, heavy crop		17	11	$\frac{6}{18}-\frac{7}{23}$	0.73	.60	0.73	7.0	26	508)	Fine silt, 6/28		
Oats, light crop		23	12	$\frac{6}{18}-\frac{1}{80}$	none	.45	0.73	6.0	18	60	½ inch sand, 6/28		
Native grass		26	11A	$\frac{7}{23}-\frac{1}{80}$	none	.40	1.59	.4	1	508)	Trace sand 9/9		
Dense oak woods		33	12A	$\frac{7}{23}-\frac{1}{80}$	none	.40	1.59	.4	0.5	70	Clear water only		
Average									10				

- 1) Accumulated quantity from rains of 9/4 and 9/9
- 2) Depth corrected to basis of the rectangular trap, and drainage area to basis of a 2-foot width.
- 3) Undefined area.
- 4) Not over 3 per cent after placing above steep cut bank.
- 5) Trap 31, 3 per cent in this rain.
- 6) Area in steep slopes.
- 7) Indefinite, slight hollow. After 7/13 in higher position, limited to 50 square feet. Highest run-off thereafter 27 per cent, 9/29.
- 8) Also, trap 25, sand near mouth of Trempealeau River.
- 9) Probably a higher percentage in rain of 0.73 inches on June 28, when trap floated.
- 10) See footnote 16, page —. Use 20% in computations.

grass. Below this the forest began, Trap 7 being placed near its lower edge on the steepest part of the slope, 45 per cent. The forest consisted mainly of dense young birch. Trap 8 was in the pasture about 200 feet below, on a 35 per cent slope. This pasture was seeded more than 10 years ago, but was not severely grazed and had not become hard-packed owing to its moistness, sourness, and tendency to grow moss. It was considerably roughened by cattle tracks made in the spring, and should have had a high absorptive capacity after drying out.

As is readily seen from Figure 30, the pasture began to yield run-off with most of the rains of .15 inches or more, and filled the trap every time that the rain exceeded .70 inches. The fallow field was next in order, although it showed more capacity for the small rains than did the steeper pasture, that is, up to about one-fourth inch it yielded little run-off. The hayland made a very good showing in holding back the larger rains, but owing to the effect of dry matted grass or leaves in carrying water along the surface, it began to give run-off with very light rains. Similarly in the forest, the leaves which overhung the lip of the trap often brought small quantities of water into it, even when there was no general run-off. This bare trickling characterized the forest run-off even in the hardest rains, one of which, on July 23, amounted to 1.17 inches in about one hours time.

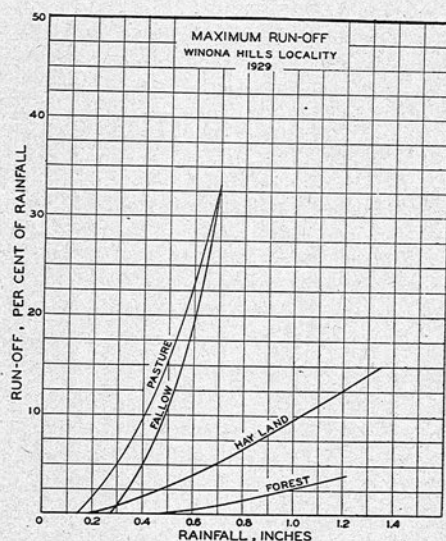
The greatest run-off from the forest amounts to about 4 per cent of the rain. The greatest relative run-off retained by the traps for the fallow land and pasture was about 33 per cent. The percentage was higher than this for the largest rains, which yielded apparently several times the capacity of the traps. The greatest run-off for the hayland can be placed at about 15 per cent, the trap never overflowing.

The erosion into these traps was negligible except from the fallow field. The small quantities of water from the forest were nearly clear, those from the pasture and hayland mostly free from actual soil except that which probably was taken off just above the lip of the trap. The greatest amount of silt from the fallow land filled the trap to a depth of $\frac{1}{2}$ inch, this being brought by the most rapid rain, while the largest rain, coming more slowly, gave only one-fourth inch of silt. The largest amount would represent about one-sixtieth inch from the drainage area.

Traps 26-29 may next be considered as they were very close to those just discussed, but on a drier southwest exposure. The first number was near the foot of the slope, gradient 31 per cent, and on a slightly rounded point so that the trap received, if anything less than its due amount of run-off. Number 27 was slightly higher up the slope, in a hollow where run-off water would tend to converge, the slope gradient being 32 per cent. These two were compared in order to indicate the importance of humus in the soil, the rounded point at

FIG. 30—RATES OF RUN-OFF FROM FIELD, HAYLAND, FOREST AND PASTURE

Comparative rates of run-off from fallow field, hayland, forest and pasture under identical conditions of rain. Winona hills. Note that forest with lowest percentage of run-off occupies the steepest ground.



Number 26 having been washed bare, while the area of Number 27 showed a black spongy soil to a depth of a foot or more. Both of these were in closely-cropped blue-grass pasture, and were much drier than the pasture area of Trap 8. Trap 28 was in the rather open oak timber just above Number 27, the area being also pastured, and exposing a good deal of bare soil, although it was black with humus. The ground here becomes steeper, 38 per cent slope. Trap 29 represents the steepest slope of any of the traps placed, 52 per cent, and had no cover except the native bunch-grass. However, the rocky character of the residual soil, with large fragments of limestone on its surface and buried in it, undoubtedly give it high absorbing capacity.

While this series was started a little later than numbers 5 to 8, and operated later in the fall, both groups were subjected to the very hard rains of July 23 and August 7.

The bare point in the short-grass pasture gave the greatest run-off for given amounts of rain. The depression, with a humus soil, began to yield run-off nearly as soon, that is with about .30 inch of rain, but the quantities did not increase so rapidly, despite the opportunity which this trap had to take in a little water from the sides. In contrast, neither the woods area nor the limestone slope began to yield until rains of about .50 inches were had, and above that point the limestone slope showed better absorbing capacity than the open woods. The poor showing of the woods area in this case is readily explained by the numerous cow-paths and by the fact that the southwest exposure does not permit a dense forest nor much accumulation of forest litter. In truth it must be stated that open pastured forest is not much better in holding water than pasture without trees.

The maximum run-off percentages indicated for this series of traps were 27 per cent from the bare pasture soil, 17 per cent for the pasture soil with humus, and practically the same, 13 per cent, for open woods and rocky slope, but of course the greater steepness of the last two must be kept in mind in the comparison.

Run-off Observations on Loess Soil Near Galesville, Wisconsin

The series of traps east of Galesville, Wisconsin, located for the most part on heavy loess soils less affected by residual deposits than that on the Minnesota side of the river, may next be considered. Because some of the traps were 10 miles apart, all did not receive the same amounts of rain. The run-off rates at the most important traps of this series are shown in Figure 31.

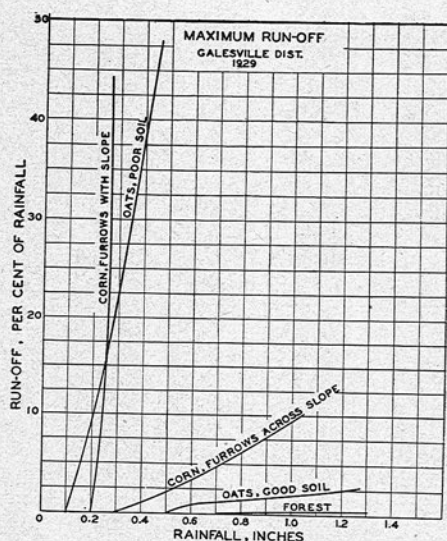
Traps 1 and 4 represent pastures, the former on steeper ground than the latter (27 per cent and 10 per cent respectively) and also grazed much more closely. This difference shows up plainly in a higher starting-point for the flatter ground with its heavier mat of old grass, the maximum run-off rates being 37 per cent and 14 per cent, respectively.

Traps 3 and 15 represent oat fields in this series. The former was near and exactly comparable to Trap 4 in slope, (10 per cent to the south), and the soil was in excellent condition, growing a very heavy crop of grain. Trap 15, on the contrary, represented a slope of 17 per cent, the soil having been so badly washed in times past that the humus layer had entirely disappeared at this point. The contrast in run-off between these two fields is very striking, the flatter field with its heavy crop of grain yielding practically nothing from the heaviest rains, while the washed and steeper soil, with its sparse cover, yielded appreciable amounts from most rains of one-tenth inch or more, and filled the trap with rains of less than .60 inch. This surface was nearly as impervious as some road surfaces observed in the same vicinity. The good and poor soils compare by maximum run-off percentages of about 2 and 48, the difference in slope also having its effect here. These data are very conclusive in showing that good tilth and good productive properties of the soil, producing heavy crops, tend to reduce erosion to a minimum. This was apparent even after the harvesting of the oats.

Trap 32, representing a cornfield directly across the road from the good oatfield, with a slope of 9 per cent, is also in decided contrast. The last cultivation in this field was up and down the slope, and run-off began very easily. With the overflow into a pit it is possible to state that with one rain of .26 inch, this ground gave the equivalent of at least 11.4 inches of water in the regular rectangular traps. This, with the drainage area running back 66 feet, is equivalent to a run-off of 44 per cent. Probably a more normal run-off for this cornfield, with

FIG. 31.—RATES UNDER DIFFERENT CONDITIONS

Comparative run-off rates under different conditions of slope and cultivation in the Galesville district, with fine loess soils.



less intense rain, would be one of about 30 per cent. Obviously this is greatly affected by the furrows running straight down the slope.

Trap 33 was in another cornfield several miles removed from the last-mentioned, in which the last cultivation was made across the slope, or parallel with the contours. The slope above the trap was 17 per cent. Run-off began with rains of about .30 inch but it did not increase nearly so rapidly as the run-off at Trap 32, and its maximum rate was not greater than seven per cent, with a rain of .85 inches. A steeper pasture slope immediately adjacent (Trap 34) with a much sandier soil, gave in this same rain a run-off of about 12 per cent (area indefinite).

The three forest situations in this series may now be considered. Trap 2 was on a short piece of forested slope with dense underbrush, having a slope of 42 per cent to the west. Trap 13 was also on a steep (38 per cent) northeasterly slope, damp and fern-covered, with a deep black mull soil capable of absorbing much water. Trap 14 was nearby, on an opposing slope or bench with a gradient of only 13 per cent, a drier situation with firm ground and with enough grass to attract grazing. Both 13 and 14 were in an area pastured by horses and cattle, but owing to steepness of the ground and lack of feed there was little trampling in the vicinity of the former.

As has already been pointed out, the forest soils, with their cover of more or less matted leaves, often conducted small quantities of water into the traps which, under natural conditions, could not have moved more than a few inches without soaking into the humus layer. It is, therefore, not surprising to find that Trap 2 several times had a

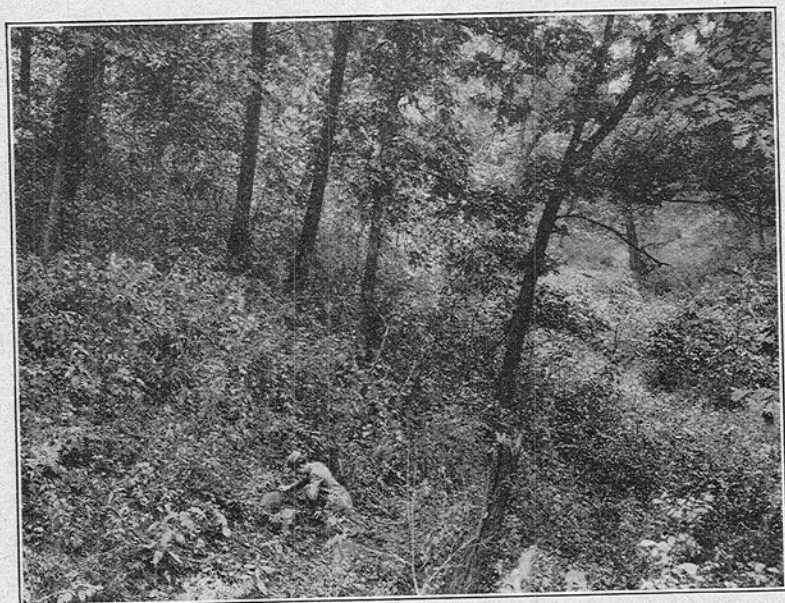


FIG. 32.—THIS AREA YIELDED LESS THAN ONE PER CENT RUN-OFF

The location of trap 2, on a short, steep forested slope, is shown in the middle foreground. Brushy timbered areas such as this yielded less than one per cent of run-off during the most violent rains of 1929.

few hundredths of an inch of water after light rains. However, the greatest amount was less than 1.5 inch and a run-off percentage of about 0.2 is indicated. Trap 13, gave a little more realistic quantities, with a rain of 0.59 on July 7 showing a run-off percentage of about 2. Trap 14, despite its firm sod and packed soil, being favored by a slope only one third as steep, yielded little more run-off, its percentage being less than 3.5 in the rain of July 7.

