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SOIL

The Most Valuable Mineral Resource
Its Origin, Destruction and Preservation

by
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FOREWORD

The serious effect of erosion upon agricultural lands has been the subject of many reports, most of them published as a part of the regular program of the Soil Conservation Service of the U. S. Department of Agriculture.

This bulletin, however, is by no means just another report on soil conservation; it is, rather, a geological study. It was so conceived by the author and it is so presented by this Department. It presents a geological approach to a universal problem not commonly associated with geology by laymen. The fact that the paper was written with direct application to Oregon localities and conditions justifies its issue as a bulletin of the State Department of Geology and Mineral Industries.

The paper is truly a labor of love as well as the work of a crusader. The author did a tremendous amount of work in preparing the manuscript, all without compensation, and, as an internationally known specialist and author on sedimentation, his observations over most parts of the United States have created in him a deep and sincere regret over the widespread soil losses from destruction by erosion.

It may be pertinent to relate that the writing of this paper, which, it is hoped, will be of benefit to farmers and ranchers in Oregon and elsewhere, came about as a result of a discussion, almost a quarrel, between Dr. Twenhofel and myself while on one of our geologic field trips to the Oregon coastal area. I was prone to underestimate the destructive effects of "burning off the grass" and of the subsequent erosion in this country of gentle but steady rains until Dr. Twenhofel began to prove his position by pointing out the evidences. It then seemed necessary that we, who are trained to observe and record such effects, should describe the conditions and effects of erosion in such manner that the lesson to be learned from their destructive results can be published far and wide for the general good.

We recommend the reading - or better still the careful study - of this paper not only to every farmer, rancher, and fruit raiser in Oregon, but also to every other citizen who has within his consciousness a grain of care for the land that gives us food.

Earl K. Nixon
Director

Portland, Oregon
April, 1944

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SOIL

The Most Valuable Mineral Resource
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Chapter I

Introduction

The author wrote in 1915, "Soil, to man and life, is probably the most valuable of nature's productions. This is a statement which can not safely be challenged. Its character determines the human history of a region, and the care bestowed upon it determines the survival of nations." Soil is the mineral resource most valuable and important to man. He can do without gold, without silver. He can even do without copper, iron, and aluminum. The race existed and survived long before it knew these metals, but the race never could have existed if it had not been for soil.

Soil has always been essential for the existence of the race. It was essential to man's precursors, to man as a savage, although neither the precursor nor the savage had any idea of its importance. In the early days of savagery and in earlier years, the forbears of modern man used no mineral resources other than the soil and rocks for occasional utensils or weapons. Man has extended his uses of mineral resources as he has gained in knowledge, but always the soil has been the most important of all the mineral resources used.

Soil is the source of all food produced on the land and without it there would be no food other than that grown in water. Perhaps the day may come when all food will be synthetic and made from inorganic materials, but until that day comes, if it ever does, man will have to depend largely on the soil for production of food. Nations facing loss of their soil are facing extinction. They may expect to decline and ultimately to disappear, as some of the nations of the past have done seemingly for this reason. Their large cities will become silent and deserted, inhabited only by the ghosts of the past. A nation to be great and remain great must have an excellent and fertile soil in order that it may have an adequate supply of food. In his Eighth Annual Message to Congress, December 8, 1908, Theodore Roosevelt realized this when he stated: "When the soil is gone, men must go; the process does not take long." The decay and decline of a nation may be measured by the carelessness with which the people of the nation use their soils.

Some cities depend for their prosperity upon things which are mined from the earth and others upon those which are grown upon its surface. With the best of care, the former is a wasting resource, the latter with care remains an inexhaustible resource. Coal and iron mines must ultimately become exhausted, but with proper care the soil will yield a continuing annual harvest of grain, fruit, and timber.

Nature's resources are at human disposal and thus man is the arbiter of his future. He may make soil a permanent asset, and the water which seeks to destroy it may be made to preserve it and to make it produce bountifully. A nation continues to go forward if its soil resources are husbanded. Its people become decadent if this is not done. Soil is the fundamental basis for the wealth, culture, and general prosperity of a nation. Lack of these attainments may be due to the character of the people but, in any event, without a good soil these attainments are impossible to obtain. It is not due to the character of the people of the "mountains" of eastern Kentucky that they have squalid homes, poverty, ignorance, disease, and low standards of living, or that the people of the Blue Grass region of central Kentucky have good homes, good schools, and general prosperity, as the peoples of the two regions are of the same stock and previous history. The differences are due to the soils, sterile in the former region, and fertile in the latter. The climates are essentially the same.

Soil is a mineral resource produced by geologic processes. Its formation is a segment of sedimentary geology. It is the chief source of sediments and its destruction is the acquirement of sediments by the agents of transportation. Many soils are produced by the deposition of sediments.

Soil is composed of the products of rock destruction, together with the inclusion of some organic matter. Destruction is brought about by decomposition (rotting) and disintegration (breaking) of rocks. Decomposition of rocks produces minerals which are mostly different from those in the rocks which are decomposed. The new minerals are mainly iron oxide and hydroxides (hematite, goethite, turgite, limonite, etc.), some of the various forms of quartz, minerals of the clay group, and various others of which the most common are carbonates. Disintegration reduces rocks to smaller pieces. This is largely done through frost action, expansion and contraction caused by changes of temperature, abrasion, grinding and impact, the last three due to the work of wind or water. The small particles may either be pieces of the original rock, or minerals of that rock. The products of decomposition and disintegration under natural conditions largely remain at, or near, the places where the rocks are destroyed and thus a cover is produced over the rocks which have not yet been destroyed. This cover serves to protect these rocks to some degree from further change. The cover has been termed the residual rock mantle. It is composed of the soil and the raw materials of soil. Three horizons have been differentiated for the rock mantle of humid regions. The top part has been subjected to long leaching and has lost most of its soluble constituents. This is designated the A horizon. Just below is the B horizon with the composing materials more impervious than those of the A horizon and containing substances leached from the A horizon. The C horizon lies below. This contains many pieces of undecayed rock and is evidently the youngest part of the rock mantle. Some rock mantles result from deposition. These are transported rock mantles.

Under natural conditions many plants grow upon the surface of the mantle and its upper part is penetrated in all directions by their roots. The roots die and their remains become a part of the mantle, and passages remain where the roots formerly were. The surface parts of the plants fall and form a protective cover over the mantle. Animals - angle worms, beetles, larvae of many insects, moles, gophers, chipmunks, and many others - burrow through the mantle, chiefly in the upper part, searching for food derived from the roots and other parts of plants which may be present. Finally most if not all of the A horizon, and much of horizon B, together with any organic matter present in these zones, pass through the digestive tracts of burrowing animals and is excreted either in the burrows or on the surface. Some of these phenomena also take place in horizon C. Ultimately many of the animals die within their burrows and their remains are mingled with the decayed and excretory products. Molds, bacteria, fungi, and diatoms live in and on the mantle and assist in the decay of the organic and inorganic materials. As a consequence of all of these activities the top part of the rock mantle - its most valuable part from the point of view of agriculture - is produced. A very long time is generally required for the formation of the rock mantle, and a great thickness of the parent rock is generally required for the formation of each foot of mantle. The top part of the mantle - zones A and B - requires a longer time and a greater thickness of rock for its production than any other part of the mantle of equal thickness.

The rock mantle increases in thickness at the base through disintegration and decomposition of the rock upon which it lies. Under natural conditions the increase in thickness at the base proceeds at about the same rate at which some of the mantle is lost through erosion on the top. The thickness thus remains about the same from year to year. This represents a condition of equilibrium, the status quo of the rock mantle. The equilibrium is due to the presence of a vegetal cover. Agriculture is an unnatural condition. It substitutes a selected but sparse growth of plants for a dense adapted growth. It maintains clean culture and eliminates all plants except those desired. It requires a bare surface on the soil in place of a surface covered with plant litter. Agriculture destroys the guardian of the mantle - destroys equilibrium.

The writer believes that the great nations of the future will be those that learn to protect their soils. He believes with Bennett and Chapline that erosion of the soils "is the biggest problem confronting the farmers of the nation over a tremendous part of its agricultural lands," but he would go much further and state that it is the biggest problem confronting the nation as a whole.

Chapter II

Formation of the Rock Mantle

The residual rock mantle is a product of rock destruction - the disintegration and decomposition of rocks. The only exceptions are the organic materials which are present in greater or less abundance in the top parts of the mantle and the volcanic ash which is present in some regions. No rock is exempt from possible destruction, and the rate of yield to the destroying processes depends on the character of the rock, degree of exposure to atmosphere and water, climatic conditions, slope of surface, and extent of development of a vegetal cover. The actual rate of rock destruction under natural conditions is not known and can only be approximated as an average. The rate evidently varies greatly, but the process of destruction is continual on all rocks exposed to atmospheric conditions.

In whatever manner the destruction of rocks is accomplished, almost invariably there is, beneath most surfaces, an assemblage of materials which at the top consists of more or less maturely decomposed soil materials. These gradually pass downward into materials that differ little from the unaltered rocks. This is shown in figure 1, a photograph of a road cut showing fresh and unaltered rocks at the base which pass gradually into the surface soil at the top of the cut. How long a time was required to produce this mantle of partially decayed rock at the base and the overlying maturely and immaturely decomposed materials, and how much rock had to be destroyed to produce the thickness of rock mantle present? Before attempting to answer these questions, an attempt is made to explain what takes place when rocks are destroyed. Several kinds of rocks are considered.

Limestones consist of calcium carbonate, $CaCO_3$, or calcium-magnesium carbonate, $CaMg(CO_3)_2$, and various impurities among which the most common are silicon dioxide in some form of quartz, one or more of the several clay minerals, and iron oxide or hydroxide. Many limestones also contain pyrite or marcasite (iron sulphides) and siderite (iron carbonate), $FeCO_3$. These minerals largely change to iron hydroxides as the limestones are destroyed. The limestones may be expressed as: Calcium or calcium-magnesium carbonates (90% ±) + impurities (10% ±).

Destruction of limestones is largely done by solution which removes the carbonates. This is the form of destruction in all climates except those which have freezing weather all the time, or are so dry that solution can not take place. In regions with humid climates, as in western Oregon and Washington, and most of the United States east of the Rocky Mountains, the carbonates are taken into solution and ultimately carried to the sea. Thus the major proportion of these rocks has no part in forming the soil materials. A part of the silicon dioxide, clay minerals, and iron oxide and iron hydroxides may also be removed in solution or in colloidal suspension at the same time that the carbonates are taken into solution. Only a small part of the impurities ultimately remains to form the rock mantle.

Fig. 1. Road cut on Mt. Sexton, 10 miles north of Grants Pass, Oregon. The photograph shows the formation of soil and the residual mantle rock from fresh rock. Fresh to little altered rock is shown from the bottom of the photograph to a short distance above the top of the car. Considerable alteration of rock is shown about the middle of the photograph and the degree of alteration increases upward. Alteration to soil is essentially complete in the top part of the road cut.

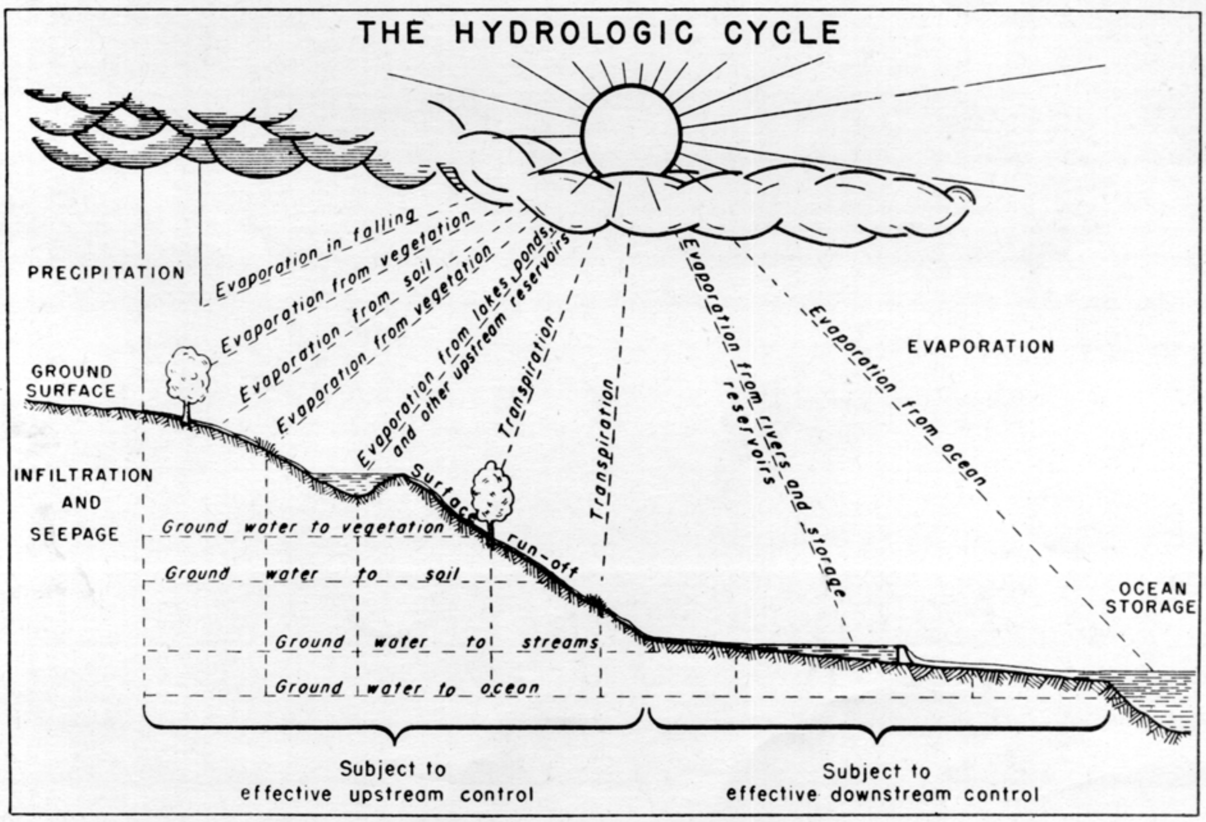

Fig. 2. Diagram showing the fall and disposition of meteoric water. The water falls as rain, snow, hail, and dew. A part soaks into the ground, a part is evaporated, a part is taken from the ground by plants and returned to the air by transpiration, and a part is runoff on the surface. It is the runoff which should be prevented, or at least kept at a minimum. (*Bull. 397, U. S. Dept. Agriculture, Fig. 1.*)

Comparative analyses of a limestone and the residual materials from Staunton, Virginia, are given in table 1. These analyses serve to show to a partial degree what takes place when a limestone is destroyed.

Table 1.

Analyses of a limestone and the residual materials from Staunton, Virginia (Merrill, p.219)

	Fresh Rock	Residual Materials
Silica (SiO_2)	7.41%	57.57%
Alumina (Al_2O_3)	1.91	20.44
Iron oxide (Fe_2O_3)	0.98	7.93
Lime (CaO)	28.29	0.51
Magnesia (MgO)	18.17	1.21
Potassium oxide (K_2O)	1.08	4.91
Sodium oxide (Na_2O)	0.09	0.23
Carbon dioxide (CO_2)	41.57	0.38
Phosphorus pentoxide (P_2O_5)	0.03	0.10
Water (H_2O)	0.57	6.69
Total	100.10 %	99.97 %

It is impossible to determine how much of each substance is removed as a rock is destroyed, but it may be assumed that not every constituent of the original rock becomes a part of the residual material. It also may be assumed as certain that all or nearly all carbonates are removed in solution as a limestone is destroyed. As a basis of comparison in order to arrive at the minimum extent of removal from the original rock to form the residual products, some substance of great insolubility may be selected. Aluminum oxide is perhaps the substance least likely to be lost and it is selected for this reason. The aluminum oxide is in the clay minerals which are mostly of colloidal dimensions and some of these certainly would be removed as a limestone dissolved. Furthermore, it is considered likely that more aluminum oxide is removed than remains, particularly if the solution of the limestone requires a long time. The aluminum oxide in the residual materials shown in the above analyses is approximately ten times the quantity in the original limestone, thus indicating that a thickness of at least 10 feet of the original limestone had to be destroyed to produce a foot of residual materials. The quantity of aluminum oxide lost as the limestone dissolved is not possible of determination in the present state of knowledge, but it may reasonably be assumed that perhaps three fourths was carried away as the limestone went into solution. This increases the thickness of limestone necessary to produce the residual materials to forty times the thickness of the latter.

The top foot of the rock mantle, the top soil, required a much greater thickness than 40 feet of the original rock, as these oldest parts of the rock mantle were subjected to leaching for a far longer time than any other part and hence must have lost substance continuously during the entire time of formation of the existing rock mantle.

Granite is one of the most resistant of rocks to destruction. It is composed of quartz and feldspar with which are usually associated some mica, apatite, and small quantities of other minerals. Granite decays very slowly and hence there is excellent and protracted opportunity for the products of decay to be carried away. The soluble products produced by decomposition seem to be removed almost as rapidly as formed, and at the same time a large percentage of the particles of insoluble substances of colloidal dimensions may also be expected to be removed. The feldspars decay to hydrous aluminum silicates (the clay minerals), silicon dioxide (silica), and carbonates as shown by the following equation for potash feldspar: $2KAlSi_3O_8 + 2H_2O + CO_2 = K_2CO_3 + H_4Al_2Si_2O_9 + 4SiO_2$.

The potassium carbonate is removed about as rapidly as formed. The clay minerals and the silicon dioxide are in colloidal form and they may also be expected to be extensively removed. If any iron hydroxide results from decomposition it is also likely to be of colloidal dimensions and to be in considerable part carried away. The products of destruction which remain to form the rock mantle may thus be composed of only a small part of those produced. Analyses of a granite and the residual materials resulting from its decay are given in table 2.