Of this entire group in the Galesville region, only the improperly cultivated cornfield and the oatfield with the badly washed soil yielded appreciable quantities of silt into the traps. The oatfield gave more than an inch in the trap, or about one twentieth inch from its drainage, with a sharp rain of 0.66 inches, the "shoe-string gullies" above the trap increasing very appreciably in size in this rain. The heaviest silt deposit from the much better soil at Trap 32 was, for a similar area, about one-fourth inch in the trap. The cornfield which had been cross-furrowed gave still less, or a maximum of about .05 inch in the trap. The steeper of the two pastures occasionally yielded a trace of silt, but on the whole, the conclusion is inevitable that pastures, while yielding water very readily, and in this way often damaging plow-land which lies below them, are themselves eroded by this run-off only in trails or where the sod is otherwise broken.

Within this group, the protective and absorptive capacity of the heavy oat crop was most surprising, and the conditions here point clearly to the fact that an originally good soil is kept up by abundant manuring and intelligent use of commercial fertilizers, so that it grows good crops, erosion need never gain much headway, although a little may occur in the year of the rotation devoted to corn¹⁶

Run-off in the North Bend Region

The small group of three traps placed in the North Bend region above a large active gully is worth considering separately, first because the area doubtless received the heaviest and most severe rains during nearly every storm period, and also because the soils involved are either alluvial or residual, with a large component of sand in the latter case. The three traps were placed, respectively, in the gently sloping pasture which borders the active gully, in a cornfield farther back toward the head of the watershed, and in a grassy patch of open oak timber slightly closer to the ridge. (See Figure 34) The soil of the ridge at the head of this watershed is almost pure sand, with sandstone outcrops exposed here and there, and at the last two trap loca-



FIG. 33.—THESE SLOPES NEVER YIELDED MORE THAN THREE PER CENT RUN-OFF

Locations of Traps 13 (to right of center) and 14 (on gentle slope at the left), in woods in the Galesville district. Although pastured, these slopes never yielded more than 3 per cent of run-off from rapid rains.

¹⁶ Since the above was written this field has eroded badly immediately after being sown to peas.

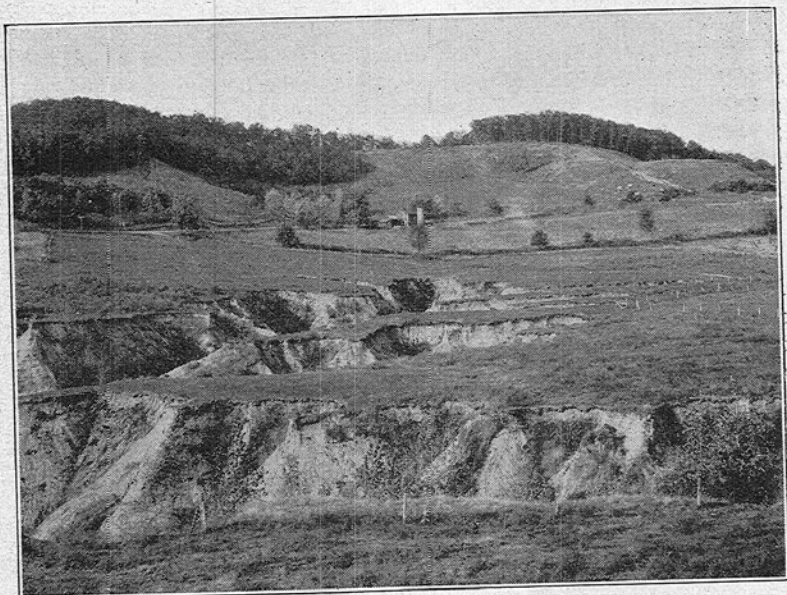


FIG. 34.—THIS GULLY IS STILL ACTIVE

This gully still remains active with its watershed reduced to a few acres of pasture and plowland, due to the highly erodable character of the sandy residual soil at its head. The location of Trap 18 was at the extreme right middle ground of this view, while Trap 17 was in the cornfield which barely shows beyond.

tions mentioned, is scarcely any better. That in the pasture is essentially like the Black River terrace soils, being a fairly light soil deposited either by the finer wash-in from the slopes above or by a larger stream at some remote period. Because of the soil difference we should naturally expect the pasture area, which was cropped very closely, to yield run-off most readily. Probably because of a clay component of the sandy soil of the cornfield, making it readily "fluxed", the cornfield, however, not only began to yield water from lighter rains, but gave at all times fully as heavy run-off and, of course, much greater quantities of silt. In fact, the first heavy rain after installation of the trap, that of 0.97 inches on July 13, caused distinct gully-ing over the entire cornfield and filled the trap half full of sand. Later, silt of about an inch depth was recorded several times, while the smooth and hard-packed surface of the pasture yielded, at most, traces of sand. The run-off percentage of the pasture went as high as 53% for the smaller, hard rains, that of the cornfield, (draining back about 35 feet to the edge of field) up to 61 per cent. For the timbered area the run-off was at first quite appreciable (21 per cent) as the

¹⁷ When this high record was made, however, the drainage area was not defined by ditch, and after limiting it the run-off was only about one-third as much as from cornfield.

trap was set on the steep cut bank at the edge of the cornfield, and the drip from branches of the trees caused a good deal of run-off on this short slope, which did not come from within the forest. After the trap was moved back a few feet into the woods, only very moderate run-off was noted, reaching at times a figure slightly under three per cent.

The run-off yields of the cornfield and pasture, in this group, and the evidences of erosion noted in other fields which occupy the small basin above the present active head of the large gully, explain how the gully is still able to obtain sufficient water to continue its cutting. Judging by the results from the timbered area, and by other results which have been reported for better soils, it would distinctly pay either to let this small remaining basin "run wild" for a few years, during which the active gullying would probably cease and the walls of the present gully become stabilized; or to seed the entire area to alfalfa or clover, which would promptly reduce the run-off, while at the same time starting a much-needed improvement of the soil. To continue to till, and to keep in closely-utilized pasture, such a critical area, means nothing but ruin of the farm.

Observations along the Mississippi Bluffs

Several traps were placed on the steep slopes facing the Mississippi River, near Fountain City, Wisconsin, to determine whether these slopes which drain most directly into the river are important sources of run-off. Such a supposition is but natural in view of the large number of so-called "limestone runs" which come out of these precipitous bluff areas, bringing veritable "torrents" of rock fragments after sharp rains. (See Figures 2 and 4) The conclusion which must be reached from the observations is that the bluffs in their natural condition, with a cover either of trees or sod, are reasonably stable, and that the destructive element in the situation is the water which originates on table-land fields above the bluffs. The residual soil of the bluffs, while sometimes heavy, usually contains enough sand to make it reasonably porous; the large number of rock fragments aids materially in maintaining good absorptive capacity.

Traps 31 and 38 were maintained on closely grazed and lightly grazed natural sod areas separated only by a fence, the slope being about 34 per cent to the west; Trap 36 on a narrow cultivated strip at the foot of the steepest bluffs, having a similar slope of 28 per cent; and Trap 30 in an area¹⁸ with a dense tree cover and deep and spongy leaf-mold. The slope above the last-named trap was variable, the trap being placed at the outlet of a small basin where it would receive the water from a considerable area if any general run-off occurred. While the slope was 52 per cent immediately above the trap, it was not more than 15 per cent across the basin itself.

¹⁸ Within a pasture but offering nothing at this point to attract cattle.

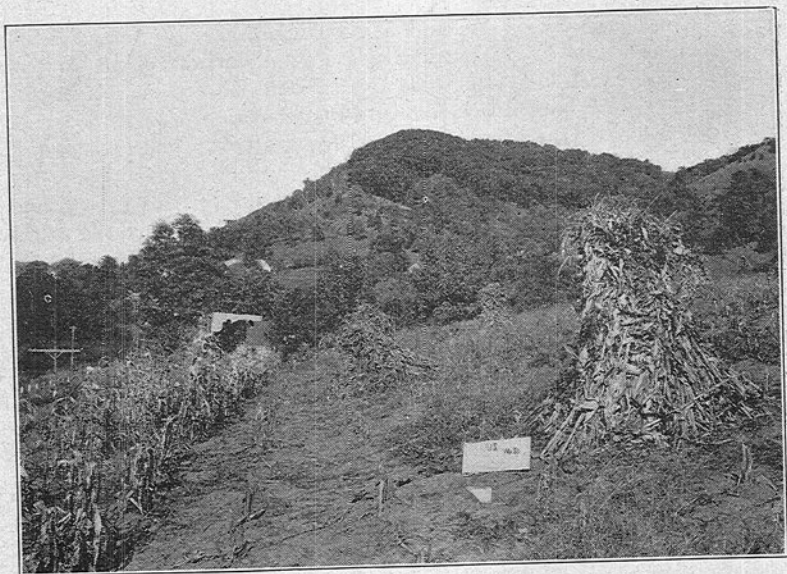


FIG. 35.—CULTIVATION OF CORN ATTENDED BY SEVERE RUN-OFF

Cultivation of corn on such a steep slope as this (28 per cent) was attended by severe run-off and much movement of the soil, despite the fact that the residual soil of the Mississippi bluffs shows itself to be strongly absorptive. The location of Trap 36 is shown. (See also Fig. 29, Trap 38).

The run-off from the forested area was negligible throughout the heaviest rains of the season, although in one instance 0.9 inch of water accumulated in the trap, probably coming from the few inches of exposed soil immediately above it. After moving the trap to a point where it could be set without encountering rocks in the soil, these small contributions of water from the "lip" were no longer received.

The run-off from the two pastured areas was also surprisingly small. A very sharp rain of 0.40 inches on August 7 gave for the closely-pastured area a run-off of about 10 per cent, the other trap not having been installed at this time. While both were in operation, the only rain giving appreciable run-off from either area was that of 0.61 inches on August 13, when the heavily pastured area showed three per cent run-off and the area with more grass four per cent. Such a difference can not be considered significant. During the slower heavy rains of the fall the soils above both traps absorbed the water very completely. Only traces of silt came into them.

Much different was the run-off from the cornfield, (see Figure 35) which, on August 7, with 0.73 inch of rain, filled the trap to overflowing and deposited 2.5 inches of soil therein. This represents a run-off of at least 21 per cent and probably much more, but this was a rain of extraordinary intensity. In the rain of August 13 the run-off percent-

age was less than five, but again with the 1.12 inches rain on September 13, about thirteen per cent ran off, and considerable silt was brought down. Although these showings are much better than those made under corresponding conditions with loess soil, run-off percentages as high as twenty indicate conditions unsuitable for cultivation of the soil, and speak for the retention of continuous vegetative cover on all slopes exceeding 20 per cent.

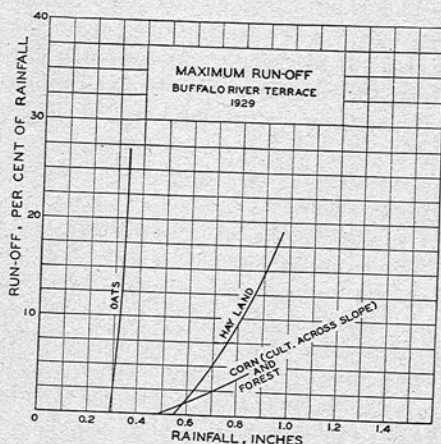
Run-off from Buffalo River Terrace

The series of seven traps maintained on a typical farm occupying the terrace of the Buffalo River, whose deep gullying tendencies have already been dwelt upon, was the most complete in a single locality and best shows the relations and interdependency of different parts of the farm, when the fields are so located as to utilize different sections of the profile to good advantage. (See Figure 36)

The cornfield on this farm was in 1929 located close to the outer or river edge of the terrace, and was a direct contributor to a gully which has been slowly eating its way back into the terrace through one of the larger gulches. The slope above trap 35 was about 14 per cent, and the last cultivation of the corn was across the slope. The oatfield, while still on nearly flat (seven per cent at Trap 19) ground, was near the inner edge of the terrace. Beyond it the slope increased in steepness toward a low-lying ridge. Forty feet from the lower edge of the hayfield, and about seventy feet from Trap 19, Trap 20 had a gradient of ten per cent. Trap 21 was at about the middle of the hayland, with a slope of fifteen per cent. Trap 22 was placed at the lower edge of the steep bank which demarked the upper edge of cultivation, having a slope of at least 60 per cent above it, for a few feet, then resuming the gradient of the forest area. The first trap

FIG. 36.—COMPARATIVE RUN-OFF FROM DIFFERENT FIELDS

(A farm on the Buffalo River terrace). This series represents most closely the normal or average relationship of different parts of the farm in this region, except perhaps that the hayland soil was not as receptive to water as it might have been.



(23) about ten feet inside the edge of the woods, showed 49 per cent gradient, while trap 24 about 100 feet from the crest of the ridge, was above the steepest slope with a gradient above it of only 30 per cent.

This series of traps was observed consistently from July 2 (except Trap 35, July 16) to the end of October, and especially in the early part of this period experienced a succession of very severe rains. Thus, July 3, 1.19 inches in seven hours; July 6, 1.33 inches in seventy minutes, following 0.34 inches earlier in the day; July 8, 0.97 inches in forty minutes, and July 13, 1.06 inches in thirty minutes more or less. These rainfall records were made in the open, while a separate rain-gauge under the cover of the trees between Traps 23 and 24 showed less than two-thirds of some rains reaching the ground. It is not to be assumed that more than a few hundredths of an inch of each rain were actually held on the trees, but the remaining intercepted water probably ran down branches and stems, with no beating force. This mechanical effect of forest cover is worth keeping in mind.

Owing to the fact that most of the severest rains came before the installation of Trap 35 in the cornfield, this kind of cultivation was not observed under such severe tests as were the other crops. It yielded small quantities of run-off with rains of 0.96 inch and 0.69 inch on August 28 and September 25, respectively, the latter yielding also an appreciable amount of silt, but at the worst the cornfield run-off can not be placed at more than two per cent. This remarkable showing must be ascribed primarily to the cultivation of the field across the slope when it was "laid by," or in short, to sane and rational farming.

Trap 19 in the oatfield was filled repeatedly by the early severe rains, being floated out of its pit on more than one occasion until provision was made to anchor it. This was partly due to the fact that the trap was located in a slight depression, but quite as much to the lack of humus in the soil at this point. As the smallest rain to fill the trap was one of 0.34 inches, its run-off in the depression must be placed as high as 27 per cent on an estimated drainage area of 100 square feet. After the cutting of the oats, and replacement of the trap in a different position, the greatest run-off (September 25) was at this same rate. The trap on several occasions received contributions of fine silt, but owing to the compactness of the soil, the quantities moved were always small.

In view of the last statement it is not surprising to find that both locations in the hayfield nearby, gave heavy run-off under the beating rains of July, while under the more mellow condition of the soil in September they were able to absorb even larger rains. The smallest rain to fill both traps was that of July 8, while the rain of July 6, which flooded the oatfield had practically no effect here. The run-off rate (with very great intensity of rainfall) was, therefore, at least 19 per cent for the hayfield.

The upper edge of the hayfield, despite the steepness of the ground immediately above it, was sufficiently shaded and otherwise influenced by the trees above as to yield only very light run-off. The largest quantity, in the 1.06 inch rain of July 13, represents only three per cent of the rainfall.

The two traps in the forest made an even better showing than the last, receiving in fact, no contributions during the entire season of more than one-half inch of clear water. If we were to charge this quantity to actual run-off, rather than merely to drip from the overhanging leaves, it would, relative to the rain of 0.69 inches on September 25, represent two per cent more or less. However, it can not be said that any run-off in the true sense occurred at these traps during the four summer and fall months. That the forest must yield some run-off under winter conditions is freely admitted, but it is seriously doubted whether it is a large percentage even then.

This closely related set of observations, together with those made elsewhere gives a very strong indication that on a well-handled farm, the greatest risk from erosion arises in those years of a rotation in which fields—even though essentially flat—are in small grain. There is better opportunity, through cultivation, to keep the surface soil of cornfields so receptive that only extraordinary rains will cause them to wash, and to make the last cultivation run counter to the direction of surface drainage, which is of very great importance. Hayfields on short rotation are not safe from run-off, although pretty well protected against erosion, and are in less danger if some of the growth is left uncut to protect the surface of the soil. On this farm the hayfield seemed to demand the protection which can be given by terracing. In this instance there was no pasture immediately above the cultivated fields, as is so often the case. The timbered area which occupied the higher ground had not been pastured or burned for many years, and was offering protection of immeasurable value to the fields below it, which is to say that the latter were in danger only from water arising within their own limits.

Run-off from Very Sandy Soils

The final group of erosion traps was placed in fields in a sandy area near the mouth of Waumandee Creek, while a single trap was placed about five miles east of Winona in an equally sandy area. The last-named had special reference to a somewhat critical road situation, caused by cutting a highway through a very sandy hill, surfacing it with clay and permitting the run-off from the road to flow a distance of about one-eighth mile through an unlined road gutter. Frequent observations on the road showed that only one-tenth of an inch of rain was required to start run-off while about .25 inches caused sufficient flow in the road-ditch to transport large quantities of the loose sand. (See Figure 10) In contrast to this the native grass sod of a

pasture only a few feet from the road, even with a slope of 26 per cent, yielded at the most 1.3 inches of water in a trap from a very sharp rain of 0.51 inches, a run-off of 8 per cent. All other rains during the period of observation were absorbed almost entirely.

In the Waumandee Creek area traps were placed early in the season as follows: No. 9 is open scrub-oak forest typical of light soils; No. 10 in cornfield; Nos. 11 and 12 in oatfields, these situations having slopes of 18, 19, 17, and 23 per cent respectively. The record may be briefly summarized by saying that, except in the cornfield, there was but one rain which gave appreciable run-off in any of the situations, this being a very rapid rain of 0.73 inches on June 28. This filled the trap in the cornfield, and the flatter of the two oatfields, but fell somewhat short in the steeper oatfield where the soil was very light indeed. The trap in the woods on this occasion collected a bare pint of water. Owing to the floating of the traps it is impossible to make an estimate of the silt removal in this rain, but it was obviously much greater in the cornfield than elsewhere, as the field was gullied in every furrow. The two fields, then, probably gave run-off of 25 per cent or better, while the more accurately-measured rate for the sandiest field was 18 per cent. This is obviously much less than could be expected with any other type of soil. The cornfield continued to yield small quantities of run-off with later rains of 0.44 inches and 0.34 inches, but the percentages were much lower than that indicated above.

To complete the series for this type of soil, additional traps were placed in open natural grass-land near the cornfield, and on a steep north slope under timber where the density of the cover and condition of the soil were more typical of effective forest conditions. Neither of these situations at any time yielded more than insignificant quantities of water and no actual run-off was indicated. It must be admitted, however, that this locality, with the exception noted for June 28, apparently received none of the very hard beating rains which were experienced elsewhere.

Summary of Trap Records

It will be seen by reference to Table IX that with the exception of the limited area studied in the North Bend district, where the maximum run-off percentages for three situations averaged 45, the loess soils in the Galesville district and near Winona, Minnesota, have the highest averages for all sites, 17 and 19 per cent respectively. These averages are, of course, only suggestive, as no attempt was made exactly to duplicate the series of set-ups in each locality. The Buffalo River terrace soils came next in order, their relatively low figure of 11 per cent bearing out the contention that this class of soils is not so much subject to surface erosion as to undermining. The porous soils of the Mississippi Bluffs, with the exception of the cornfield, gave

very low run-off, averaging only nine per cent with the cornfield included. The group of sandy soils would probably in a long average, come lowest in the scale, but was subjected to one very hard rain during which the cornfield and oatfields in this group came well up to the general average. This is the usual story of sandy soils—they appear quite safe until the extreme rain is experienced, when they literally “float away.”

More important still is it to compare the average figures for different uses of land, as given in Table X.

TABLE X.—SUMMARY OF MAXIMUM RUN-OFF RATES
UNDER DIFFERENT COVER CONDITIONS

Character of cover or class of land use	Number of examples	Average maximum run-off percentage
Forest		
Wild pastures (native grasses)	12	2.8
Cultivated hay	5	7.2
Small grain and fallow	3	17.7
Cornfields	6	25.6
Seeded pastures, mostly blue-grass	6	25.7
	7	26.7

Seeded pastures, due to close cropping, packing of the soil, and in general to steeper slopes than prevail in the fields, are probably the largest contributors of run-off water. Their importance as gauged by the maximum run-off figures is accentuated when it is realized that they also yield run-off from smaller rains than are required to start activity on cultivated lands. Wild grass pastures make an excellent showing in comparison, partly due to the fact that the selection here was largely on porous soil types, but undoubtedly due also to the fact that their soils have never been “puddled” by working, and the humus has been left entirely at the surface where it can have the greatest effect. Hence they maintain a more natural porous character despite the trampling which they receive.

Both corn and small grain fields are large contributors to run-off, and stand out as even more menacing than pastures because erosion actually goes on within them. Because of their erodability grain fields should not be expected to carry the additional burden of run-off from pastures located directly above them. Haycrops lying above the fields, while they have not in these few examples made an especially strong showing, are believed, when not cropped too closely, to represent the best protection for open fields except only the forest itself. The showing of most of the timbered areas in this investigation speaks for itself. Wherever the land was devoted primarily to timber-growing, the run-off was negligible from summer rains. There is as yet no information which can be used in this connection to show to what extent they keep up this showing when the ground is everywhere frozen.

VI. THE CONTROL OF EROSION

IN GENERAL terms, soil erosion is caused by water running from higher to lower levels over the surface of the ground. Erosion control therefore, means either decreasing or diverting the run-off, or both. Thus, the possible methods are:

1. Reducing the run-off by making the soil more absorbent.
2. Keeping the soil covered. A rank growth of vegetation also slows up the run-off and causes more of it to be absorbed.
3. Holding and diverting the water along courses having such a small gradient that no damaging erosion occurs. This principle is employed in terracing.
4. Conveyance of water from higher to lower levels in artificial channels. This principle is generally applied in disposing of concentrated run-off from fields and in checking deep gullying.

1. Reducing the Run-Off by Making Soil Absorbent

The absorbing power of soils can be increased by improving the underdrainage, by certain cultural practices, and by the increase of organic matter and improvement of tilth.

Underdrainage of soils can be somewhat improved by the growing of deep-rooted crops or crops with a tap root such as alfalfa and clover. The decaying roots leave channels that promote percolation of water.

Absorption of water can be encouraged by cultural practices. Deep plowing conforming nearly to contour lines slows up run-off and increases absorption of water. This is especially effective if a reversible or side hill plow is used and the furrow slice always thrown up hill. This position of the furrows causes a larger amount of water to find its way into the soil. The incidental benefit of this plowing is that the mechanical movement of the soil up hill partially counteracts removal to lower levels by erosion. Intertilled crops ought to be planted on contour and cultivated only on contour.

Increase of organic matter and improvement of tilth by manuring and plowing-under legumes or hay crops promotes absorption of surface water to a remarkable extent. But to obtain permanent increase in organic matter under field conditions is a very slow process at best, and frequently on soils subject to erosion little progress can be made in this direction unless the erosion is first checked by some mechanical means.

2. Keeping the Soil Covered

Land utilization on farms of Wisconsin involves growing limited amounts of cash crops, hay, corn, and grain as feed for livestock and pasturage for cattle. The prevailing rotation is corn, grain,

clover one year, or clover and timothy hay two years. A longer rotation in more limited use is corn, grain, and alfalfa for three to five years. The first rotation is suitable for soils with a slope up to 10 per cent, provided good soil management methods are used. On land in the steeper part of this classification, especially if on long slopes, special care in cultivation and use of erosion control devices is desirable. Land with 10 per cent to 15 per cent slope used for farm crops ought to be in the longer rotation including alfalfa. Land steeper than 15 per cent ought to be kept in permanent pasture.

If farmers would study their soil problems and production costs, and apply the obvious remedy they would come to these standards more nearly than at present. They are accustomed to extensive practices, whereas more intensive use of land would be just as profitable and better from the point of soil conservation. For instance, many farmers attempt to pasture some very rough stony land that is too droughty to justify such use. To make a large number of crop acres, they use areas of steep land suitable only for pasture. Following a soil improvement program, the same amount of cash crops and feed for livestock could be grown on fewer acres of the leveler land. The rougher parts of the land now cultivated should be added to the better parts of the pasture, the feeding quality and capacity of which can be greatly improved by proper fertilization and management. This would release the roughest land for timber.

The farm need attain no greater total production, but the net profits will be greater. The cost of better fertilization will be offset by less labor and wear on machinery, and the value of the rough land will increase with the growth of timber. The increase of the proportion of forest would in itself have an important effect in reducing the erosion problem. On some farms this plan can be materially aided by the tile drainage of flat bottom land.

After the land is put in use as here suggested, some other principles of good management need to be followed. On side hills of any considerable length, fields ought to be laid out in long, comparatively narrow strips across the slope, so that the land in intertilled crops will alternate with strips in hay. This reduces the area most subject to erosion and gives run-off little opportunity to collect. Rotations with the maximum of sod crops and the minimum of intertilled crops should be used. Permanent sod strips should be left in the depressions or side-hill runs where considerable volumes of water collect and flow down the slopes. Such strips build up when the field is in intertilled crops and washes may start at either side of the sod. This trouble is reduced by plowing several furrows through the sod strip every few rods, leaving the sod in long patches rather than in a continuous strip.

All of these cultural and rotation practices have been advocated for years and adopted by many farmers, but it is apparent even to the casual observer that soil is wasting away much too rapidly. Much

sloping land is still being used in a manner which will make it absolutely useless in a few years. Mechanical control methods described in the following pages will have to be more generally adopted as supplements to present practices.

Some practices only recently inaugurated should be discontinued. For instance, clean continuous cultivation of fields during the spring months in preparation for alfalfa seeding in June ought to be avoided on all rolling land. The damage to the soil is much greater than any possible gain. Summer fallow for weed eradication on rolling land should invariably be preceded by terracing.

3. Holding and Diverting Run-Off Water: Terracing

Terracing farm lands to prevent erosion and conserve moisture has been practiced in the south Atlantic and Gulf states for upward of forty years. The practice has gradually spread northward in the Mississippi Valley and is at present expanding rapidly in the corn belt states. Enough terracing has been done in Wisconsin in the last few years to prove that this practice has an important place in soil conservation in large areas of the state. Only the broadbase graded terrace has been tried and the discussion herein is limited to that type because it appears the best adapted to the climatic and soil conditions.