Table 2.

Analyses of a granite and the residual materials from its decay.
District of Columbia (Merrill p. 185).

	Fresh Rock	Residual Materials
Silica (SiO_2)	69.33%	65.69%
Titanium dioxide (TiO_2)	n. det.	0.31
Alumina (Al_2O_3)	14.33	15.23
Iron oxide (Fe_2O_3)	4.00	4.39
Lime (CaO)	3.21	2.63
Magnesia (MgO)	2.44	2.64
Potassium oxide (K_2O)	2.67	2.00
Sodium oxide (Na_2O)	2.70	2.12
Phosphorus pentoxide (P_2O_5)	0.10	0.06
Ignition loss	1.22	4.70
Total	100.00%	99.77%

The amount of alumina in the residual materials is only a little larger than in the granite and superficially it would seem that most of the products resulting from destruction of the granite are present in the residual materials, but when the slow decay of the granite is considered it must be concluded that there was a long time in which colloidal silicon dioxide, iron hydroxides, and clay minerals could have been carried away. Therefore it may be reasonably assumed that several times as great a quantity of the products of destruction was carried away as remained to form the residual materials. Again it should be noted that the top part of the mantle requires the greatest thickness of original rock for its formation.

Rocks, high in iron and magnesium, decay more quickly than granites because they contain much iron in a form that permits its rapid oxidation. Rocks of this variety cover much of Oregon from the Cascades to the eastern boundary. These rocks are known as basalts. Analyses of such a rock and the residual materials produced by its decay are given in table 3.

Table 3.

Analyses of an ultrabasic rock (alnoite) and residual materials from its decay.

Herkimer County, New York (Merrill p. 209).

	Fresh Rock	Residual Materials
Silica (SiO_2)	35.25%	33.10%
Titanium dioxide (TiO_2)	2.25	2.90
Alumina (Al_2O_3)	6.10	7.88
Iron oxide - ferric (Fe_2O_3)	8.53	16.71
Iron oxide - ferrous (FeO)	5.60	1.48
Lime (CaO)	7.40	5.25
Magnesia (MgO)	20.40	13.42
Potassium oxide (K_2O)	2.88	0.29
Sodium oxide (Na_2O)	0.70	0.23
Ignition loss	10.15	17.85
Total	99.26%	99.11%

As this rock is so largely composed of ferromagnesian minerals, the products of decay would be largely magnesium carbonate, iron hydroxides, silicon dioxide, and a little clay - all either soluble or of colloidal dimensions and hence possible of removal after release from the parent rock. According to Merrill the total loss of the rock on decay, on the assumption that no alumina and titanium taken together are lost, is 26.89 percent, or a little more than a fourth. On this assumption, four feet of rock would be required to produce three feet of residual materials. However, it may be expected that, as the total quantity of alumina in both rock and residual materials is not large, the quantity removed as the rock decayed was probably several times that which remained, and thus many feet of rock were probably required for each foot of thickness of residual materials. The top foot of residual materials, as in the other cases, would have required the greatest thickness of the parent rock.

An argillite is a rock which has undergone metamorphism to a limited degree without having progressed so far that a slate was formed. The rock is hard, fairly resistant to destruction, and lacks the cleavage of slate. The Analyses of table 4 gives the composition of a fresh argillite and the residual materials resulting from its decay.

Table 4.

Analyses of fresh argillite and the residual materials resulting from its decay, Harford County, Maryland (Merrill p. 213).

	Fresh Rock	Residual Materials
Silica (SiO_2)	44.15%	24.17%
Alumina (Al_2O_3)	30.84	39.90
Iron oxides - ferric and ferrous ($Fe_2O_3 \cdot FeO$)	14.87	17.61
Lime (CaO)	0.48	0.00
Magnesia (MgO)	0.27	0.25
Potassium oxide (K_2O)	4.36	1.24
Sodium oxide (Na_2O)	0.51	0.23
Ignition loss	4.49	16.62
Total	99.97%	100.02%

Assuming that no alumina was lost, the figures indicate that 1.3 feet of rock was required to produce a foot of residual products, but it seems very certain that some alumina was lost and thus a greater thickness than 1.3 feet was required. However, it must be remembered that argillite itself is composed of residual materials which withstood the destruction of an earlier cycle and hence would be likely to resist removal during the second cycle. The rock decays rather slowly and hence a long time would be required, giving time for leaching and removal of something of every constituent. It is reasonable to assume that several feet of rock would be required for each foot of thickness of the residual materials and, as in the cases of the other rocks, the top foot of the rock mantle required the greatest thickness of rock to produce it.

Sandstones and quartzites are composed of cemented sands. The cements of sandstones ordinarily are carbonates, iron hydroxides, and silica. The cement of quartzite, the metamorphic equivalent of sandstone, is silica. The breakdown of sandstones into residual materials depends on the nature of the cement and the porosity of the rock. The porosity in turn is determined by the extent to which the spaces between the grains are filled with cement. A carbonate cement is rather easily removed by solution, and when this is gone the grains fall apart to make a thickness of residual materials about equal to that of the original sandstone. If the cement is composed of iron hydroxide or silica, removal of the cement is not so easy and the rock may persist for a long time. If a sandstone is porous and the region has a freezing climate, the freezing of water in the pores will crumble the rock in a few years irrespective of the kind of cement. If the rock is a quartzite, destruction is very difficult and very slow. This rock is essentially non-porous and insoluble; it can not be decomposed; frost has little effect on it; and it does not readily yield to changes of temperature. Any small particles loosened from a quartzite may be expected to be removed about as rapidly as released and very few residual materials would remain.

Claystones and siltstones have little resistance to destruction and crumble to form residual materials very rapidly. The products of destruction may have a volume exceeding that of the parent rocks.

In all cases of rock destruction there are variations in the rate and in the composition of the residual materials produced. These arise from climatic conditions and topography. Under some conditions the residual materials contain little silicon dioxide and clay minerals and much iron oxide or hydroxide. Under other conditions the residual materials contain much silicon dioxide and clay minerals, but little iron in any form.

Summarizing, the destruction of rocks under the conditions of a region with ample rainfall results in removal of all soluble substances and to a large degree the substances of colloidal dimensions, so that the residual materials consist of only a part of the insoluble substances in, or derived from, the original rocks. If the rate of destruction of the parent rocks is slow, a long time is involved, and the insoluble substances may be carried away about as fast as released. Thus a very great thickness of rock will be required to produce a foot of residual materials. If destruction is rapid and the rocks contain a large percentage of insoluble materials, a large thickness of residual materials may be expected to be left at the places of destruction and, correspondingly, a much smaller thickness of rock will be necessary to produce them. If destruction is rapid, and the rocks contain only a small percentage of insoluble substances, a great thickness of rock will be required to produce a small thickness of residual materials.

Chapter III

Rates of Rock Destruction

The rates at which rocks break down to form residual materials are not known. It is known that some igneous rocks have lain on or near the surface since the last Ice Age in many parts of the world without experiencing very appreciable alteration. Limestone surfaces at the Lannon limestone quarries in eastern Wisconsin have retained polished and striated surfaces almost without change since they were passed over by the Wisconsin glacier some 25,000 to 50,000 years ago. There are polished surfaces on quartzite in the Devils Lake region of Wisconsin which were made some hundreds of thousands of years ago. Some of these surfaces have existed almost without protection.

The rates at which rocks break down to residual materials obviously vary with the kinds of rocks and the climatic conditions. The rates are very slow for quartzites and many granites and probably very fast for siltstones, claystones, and many sandstones.

The destruction is considered to be relatively fast under conditions of moderate relief, warm and moist climate, and in climates which have freezing temperatures for considerable parts of each year. The destruction is thought to be much slower in regions with little to no relief, moderate rainfall, and either very dry or very cold climates. The Coast Range region of western Oregon is probably a region of relatively rapid destruction of rocks, as the climate is moist and warm for much of the year, as the relief is great, and as there are several months of each year with little or no rain. The period of little to no rainfall permits the rocks to be drained of water to considerable depths and at the same time permits penetration of the gases of the atmosphere to equal depths. This promotes decomposition of the rocks. There is plenty of water during the rainy season to remove soluble and colloidal materials. A warm and dry region with a deep water table favors the rapid breaking down of rocks as the warm climate promotes high absolute, but low relative humidity. This atmospheric condition and the deep water table permit air to circulate through cracks of the rocks to depths where cooling leads to condensation of water on the cold rocks with consequent decomposition of the rocks concerned. This is the same process which causes cellar walls in humid climates to become very wet. Disintegration promoted by the wedging action of the minerals of decomposition would follow. There would be little solution as the quantity of water would rarely be adequate and thus the soluble materials resulting from decomposition would not be carried away.

The water which falls in dry regions sinks at first into the ground, a part is later brought to the surface by capillary attraction as the water in the surface materials is evaporated. The rising water contains substances in solution and colloidal suspension. These are deposited in and on the surface materials as the water evaporates. Under these conditions, a much less thickness of rock is required to form a foot of residual materials than is the case for the same kind of rock in a humid region where all of the soluble and much of the colloidal materials are carried away. However, in dry regions, another agent, the wind, enters the picture and carries away from the surface all particles of small dimension. The surface residual materials then consist of the particles too large for the wind to move.

It has been assumed that limestones under favorable conditions will pass into solution at the rate of about one foot in a thousand years. This is supposed to be the rate in regions with rainfall like that of southwest Oregon, the eastern and central parts of the Mississippi Valley, the eastern side of the Appalachian Mountains south of Canada, and other places of similar relief and climatic conditions. Claystones and siltstones are more rapidly broken down into residual materials than other kinds of rock and only a few years may be required to change these rocks to rock mantle materials. This is particularly true in regions which have freezing weather as only a couple of freezes suffice to crumble these rocks when they are saturated with water. It is believed that granitoid rocks other than the basic and ultrabasic varieties are far more resistant to destruction than are the limestones and that perhaps a thickness of a foot of granite may be destroyed under average natural conditions in 5,000 years. The more basic granitoid rocks, like the alnoite of which the analysis is given, (page 7), may be destroyed more rapidly than the other granitoid rocks, but not as rapidly as the limestones. The rate of destruction of these rocks under average natural conditions is estimated at about one foot in 3,000 years. These figures are considered to have the value of conservative guesses but to err in being too small rather than too large.

If the rate of destruction of a limestone is placed at one foot in 1,000 years, it follows that 100 feet of limestone of one percent impurity would require 100,000 years to form a foot of residual materials provided that none of the impurities are removed as the limestone is dissolved. This assumption can not be proved and it seems better to assume that three fourths of the impurities are carried away as a limestone of this purity is dissolved. On this assumption 400 feet of rock would be required to form a foot of residual materials and the time involved becomes 400,000 years. Something more than a million years would then be required to produce the average thickness of rock mantle from limestone terranes of one percent impurity. To the extent that the parent limestones contain a greater percentage of impurity, the time involved would be decreased. If the impurities in a limestone consist of 10 percent, the minimum time needed to form a foot of residual materials would be 10,000 years if all the impurities remain as the limestone dissolves, and 40,000 years if three fourths are lost. As, however, the time of solution of the limestone is reduced, it may be assumed that only half of the impurities are lost and the time required for the accumulation of a foot of residual materials becomes 20,000 years, and 60,000 to 80,000 years for the accumulation of an average thickness of rock mantle.

Thus, the time involved in the formation from limestone terranes of an average thickness of upland rock mantle, as over the Blue Grass and Pennyroyal districts of Kentucky, the limestone region of the Nashville Basin of Tennessee, the limestone region of the Shenandoah Valley of Virginia, the Driftless region of southwestern Wisconsin, and similar regions with climatic conditions like those named, ranges from something over 50,000 years to over a million years. The point intended to be made is that rock mantle resting on limestone terranes from which the materials of the mantle were derived, requires a great thickness of rock for the formation of these materials and an immense time for the destruction of the limestone. From this it follows that erosion of rock mantle over limestones means that this mantle is gone essentially forever so far as existing nations are concerned. It would seem to be the part of elemental wisdom to care for mantle materials of this parentage.

The production of a foot of mantle materials from siltstones and claystones may be a matter of a decade or even less, particularly if the region is one of freezing temperatures. Also the thickness of rock required to produce a thickness of a foot of mantle materials may be no greater than the thickness of the mantle materials. The rock mantle may be removed from terranes of siltstone or claystone and may be more or less quickly replaced in thickness as long as these rocks underlie the area. The fertility and materials of the new mantle would be another matter as humus and nitrogen would need to be introduced and the materials worked over by organisms. There might be more lime, potash, and phosphorus in the new mantle than in the one removed. Rocks of this character underlie extensive areas of the Atlantic and Gulf Coastal Plains of the United States and, no matter to what extent the mantle materials of these regions may be carried away, it will be possible to restore the mantle materials within a few years provided gullying is not so severe as to make utilization of the lands impossible. This must not be construed as permitting carelessness in management of mantle materials derived from these rocks, as the productivity of the new mantle will not equal that of the old.

If a region is underlain by poorly cemented sandstones, as beneath the Central Plain of Wisconsin where such sandstones are responsible for the mantle materials, one need have little worry even if the mantle materials are carried away. The original thickness of mantle materials may be restored within a few years as these sandstones quickly crumble into sands. Mantle materials derived from rocks of this kind generally have little agricultural value.

The production of a foot of rock mantle from a granite, syenite, or diorite, or from gneisses and schists derived from these rocks, requires an immense time as these rocks are very slowly destroyed. The time is so long that not only are all soluble substances produced by the destruction carried away, but large quantities of insoluble substances of colloidal dimensions are also removed. Little of an original foot of rock may remain to form rock mantle. Under some climatic and topographic conditions the substances produced by the destruction may be removed about as fast as formed. Thus, the time required to form a foot of rock mantle from granitoid acid and intermediate rocks must be very long.

An almost infinitely long time would be required to produce a rock mantle from quartzite. This variety of rock breaks down with such extreme slowness that it would seem impossible for residual materials to accumulate at all under any conditions of relief permitting water to flow. A thick rock mantle on and formed from terranes of strong quartzites is probably a rare occurrence.

The essence of the foregoing discussion on the cost of residual materials in time and rock is that the cost varies with the kinds of rock and climatic and topographic conditions;

that for all strong rocks the thickness of rock required for the production of a foot thickness of residual materials is many times this thickness, and the time required for the destruction of the rock and the accumulation of the residual materials is so long that many thousands of years must elapse after a rock mantle has been lost before a new one can be formed. It is probable that before the lost mantle materials derived from resistant rocks are restored the present nations will have ceased to exist and even their histories shall have become dim.

Weak rocks, like the siltstones, claystones, and some poorly cemented sandstones, are easily broken down into residual materials, and if these materials are removed it may be a matter of a short time for a somewhat similar mantle to be made from these rocks. The same statement may be made with respect to volcanic ash, tuff, scoria, and pumice as these rocks crumble to residual materials quite rapidly.

Chapter IV.

Erosion of the Rock Mantle

The destruction of soil and the rock mantle is brought about by erosion. Erosion has the correlative process of deposition. Erosion is a geologic process produced by geologic agencies. Erosion of the soil and rock mantle is just one phase of the work of several agencies which are eternally striving to reduce the surface of the land to a low plain and finally, through erosion by the waves of the sea, to a surface below the level of the sea. Erosion can not be stopped. It began when the first rains fell and the first winds blew and it will continue until there are no more rain and wind. The formation of residual materials is the beginning of erosion. This is of the nature of a softening process to make rocks easy to remove. Erosion is done on land by means of wind and water with some aid due to the attraction of gravity which causes loose materials to creep or flow to lower levels. The atmosphere does its erosive work by means of its composing gases, the water vapor in the atmosphere, and by the winds. Water and its contained gases and dissolved solids representing various elements bring about chemical changes in any rocks with which the water comes in contact. Finally its solvent ability and its flow erode the rocks and the products made by its chemical activities.

Erosion by wind naturally takes place where there is little rainfall and little vegetation. Accelerated erosion by wind has been produced through cultivation of lands in areas with climates bordering on semiaridity. Erosion by water takes place wherever water falls. It has been greatly accelerated by cultivation of lands under any condition. Like the statement in the Scriptures which says that the rain falls on both the just and the unjust, erosion is impartial in its treatment of men. The lands of both the good and the wicked are affected alike. Erosion respects only him who manages his lands in such ways as to protect them in the ways that nature protects them.

The term soil erosion, frequently used in recent years, is that erosion which takes place in addition to the normal erosion occasioned by natural conditions of vegetative cover and ground equilibrium. Soil erosion, perhaps, may be better defined as that erosion induced by agriculture. It is most of the erosion due to the activities of man (Bennett, 1928; Sharpe, 1938).

Erosion by Water

Soil and the rock mantle can not be considered apart from water or apart from plants and animals. If there were no water, there would be no soil or rock mantle, no plant or animal matter, and no erosion by water. Wherever there is water there is rock decomposition and erosion. Plants and animals can not exist without water, and where they do exist, they assist in the decay of rocks, thus helping to form soil; the plants protect the soil against erosion on the surface. Soil, water, and organisms form a great triumvirate which through and from the decay of rocks is responsible for the materials which in various degrees of thickness cover the rocks and form the surface of the earth. For millions of years each surface has had a rainfall (precipitation), a slope, a thickness and character of mantle rock, and a plant cover together with its associated animals - all of which have determined the rate of destruction of the underlying rocks, the extent of runoff of the water which fell, and the infiltration of this water into the soil and rocks below. The vegetation aided in increasing the infiltration of water into the soil and in preventing runoff. George P. Marsh wrote in 1864 "Nature has provided against the absolute destruction.....of the raw materials of her works.....but has left it within the power of man irreparably to derange" that arrangement "which through.....aeons she has been proportioning and balancing." Cultivation of land with no control of runoff has produced the derangement.