This terrace is a flat ridge of earth like a steeply graded road or an extra large back-furrow from 15 to 20 or more feet wide at the base, built nearly on contour lines, around or across the slope. Above the ridge is a flat, broad channel, shaped like a very wide dead furrow. (See Figure 37) The crest of the ridge is from 15 to 24 inches above the bottom of the channel or waterway. These terraces have enough slope along their length to discharge the water to an outlet. The shape is such that the terraces can be cropped. It is admitted that they offer more obstruction to implements than a smooth field, but they are infinitely less inconvenient than the numerous little gullies and washes that occur on the sloping fields. The protection to the growing crop, the conservation of moisture, plant food, and the soil itself is net gain.

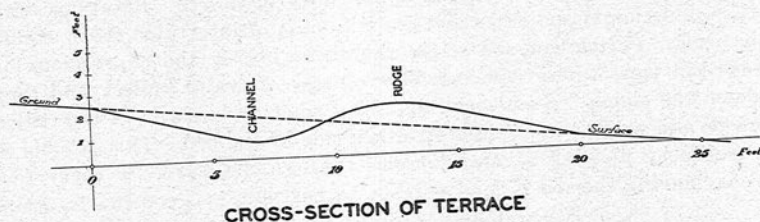


FIG. 37.—TERRACE CROSS SECTION

Cross-section of a terrace showing height and width which should be striven for in grading the field.

Terraces Control Run-Off and Reduce Sheet Erosion

The power of flowing water to cut soil increases very rapidly with increased velocities. For example on land with a slope of eight feet, water flows with about twice the velocity that it does on a two-foot slope. Doubling the velocity increases the cutting power 64 times. The increased volume of water and the cutting tools of soil particles in suspension furnish the cause of the maximum erosion near the foot of the steep slopes.

Terraces control this run-off because they are spaced in a series like steps down the slope, each taking its share of water before the total quantity becomes large enough to do damage. Since these terraces are built with a very flat slope, the water that each traps is carried in a broad slow-moving stream to the side of the slope without damage to the field. This slow movement keeps the water in the field for a longer time, causing more of it to soak into the soil and reducing the run-off and damage to the lower lying land.

Outlets for Terraces

The first and frequently the most difficult problem in the design of a system of terraces is a suitable outlet. The cheapest satisfactory outlet is a permanent pasture or wood-lot high enough up the slope on the side of the field to permit emptying each terrace beyond the edge of the field. Frequently a natural draw or drainage channel can be left in permanent sod and used as an outlet. Sometimes it is necessary to provide an outlet along the edge of the field. If the slope is not too long nor steep the best cheap structure is a road-grader ditch a rod or more wide and about two feet deep. This ought to be sodded before the water from terraces is discharged into it. The strip of sod serves also as a headland.

Sometimes active gullies must be used as outlets. To prevent branching of the gully at each terrace outlet, it is necessary to carry the water over the lip of the gully to the lower level by means of a sheet metal or other flume or some other erosion-resistant conduit. Frequently it is cheaper to fill the gully partially by soil-saving dams. A practice frequently followed has been to install soil-saving dams in the main gully and empty the terraces over the narrow useless points of land left between the branches of the gully. As these points are cut back, the soil is trapped by the soil-saving dam as fill for the gully. After the margins are made more regular and the slopes more gradual by this cut and fill, sod strips can be made for the outlets of the terraces. It is better to utilize the smallest number of gullies possible in this way and fill the balance by temporary dams and terracing.

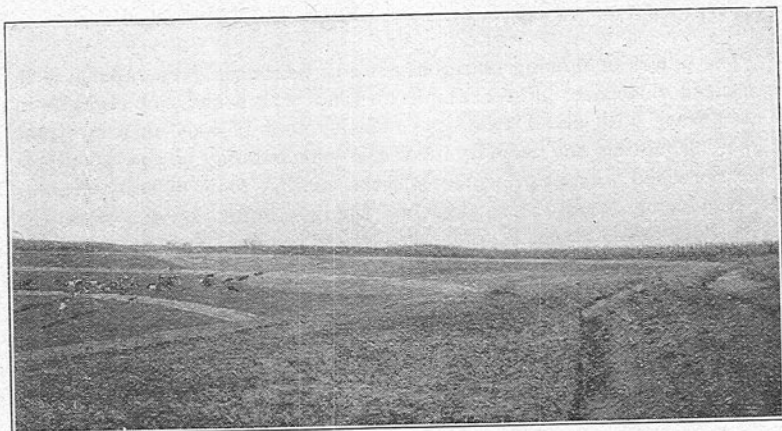


FIG. 38.—TERRACES FOLLOW CONTOURS

They have only a very slight slope toward their outlets. The need for terracing this field can be seen in the gullies forming near the cattle.

Location of Terraces

The determining factor in locating the first terrace is some critical point. This may be the outlet, head of active gullies, sink holes in limestone regions, rock points, location of buildings or barnyard or some other controlling physical feature. Locate one terrace with reference to such critical points if any exist and then space other terraces above and below it. In the absence of critical points, locate the upper terrace at the desired interval below the crest of the slope and then place the other terraces below at the proper intervals.

The lines of terraces are located by the use of a surveyor's level and rod. They are marked by stakes set at 50-foot intervals and occasionally at shorter intervals where the ground surface is very irregular. The slope of rolling land is deceiving to the eye and terraces laid by "guess" are certain to be unsatisfactory and more expensive in the long run.

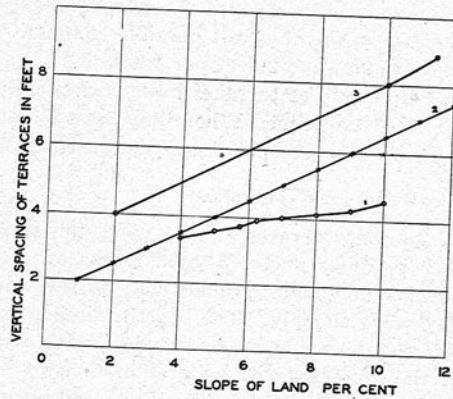
If the contour were followed where terraces cross small gullies or washes in a field, it would bring the terrace to a sharp point. This is objectionable, both because of inconvenience and danger of breaking. If the terrace is run nearly straight across such depressions, it is necessary to put in an extra fill with scrapers, otherwise a low joint will be left in the "ridge" just where the most water comes down the slope.

Spacing of Terraces

Figure 39 illustrates the variety of standards used in spacing terraces. The outstanding feature is the lack of consistency with reference to geographical location, differences in precipitation, character

FIG. 39.—SPACING FOR TERRACES

Standards followed in different parts of the country for spacing terraces. Curve 1, for tobacco fields and other soils very susceptible to erosion; curve 2, standard for loam and silt-loam soils; curve 3 standard for sandy loam soils.



of the soil, etc. In the absence of fixed standards, an effort has been made in Wisconsin to classify soils with reference to resistance to erosion, and adapt different spacing standards to different soil conditions. For instance fields used for tobacco growing are made and kept extremely loose and friable by the incorporation of enormous amounts of barnyard manure. Regardless of original soil type, these fields have been very much modified by cultural practices and fall into a distinct type with reference to susceptibility to erosion. For such soils the standard of curve 1, Figure 39, has been used. The general farming soils most susceptible to erosion are the Knox silt loam of southwestern Wisconsin and the loam soils. For these soils standards approximating curve 2, Figure 39, have been used. For the sandy loam soils and other soils more resistant to erosion, the greater interval shown in curve 3, Figure 39, has been used. The upper terrace ought to be located the same distance below the crest as the spacing between terraces, or at the upper limit of erosion. It is important to divide the water by terraces before the volume becomes excessive.

Slope and Length of Terraces

In some southern states terraces are laid level in order to hold all of the rainfall on the field. Since deep freezing of soils in winter prevents percolation in the early spring, such terraces are not practical in Wisconsin except on permanent pastures where the terrace is sodded.

The variable gradient has been generally used. The lower 200 to 300 feet of terrace which must carry the largest volume of water is given a slope of six inches or slightly more per 100 feet, the next 200 to 300 feet 5 inches per 100 feet and so on upward, reducing the gradient one inch per 100 feet for each 200 feet up the line. Frequently the 200 feet at the head has been left level. When terraces are used to divert the run-off from areas of higher land, the maximum safe

gradient is used because the purpose is to dispose of a large volume of water in the cheapest possible channel. Trial has proved this slope to be from $1\frac{1}{2}$ to 2 feet per 100 feet.

The length of terraces built with standard cross section ought not to exceed 1200 feet. When they must be built longer, the terrace ridge ought to be correspondingly increased in height.

The Building of Terraces

Building terraces is work very similar to grading a road. The small patrol grader and two good teams or a tractor are commonly used. The larger tractor graders will do the work more quickly and generally more cheaply. The Martin ditcher is frequently used. Terraces can also be made by repeated plowing with back-furrow at the crest of the terrace. The general method of building the terrace and reducing the amount of subsoil exposed is shown in Figs. 37 and 40. It is preferable to work soil into the terrace from the upper side only. If much earth is worked into the terrace from the lower side, the slope is necessarily made steeper or more labor is required. The secondary channel formed below the terrace discharges water into the small ravines and thus keeps the washes between terraces. Subsoil exposed on the lower side of the terrace is not as readily covered as the subsoil exposed in the channel above the terrace.

The low spots that occur where the terrace crosses ravines or other depressions ought to be built up with a scraper to prevent overtop-

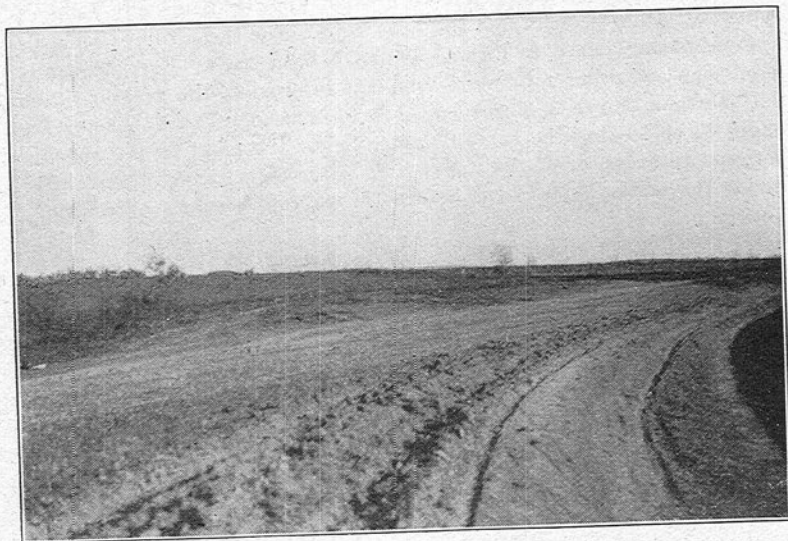


FIG. 40.—THE GRADING OF A TERRACE IS SIMILAR TO ROAD-BUILDING ON GENTLY SLOPING GROUND.

Work may be done with road machinery. A good terrace does not interfere with cultivation, but contour plowing, parallel with terraces is preferable to crossing them.

ping. Extra height at such points is good insurance. Check the finished terrace by moving down the slope until the eye is level with the top of the terrace. The crest ought to be nearly a level line.

Land Adapted to Terracing

When the farmer decides on erosion control he usually wants to terrace his roughest, steepest field on which the damage is obvious. This is often too steep to be in any crops except hay and permanent pasture. He does not realize that the damage to relatively gentle slopes, although less obvious, is great enough to justify the cost of terraces. The most satisfactory results from terracing have been obtained on land sloping from five to ten feet per 100 feet. It is possible to terrace land with a ten to fifteen per cent slope and the results are good if contour farming is practiced in conjunction.

The terracing of tobacco fields can be unqualifiedly recommended even where the slope may not be over two or three per cent. It appears that level terraces are justified on permanent pastures merely as a soil conservation measure. Most orchards in Wisconsin are grown on rolling land. Planted orchards are difficult to terrace. The land should be terraced before the trees are planted. On the steeper parts of the ridge land the rows ought to conform to the terraces.

Maintenance of Terraces

The time of constructing terraces is, except on pastures in rotation, limited to short periods in the spring and fall. These are not ideal times to build terraces. In the spring there is the rush of seasonal work and the resulting tendency to slight the terracing job. Terraces built in the late fall freeze before they are thoroughly settled and as a result are easily damaged by the spring thaw. These limitations make some repair work necessary soon after the original construction. This rarely exceeds one-fourth of the original work. The best place in rotation to terrace a field is before the grain seeded to clover or alfalfa. Then the terraces will be thoroughly established before an intertilled crop is grown. If corn is to be planted on the freshly terraced field, the terraces ought to be built somewhat higher. Each year after corn is grown in the rotation repair work to the extent of one-fourth to one-third of the original construction will be required. During the years of small grain and hay crops repairs are seldom found necessary.

On slopes up to ten per cent, terraces are usually disregarded in cultivating, even with intertilled crops. On slopes approaching fifteen per cent, plowing ought to be on contours with the back-furrows on the terrace. On any land care must be used where dead furrows cross the terrace.

The Cost of Terracing

The first cost of terraces built in Wisconsin has ranged from about \$1 per acre, where a large grader was used, to a maximum of about \$4. The item is largely labor and in the long run is far less than the labor spent in filling gullies. The conservation of fertility, the soil, and moisture is net profit.