The water reaching the surface of the earth falls as rain, snow, hail, fog, or dew. (Fig.2). A fraction of such water or moisture roughly estimated as a fourth to a third of the whole, flows away on the surface to make what is known as the runoff. This water is partly responsible for streams and produces soil erosion as well as some natural erosion. A second fraction of the water evaporates shortly after falling and thus returns to the atmosphere. A third fraction sinks into the ground to become a part of the ground or underground water. Some of the underground water is returned to the atmosphere by means of the transpiration of plants. The relative proportions of runoff, evaporation, and water sinking into the ground probably differ at a given location with every rain and they certainly differ greatly from place to place. They vary because of differences in the rate and amount of rainfall, differences in the growth of vegetation, slopes, characters of the rock mantle, and characters and structures of the underlying rocks. If the rock mantle and the underlying rocks are porous, permeable, and greatly fractured, the slopes gentle, the precipitation large and even, and the cover of vegetation excellent, then the quantity of water

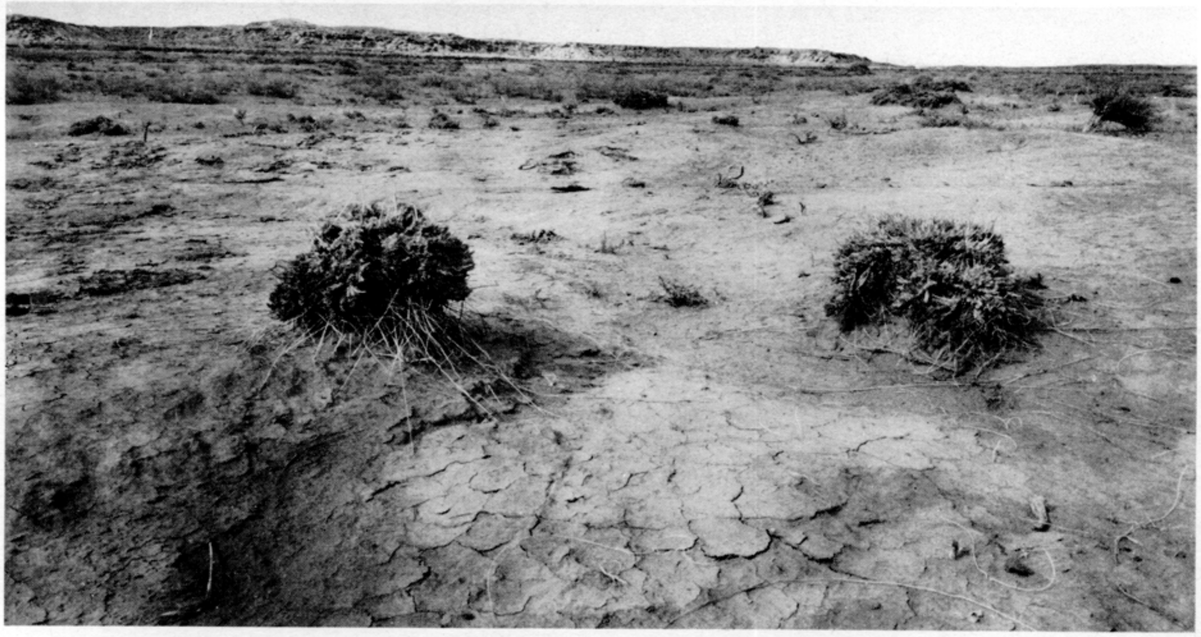

Fig. 3. Results of sheet erosion. Erosion has been rather uniform so that the surface remains essentially smooth. The tufts of dead vegetation show the minimum thickness of rock mantle removed. If the land were under cultivation, the extent of removal would not be noticed. Navajo County, Arizona. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 4. Land in west Tennessee ruined through erosion by gullying. The good soil which once covered this land is now distributed over the Mississippi River flood plain and the bottom of the Gulf of Mexico. This was good land less than half a century ago; it is now essentially worthless. Erosion control measures would have prevented this loss. The land can not support the elaborate houses shown in the photograph. The photograph shows that the land at the time it was taken was being pastured too heavily and that little protection existed for the soil on the parts still not gullied. (*Photograph by the U. S. Soil Conservation Service.*)

which soaks into the ground is large; the runoff is correspondingly relatively small. On the other hand, if the rock mantle and underlying rocks are dense and impermeable, the underlying rocks little fractured, the slopes steep, the rainfall very rapid, and the vegetation scanty, then the runoff takes care of most of the water and little enters the ground. The runoff may move over the surface as a sheet, as numerous little rills, or as concentrated flow in small to large channels. It is probable that the flow of runoff rarely occurs as a sheet, but that the flow generally designated by this name really consists of numerous little rills. This brings about the so-called sheet erosion by which the entire affected surface is more or less uniformly lowered. The surface remains essentially smooth during the erosion. (Fig.3). Concentration of the water into small to large channels leads to gullying and great irregularities of the suface. The so-called sheet erosion to a considerable degree is the precursor of gully erosion. Sheet erosion is more insidious and more dangerous than gully erosion, as it is not so readily recognized, and the top mantle materials, the top soil, may be gone before the menace is realized, whereas gullies are obvious from the beginning. Sheet erosion may not be followed by gullying on lands which are continuously cultivated as the cultivation may destroy the small depressions which, shortly after they form, lead to gullies.

The top soil, the A-horizon of àgriculture, is more friable and more absorptive than the underlying B-horizon which in turn is less absorptive than the underlying C-horizon. The A-horizon may contain numerous root passages and animal burrows and also may contain much organic matter. The B-horizon has limited permeability and few passages due to organisms. The C-horizon is porous and permeable because it consists of much little-decayed rock. Erosion of the A-horizon places the runoff on the B-horizon whose limited permeability hastens its erosion when thus exposed. After gullies cut through the A- and B-horizons, the C-horizon is easily eroded, the A- and B-horizons are thus undermined and collapse into the bottoms of the gullies concerned, leaving steep slopes on the sides and at the head of every gully. Vegetation on the surface of the ground above the gully protects that surface from erosion from above but has no effectiveness in preventing waterfall erosion on the steep wall at the head and on the sides of a gully. There is thus constant collapse of chunks of sod to the bottom of the gully. If a field is once deeply gullied it is destroyed so far as further cultivation is concerned. (Fig.4). However, steps should be taken to prevent additional growth of gullies,"As an active gully threatens everything within its drainage basin, and unless gully enlargement is stopped, entire fields or farms may be rendered altogether useless for cultivation" (Ireland, Sharpe, and Eargle). Heavy rainfall on sloping cultivated land without protection against erosion may reduce such land to a maze of gullies in a single day (Fig. 5). Gullies are often produced by the building of roads. Ditches on the hill-side of a road conduct water to culverts. This concentrates large volumes of water below the outlets of the gullies where it is frequently discharged upon fields below the road. This concentration of water almost inevitably leads to gullying (Davis, 1938). Effects are extremely likely to be most intense on the down-hill sides of mountain roads (Kraebel, 1936).

All rock mantle materials are in process of movement down hill. The movement ordinarily is extremely slow, and is observable only in its accomplishments or effects. It may be recorded by the bending of trees down slope, by fences and roads getting out of line, and similar phenomena. At times, however, the mantle may actually be seen to be in slow movement and numerous occurrences of rock and earth slides are known. The movement may become that of a mud flow, a form of movement very common in dry and cold regions wanting in vegetal cover. This takes place in arid regions and on sloping cultivated fields during heavy rains. The mantle materials become thoroughly saturated with water so that they flow as a viscous fluid. In cold regions after frozen soil thaws on sloping land, the surface layer of soil may also move down hill as a thick mud. (Bamesberger, p. 15.) Humid regions, such as in western Oregon, under natural conditions have the mantle materials anchored by vegetation, and mud flows are not common. Movement of mantle materials in the form of thick fluid is known as <u>solifluction</u> (Andersson) and this is particularly common in desert areas of considerable relief, as in Utah, Nevada, southeastern Oregon, and California, and in the cold regions of the sub-polar parts of the earth.

Creep, slump, and solifluction merely move materials from the higher to the lower parts of a region and lead to thick accumulation about the bases of the elevations. The processes also serve as feeders for streams and the streams, in turn, by cutting against the slopes, encourage this form of erosion. Mantle materials are thus made thinner on the upland slopes and thicker about the bases of the slopes.

Water flowing on the land is assumed to be in some form of stream. Such water is generally turbulent, that is, it has a maze of individual currents flowing in various directions. Many of the currents are directed toward the bottoms of the channels where they are reflected and thus have ability to lift particles from the bottom. This ability to detach and lift particles from the surface over which water flows is termed its <u>hydraulic action.</u> After the particles are lifted above the bottom they remain in suspension either because they are so small that gravity cannot compel them to settle, or because the turbulence of the water prevents settling. To the extent that settling is prevented the particles travel down-current from the places of acquirement. This is <u>suspension transportation</u>. Sediments are also transported in <u>solution</u> and by rolling or sliding on the bottom of a channel; the latter method is termed transportation by <u>traction</u>.

The ability of water - also wind - to transport in terms of dimensions of particles is termed the <u>competency</u> of the transporting agent. Ability to transport in terms of quantity is termed <u>capacity</u>. <u>Load</u> is the actual quantity transported.

Fig. 5. Extensive erosion of unprotected land by a storm on March 2, 1938. The field was planted to flax before the storm and no erosion control existed. About one half of the 65-acre field was gullied with an estimated loss of 65 percent of the crop. The thousands of tons of soil removed by the erosion were washed across a state highway and much of it was deposited in valuable orange groves on lower lands. Failure to control erosion on the field of flax damaged more valuable land on lower levels. Camarillo District, Ventura County, California. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 6. One effect of either wind or water erosion is concentration on the surface of any large pieces of rock which may be in the soil. Such pieces are almost universally present and thus the surface ultimately becomes veneered with gravel and boulders. The photograph is that of a farm in Beadle County, South Dakota. The boulders and gravel on the surface were originally disseminated through the soil which has been removed by erosion. (*Photograph by the U. S. Soil Conservation Service.*)

The water and the sediments carried abrade the surfaces over which movement takes place and the transported sediments mutually abrade each other. There may also be blows by the transported sediments on the bottoms and sides of the channels and upon each other. In these several ways the bottoms and banks of streams are eroded and the sediments acquired are transported downstream. Likewise, all water, whether in streams or other places, produces chemical changes in rocks and mantle materials and removes soluble substances. The result is that every drop of water in every stream may be expected to carry something in solution and suspension and the combined drops may be expected to roll large particles on the bottoms of the channels. Agriculture does, but should not, play a large role in providing streams with very large loads, and in promoting erosion of mantle materials.

Under natural conditions regions with sufficient rainfall are provided with an efficient armor in the form of an adapted growth of vegetation. The falling water first comes in contact with the trees and larger plants where much of it is held. Studies have shown that a good stand of pulpwood spruce, fir, and some paper birch in Maine intercepted 26 percent of the rainfall, pure spruce 37 percent. A dense saw timber stand of white pine intercepted 24 percent. A heavy virgin growth of white pine and hemlock in Idaho intercepted 21 percent, jackpine and hemlock-hardwood stands in Wisconsin intercepted 22 percent in spring and 19 percent in fall. Hardwoods when in leaf intercepted 25 percent. This declined to 16 percent when the leaves fell. (United States Dept. Agric., Misc. Pub. 397, p.18.)

Some of the water caught by the trees flows down the trunks or drops to smaller plants; ultimately it flows or drops to the ground and is caught by the litter of dead leaves, stems, and bark. Soaking through this litter the water finds a porous and pervious rock mantle which is made so by the inclusion of organic matter, by root passages, by burrows of animals, and by changes produced in the mantle materials by the animals and plants dwelling therein. At no time in the journey from the tops of the trees and large plants to its entrance into the ground is there opportunity given for the water to become muddy; hence it contains little or nothing which can be removed by filtering and there is no possibility of the soil passages becoming filled as the water passes through them. The result is that permeability of the rock mantle is maintained and large quantities of water can continue to soak into the mantle materials and ultimately into the underlying rock. Correspondingly, the runoff is decreased. This is the case over any timbered section of Oregon. Under ordinary conditions there is little direct runoff and it is only at times of excessive rainfall, or when rain falls on frozen ground that runoff is appreciable. It should also be remembered that the lands covered with vegetation do not freeze as deeply as bare lands, and may not freeze at all, even in very cold weather, because of the protection afforded by the plant litter on the ground. Thus water can readily enter the ground even in cold weather, whereas in cultivated fields and closely grazed pastures, this protection is wanting as the ground freezes and runoff is forced. Much experimental and observational work has demonstrated that forest soils are able to absorb very large quantities of water. Comparative studies showed the following: Forest soil at the depth of 3 inches absorbs 14 times - and, at a depth of 1 inch, over 50 times - as much water per minute as a field soil at corresponding depths. After old fields have been reforested, absorption of water is increased. The average rate of absorption of water at 1-inch depth in a 17-year old plantation was found to be 107 cubic centimeters per minute as contrasted with 8 cubic centimeters per minute in an adjacent open field. (United States Dept. Agric., Misc. Pub. 397, pp. 9-10.)

Soil deprived of its vegetal cover may be compared to a medieval knight in battle without armor. Death would likely have been his fate; likewise, mantle rock without vegetal protection stands a strong probability of being destroyed unless artificial measures are taken to prevent erosion on the surface, that is, to prevent runoff.

The rock mantle and the soil which is on the top is the greatest friend and benefactor of the farmer, but the farmer has been the greatest enemy of the soil and the rock mantle. He harrows and rolls the soil in order to reduce it to powder and thus he places it in the most favorable condition for erosion by water and wind. Not content with removing the armor and weakening the soil, he plows furrows over the fields in directions which all too frequently are downslope and thus arranged to lead the waters rapidly away. Many combinations of the three factors, namely, removal of armor, powdering of soil, and preparation of channels for flow, lead to large runoff and great erosion. The rain strikes naked soil; the water is made muddy; no root passages or animal burrows are present; the water must flow through interstices between small particles; the mud in suspension is shortly filtered out; the small passages are quickly closed by the mud filtered from suspension and the expansion of the clay and silt particles; further infiltration is prevented; runoff is increased; and erosion on a large scale is inevitable (Lowdermilk, 1930). It is little wonder that the rock mantle is rapidly stripped to the surface of solid rock.

Studies made in Iowa between July 1, 1934 and December 31, 1935, on a silt-loam soil with a surface having a slope of 9 percent showed the large increase in runoff on a cultivated surface as compared to one covered with bluegrass. On a slope length of 72.6 feet in each case for the same rainfall, the runoff on the cultivated surface (cornfield) was 5.07 inches, whereas on the bluegrass surface it was 0.50 inch (Musgrave and Free). Differences in runoff on cultivated and forested lands were shown by measurements made at Ithaca, New York, between March 1 and 19, 1935. Water losses from a field in potatoes with a slope of 14 percent amounted to 88 percent of the total precipitation and soil was lost at the rate of 0.53 ton per acre. Of the 9.47 inches of precipitation, 8.38 inches were lost in the runoff. A neighboring forested area with the much greater slope of 27 percent lost only 0.5 percent of the total precipitation. The ground beneath the potato field was frozen, that beneath the forest was not. A neighboring field in grass with a slope of 20 percent with the ground not frozen lost no soil and had a runoff of less than 0.2 percent. Another grass plot with less growth and a slope of 14 percent lost 88 percent of the total precipitation but little soil was carried away. In northern Mississippi in 1931-1932 during a time of 27 inches of rainfall, 62 percent of the precipitation was in the runoff from cultivated fields, and the loss in soil amounted to 27 tons per acre; on barren abandoned fields the runoff was 54 percent of the rainfall. On these same fields at the times of heaviest precipitation, the runoff ranged from 75 to 95 percent. An undisturbed oak forest in the same locality with the same precipitation had a runoff of less than 0.5 percent of the total precipitation and the loss of soil was only 75 pounds per acre. The loss of water from the surface of a scrub oak forest with a litter cover in the same area was only 2 percent. The surface of the cultivated land had a runoff 127 times greater than the land in forest and suffered a soil loss 900 times greater. During a 2-year period in this region from October 1931 to September 1933 there was a total rainfall of 130.7 inches. The loss from a cotton field in which the rows paralleled the slope was 195 tons per acre for the two years; the total runoff was 58 percent and in some of the heavy rains the runoff was 95 percent. The runoff from a cotton field where the rows paralleled the contours was 47 percent and the loss in soil was 69 tons per acre for the two years. (U.S. Dept. Agric. Misc. Pub. 397, pp.28-29.) In Missouri on a 3.7 percent slope on silt-loam with the average depth of plowing 4 inches, 41.2 tons of soil was washed from each acre each year, but from a bluegrass field on the same soil and slope the loss was only 0.28 ton per acre per year. For the bare ground this is equivalent to the removal of a 7-inch soil layer in 24 years; for the sod the comparable time figure is 3,547 years. The grass held back 137 times as much water as the bare ground. (Bennett, 1928, pp. 4-5.)

Cultivation of land is not the only way in which it is made vulnerable to the erosive work of flowing water. Many farm lands are pastured until the surface is essentially bare; no vegetal litter mantles the surface; and there is little to check the flowing water in its journey from higher to lower places (Fig.4). If too many animals are pastured on too small areas, the grass is nibbled almost to its roots; the numerous little dams produced by the living and dead vegetation are wanting, and the waters flow without control. If too much stock is present, there will be much more wandering on the fields and thus many cattle trails. These will be traveled over more often and every cattle trail is almost certain to become a gully. Observations made at the Upper Mississippi Valley Erosion Station near LaCrosse, Wisconsin, showed that a four-hour storm on August 5, 1935, precipitated 2.4 inches of water. Measurements were made on a cleared grazed field, on a grazed woodlot, and on an ungrazed woodlot. The grazed field had a runoff of 6 percent of the precipitation and a loss of soil of 220 pounds to the acre; the grazed forest woodlot had a runoff of 17 percent and a loss of soil of 745 pounds per acre; and the ungrazed woodlot a runoff of 0.7 percent and a soil loss of only 17 pounds per acre. (U.S. Dept. Agric., Misc. Pub. 397, pp. 47-48.)