4. Conveyance of Water from Higher to Lower Levels in Artificial Channels

Temporary Dams Applicable to Small Gullies

Some small gullies are formed as the result of carelessness in cultivation, by improper direction of crop rows, location of cattle paths, wheel tracks, dead furrows, etc. The small gullies formed as a result of such minor causes or incidents can readily be filled mechanically with plow, or plow and grader, and the larger ones by installing temporary structures that will promote fill by sedimentation. The most common method of filling small gullies is to place a layer of straw, corn stover or manure in the bottom and roll earth on to it by plowing from the sides. Sometimes a grader or road drag is used in addition. The fill should be made higher than the land on either side to prevent its cutting out with rain while the soil is loose. Temporary dams for the larger gullies that fall in this class can be made of straw, poles, stakes and brush or woven wire fencing. Several general principles must be followed in building any of these struc-

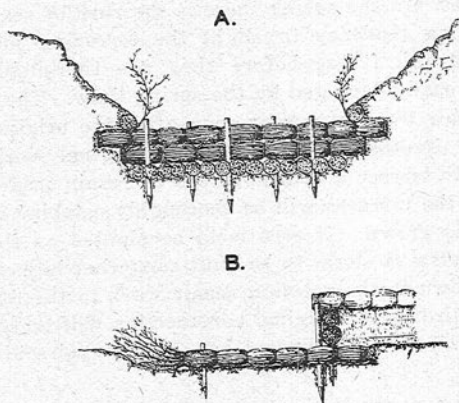


FIG. 41.—BRUSH DAMS

Substantial, but still temporary brush dams for assisting in the collection of soil in shallow gullies. Willows bound into bundles.

THE BRUSH DAM—A TEMPORARY FORM OF PROTECTION.
MAY BE BUILT WITH ADDITIONAL STAKES AND LOOSE BRUSH.

tures, which are illustrated in Figure 41. (1) Use only low heads, not over two to three feet. (2) Build the sides well into the banks of the gully and some distance up the slopes to prevent cutting around the dam. (3) Build the dam low in the center to provide a spillway. (4) The material should be thatched on the downstream side to form a gradual descent and avoid a damaging waterfall. (5) Fasten the straw or brush in place by nailing cross bars or by wrapping heavy wire to posts that were set in a line across the gully on the site of the dam before placing the straw or brush. (6) Get the gully sodded before this temporary material decays. Since these structures require labor and are only temporary, they are suitable only where the gullying is the result of minor causes of erosion or to secure fill where further gullying will be prevented by terracing.

More Permanent Structures for Large Gullies

When a large active gully must be controlled, temporary structures are ineffective and, if used consistently enough to give results worth

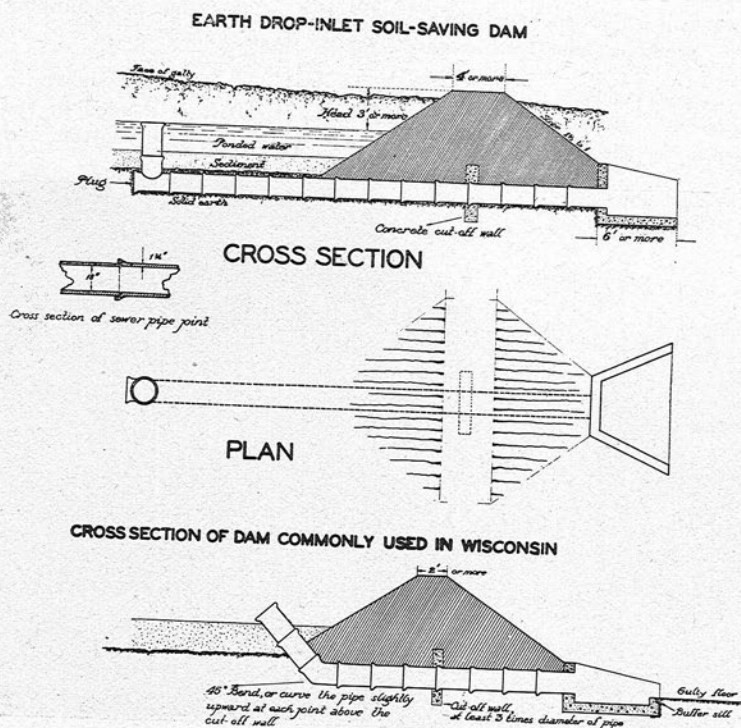


FIG. 42.—STANDARD AND WISCONSIN DESIGNS OF EARTH-FILL SOIL-SAVING DAMS

They are based on the use of sewer pipe. Where large capacities are required use monolithic concrete.

mentioning, will, over a period of years, cost more than permanent structures.

Earth-fill Soil-saving Dams

In the extension work in erosion control in Wisconsin, the soil-saving dam built with erosion-resistant conduit through the earth-fill has been stressed much more for this purpose than other structures because it is:

- 1) The cheapest permanent structure.
- 2) It can be used to fill gullies by sedimentation. This feature is important because the farmer ordinarily does not start systematic erosion control until he has a gully that is bad and needs filling. Many men must discover the cost of repair before they appreciate the value of prevention.
- 3) Raising the head of the earth dam is simple and can be done whenever needed.
- 4) Control of the erosion at the outlet of the pipe is a simpler problem than from notched overfall dams.

A cross section of such a dam as commonly built is shown in Figure 42. Run-off water bearing its load of silt is ponded in the basin above the earth dam. Most of the silt settles to the bottom and



FIG. 43.—THE WISCONSIN TYPE OF EARTH FILL DAM

This requires two 30-inch pipes to carry the expected maximum flow of water. The pipes are laid in the sloping banks, with a gradual ascent, so that the danger of their settling is reduced to a minimum.

the top layer of water flows into the inlet and down through the pipe into the gully below the earth dam. When the settling basin is filled to the top of the inlet pipe, another section of pipe is added and the earth dam raised by an equal amount, unless it was built to the desired height in one operation.

Essentials of successful construction of soil-saving dams:

1. The pipe must be leak-proof. Sewer pipes with cemented joints are commonly used. The number 2 grade are satisfactory. For large structures, reinforced monolithic concrete is perhaps best.
2. Put a concrete cut-off wall around the pipe under the dam to prevent seepage along the pipe.
3. Secure water-tightness around the pipe by shaping the bottom of the trench carefully to the pipe and by tamping earth well around the pipe.
4. Use pipe large enough to carry the water. See Table No. XI for sizes.
5. Build earth dam at least three feet higher than inlet into the pipe.
6. Provide a spillway on solid earth around the dam for excessive rains by building the earth fill higher than the banks of the gully and at least as high as the highest water expected.
7. The earth-fill dam should be covered with vegetation at the earliest possible time to protect it from washing. Sodding the down-stream face and top of dam is the simplest and quickest covering.

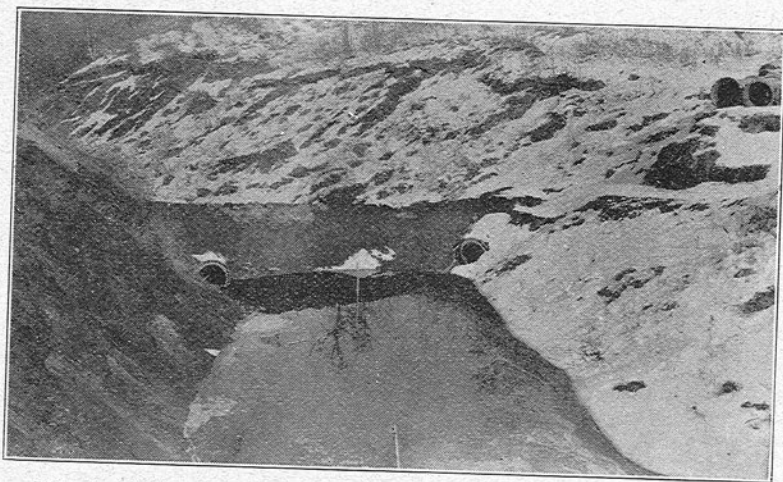


FIG. 44.—SAME DAM SHOWN IN FIGURE 43 WHEN FILLED WITH WATER FROM MELTING OF SNOW

The soil-saving feature of these dams is entirely dependent on sufficient ponding-space to permit the silt to settle. Consequently both dam and pipes, should be raised, as the space fills with mud. Rains during April and May have filled this gully with sediment to tops of the stakes seen in the pond. The intake pipes and dam have been raised 4 feet.

Good judgment in selecting the sites may save considerable labor and expense. Frequently, a dam can be located where it serves as a road to an inaccessible part of the farm. Find a place below which the gully floor is stabilized to avoid danger of serious undermining from the outlet end. Even at such locations, some provision must be made at the outlet of the pipe to dissipate the energy of the rushing water. A concrete spillway with a sill at the lower end as shown in the cut is excellent. This had better be cast separate from the pipe because it will be differently affected by frost. Brush and rock aprons are also effective. Select a narrow point in the gully, if available, to reduce the amount of required fill. Above all, find a place that affords a good firm uniform foundation for the pipes. Settling that causes breaking of pipes or joints will prove disastrous.

In building the dam, make every effort to secure watertightness, especially if the head is over eight feet. Clean all trash and growths of weeds and grass away from the site of the dam to prevent leakage under the dam. The fill can best be made with teams and scrapers in layers to secure maximum tamping by the horses feet. Moderately wet soil packs better than dry soil. Mere thickness of fill and weight make for water tightness. Sedimentation seals the minor imperfections if care was used in clearing the site, and good judgment was used in selecting and shaping the foundation to the pipe and tamping earth next to the pipe.

In Wisconsin a modification of the empirical design has been used with good results for a couple of years. (Figure 42) The essential difference is that at about two-thirds of the thickness of the dam from the outlet end, the pipe is curved upward at an angle of 35 to 45 degrees. This is done by a manufactured curve or by bending the pipe slightly at each joint. Advantages of this design are:

- 1) Less pipe is required.

TABLE XI.—SIZE OF CONDUIT PIPE FOR EARTH SOIL-SAVING DAMS

Acres in Drainage Area	For Heads up to 6 feet. Earth Fill at least 3 Feet Above Intake	
	Cross-sectional area in square feet	Diameter of Pipe in Inches
7	.55	10"
10	.79	12"
17	1.23	15"
25	1.77	18"
31	2.41	21"
43	3.14	24"
55	3.98	27"
67	4.91	30"

Capacities given are for 1 inch run-off per hour.

For the rare occasions when this will be exceeded, an auxilliary spillway ought to be provided.

If a head of over 6 feet is obtained at installation, the horizontal pipe may be reduced to the next smaller size. Larger capacities can be attained by using a funnel shaped intake.

- 2) The slant of the inlet prevents eddies and reduces the danger of eroding the upper face of the earth dam.
- 3) There is less danger of the pipe becoming clogged at the bend.

A necessary precaution in making this installation is to secure a firm foundation for the slanting part of the pipe. This has usually been accomplished by laying the horizontal pipe into the heel of the gully and working gradually outward as the top of the gully was approached. In this way, solid undisturbed earth is used for foundation.

Since the size of pipe varies directly with the size of watershed, the cost of material can readily be estimated from the size of the watershed. This usually ranges from \$4 to \$5 per acre of watershed. The item of labor varies. With good working conditions, two men can place about fifteen 24-inch pipes in a day and pour the concrete collar. The cost of fill will vary with the size of gully, ease of getting earth, kind of scrapers, experience of men, etc.

Since the cost of gully control is considerable, select only important outlet gullies for control work. Build good control works at these critical points. Utilize them as outlets for terraces built to control small gullies and tendencies to gullying on the area served. In gullies with numerous branches, it is usually possible to stop the heads by terracing around them and emptying the water over the narrow tongues of land between the branches. This serves the double purpose of preventing advance of the gullies and securing fill for the large gully.

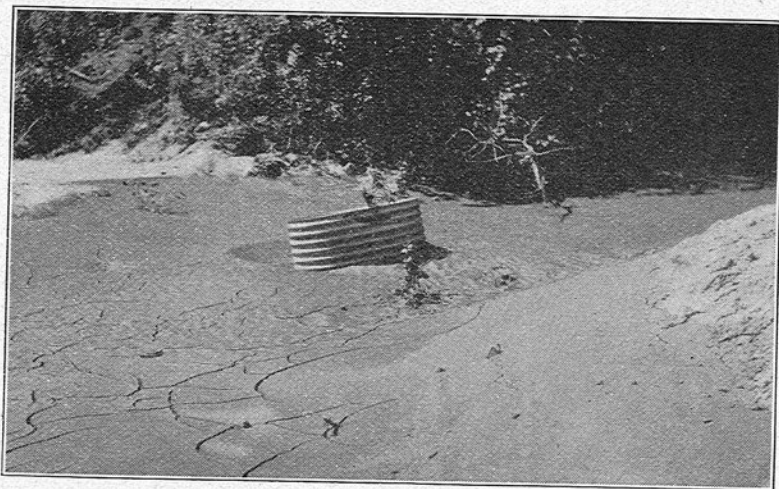


FIG. 45.—SOIL SAVING DAM WHICH AFTER TWO YEARS HAS PRACTICALLY BEEN FILLED BY THE WASHED-IN SOIL

Not only has the ponding capacity been reduced to almost nothing, but the dam itself (right) is in danger of being overtopped by a sudden rush of water, and needs to be raised.

Other Permanent Structures

Any dam which impounds run-off water even temporarily is a soil-saving dam and this feature may be enlarged or minimized according to the size of the basin. The run-off of large watersheds may be of such large volume that masonry or concrete spillway dams offer a cheaper solution than the soil-saving dam described above. These larger structures of durable material will recommend themselves, if not to the farmer, at least to public agencies which may attempt erosion-control work. Accordingly there are presented a number of suggestions which have largely grown out of varied experience in older countries, beginning with the simplest designs and following through to the most stable form of masonry dams adapted to comparatively large channels. The choice of materials to be used will, of course, depend not only upon the local requirements for strength and permanence but also upon the relative availability and cost of timber, stone, cement, and sand, and the cost of skilled and unskilled labor. No attempt will be made to go into the technical details of these structures except as they may be suggested by Figures 47 to 51

When the important aspect of erosion is the cutting of stream banks along otherwise settled channels, the methods suggested in Figures 52 and 53 will be found applicable.



FIG. 46.—A HIGHWAY CULVERT WITH A DROP-INLET FIFTEEN FEET DEEP
This serves exactly the same purpose as a soil-saving dam and is very worth-while to the adjacent land-owner since the gulch has filled in the few months since this was completed.

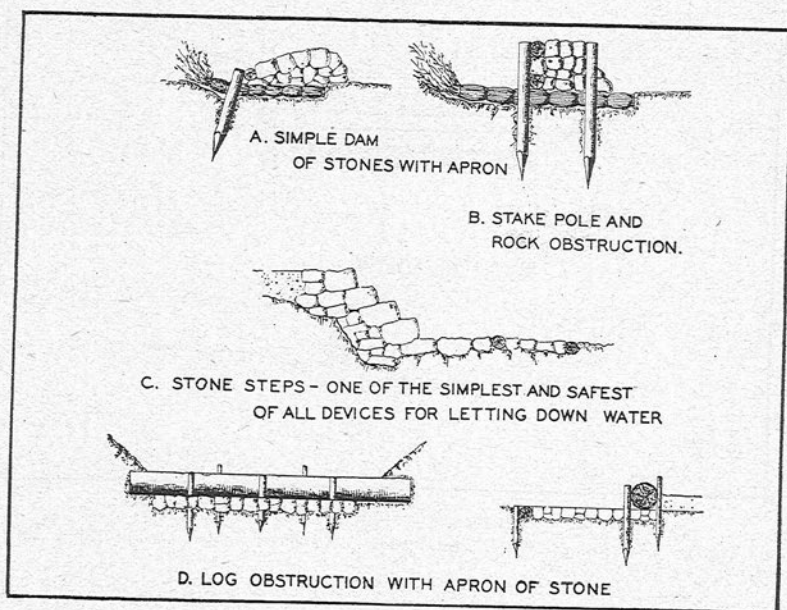


FIG. 47.—SIMPLE BUT PERMANENT STRUCTURES FOR IMPEDING THE FLOW
IN SMALL CHANNELS
They also prevent cutting or cause filling.

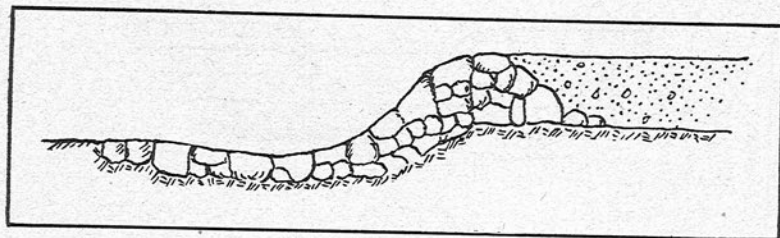


FIG. 48.—EXCELLENT DESIGN FOR SMALL RUBBLE DAMS
When the soil has filled in behind them, they become a permanent part of the drainage
system, taking up the force of falling water.

Flumes

A peculiarly American development for conveying water from higher to lower levels, particularly at the heads of gullies and over steep banks where the fall is short and direct, is the flume or corrugated iron pipe. Flumes may be made either of strong sheet-metal or planks: flumes and pipes serve exactly the same purpose but do not in any sense take the place of soil-saving dams, although their use may quite effectively check the advance of a gully, or the formation of a new one when it becomes necessary to concentrate a good

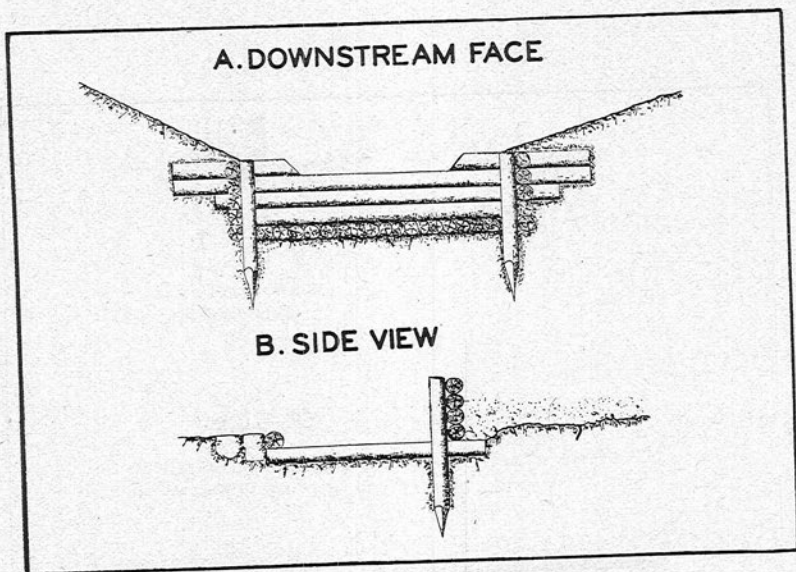


FIG. 49.—MODERATELY PERMANENT SMALL DAM

This is constructed entirely of small timbers. An effective apron for the falling water is here illustrated.

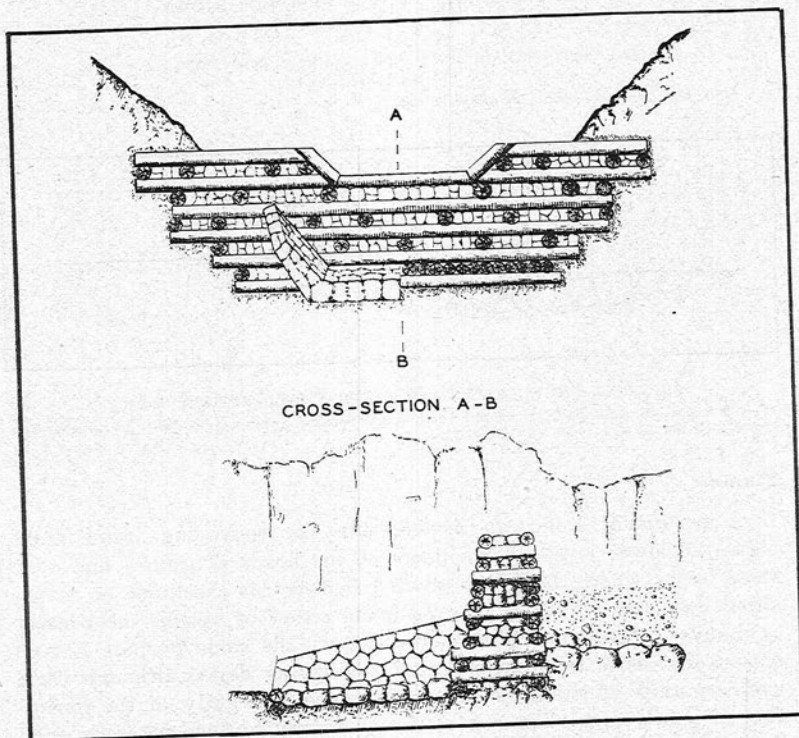


FIG. 50.—THE ROCK-FILLED LOG-CRIB DAM

This will recommend itself for a structure of moderate to large size where both timber and small stones are available as in most of the so-called "limestone runs" of southwestern Wisconsin. The character of the spillway, narrow or wide, should be determined by the character of banks to be protected from running or splashing water.

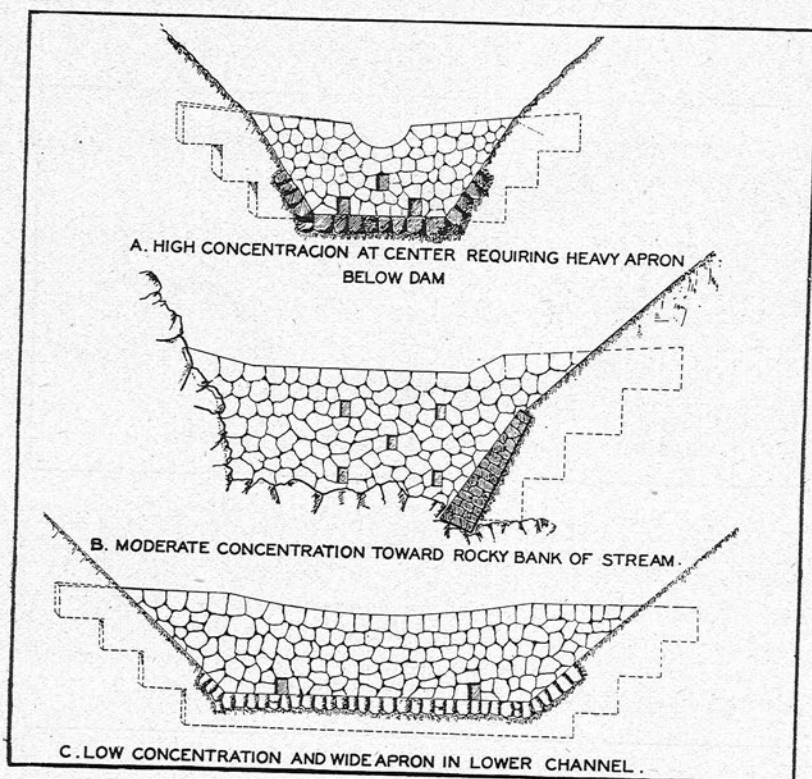


FIG. 51.—RUBBLE OR SOLID MASONRY DAMS

These are recommended where considerable height is necessary, and where the foundations and banks are firm. The varied types here illustrated all provide for the seepage of part of the water through openings in the lower part of the dam. Character of spillways determined by the character of soils and rocks found at the sides, so that banks are adequately protected.

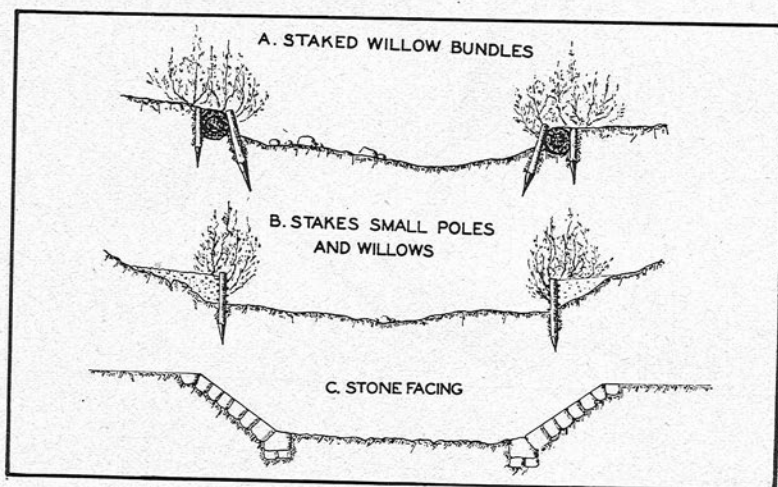


FIG. 52.—SIMPLEST FORMS OF BANK PROTECTION

These are suitable for temporary streams which have begun to cut through the sod of pastures, etc.

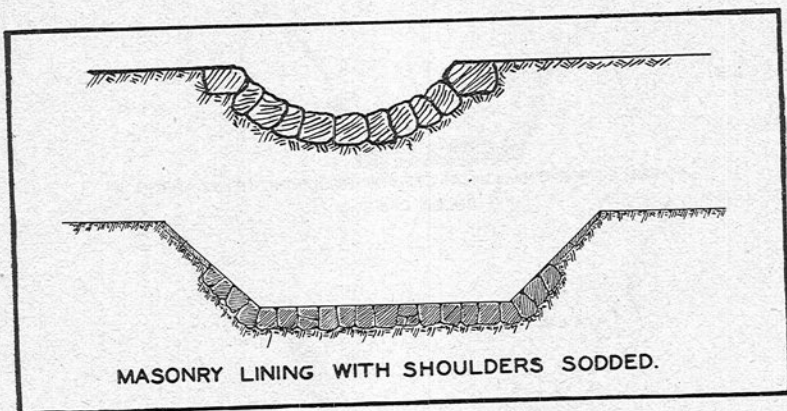


FIG. 53.—ROCK-LINED ARTIFICIAL CHANNELS

These are especially designed for steep slopes, or for carrying water from terraces or pavements, where there is no natural channel. They are sometimes used to protect natural channels where the value of the adjoining property justifies them.

deal of water in one gulch, as at the outlets of terraces. Where water must be conducted a considerable distance down a slope, a rock-lined channel such as is illustrated in Figure 53 will probably prove cheaper in most situations than a metal or plank flume.