Close grazing in the Wasatch Mountains between Salt Lake City and Ogden, Utah, has produced floods of great severity and many thousands of tons of debris have been washed from the canyons. Boulders weighing as much as 200 tons have been moved and deposited over fertile valley lands. Excellent farmsteads were wrecked and many lives were lost. The overgrazing led to destruction of lands both at the places of removal of soil materials and at the places of their deposition. A commission appointed by Governor Dern of Utah established the fact that the destruction of the upper lands by erosion and the lower lands by deposition was due to the destruction of the vegetal cover by overgrazing, fire, and to some extent by logging, and that gullying did not originate on slopes with a dense vegetal growth where a thick cover of plant litter and large content of humus in the soil permitted absorption and prevented or retarded the runoff. (Bailey, R. W. et al, 1934.)

Another destructive and much to be condemned practice which still prevails in many sections of the United States is the burning of lands in order to destroy or retard the growth of undesired vegetation. This practice is generally thought to increase the growth of grass. It is possible that it may do so to a slight degree, but it leaves an unprotected surface after the plant litter is destroyed. This bares the surface to attack and, if heavy rainfall takes place before vegetation is re-established, it is absolutely certain that there will be large runoff, much top soil will be removed, and correspondingly the productivity of the soil will be impaired. Deposition in the lowlands may greatly damage lower areas. This practice of "burning off the grass" is a common one in southwest Oregon. Observations made in Illinois on yellow silt-loam soil showed that in a forest of undisturbed oak, the absorption of water averaged five times as much as was absorbed where the woods were burned, and 15 times as much as on poorly managed pasture. (U.S. Dept. Agric., Misc. Pub. 397, p. 10.) A fire above Burbank, California, in 1927 burned over 704 acres. A rain of only 1.07 inches in the following year in three hours, but with a maximum intensity of 1.70 inches per hour for 10 minutes, produced runoff from the burned over land three times as great as over adjacent unburned areas. The runoff from the burned over area removed between 25,000 and 50,000 cubic yards of soil materials. There was no noticeable removal of soil materials from the adjacent unburned areas. A single storm of December 30-31, 1933, and January 1, 1934, in Los Angeles County, California, removed 50,000 to 67,000 cubic yards per square mile from the Verdugo and Haines watershed with the runoff in the form of a torrent of 1000 cubic feet of water per second from each square mile of burned area; whereas, in the watersheds of the unburned San Dimas and Arroya Seco canyons with the same rainfall, the runoff averaged only about 55 feet per second from each square mile and only 56 to 58 cubic yards of soil materials were eroded from each square mile. The water from the burned area contained nearly as much mud as water; that from the unburned area was clear. (U.S. Dept. Agric., Misc. Pub. 397, p. 36.)

It seems absolutely certain that continuation of the practice of burning of sloping lands can be attended only with total removal of the rock mantle down to bare rock. The burning over of areas with steep slopes leads to rapid removal of the rock mantle accumulations of thousands of years and greatly impairs bottom lands over which the eroded materials are deposited.

The teachings of these observations are so patent that even the blind should see and, unless efforts are made to substitute artificial protection for the natural protection that man has destroyed by cultivation, burning, and close pasturing, there will come a time in the very near future when the soils of this nation will be spread over the bottoms of the Atlantic and Pacific oceans and the Gulf of Mexico, and crops can be grown only in the few areas where erosion has not taken place. Standards of living must fall, wars will become inevitable, and the weakened nation can no longer exist. It will become the subject of the nation or nations that have guarded their soils.

The water which sinks into the ground also affects erosion. Every drop of water which passes through the rock mantle and underlying rocks takes on a load of soluble and colloidal material. If the region concerned has a humid climate, the movement of the water is downward and thus the mantle materials are leached of carbonates, phosphates, potash, and other soluble substances. The water passes downward to the underlying little-decayed or unaltered rocks. These are affected by the chemical action of the water, and soluble substances together with some colloidal materials are removed, leaving behind the insoluble substances of the original rocks, or insoluble substances produced by the chemical changes. The layer of mantle materials is thus increased in thickness at the base. Under normal conditions of erosion these additions to the thickness of the mantle materials are essentially equal to the losses which take place in the top part and on the surface of the mantle, and thus the thickness of the rock mantle remains essentially constant. Under conditions of unguarded agriculture, removal of mantle materials at the top greatly exceeds additions at the base and thus the thickness decreases and ultimately no mantle materials remain.

If a region has a dry climate, there is downward movement of water during and for some time after rains, followed later by upward movement, as water is evaporated from the surface. This rising water returns something to the top soil which has been acquired therefrom, together with additional substances dissolved from underlying materials. The new substances placed in the surface materials either cement them into a crust, or reduce the surface materials to powdered form by means of the wedging action of the minerals deposited between the particles. These results may be seen in the arid and semiarid regions of the United States and similar regions in other parts of the world. The alkali areas in semiarid parts of the western states are expressions of this action. These soluble materials may be removed to a considerable extent when the next rain falls. Much is also removed by the wind.

Erosion by water - and such is also true for wind erosion - ultimately concentrates all coarse materials in the soils eroded on the surface. This increases the difficulty of cultivation. Large particles are scattered in greater or less quantity in all soils; soil erosion ultimately produces a gravel- or boulder-veneered surface. (Fig.6)

It seems obvious that protective devices must be constructed on cultivated and pastured fields which will take the place of vegetation to compel water to enter the ground, since the more water entering the ground, the less the runoff, the less the surface erosion, and the greater the formation of new soil materials at the base of the rock mantle. Groundwater erosion increases soil materials; surface water erosion loses them.

All materials acquired by water in its passage over the surface, or through the soil materials and the underlying rocks are transported from the places of acquirement, and are maintained in transportation until the waters reach places where velocities are lowered and deposition is compelled. This takes place where the waters pass over surfaces of less slope than those over which they have been flowing or where there is any condition which lowers the velocity of movement. Examples of places of less slope are those points where the steep slopes of valley sides change to the gentle slopes of valley bottoms. The deposits are spread in the form of lenses which thin to nothing up the slopes and also thin out down the slopes toward the streams which flow through the valley bottoms. The surface originally present is buried beneath the later deposits. This is not detrimental to the land in the beginning, as the deposits then consist of sediments which were derived from the top soils. The damage becomes progressively greater at a later time when the sediments deposited are derived from the basal parts of the rock mantle and consist to some degree of rock fragments. (Figs. 7 & 8.) This is an example of killing two birds with one stone: One bird, the land which is ruined by erosion; the other, the land which is ruined by deposition.

The deposits made at the foot of the steep slopes consist of the largest substances carried. The water with lessened capacity and competency continues over the lower lands, loses velocity more or less constantly, and deposits the finer sediments originally carried. The valley bottoms are thus raised and the raising may be extensive. In some valley bottoms of the upper Mississippi River region, places are known where fence posts have been completely buried in such short intervals of time as from 10 to 15 years. (Fig.9.) As the sediments over the valley bottoms are fine-grained, the lands may not be greatly injured.

Roads and railroads along the bases of steep slopes are known locally to have been completely covered in a single rain by sediments washed upon them from bordering steep slopes. The deposits are in the form of fans made at places where gullies intersect the

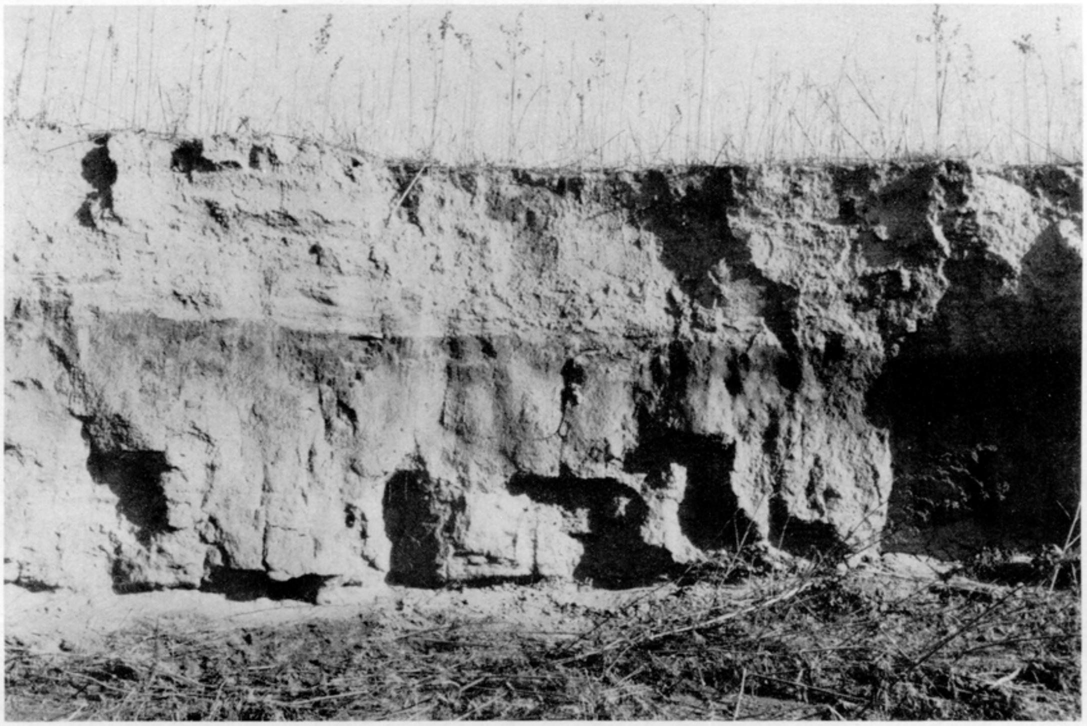

Fig. 7. Good soil covered by deposition of sediments eroded from higher lands. The light-colored upper part of the section is about 3 feet thick and this deposit is a part of an alluvial fan. The soil produced by the deposition is poorer than that which was buried. The deposition took place subsequent to white occupation of the country. The land eroded to produce the deposit was made poorer because of the erosion. On a tributary of the Zumbro River, near West Albany, Wabasha County, Minnesota. (*Photograph by the U. S. Soil Conservation Service.*)

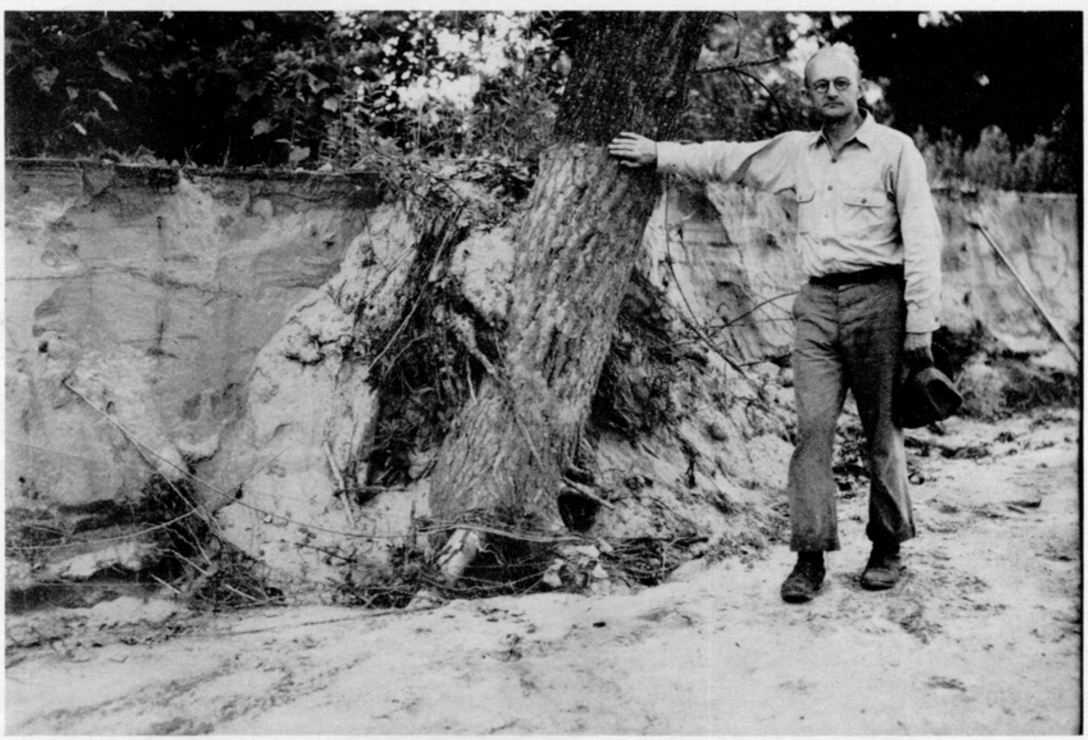

Fig. 8. Alluvial fan deposit of sand with thickness of about 5 feet. The tree obviously is probably less than 25 years of age. At mouth of a small tributary of the Whitewater River, Winona County, Minnesota. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 9. A fence in process of being buried by deposition over a valley bottom. Good soil is being buried by what is likely to be poorer soil. This is a study of deposition of sediments. On Whitewater River, Winona County, Minnesota. (*Photograph by the U. S. Soil Conservation Service.*)

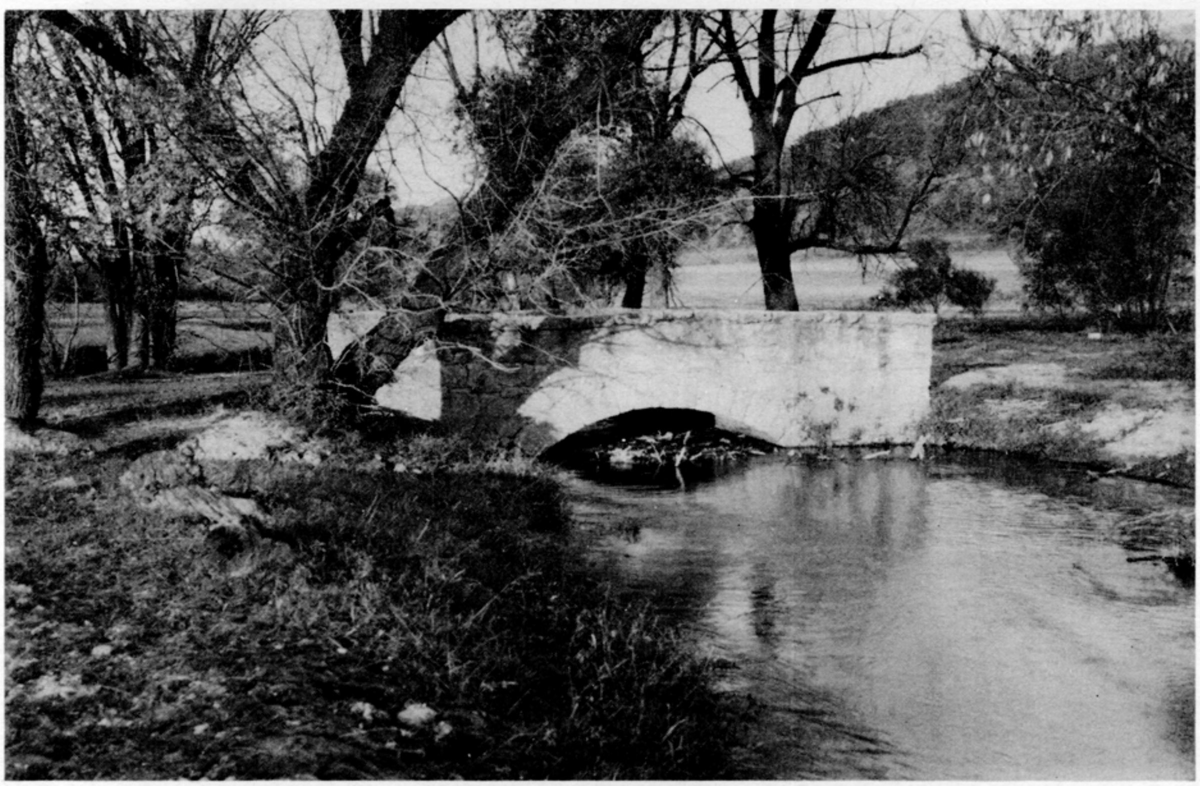

Fig. 10. Closing of a culvert on highway due to deposition of sediments. When the closing is complete, water will flow over the road which it probably does at times of floods. Construction of a new culvert will be necessary. Morman Coulee Creek, south of LaCrosse, Wisconsin. (*Photograph by the U. S. Soil Conservation Service.*)

roads. The levelness of the roads and the road ditches on the uphill-side check velocity and force deposition. This is a very common occurrence where Wisconsin State Highway 35 between LaCrosse and Prairie du Chien passes along the foot of pastured slopes on the east side of the Mississippi River. Deposits of rocks in large and small fragments to heights of three or more feet with widths up to 50 feet or more have been made by a single rain. Deposits of this character may be expected in Oregon on U.S.Highway 101 between Port Orford and the California line and thence south, if ever the steep slopes along that road are cleared of timber and either cultivated or closely pastured. Deposits of this character seem to have been made between Bandon and Marshfield on this road. Landslides may also be expected after the slopes of the hills are bared of efficient vegetal protection.

This is not the only damage done to roads under such conditions. Ditches along roads and railroads may become filled with sediments. Culverts are certain to become filled, thus aiding deposition in the ditches. (Fig.10) Even bridges may catch enough materials to dam the waters. If flow beneath the roads is prevented, the waters are certain to go over them with consequent great danger of washing away of road or railroad. This is known to have occurred repeatedly. The Chicago, Burlington and Quincy (The Burlington) Railroad which follows the foot of the Mississippi River bluffs from northern Illinois to the mouth of the St. Croix River in Wisconsin has this as a serious and expensive problem. Expenditures to clean culverts, re-excavate ditches, and move debris from the road bed annually amount to considerable sums of money.