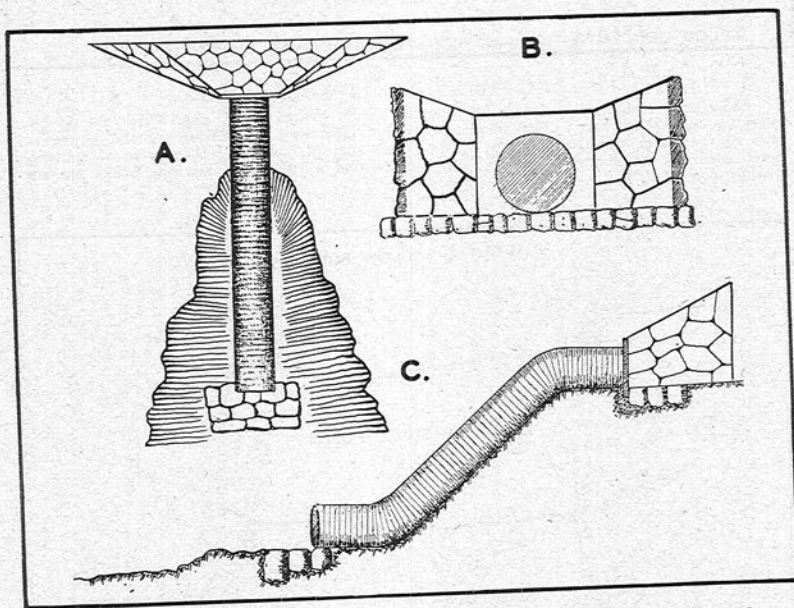


FIG. 54.—THE CORRUGATED IRON PIPE MAY BE USED FOR DROPPING THE WATER FROM THE HEIGHTS

This design shows safe intake provisions but inadequate apron at the bottom. An improvement would also be a flare in the pipe at the intake to increase the capacity.

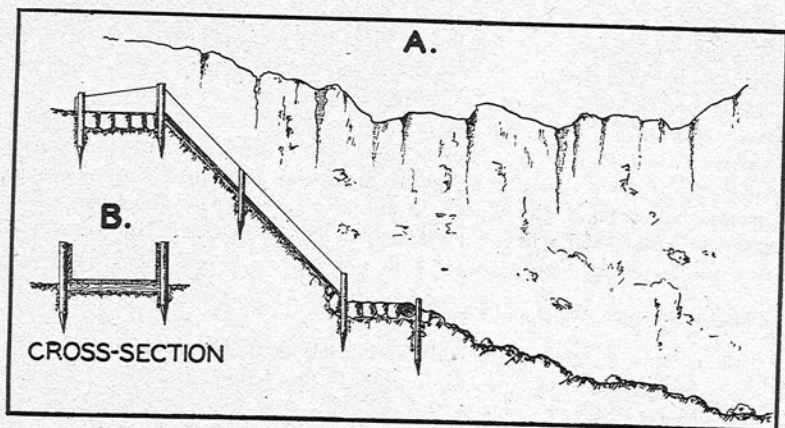


FIG. 55.—SHEET METAL FLUME TO CARRY WATER OVER FALLS

The open type of sheet-metal or plank flume has been most used to carry the water over falls and thus check cutting at the heads of gullies or elsewhere that much water concentrates. It possibly has the advantage of being less readily choked than a pipe. Economy of construction calls for higher walls at the intake where the velocity of the water is slowest.

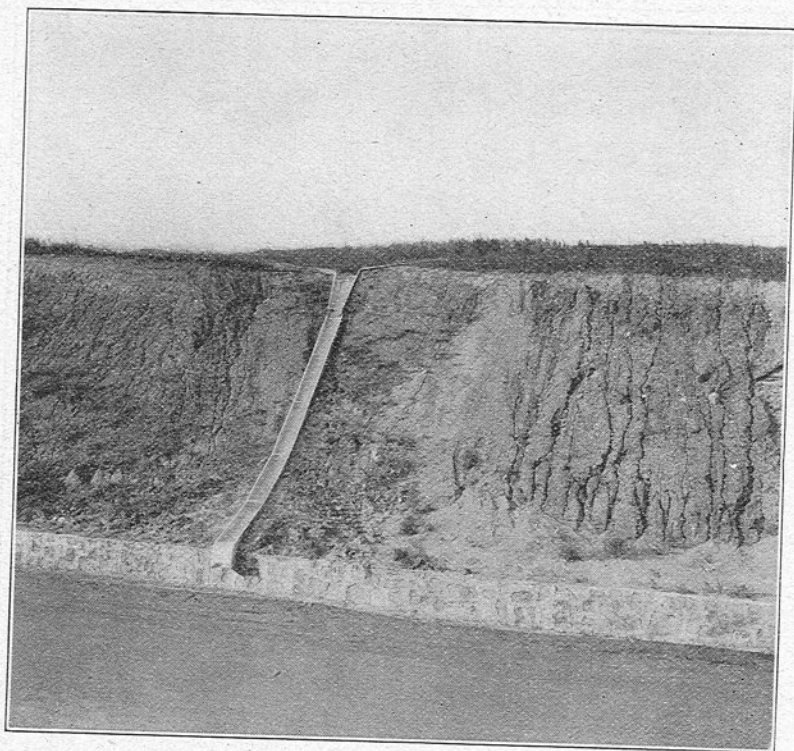


FIG. 56.—METAL FLUMES SERVE A SPECIAL PURPOSE IN CARRYING WATER DOWN OVER STEEP BANKS

Used effectively in this case to keep a steep cut-bank from washing into the highway, at the same time saving the land above. Note the small gullies which started to form before the flume was placed. This road construction also excellent in providing a lined gutter and retaining wall.

The most important feature of any flume, particularly where the ground breaks sharply below it, is the intake, for if the water is given the slightest opportunity to go around or under the flume, rather than through it, both the supporting bank and the flume itself may easily be lost in a single rain. Next to the intake, the apron at the foot of the flume should be given attention, and provision made to break the force of the water as it rushes from the steep metal or plank surface. The first provision is better illustrated in Figure 54 and the latter in Figure 55.

Control of Rock Washes on Steep Slopes

The run-off from many table-land farms finds its way down the steep, rough hill sides into the valleys. This steep gradient gives the water enormous cutting and transporting power, as evidenced by the fans or deltas at the outlets of such washes, composed largely of stones ranging in size up to a cubic foot and even more. Where a number of such washes converge into one channel they often cause

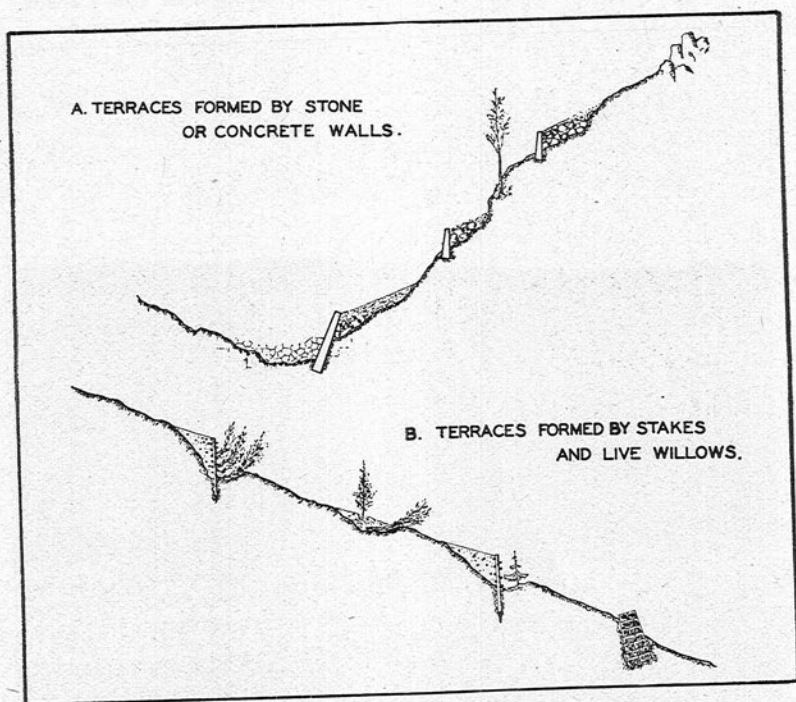


FIG. 57.—SMALL OBSTRUCTIONS OFFER ONLY CONTROL

On steep rocky slopes and in the small gullies which form when excess water is released upon them, numerous small obstructions offer about the only means of control. Each has a small capacity for collecting debris, but serves principally to retard the water and encourage its percolation into the soil or rock.



FIG. 58.—ROCK-LINED CHANNEL BUILT NEAR FOUNTAIN CITY, WISCONSIN

This carries accumulated water off the steep bluff lands. The weakness of this rectangular form lies in the possibility of the uncemented walls being battered down by large rocks which may be carried in high water. The floor is built as a series of low steps.

considerable bank-cutting in the lowlands, as well as covering bottom-land with their debris. They are often a problem in the construction and maintenance of highways and railroads.

Two general methods of control have proved satisfactory. The entire wash or run can be lined with the floating rock to form an erosion-resistant flume. The cross section may be rectangular with a flat bottom and nearly vertical sides, the height of the walls being determined by the volume of water to be carried. Figure 58 is such a structure at Fountain City, Wisconsin. This is probably not as durable a structure as one of semicircular or saucer shaped cross-section. In either type of structure the stones need to be packed in closely to prevent displacement by the rushing water.

The general method of control adapted to the larger gulches in the rocky bluff areas consists of a series of dams in the gulch which correspond to the risers of a stairway. Above each dam of concrete masonry or rubble there is a settling basin. At the foot of each dam an apron is necessary to prevent damage from the waterfall. The dams are usually built with heads under ten feet. They are placed close enough together to give the fill a gradient of about two feet per hundred. Figure 59 shows a series of such dams near Genoa, Wisconsin. These are constructed of quarried limestone without mortar.

VII. SUGGESTIONS FOR MEETING THE PROBLEM

THE CAUSES of soil erosion are now pretty well understood. The menace of soil erosion has been discussed with application to nearly every part of the country. There is no lack of understanding as to what is happening and why. It, therefore, appears to be the time to

suggest a comprehensive plan of action which offers an actual remedy for the losses now being incurred on every hand. This covers both individual and public responsibilities. The situation as regards southwestern Wisconsin, may be summed up as follows:

1. The most immediate and direct cause of destructive erosion is soil disturbance, that is, a disturbance, of any kind, of the natural balance between gravitation and the binding power of roots, tending to hold the soil in place, and on the other hand the force of running water tending to move it. Disturbance of the soil often creates, in itself, an increased quantity of run-off, but this may also arise from other causes which tend to concentrate run-off on the areas or at the points where the soil is unstable.

2. The formation of deep gullies may nearly always be traced to a disturbance of soil on or at the foot of steep slopes, of such a nature as to create a direct fall for any run-off which may be concentrated at that point. Such cuts are frequently made by streams eating into their banks, but quite as often in the excavations necessary to road building and similar works. Given a fall of water, the concentration of great quantities of run-off is not essential to the develop-

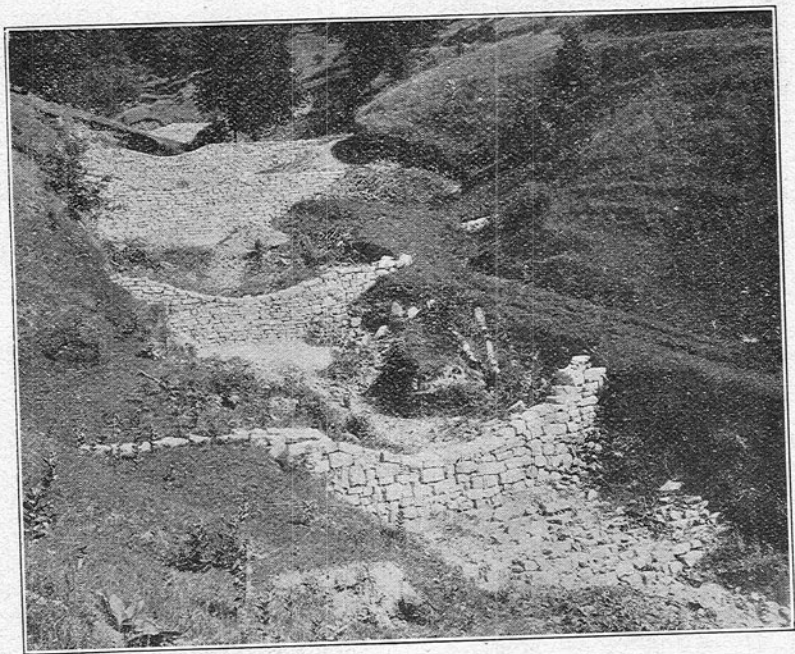


FIG. 59.—SERIES OF RUBBLE DAMS BUILT NEAR GENOA, WISCONSIN
They were built for protection of a railroad fill from the heavy wash of silt and stone.
“Note the complete filling of the two older dams (foreground) which have been in place about 3 years, and the ample concrete aprons below the newer dams.”

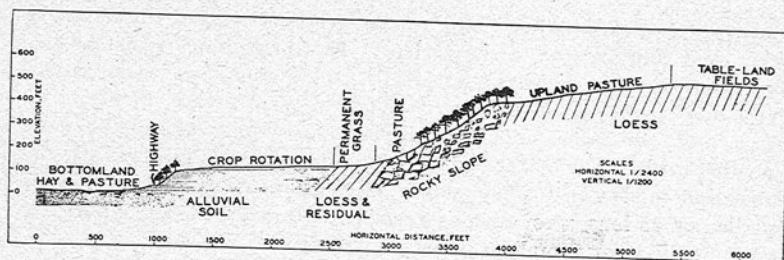


FIG. 60.—PROFILE OF A WISCONSIN FARM

This shows the common relationship of the fields, pastures, and forest, as determined by the topography. More often than not the table-lands are in units separate from the farms of the bottoms and terraces.

ment of a gully: likewise, moderate decreases in the quantity of run-off reaching a gully will seldom prove effective in checking its development, although such a decrease may cause the gully to develop more slowly. Rather must gully-cutting be checked by decreasing the fall and cutting power of the water until it becomes negligible. This is accomplished (a) by complete diversion of the water to another channel, (b) by providing an artificial channel at the fall, such as a flume or pipe or even the sloping face of a dam, or (c) by raising the level of the floor of the gully by means of soil-saving dams. To check a gully by any method work should always begin at its head, or just below its head in the case of soil-saving dams, while the lower part of the gully can later be reclaimed by additional dams if the land to be built in this way will be sufficiently valuable.

3. Sheet erosion or the relatively shallow gulying of fields is primarily the result of the soil disturbance which attends any form of cultivation. There is no use in belittling the fact that the act of cultivation is a very serious soil disturbance. It inevitably increases the opportunity for erosion (a) by removing the roots which bind the soil together, (b) by taking from the surface, if only to "turn it under," the layer of partially digested organic matter which is largely responsible, except in very sandy soils, for the ability of the soil to absorb water, (c) by destroying most of the humus in the surface layer through continuous cropping and exposure and (d) by decreasing the natural cohesion of the soil elements, or in other words making it loose and friable. This last is not altogether a bad feature, since it helps water absorption up to a certain point, but when water begins to run off despite this looseness of the soil, the soil is moved much more readily and rapidly.

4. The most certain preventive of erosion, therefore, is to keep the soil continuously covered with vegetation. For steep slopes and poor, rocky soils there can be no better or safer cover than forest, and probably in the long run forest cover will produce a more valuable yield from such land than any other cover, although lack of organization of

markets for forest products often makes the growing of timber crops seem very unprofitable to the farmer. This protection is just as important for short steep slopes as for the higher hills, and possibly even more so because the short slopes of terraces are underlaid by much more erodable soils, and are the supporting walls of the most valuable fields. For better soils capable of producing good yields, the cover for moderately steep slopes is permanent sod or hay crops handled on as long a rotation as possible so that the soil is exposed to erosion only a very small proportion of the time.

From all the evidence available on conditions of run-off in southwestern Wisconsin, it is believed that the economic interests of the individual farmer and of the community would be best served if it were required that all slopes of more than 25 per cent gradient be kept in timber and protected from fire and overgrazing, and if slopes of greater gradient than 15 per cent were only rarely plowed.

5. In southwestern Wisconsin, except on the table-land farms, there seems to be no escape from the placing of pastures on the somewhat steep ground above fields. This is unfortunate since the soil of pastures almost invariably becomes packed, run-off occurs even with quite small rains, and this run-off water may do a great deal of damage to the fields lying on the flatter ground below, unless such water is diverted at the upper edges of such fields, to some safe channel. Such being the unavoidable situation, it would seem to be the best economy for the farm unit as a whole

- a) to terrace pastures with rather deep terraces not provided with outlets, so as to increase the amount of absorption by pasture soils, which are often, because of needless run-off, inadequately watered;

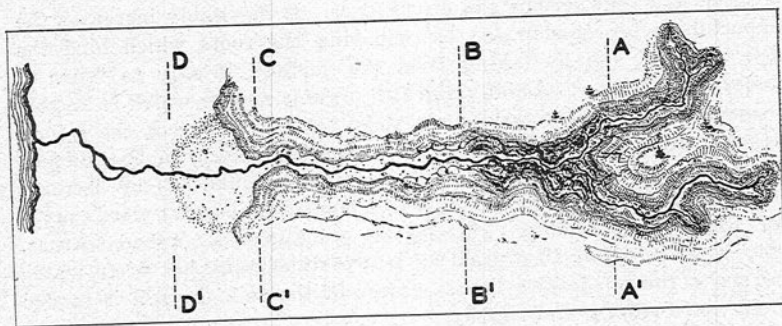


FIG. 61.—TYPICAL WATERSHED IN THE BLUFF LAND

Schematic drawing of a typical watershed in the bluff-land which further illustrates the inter-relationship of different farms and different parts of the same farm. The area above A-A' is in table-land field or pasture, and suffers from sheet erosion, with possibly small gullies at the break of the slope, and rocky washes on the steeper slopes; A-B is the area of coarser deposits; B-C the area of terrace and bank-cutting; C-D the area of finer deposits, merging into the main river bottom beyond D-D'.

- b) to fertilize pastures, and build up the humus content of the soil, both because a heavier cover of grass will again increase absorption of rain, and because such intensifying of land use is by all means the most profitable;
- c) to avoid "puddling" of the surface of pastures, which results primarily from trampling, by keeping stock off of the ground when wet, especially in the early spring.

6. The prevention of soil erosion is often beyond the powers or capacity of the individual land-owner. The prevention of sheet erosion from fields, and of the loss of the most valuable soil is of enough direct interest to the individual farmer to justify better and more intensive methods of soil management, better location of pastures, increase of timbered areas, and even the construction at considerable expense of soil-saving dams within the cultivated fields. But, these individual developments do not alone offer a complete solution of the erosion problem. In fact, some of its more important phases present the necessity of public action since their effects extend far beyond the confines of any farm. The long and bitter experience of European countries has shown that the effective control of erosion on a comprehensive scale must eventually be through the initiative and participation of governmental agencies.

7. Wherever any question arises as to damage done one farm by water arising on the fields of an adjoining farm the local government should step in either to compel the offending land-owner to abate the nuisance, or, itself to construct such public works as will eliminate its damaging effects.

8. In the case of flood or silting damage done by streams of any considerable size, to which many farms and even towns and cities are usually contributors of run-off, the state would seem to be the logical agency to exercise police power and to construct necessary protective

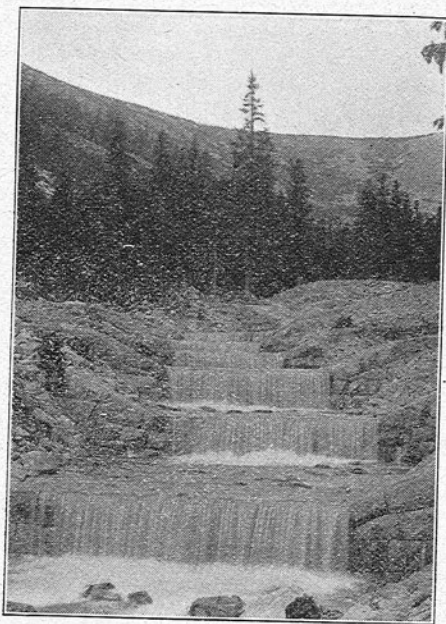


FIG. 62.—STREAM CONTROL IN SOME PORTIONS OF EUROPE HAS GONE TO GREAT LENGTHS

This system of low dams which gives practically complete lining to the stream channel is not only an engineering feat, but a thing of beauty. It seems inevitable that in the United States stream preservation and control will soon be accepted as a public responsibility.

works, since the state has certain rights and responsibility with respect to such streams. In addition, sportsmen have a definite interest in the condition of the smaller streams. Many a trout stream has been spoiled permanently by the material eroded from adjoining fields. The connection between erosion and condition of streams is now becoming generally recognized. Here is another justification for state interference.

9. State and county highway departments have peculiar responsibilities in connection with the erosion problem. The construction of roads often disturbs the natural soil balances and leads to the beginning of deep gulying in adjacent private land. Furthermore, road surfaces add a very appreciable quantity to the total run-off. The state has no more right to undermine a citizen's land by means of road cuts, or to flood his land with run-off water, than it has to cart his soil away in trucks. It goes without saying that a different attitude of highway departments toward road construction adequately protected against erosion, must originate in an awakened public sentiment. There is a general demand at present for the greatest mileage of improved roads at the least possible cost, and so long as "more roads" is the common cry, we are not likely to have better roads.

However, it should be obvious to highway engineers and to the thinking element of the general public that "better roads" in the sense here implied of better-protected roads, would in a short time prove cheapest through decreased maintenance costs. Not only is this true of road construction itself, but it is evident that in some cases protective works to keep roads from being flooded by water and covered by sand and boulders from outside sources would be less expensive to the taxpayer than the continuous task of repairing damages and finding new locations for roads.

10. The proximity of southwestern Wisconsin to the Mississippi River gives to erosion in this region a national significance. When one comes to consider such problems as that of the silting of the Mississippi, with its attendant problems of keeping channels open for navigation, of keeping the river within bounds in its lower reaches, and preventing damage by floods, of keeping the river from changing its course with complete destruction of valuable bottomland holdings,—one turns naturally to the Federal River Commission as the first authority, since it is specifically charged by Congress with correcting a situation of ever-growing seriousness. One turns, naturally, to this Commission which although it is responsible to the Congress of all the people for general authority and for the direction of its efforts, is certainly in a position to suggest to this authority the manner in which the public funds could be most effectively spent. But one finds that among the activities of the River Commission there has never been included any serious attempt to prevent silt from entering the Mississippi, and aside from a few dams in northern Minnesota, no attempts have been made to decrease the volume of water entering the river in flood times. Most of the effort has been expended in dredging, build-

ing wing-dams, and other means of coping with silt after it enters the river channel.

Could the enormous sums of money which are being spent annually be applied for only a few years to the prevention of erosion and the creation of innumerable small settling basins outside the river channel proper, in critical areas of the Mississippi watershed such as southwestern Wisconsin, there would be some hope of gaining an advantage over the monster which threatens the entire Mississippi valley as certainly as the Yellow River ever threatened China. Obviously small dams which would keep silt out of the River would accomplish much benefit to the adjacent land as well.

But even granting that engineering works of a public nature might never alone solve the problem, what better undertaking for the federal government, what better use of public funds could be suggested than the practical education of the individual farmer and land-owner in erosion-prevention, which would more than pay for itself in conserving the national wealth in soil resources, and at the same time go far toward solving the river problem. By no means, however, is "education" suggested here as a substitute for action where and when the latter can be effectively taken. But so long as the engineers of the River Commission stay upon the water and expend their energies upon wing-dams, levees, and the like, it is feared that the individual land-owner whose erosion is really responsible for the present situation will never have a very acute realization of his responsibility.



FIG. 63.—JETTIES HOLD MISSISSIPPI SILT

The series of wing-dams or jetties extending into the Mississippi from the left bank has been built to collect and hold the silt which has already entered the stream, thus tending slightly to keep an open channel next to the right bank. How much more effectively might channels be kept open, and other damage averted, if dams were built to keep both coarse and fine material out of the river!

11. Besides decreasing erosion into side streams and thence into the Mississippi by engineering means, there is one obvious public activity that might be undertaken, either by the State or Federal Government. This is the creation of public forests or parks in the most critical areas, which means in southwestern Wisconsin the steepest lands now in farms. The bluff-lands immediately adjacent to the Mississippi in Wisconsin (as well as in Minnesota and Iowa) are the most critical in respect to steepness, and have the added importance of great scenic beauty, where clothed in their natural cover of timber. Yet in the light of the present investigation it is impossible to assume that the steep bluffs are in themselves the most serious contributors to river floods and silting. It is doubtful if anything important along the line of river improvement is to be attained without including also (a) the narrow valleys through these bluffs which lead back to the high table-lands and are themselves eroding in a most serious manner, and (b) some of the adjacent table-lands of moderate slope, now in fields, whose run-off water is performing a double service of destruction before it reaches the river. With these lands clothed with timber—a thing which would occur naturally in a few years with cultivation and fire eliminated—and including also all lands—mostly narrow steep fields—adjacent to the river itself, a public forest could be said to serve something more than an aesthetic purpose.

12. In addition to the navigation, engineering, forestry, and aesthetic interests which might be brought to bear upon the recognition of the erosion problem for what it is, those interested in the conservation and development for human use of the wild life, or briefly the sportsmen of the entire central region, must not be lost sight of. The Mississippi River bottomlands are sponsored by sportsmen as a wild life refuge extending along the river for the entire length of the rugged non-glaciated region, from the lower end of Lake Pepin to Rock Island, Illinois. The development of this Refuge is confined to the acquisition of lands subject to overflow. Obviously such lands are rather transitory and changeable in character due to the mere fact of being overflowed. The question of silt depositions from the many small side streams, which empty directly into the river, has, therefore, a direct bearing upon such lands, and upon the character, location, and feeding value of sloughs and bayous upon which fish and wild fowl depend. The sportsmen's interest demands that cover for game be increased and the stability and purity of streams be protected by an increase in the natural growth of timber and brush in proximity to small streams and gulches. It is certainly true that game and fish will be conserved and increased upon the Mississippi itself as its tributaries return to more normal condition. A growing realization that a large part of the game problem is represented in the cover problem, and in the condition of streams brought about by man's destructive activities, seems to be finding expression in many ways.

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