Because of slides and washouts many roads and railroads in various parts of the United States have had to be relocated or raised. This has meant the building of new bridges and culverts or the raising of old ones. The annual expense in the United States in connection with roads and railroads due to deposition of soil materials at the foot of steep slopes and over valley bottoms is an extremely large sum.

Eventually the mud-laden waters enter the channels which are present to some degree in every valley. Various obstructions, such as crooked channels, lodging of trees, and growth of bushes and trees, check velocities and compel some deposition of sediments. Stream channels are thus raised and the flooded streams more and more often leave their channels and spread laterally over their flood plains. These plains are then raised because of deposition. Bridges which originally were built at a safe height above the water are now in danger and under conditions of heavy rainfall or rapid melting of snow may be carried away. The writer is acquainted with a bridge across Coon Creek, a small tributary of the Mississippi River in western Wisconsin. At the time it was built, this bridge was so high above the water that it was thought impossible that flood waters could ever reach it. Twenty-five years later the writer could not walk under the bridge without stooping. Numerous examples of this condition may be seen in most parts of the United States.

Silting of channels has developed many problems affecting the flood plains bordering the channels. This effect has reached a critical stage in many parts of the United States in that such silting makes floods possible where none have occurred before. Silting often renders irrigation and drainage channels useless and it may change irrigated lands to swamps. Many streams have had their navigability reduced or destroyed on account of deposition of sediments in their channels.

The deposition of sediments over the land of valleys may ruin them or greatly impair their productivity for agriculture. In 1860 Hilgard noted that the Yazoo basin of Mississippi had been seriously damaged because of the deposition of sediments over it. This was only about 20 years after the basin had been settled. Many square miles in the Piedmont area of the Carolinas and Georgia, formerly excellent bottom lands, have been ruined because of deposition of sediments derived from higher lands. Such is also the condition over thousands of acres of bottom lands in other parts of the United States. Tremendous damage may be done by a single heavy rain. This will be the ultimate fate of much of the good bottom land of western and southwestern Oregon, if and when the highlands about these lands are denuded of their armor of protective vegetation. Among them are the valleys of the Coquille, Coos, Sixes, Rogue, Umpqua, Chetco, and other rivers. Every time a field on the hills is burned, overgrazed, or improperly cultivated, runoff and surface erosion are increased, and some damaging deposition on the lowlands is a consequence. (Figs. 11 to 14) (Happ, Rittenhouse, and Dobson)

The obvious teachings of these facts are that the rock mantle materials should be kept on the hills where they may serve the nation and they should not be permitted to be carried to the valley bottoms where they bury excellent soils and do other damage. To keep the rock mantle on the hills the rain waters which would carry the sediments from the hills should be compelled to enter the ground on the hills and not be permitted to flow away on the surface. That is, the water should be made to work for man and not against him. The plants collect water and force it to enter the ground where it may serve best - that is Nature's way.

The sediments have not completed the possible damage after they have entered streams and brought about deposition there. The streams may flow into lakes, or into reservoirs built by man. Here they complete deposition of most of the sediments which remain in suspension and they may bring a lake or reservoir to extinction. Lake Como at Hokah, Minnesota, was a lake and popular resort for swimming and boating in 1926. In 1936 the lake no longer existed (Figs. 15A-B). The basin had been completely filled with sediments washed from the surrounding cultivated and pastured lands. Of the 56 larger reservoirs examined by the Soil Conservation Service in the Piedmont district of southeastern United States, thirteen had been filled with sediment in an average period of 29.4 years. These 13 dams had an average height of 29.8 feet. The sediments largely

Fig. 11. Destruction of a field of corn by a flood in Ohio in August 1935. The thickness of the deposit is shown by the block in the hands of the man. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 12. Deposits made by a single flood over a farmstead on the south bank of the Republican River near Guide Rock, Nebraska. The thickness of the deposits may be judged by the extent of burial of the farm machinery and the deposits which had to be cleared away from the door of the house. This deposition arises from lack of erosion control of the hill lands. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 13. Deposition of sediments over a street and curb as well as the adjacent land by a flood in June, 1938. Kenwood Park, Salina, Kansas. The sediments came from the hill lands of Kansas. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 14. Deposits of sediments made by a flood in June, 1938, over the ball park in Salina, Kansas. The thickness of the deposit ranged from 1 to 5 inches. This and the preceding illustration shows to a small degree the effect of erosion on a city. The sediments could have been kept on the hill lands from which they came had methods of erosion control been practiced. (*Photograph by the U. S. Soil Conservation Service.*)

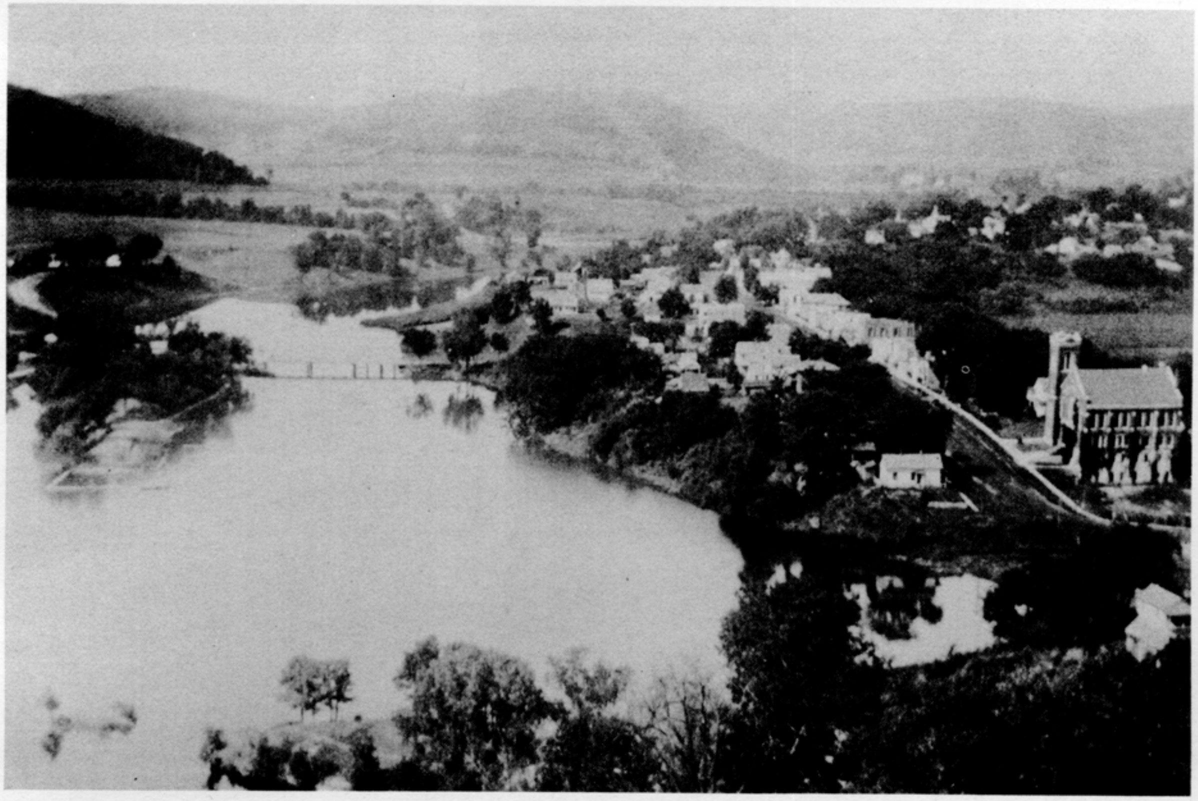

Fig. 15. (A) Lake Como, Hokah, Minnesota, 1926. Lake Como in 1926 was a popular resort for swimming, fishing, and boating.

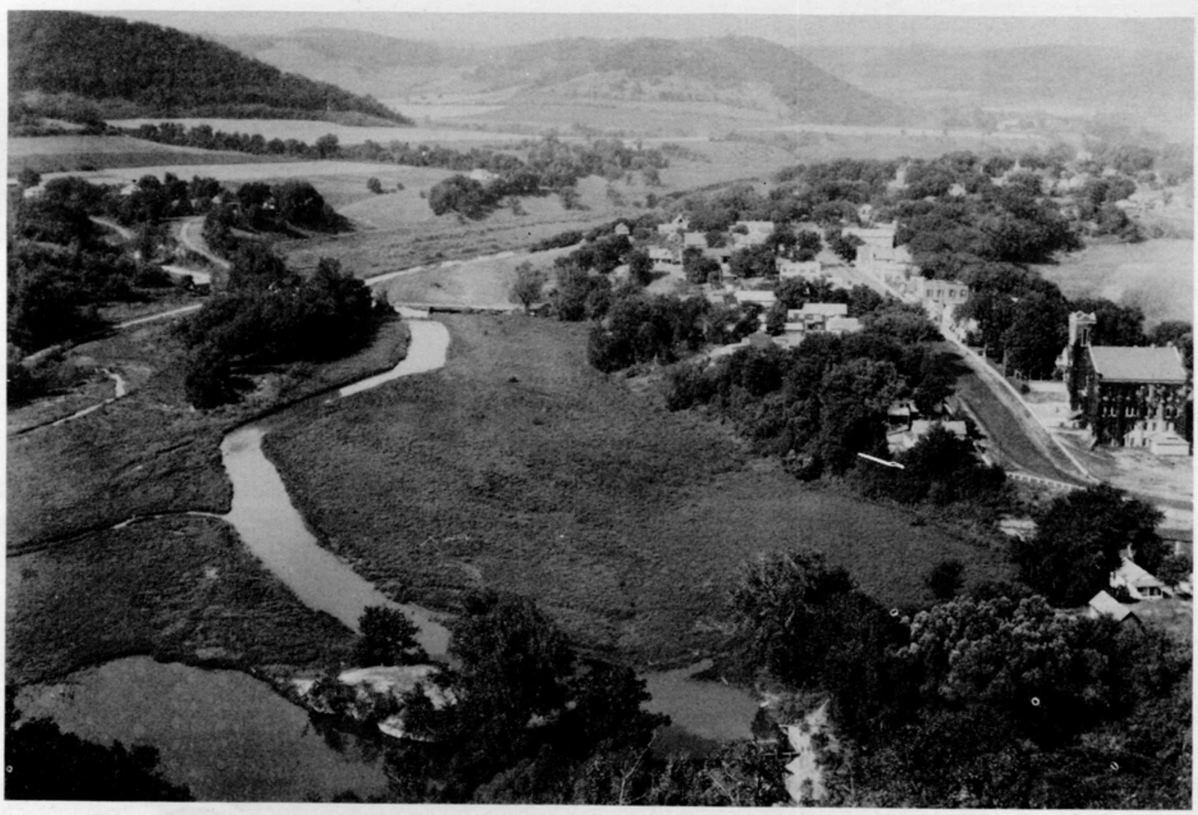

Fig. 15. (B) Lake Como in 1936. The lake has been completely filled with sediments. These photographs show the extent to which a village may be interested in the erosion of farms. (*Photographs by the U. S. Soil Conservation Service.*)

Fig. 16. Filling of the Schoolfield Reservoir, Dan River, near Chatham, Virginia. The filling consists of sediments derived from farms in the background. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 17. Deposition of sediments above a power dam on the upper Iowa River, Deborah, Iowa. The sediments are being eroded as the flood gates of the reservoir have been opened. The light colored sediments are sands. The deposition of the small tributary should be noted. (*Photograph by the U. S. Soil Conservation Service.*)

represented top soils derived from adjacent fields. Some examples of the serious effects of reservoir silting are as follows: The Austin dam at Austin, Texas, lost 95 percent of its original capacity in 13 years; the Burnt Mills reservoir in Maryland lost 46.47 percent of its original capacity in 7.8 years; the Byllesby, Virginia, reservoir, 60.21 percent in 23.7 years; Lake Calhoun, Illinois, 52.1 percent in 11.9 years; the Santa Anita, California, reservoir, 34.52 percent in 10.2 years; the Guthrie, Oklahoma, reservoir, 14.88 percent in 14.5 years; the Waco, Texas, reservoir over 14 percent in 5 years; the lake Tanoycoma, Missouri, reservoir 46.8 percent in 22.4 years; and the Gibralter, California, reservoir 30 percent in 16 years. These are not isolated instances. The same story is told to some degree by every reservoir and every lake around which the lands have been cultivated, pastured, or burned (Figs. 16 & 17). Unless reservoirs are protected very few will ever justify the cost of construction. It is useless and actually foolish, almost criminal, to construct dams where the reservoirs can not be protected against the extensive entrance of sediments. As the dams for reservoirs are presumed to be constructed at the most favorable sites in the regions concerned, the filling of the reservoirs renders just that much storage irrecoverable, as in most instances, removal of the deposits from the reservoirs does not seem feasible (Eakin, 1936, p.3). Protection of reservoirs against silting goes hand in hand with protection of the surrounding lands against erosion.

Erosion by Wind

Wind has no erosive effect on surfaces covered with dense vegetation, as the soil cannot be reached by the wind and hence cannot be removed. Conditions are different on surfaces with limited or no vegetation. The vegetation on cultivated lands is not very effective in protecting soil from attack by wind, particularly during the times of preparation and planting and the early stages of growth. Regions with very dry or very cold climates have greatly restricted plant growth which is protective only to a limited degree. Lands which are closely pastured, or those which have been burned over, are also open to attack by the wind.

Cultivation of land requires elimination of all undesirable plants, and the farmer industriously applies himself throughout the growing season to the destruction of all such plants. He pulverizes the soil, since, in general, the smaller the particles to which the soil is reduced, the better it is for the growing crop plants. Also evaporation of water from the soil is greatly decreased by cultivation. But it should be remembered that soil particles of small dimension do not encourage infiltration of water from the surface and thus there is likely to be less water lost by evaporation.

Regions with adequate rainfall are little affected by the erosive work of winds as the ground is usually kept sufficiently moist so that dust cannot form. This is not true in regions with only moderate or light rainfall as rain may not fall in such regions for long periods of time. The land is frequently plowed to destroy the capillary pores which aid in evaporation. Every plowing reduces some soil to dust and brings new soil to the surface. Conditions are thus made most favorable for wind erosion.

Regions of this character are present over the entire western half of the Mississippi Valley and parts of the Columbia Plateau in Washington and Oregon where the lands have been extensively devoted to the growing of wheat. These lands originally had an excellent cover of native vegetation which had been established as a result of conditions obtaining over a long period of years, and hence this vegetation was well fitted to protect the soils from the wind. The vegetal cover was a community of grasses and other plants, including algae and fungi. Add to these bacteria, insects and their larvae, worms, and numerous other burrowing animals which formed a condition of delicate equilibrium between themselves and the environment, each helping the others in a complex organization which could exist only if all elements were present. The organisms and the soil formed an environmental relationship which gave the organisms a home in return for which the organisms protected the soil, their home. Under unwise government encouragement and a large demand for wheat, these lands were given to the plow during and subsequent to the first world war. The grasses and their associates were turned under and the living things largely eliminated, or, as was said by an Indian, "The land was turned upside down." Good crops were grown during some of the early years when the soils contained sufficient plant materials to assist in acquiring and holding water. This plant matter also aided in preventing the winds from being very effective. Soon the plant materials in the soils were gone. The winds blew before the seeds had sprouted, the fine soils were blown away, and the seeds were left on the surface. The seeds may have been plowed in again with the hope that the plants would appear before the next strong winds came. This was repeated year after year until the farmers of the regions worst affected, concluding that they were fighting an unconquerable enemy, gave up hope and left the land to go elsewhere. They had done the best they knew, but the community of animals and plants which had been the guardians of the soil had been destroyed. Without protection, the soils succumbed to the attack of wind and water. It has been said that the good men do lives after them, but this is an example of the evil which good men do and it lives for a long time (Fig.18). Wind erosion is not confined to the West. Other parts of the United States may suffer its devastating effects (Fig.19).

The "dry farming" absurdity was strongly advocated by many who should have known better. The farmers were admonished to reduce the top soil to dust to prevent evaporation. What the advocates of "dry farming" do not appear to have known was that powdering of the surface soil prevented infiltration of water and placed the soil in the most favorable condition for attack by wind and water. The advocates of "dry farming" saw only the immediate objective and not what would happen if that objective were attained.

Fig. 18. Uncontrolled erosion by wind has made impossible the cultivation of the land shown in the photograph. Retention of all water which falls and establishment of a plant growth suitable to the conditions could restore the land. The photograph shows the land in 1936. Installation of proper methods of conservation of water saw the land covered with vegetation in 1937. Sherman County, Texas. (*Photograph by the U. S. Soil Conservation Service.*)

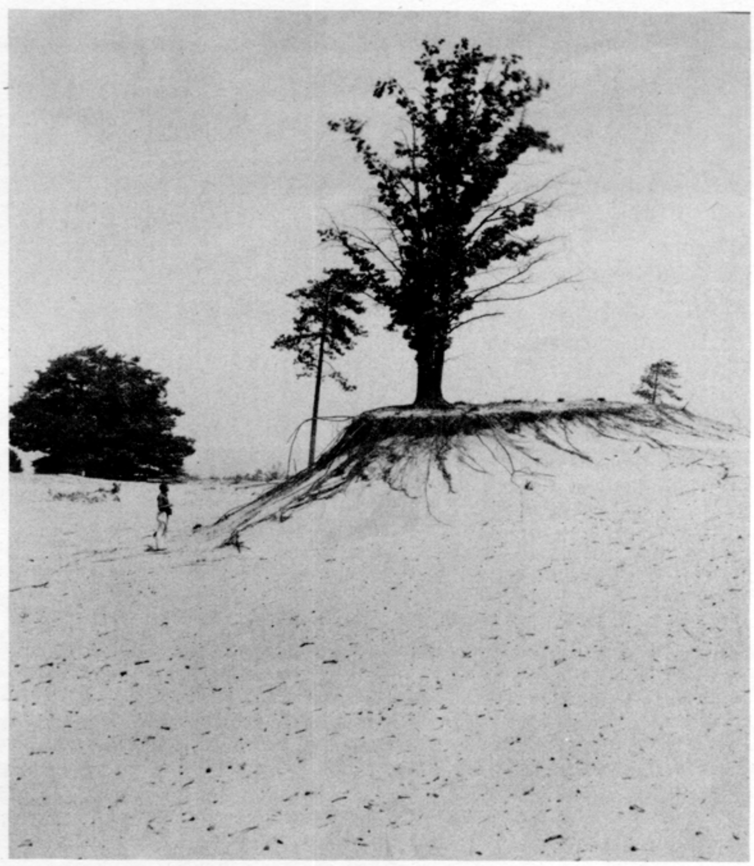

Fig. 19. Wind erosion. The extent of removal of material is shown by the tree. The area was farmed about 1915. Farming is now impossible. Near Grand Haven, Michigan. (*Photograph by the U. S. Soil Conservation Service.*)

The winds at once attacked the powdered soils of the "dry farming areas" and the "black blizzards" followed. The great "dust bowl" and numerous small dust bowls were inevitable consequences. A single dust storm on May 11, 1934, is estimated to have blown 300,000,000 tons of fertile top soil from the wheat lands of Oklahoma, Colorado, and Texas. This dust cloud was observed over the Atlantic Ocean 300 miles from the coast of the United States.

Particles too large for the wind to move are left. These ultimately give the lands some protection. Frequent plowing buries this protection and brings freshly powdered material to the surface. The ultimate sequel of the work of the wind is a barren surface veneered with wind-worn gravels. This will be the ultimate fate of the wonderful grass lands of 40 to 50 years ago unless past and present practices in handling these lands are stopped. These lands must be removed from clean cultivation and the cover of native grasses must be restored. This may not be immediately possible as the soils on which these grasses grew will have been largely carried away and the subsoils of the earlier days will form the surface. It also may not be possible to restore the old association of plants and animals as the elements of this association were not known when it was destroyed and all of them have not been learned today.

Close pasturage also makes lands vulnerable to the attack of wind. Grass is eaten to levels where the winds may reach the soil. As there is less food, the stock must move about a great deal. This means more tramping and powdering of the dry soil, and now the fine particles of the unprotected soil are blown away. A veneer of gravels is the ultimate result.

The results of close pasturage of dry lands subject to wind and water erosion are exemplified by the Navajo country of Arizona and New Mexico. The Navajo Indians were encouraged to raise sheep, goats, horses, and cattle. They learned that the public would purchase their pottery, turquoise jewelry, and blankets. There was a great demand for these products and, to satisfy the demand for blankets, the Navajos raised more sheep in order to have more wool. The scanty grass was nibbled shorter. The Indians attained some degree of prosperity and the population multiplied. More stock was necessary to support the increase in population, and this in turn led to more population. The grass was nibbled shorter. The vicious circle was in full swing. Gullies 30 to 50 feet wide and 10 to 20 feet deep with tributaries of less depth developed where originally only shallow depressions were present. The gullies extend in some cases to the hill tops. In places 25 percent of the meadows consist of gullies, and gullies are in process of cutting over an additional 40 to 50 percent of the meadows. (Rowalt, p.194; U.S.Dept. Agric., Misc. Pub.397, p.46.) Unless control is instituted, nature will wash and blow away the soil materials, the Indians will be stricken with poverty and probably will be reduced in numbers.

The only protection against erosion by the wind is the introduction of moisture or a vegetal cover. The latter is not always possible, and fields should not be plowed if neither can be done. If neither method of protection is given, the soil materials will be removed until the surface is covered with a veneer of the particles too large for the winds to remove. This is the present condition where plants do not grow either because the regions are too cold or too dry, and this will be the end of the wonderful grass lands of the western plains and similar regions elsewhere if the cultivation is not directed towards retaining the soil materials.

The sediments acquired and transported by the winds move in the direction in which the winds are blowing, which, for the United States, is generally eastward. The materials transported must ultimately be deposited. Transportation is by means of suspension and by rolling on the surface. The materials transported in suspension generally consist of particles of clay and silt size but, under conditions of strong winds, particles of small sand size are also transported. Materials rolled on the ground consist of sands, granules, and small pebbles. The dusts must ultimately settle or be washed from the atmosphere by rain or snow, but they may travel many thousands of miles before this is done. Dusts from the dry areas of western United States are known to have been deposited over the entire eastern part of the United States and even over parts of the Atlantic Ocean. The dusts deposited on the ocean are lost to the land. The dusts deposited on the lands may improve the areas over which they fall and the wonderful loess soils of China, the Rhine Valley, and the Mississippi Valley were made in this way. The sands are rolled for short distances and deposited in the form of dunes, thus making good lands worthless for agriculture.

Summary.

The lesson to be learned from the preceding examination of the erosion of land surfaces is that the latter cannot be deprived of the protection of vegetal cover without danger of permanent loss and, if this cover must be removed, some other method of protection must be employed. Every new field intended for cultivation should be studied in advance to see what will result if the land is plowed. Every field given to pasture should be studied to see to what extent pasturing may be permitted without loss. The objectives should be not only to see what crops can be grown, but also what will be the result in soil losses if these crops are grown.

Chapter V.

Erosion in the United States

When the English settled at Jamestown in 1608 in what is now Virginia, they found a land covered with virgin forest as far as they could see, and they later learned that it extended westward for many hundreds of miles, gradually passing into prairie. It has been estimated that originally there were over 800,000,000 acres covered with dense forests, and a Tarzan could have gone over a thousand miles through the trees without once coming to the ground. This forest had been established through the centuries. It was a complex organization of large trees, underbrush, mosses, fungi, algae, bacteria, burrowing insects or their larvae, worms, and some larger burrowing animals. These different organisms were bound together for their mutual welfare and each organic element played a part in the maintenance of the whole. The soil gave this organization a home and sustenance and in return the growth protected the soil. The status was one of equilibrium with respect to soil and organisms and this equilibrium would be disturbed and might be destroyed if any element of the organization were removed. This association of organisms and soil, with changes induced by changes in climate or topography and evolution, had been established for ages. It had held the soil upon which it lived - which it had helped to make; self preservation required that it protect the soil upon which it grew. That time of which we speak was 335 years ago - only a short time interval from the geologic point of view, and not long from the point of view of human history. The time interval is short compared to the time required to form the rock mantle from the solid rock. In these 335 years people from many nations of Europe and some other parts of the world have come to the United States and have gone ever westward, destroying the forest as they went. In connection with the settling of our country, we speak with some degree of boasting of what this nation has done as a melting pot, but few realize what this has done to the land. The trees fell before the ax and the saw, the underbrush was rooted out and the forest litter was burned with the slashings. Some work of this kind is now in progress in Oregon and Washington and it will not be long before the price is paid. The logs in many places had no immediate value and in the beginning they too were burned. Some of this was done less than 70 years ago in the hardwood forests of northern Kentucky. The immediate objective was to clear the land for cultivation. The effects of erosion and destruction of the mantle materials which through long eons of time had been formed and accumulated under the guardianship of the trees, smaller plants, and associates were not given consideration by those who destroyed the forests. The pioneers cut the forests and gazed with pride on what they had done. For immediate gains they sacrificed the lands which they thought they were preparing for their children. Wastefulness reigned supreme. It was the beginning of the greatest rapid degradation of land in the history of the earth. Without knowing, the pioneers destroyed the balance of plants, animals, soils, water, and rocks which had been formed and had been maintained through many centuries, and they assumed the worst was over when the forests were gone. The worst was really only the beginning. The forest gone, the lands were plowed, cultivated, and permitted to wash away. Outraged Nature destroyed what she had created. The wasted acres, no longer able to maintain those who had destroyed them, were abandoned; the pioneers moved westward to new acres and new destruction. Ultimately the prairies were reached. The ax and the saw were no longer needed, only fire. The grass was burned, the sod turned under, and destruction progressed westward across the prairie. Now the forests of the Pacific Coast are falling before the ax and saw. The war has stimulated a demand for farm products and lumber, and, in order to obtain these quickly, this nation (and the other warring nations) is sacrificing its remaining forests and soils at the altar of the god of war. Much forest land and soil are doomed to become casualties of the war. Civilization cannot stand such campaigns for long.

For a long time the pioneers hugged the eastern seaboard, but they were crossing the Appalachian Mountains in considerable numbers about the time of the Revolutionary War, and most of the Mississippi Valley states were admitted into the Union before the middle of the 19th century. The regions west of the Appalachian Mountains have been the prey of erosion for only about 150 years - a short time for all the destruction that has been accomplished.

A few men in the early days of the nation began to see the results of the destruction of the lands along the Atlantic seaboard. As early as 150 years ago, George Washington expressed concern over the erosion of land which was in progress over northern Virginia and, in particular, about North Vernon where today there are many worthless fields which once were fertile and productive. About the same time Patrick Henry stated that, "Since the achievement of our independence, he is the greatest patriot who stops the most gullies." There were men at still earlier dates who had called attention to soil losses through wind and water, and methods of combatting the dangers had been recommended (McDonald, 1941). Jefferson was another great American who was impressed with the seriousness of erosion and one has but to see the slopes about his home at Monticello in Virginia, where erosion must have been in progress when he was living, to appreciate that so intelligent a man as Jefferson could not have failed to recognize the danger that existed for the land. The voices of these men were but a few among many, and little attention was paid to their warnings. Isaac Hill of New Hampshire, once United States senator and later governor of New Hampshire, in 1839 and later, repeatedly called attention to soil losses from the hill lands of his state and other states of the Atlantic seaboard. He also noted degradation of lands by mass movement of soils (McDonald, 1941, pp. 28-35). Hill, as well as others of the early nineteenth century who advocated protection against erosion by wind and water, was a subject of ridicule. In 1849, the single officer in the Government of the United States who was concerned with agriculture, Daniel Lee, wrote of the menacing danger facing the soils of the nation. He urged immediate action to save the farming lands from becoming "poorer than the poorest old field in any state at the present time." His voice was not heard by many. Why worry, there were hundreds of thousands of acres yet unplowed! Another 60 years elapsed before another voice was raised strongly enough to be heard, in spite of the fact that during this time fertile fields had been turned annually into barren acres. The U.S. Geological Survey became aroused to the danger in the latter quarter of the nineteenth century and in 1911 W. J. McGee had a paper published by the U.S. Department of Agriculture calling attention to the dangers facing the soils of the nation. The losses due to erosion were at that time becoming very critical, particularly in the southern states. However, in his attempt to lead the American public to an appreciation of the nation's tragic waste of land, McGee's voice was somewhat like that of the prophet speaking in the wilderness. His voice was heard by few. The assumption still existed even at that late date that there was no limit to the land and timber resources of the nation, that these were inexhaustible, and hence there was no cause for worry. With few exceptions the leaders of the nation in Congress and in the legislatures of the states knew nothing of the danger even if the matter ever came to their minds. The farmers did not know how the soils originated, or what they had cost in terms of rocks destroyed and the time required for destruction. The nation as a whole did not appreciate that destruction of the farm lands meant a real loss to the country and was a menace to the national welfare. Few in positions of authority seem to have had any inkling of the danger. In his early boyhood the writer heard men say, "I have worn out two farms already. It is about time for me to move to another." The rule was to go west to new land. Ultimately the westward migration reached the Pacific Ocean; the end of free land had arrived; and the period of the greatest destruction of agricultural land in the history of the earth had ended. During the past 25 years H. H. Bennett, present Director of the Soil Conservation Service of the U.S. Department of Agriculture, repeatedly called attention in publications and addresses to the serious menace facing the United States. Finally those in authority heard, so that during the past two decades serious efforts have been made to learn how the danger to remaining farm land may be lessened and perhaps averted.

How great have been the losses? The United States, exclusive of Alaska, has a little more than 1,900,000,000 acres of land, of which about 1,000,000,000 acres consist of mountain and desert land of little value for cultivation or pasture. This land should be devoted to the growing of timber where that is possible. About 987,000,000 acres originally could have been designated "agricultural" land. Of this acreage only about 600,000,000 acres may be termed land possibly, now or in the past, subject to tillage. It was formerly forest and prairie. Of this tillage land 457,500,000 acres have been eroded or are being eroded. (Bennett, 1936) While under the protection of grass or trees, erosion did not proceed more rapidly than the production of soil by rock decay. The destruction began when man took possession. Bennett states that studies made by the Soil Conservation Service indicate that 3,000,000,000 tons of soil are washed from the fields and pastures of the United States each year and, according to Russell, at least 2,000,000 tons of suspended sediment are carried by the Mississippi River past the city of New Orleans each day. This makes an annual load of 730,000,000 tons. This is a little more than 83,000 tons each hour, equivalent to over 1660 gondola freight cars with a 50-ton load each. One of these would need to pass a given point every 2.2 seconds. If all the soil taken from the United States by erosion were carried in gondola freight cars, each with a 50-ton load, 60,000,000 carloads would be moved annually and a car would have to pass a given point every 0.52 second. Transportation of these sediments by rail would tax the transportation systems of the nation. As a basis for comparison it may be noted that the building of the Panama Canal required the transportation of about 219,000,000 cubic yards of earth and rock, probably between 350,000,000 and 400,000,000 tons. This work required several years, but the Mississippi alone moves twice as much each year.

Bennett has estimated that the removal of the soils from the lands of the United States by wind and water erosion has essentially ruined an area equal to about 100,000,000 acres. This is equivalent to 625,000 farms of 160 acres each and is an area approximately equal to the combined areas of Ohio, Illinois, Maryland, and North Carolina. These farms would support at least 625,000 families which, with four people to a family, would be 2,500,000 people. An equal number of people would be needed to distribute the products of the farms and bring to the farms the things needed by the farmers. These people would live in the towns and villages. The people of distribution and supply would in turn give employment to about twice their own number. The total number of people whose possibility of a comfortable support has been destroyed by the destruction of this land amounts to 10,000,000. That this figure is conservative is shown by the fact that the four states named have a population of more than 18,000,000.

Bennett also states that an additional 125,000,000 acres have lost all or the greater part of the top soil. This is the most valuable part of the rock mantle and surely its loss has greatly impaired the productivity of the soil, increased the difficulty of cultivation, made the lands more susceptible to erosion, and thus greatly increased the amount of labor necessary to earn a living from them. These lands may be considered gone or nearly gone. This means an additional 781,250 farms of 160 acres, each of which has been so impaired in productivity as to make dwelling on such farms a matter of nearly abject poverty. Those farms may be estimated to have been once capable of supporting a population of over ten million people.

Bennett states that another 100,000,000 acres are in serious danger. These acres are no longer capable of supporting the population which once was there.

Areas of more or less seriously eroded lands total 325,000,000 acres out of a total of 600,000,000 acres of tillage land. The annual loss in acreage due to erosion at the present time is estimated at 100,000 acres. The eroded lands were once the best farm lands of the nation. The acreage of destroyed or seriously impaired lands amounts to approximately 500,000 square miles, an area equal to more than five states the size of Oregon, or nine states the size of Wisconsin. These losses of soil mean also losses of value and losses in productivity and income. The total losses in value are estimated at $400,000,000 annually. Losses because of lessened productivity are probably as great. The total loss in soil value was estimated by Person, Coil and Beal in 1936 as not less than $10,000,000,000 and if the wastage is not stopped it is estimated that in another fifty years the cumulative loss will reach the large sum of $25,000,000,000 to $30,000,000,000, equivalent to a loss of $4,000 on each and every farm in the United States (Bennett, 1936). To those who can appreciate large figures, this loss is staggering. The figures represent a larger sum than the present total value of all the farm land in the United States. The significance of these figures should be studied with care (Fig.20).

These losses are not alone those of the farmer. The loss is a matter of vital concern to every person in the nation. The writer is acquainted with towns in agricultural regions with populations of several thousand people. These towns act as markets for the agricultural products of each area concerned. They have no large factories, no mines, but are generally prosperous. Certain groups of merchants purchase the agricultural products, other groups of people carry them to the outside world, and bring back to each town those materials and products which the people of that town and the surrounding territories need. Other merchants distribute these to the people. All prosper - the farmer, the merchant, the banker, the educator, the preacher, and the transporter. The soil of each region has been badly eroded in places. Many acres are gone, other acres are going. Productivity is decreasing. If this continues, the farmers will produce less, sell less, and buy less. The population of the farms will decrease, there will be fewer materials for the merchants to purchase from the farmers, there will be less to ship to the outside world, less will be brought in from the outside, the merchants will sell less to the farmers, the preacher and the teacher will receive less salary, the banker will handle less money, parts of the population of the town will move elsewhere, real estate values will decline and every one will suffer. <u>None can escape the relentless impact of loss of productivity of the soil. All must share in the loss.</u>

The uncontrolled erosion of the past must not be permitted to continue for, unless remedies are applied, the agricultural lands of the nation will not be able to produce the food necessary to sustain the present population. Such a statement would have been

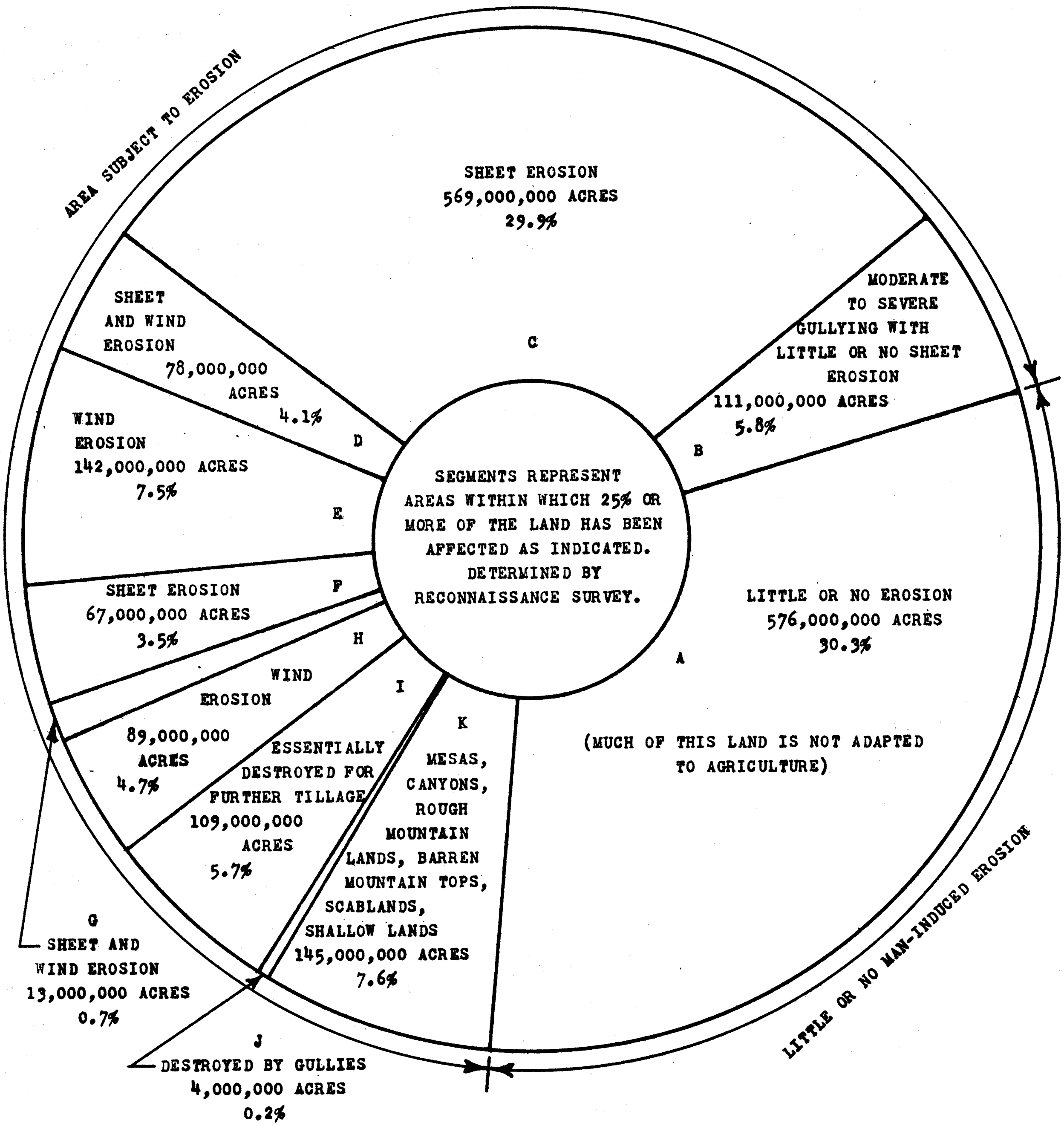

Fig. 20. Extent of erosion in the United States. Adapted from fig. 1 of Soil Erosion, Part V of the Supplementary Report of the Land Planning Committee to the National Resources Board, Washington, 1935. Areas C, D, and E have lost from one fourth to three fourths of the top soil. Areas F, G, and H have lost three fourths of the top soil and some of the sub-soil. It will be noticed that very little of the originally tillable land of the United States has escaped damage from erosion.

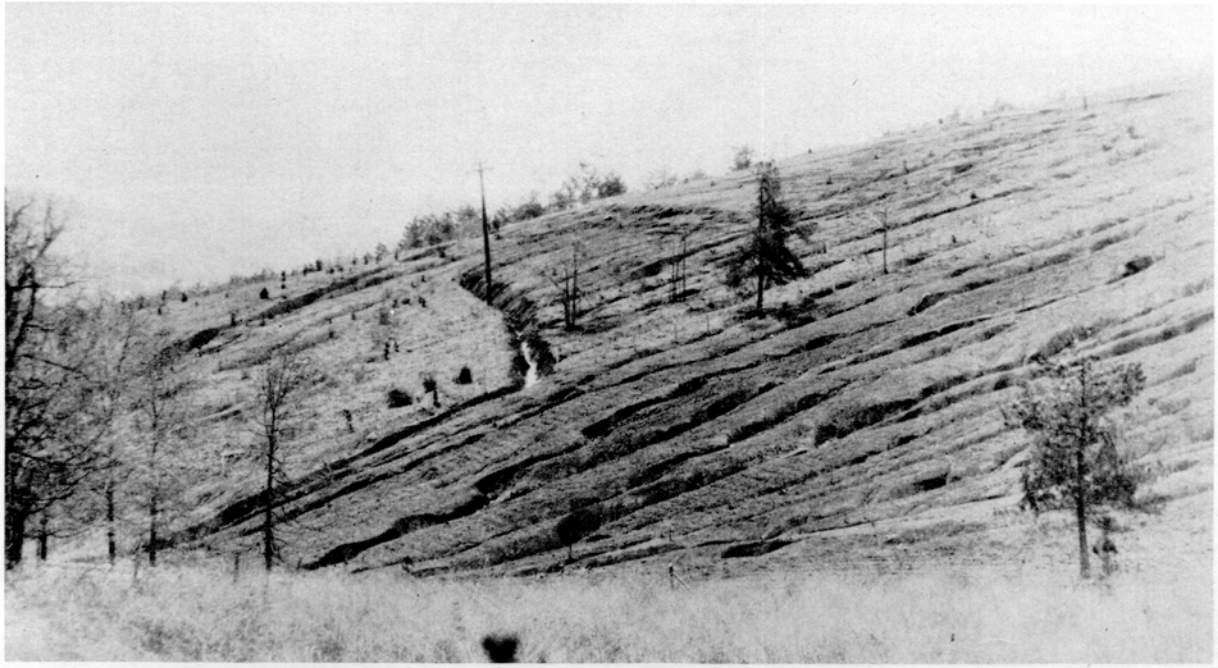

Fig. 21. Deeply gullied land in Georgia, 1 mile southwest of Lindale, Floyd County, Georgia. Reclamation of this land is not impossible, but will be difficult. (*Photograph by the U. S. Soil Conservation Service.*)

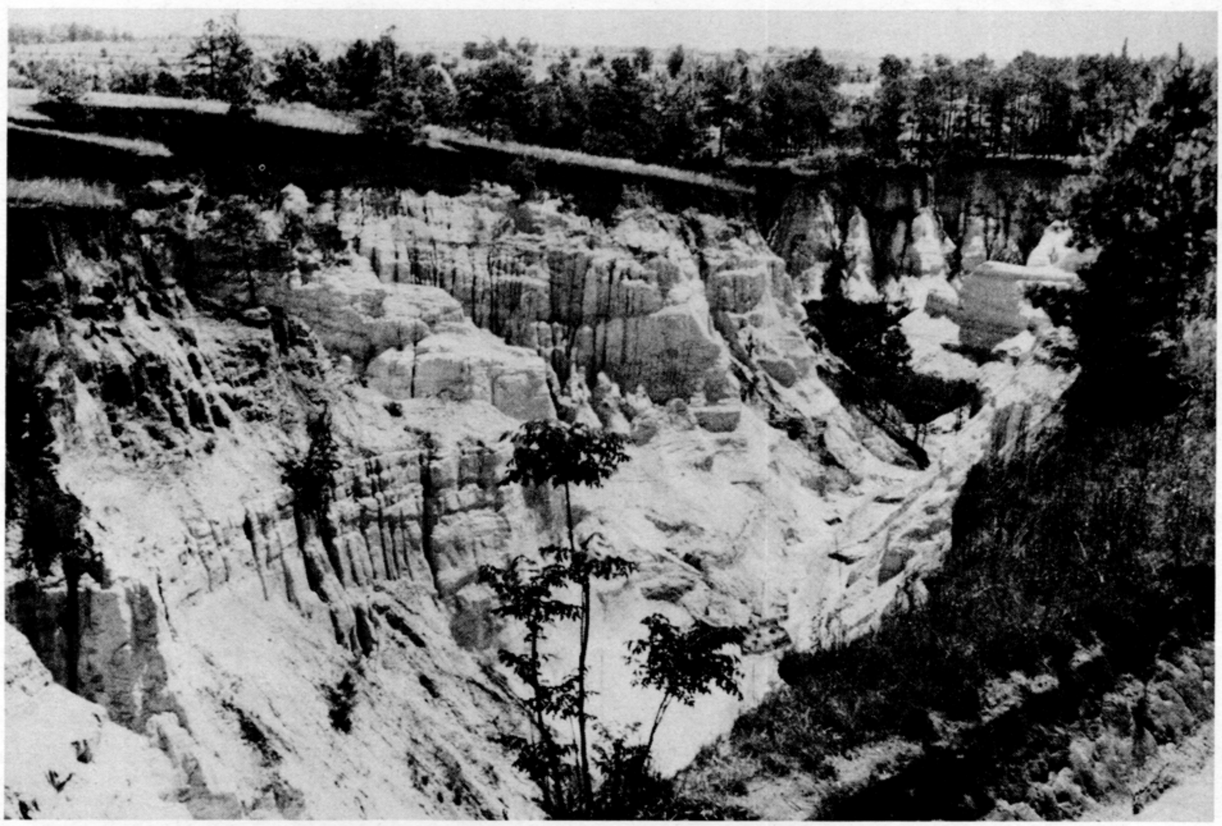

Fig. 22. Deeply gullied land in Georgia, 6 miles west of Lumpkin, Stewart County. The gully is 150 feet deep and is known as the Providence Caves. Various stages of collapse of sod-covered blocks are shown. Most of the land in the background may be expected to be conquered by this gully. Reclamation will be difficult and expensive. Planting of soil retention vegetation will be the cheapest method of reclamation, but this will not destroy but may stabilize the gully. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 23. Terraced land in Los Angeles County, California. Unterraced land is shown on the right foreground and in the background. Cultivation of lands with slopes such as these without protection would ruin them in a short time. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 24. Terraced land in New Mexico. It should be noticed that the terraces are on the contours, or nearly so. The water is led to the draw indicated by the line of trees. (*Photograph by the U. S. Soil Conservation Service.*)

considered absurd less than a century ago. But the once fertile lands of parts of Virginia (Fig.27), the Carolinas, Georgia (Figs.21,22), Alabama, Tennessee (Fig.4), Mississippi, Kentucky, Missouri, Kansas, Oklahoma, Wisconsin (Fig.23), and other states are now sterile and unproductive or but moderately productive. Less than a century ago they produced great crops of cotton, corn, tobacco, wheat and other products. This change indicates what the future may have in store for this nation. There have been nations of the past that have gone down this road to poverty and decline. What has been done is for the most part irreparable, but it is not too late to save what is left.

Some illustrations of what erosion has done are given by Bennett (1934, 385-404). Stewart County, Georgia, with an area of 280,000 acres has had one fourth of its area permanently destroyed by gullying. Some of the gullies are 200 feet deep and one destroyed a schoolhouse, two farm buildings, and a graveyard with fifty graves. A single county in South Carolina in the southern part of the Piedmont region was found to contain 90,000 acres of land, largely cultivated at one time, which had been permanently ruined by erosion (Bennett and Chapline, 1928). One farm of 1104 acres, 200 of which had been cleared since the Civil War, did not have a single acre of good farm land left. The former home of the owners has tumbled to ruin and no one lives on the former magnificent plantation (Bennett and Chapline, 1928, p.6). Five adjoining counties of Alabama contain 500,000 acres of land which was formerly cultivated but is now largely abandoned. For the most part this land originally was highly productive and would have supported comfortably at least 25,000 people. A county in southeastern Ohio has 200,000 acres of formerly cultivated land which today is no longer cultivated (Bennett, 1933, p.274). The city of Natchez, Mississippi, is noted for its annual pilgrimage on which one is taken into the outlying country to visit some beautiful old colonial homes placed in the midst of barren acres. The pictures are tragic.

What can be done to combat this ever present enemy to the future of the nation, to our homes and our standard of living? Unless something constructive is done, our lands will become barren and incapable of producing the food the people require. An answer to the question is offered in the next chapter.

Chapter VI.

Protection of Lands Against Erosion

It needs to be stated again that it is impossible to prevent erosion. What should be prevented is the accelerated erosion due to the activities of man. This is conservation of soil, and the first prerequisite of conservation of cultivated soil is conservation of water.

Nature has shown man how lands may be protected against erosion, and she does this most effectively by means of a cover of vegetation. The living plants and the dead plant litter create thousands of little dams which compel the waters to flow slowly. These dams do not permit the waters to become muddy, and the waters are conducted by the dams downward through the dead plant litter. When the waters reach the soil, they are further conducted downward through root and animal passages and between the particles of the soil, which is made more permeable by the plant growth. Passing through the rock mantle, the waters enter the rock along joints and continue downward until a level is reached where the openings of the rocks are filled with water. The rocks are then saturated to a higher level and the water table is raised. It is only when the rain falls in such quantities as to be beyond the absorptive capacities of the plant litter and rock mantle that there is runoff, or when large quantities of water fall on frozen ground which has been made impermeable because of freezing. Since in the latter case the ground is frozen solid, it is eroded with difficulty, and loss of soil materials should not be great.

But if man is to live, he must have food, and adequate food can not be produced except by cultivation of land. This destroys the protection of the plant growth, also the animal and root passages in and through the rock mantle, and invites erosion, as runoff is thus aided. Some means must be provided to prevent this, some artificial means of protection must be installed.

Artificial protection of soils, so far as possible, should parallel the methods of nature. Methods may be placed in two categories which are: (1) aids to compel the water which falls to enter the ground at or near the places where it falls and (2) to impound the runoff water to the greatest extent possible in nearby ponds, lakes, and artificial reservoirs for use when weather conditions require, for raising the water level, and for such other purposes that ponds, lakes and reservoirs may fulfil. To attain these two objectives entails the conservation of the water which falls. This conservation, it should be stated, is the first prerequisite for prevention of erosion and conservation of the rock mantle.

The first objective may be achieved in three ways, a combination of which will solve the problem. These are as follows: (1) the selective use of land; (2) employment of proper methods of cultivation among which are the cultivation of crops best adapted to the particular fields, crop rotation, contour cultivation, strip cropping, and terracing; (3) construction of check dams in gullies and placing of obstructions to flow in smaller channels. The problem is entirely one of dealing with and controlling the flow of little rivulets and not large streams, that is, controlling waters near where they fall. The problem is present on each individual farm. The nation has been attempting to control big rivers and has erected many large dams and has created large reservoirs under conditions which are essentially those of locking the barn door after the horse has been stolen so far as erosion is concerned. The large reservoirs are not devices to control erosion (no matter how many times that has been stated). The erosion was accomplished long before the waters reached the large reservoirs. (Person, Coil, and Beall, 1935, p.49)

Lands should first be differentiated into those which may be cultivated and those which should not be cultivated. The latter are lands too steep to be protected easily, and those which are so dry that the powdered soils are almost certain to be blown away. Those which may be cultivated have slopes sufficiently low that runoff can be controlled. These lands receive enough rainfall which, if conserved where it fell, would keep the ground sufficiently moist to encourage growth of enough plants so that the winds could not blow away the soil. Lands too steep to be cultivated safely should be reforested; those so dry that the hazard of cultivation is too great should be restored to grass. Neither of these land types should be closely pastured and they should never be burned over. Everything should be done on lands devoted to cultivation to accomplish, first, the conservation of the water by making it enter the ground in every manner possible, and, second, conservation of any runoff in reservoirs short distances from where the water falls.

Water may be made to enter the ground by covering the surface with vegetation. This cannot be done with crops requiring clean culture. It may be done to some extent with cover crops, particularly if the slopes are fairly gentle. Some plants are more effective in retarding or even preventing erosion than are others. The bunch grass formerly abundant over the western prairies is excellent in this repect. Studies made over the Boise River watershed in Idaho showed that runoff and erosion were negligible where the bunch grasses predominated, that other grasses were less effective, and that a growth of the common annual weeds permitted 60 to 80 percent of the applied waters to run off (Craddock and Pearse, 1938). Crop rotation and any methods of introducing plant materials into the soil also retard erosion. Winter cover-crops should always be planted, and land should never be left without protection. If plants cannot be made to serve in the conservation of the water, some artificial method must be introduced.

The ancients of long ago learned that terracing of a surface was a very effective way of preventing erosion and conserving water. Modern terraces are shown in figures 23,24. Terraces are constructed on contours; that is, a terrace is essentially level, but with gentle slope to the inner margin of the area terraced. The water is collected on the rear of the terrace where the surface under most conditions should be lower than on the outer edge. It is desirable that this inner part be so managed that the underlying soil is kept permeable. This may be done by growth of vegetation. The water stands on the rear of the terrace, or slowly flows laterally, some water sinking into the ground on the way. Any water reaching the end of a terrace should be conducted down slopes under control so that it cannot erode and thence conducted to a reservoir. The terraces should be sufficiently wide and high on their outer edges so that enough basin is provided to prevent water flowing over the edges. (Ramser, 1935; Hamilton, 1938) Special machinery has been built for construction of terraces (Fig.25).

Illustrations of the effects of terraces in conserving water, and thus soil, are numerous. Near Goodwell, Oklahoma, terracing and contour tillage increased the average soil moisture 25 percent and produced better than average yields of wheat. At Spur, Texas, in 1935, the total rainfall in May was 4.54 inches and in June 6.93 inches. Runoff was measured on three 10-acre tracts each with a slope of 0.5 percent for each method of cultivation. Three of the 10-acre tracts had the rows running with the slope, the runoff was 3 acre-inches, and the yield in cotton was 104 pounds per acre. Three of the tracts had the rows on the contour, the runoff was 0.5 acre-inches and the yield in cotton was 199 pounds per acre. Three 10-acre tracts had rows on contours and level closed-end terraces. The runoff was zero, all the moisture entered the ground, there was no erosion, and the yield in cotton was 219 pounds per acre. (U.S. Dept. Agric., Misc. Pub., No. 392, pp. 63-64.) Illustrations could be multiplied to show that terracing conserves moisture and soil.

Closely akin to terraces are contour ditches which are made by construction of ridges on contours. These retain the water on the uphill sides of the ridges and compel it to enter the ground (Figs. 27,28).

All cultivation should be done on contours, that is, every part of each row should be level. No furrows should be drawn down slope. Studies made in northern Mississippi over a 2-year period showed that runoff from a cotton field with the rows down slope equalled 58 percent of the total precipitation and the soil losses over the 2-year period were 195 tons per acre, whereas, on another cotton field with the rows on the contours, the runoff was 48 percent and the soil losses were 69 tons per acre (Fig. 28). (U.S. Dept. Agric., Misc. Pub. 397, p. 29.)

Fig. 25. Terrace building, 1 mile southeast of Quitman, Arkansas, January 16, 1936. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 26. Contour ditches, a form of erosion control akin to terracing. The gullied land in the background shows in sharp contrast the effects of uncontrolled erosion. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 27. Effects of a heavy rain. Conservation of water through erosion control. Note even distribution of the water in the ditches on the contours. This water is conserved for the use of crops and thus is not permitted to flow away and carry off soil. Kay County, Oklahoma. (*Photograph by the U. S. Soil Conservation Service.*)

Fig. 28. This picture shows the damaging results of laying off the crop rows and furrows down the slope. The slope is 20 percent, or a change in elevation of 20 feet vertically for each 100 feet of horizontal distance. Had the rows and furrows been constructed on contours, little damage would have been done. Some of the soil washed from the slope may be seen in the foreground. This soil was derived in some part from the subsoil and hence lacks fertility. The brush shows that attempts have been made to check the erosion, but with little success. Nottaway County, Virginia. (*Photograph by the U. S. Soil Conservation Service.*)

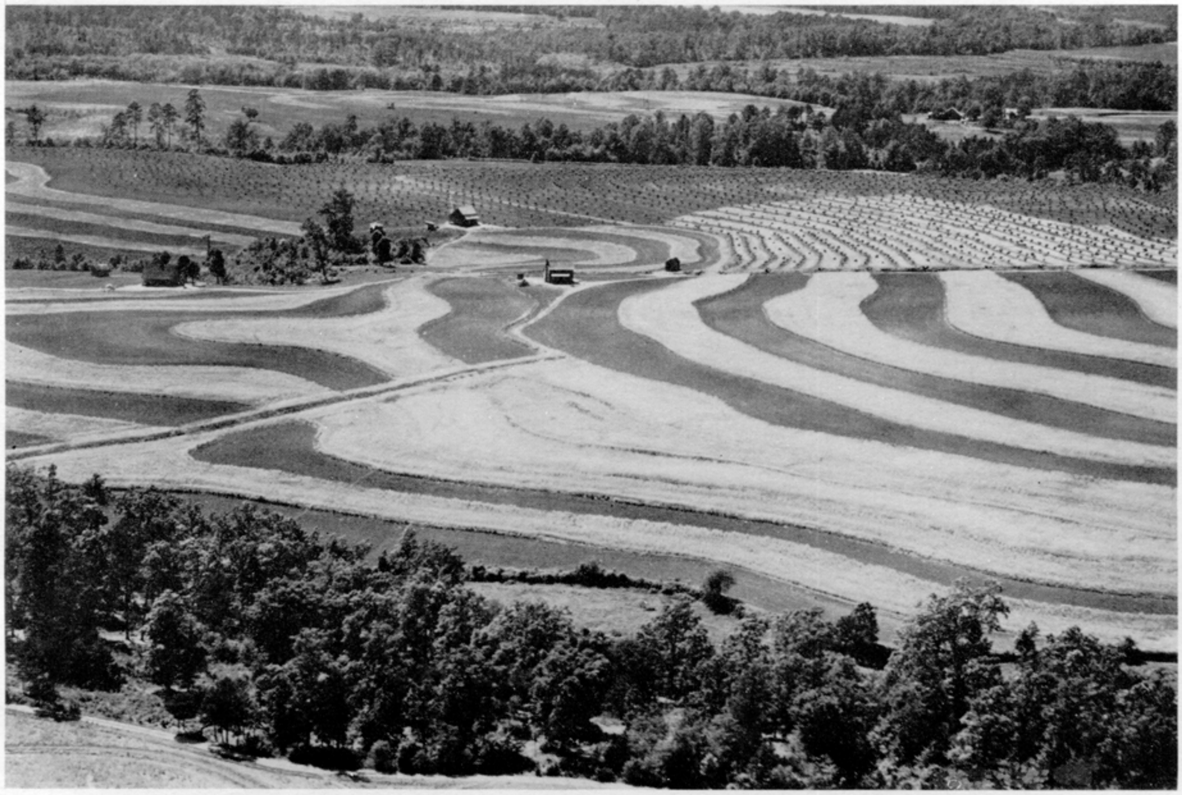

Fig. 29. Strip cropping. Width of strips equals one terrace interval. Spartanburg, South Carolina. (*Photograph by the U. S. Soil Conservation Service.*)

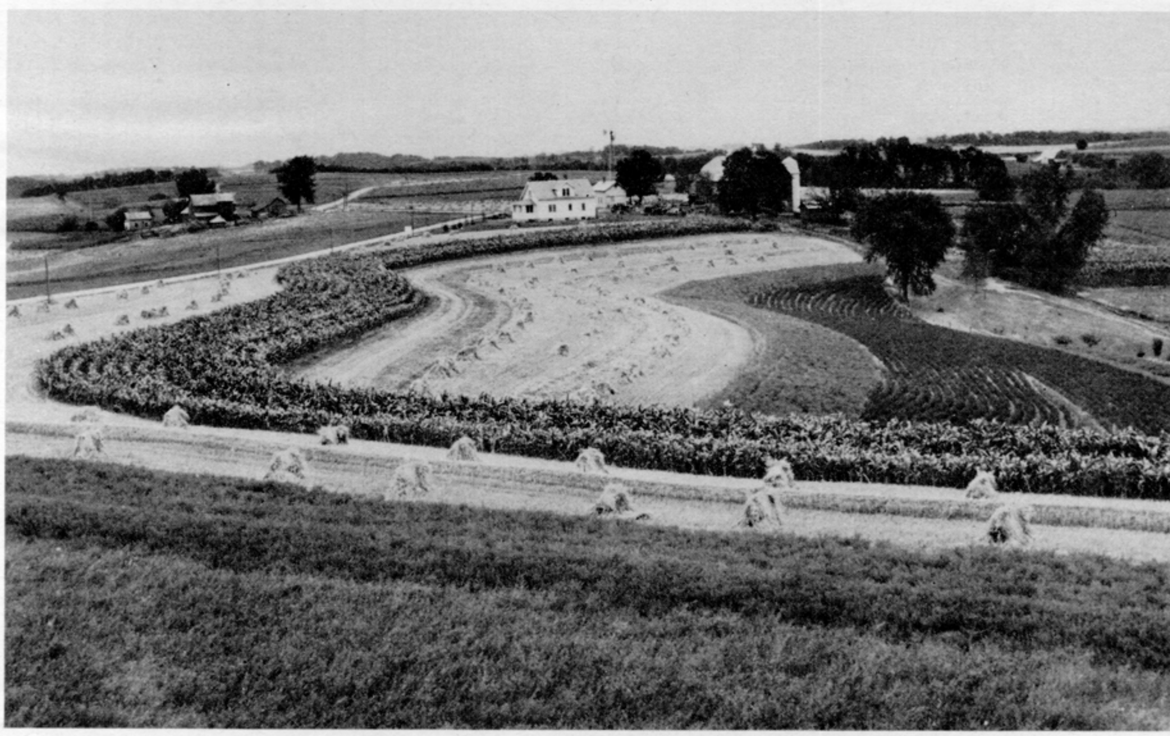

Fig. 30. Strip cropping. Strips from left to right are grain, corn, hay, grain, hay and potatoes. This land is fairly adequately protected. Little loss of soil may be expected. The field will contribute few sediments to the streams. Vernon County, near Chaseburg, Wisconsin. (*Photograph by the U. S. Soil Conservation Service.*)

Strip cropping is another device to conserve water and prevent erosion. Strips of sloping lands are cultivated on the contour. These alternate with strips which are left in grass or other cover crops. The uncultivated strips check the velocities of the down-flowing waters and rob them of their sediments (Figs. 29,30). (Tower and Gardner, 1943) The water which is conducted downslope from the terrace ends contains few sediments.

The second method for protection of soils, as mentioned on page 36, is to impound runoff water in reservoirs wherever possible. This water may be used during dry seasons of the year, and the reservoirs will serve to raise the groundwater table in the region. (Hamilton, 1939)

Entrance of water into the ground over cultivated fields and over lands too steep or too dry for cultivation makes large additions to the supply of underground water. This raises the water table and brings it closer to the surface, thus possibly making this water available to some plants. The additions to the underground water create a reservoir for springs and surface wells. The springs feed water to the streams and may provide the latter with continuous flow. The writer remembers his boyhood days in northern Kentucky when the neighboring creeks flowed throughout the year, and contained fish and excellent holes for bathing. The region then contained much timber. Today the creeks are dry much of the summer; there are no swimming holes and no fish.

It should be stated that large reservoirs such as those made by the Hoover Dam across the Colorado River, and the Bonneville and Coulee dams in Oregon and Washington are not the type of dam or reservoir considered above. These dams are on the lower reaches of large streams and are not and cannot be dams concerned with the prevention of erosion. They are constructed for power, flood control, and water supply with the water taken directly from the reservoirs. The erosion is accomplished long before the water can be impounded in reservoirs such as these. The dams considered in this paper are constructed on the heads of creeks adjacent to the lands which are cultivated and which it is desired to protect.

Every dam really brings into existence two reservoirs of which one is visible and is the topographic basin created by the dam. The other reservoir is in the pores and other openings in the ground and rock surrounding the reservoir. This second reservoir is not visible, but it may have a capacity approximating that of the visible reservoir. Some intimation of the capacity of the invisible reservoir to hold water is shown by what happened at the Hempstead reservoir of the Brooklyn, New York, water supply system. It was found that the discharge from this reservoir was 5,600,000 gallons per day when the water was maintained at the depth of 14.35 feet, but 8,000,000 gallons per day when maintained at 4 feet. The additional 2,400,000 gallons came from the invisible reservoir (Fig.31).

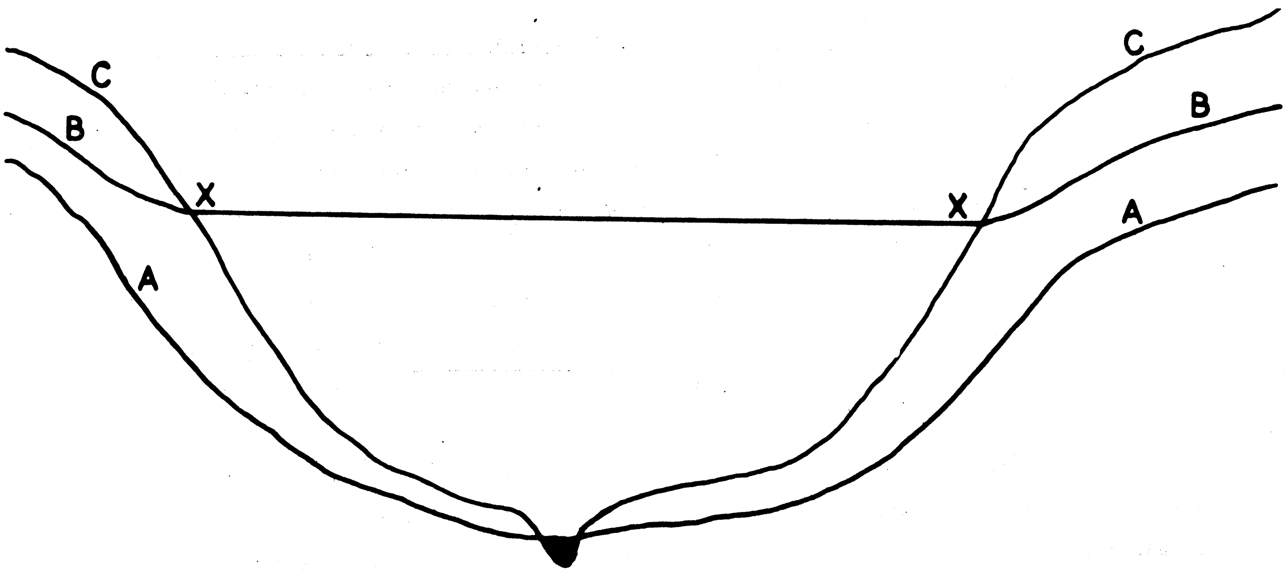

Fig. 31. Diagram to show relation of position of the water table before and after construction of a dam for a reservoir. AA. Position of the water table before construction of the dam. BB. Position after construction of the dam. The invisible reservoir is represented by the volume of the pore space between the two water tables. XX. Level of water in reservoir. This level is the position of the water table over the valley after construction of the dam.

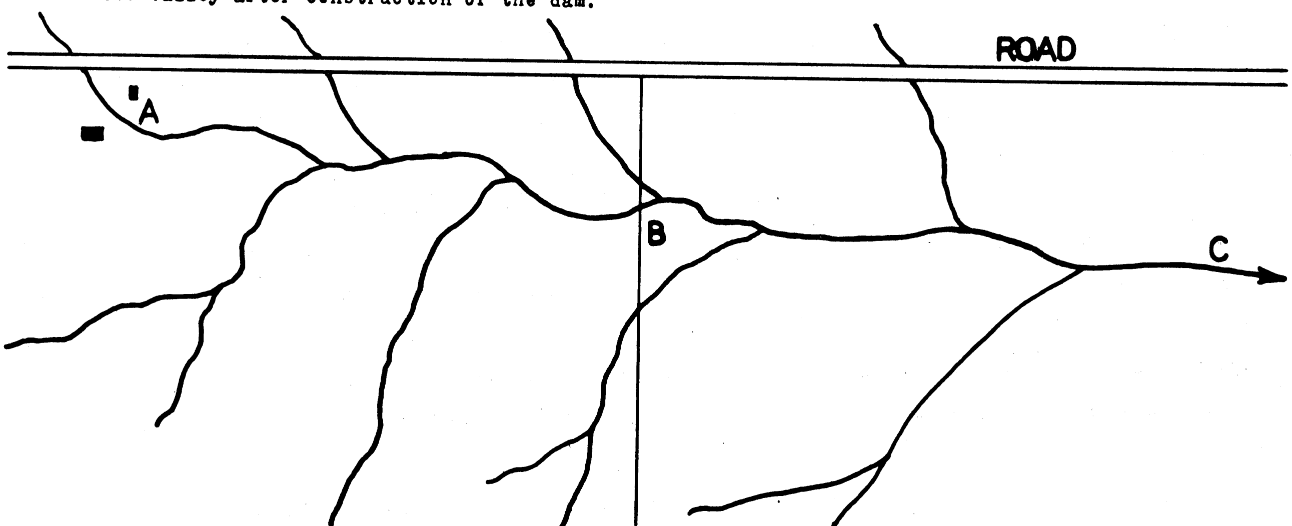

Fig. 32. Diagram to show consequences of straightening the channel of a part of a stream. The double line is a road, the single line the fence between two farms. The degree of crookedness of the channel before the straightening was done is not known. The owner of the farm in the lower part of the stream channel straightened a part of it. Within ten years a gully from 15 to 20 feet deep extended itself so that in the summer of 1940 it had reached the point A and threatened to engulf the barn which is indicated by the smaller of the two rectangles. In an attempt to prevent further extension of the gully, a flume was being constructed at that time at the head of the then present gully. The extension of the gully, over a quarter of a mile, was done in less than 10 years. Each tributary stream at the time of observation was also developing a gully which was extending itself headward. Water flowed in the stream only in wet weather. Before the straightening there was a condition of equilibrium and the owner of the upper farm could drive an automobile across the valley. This is now impossible.

The construction of a dam leads to accumulation of water in both reservoirs, and this raises the water table in the surrounding rocks to a level above that in the visible reservoir. This rising water level may make water available for trees and perhaps even for smaller plants. The water in this invisible reservoir also produces support for springs and surface wells in the area surrounding the visible reservoir, downstream from the dams, and perhaps in some remote areas. The waters from the springs assist in feeding streams which may be brought to flow continuously throughout the dry parts of the years. This produces stock water and may restore the streams, with their swimming holes and fish, as they were before the forests were destroyed.

Thus, both the methods of cultivation and the construction of reservoirs accomplish the same objectives of conserving water, preventing erosion of soils, adding to the flow and constancy of springs, increasing the supply of water in surface wells, and leading to constancy of stream flow.

Concentration of water in channels may lead to the formation of gullies. This concentration should be prevented in every way possible and, if prevention is not possible, efforts should be made to slow the flow of water and to protect the surface over which the water flows. Gullies are produced by large flow of water in a short time, and under old methods of cultivation any considerable rainfall produces such large flow. This inevitably leads to gullying.

Large gullies develop in depressions in fields which were the channels of drainage before the lands were cleared. These depressions should never be plowed and they should at all times have a protective cover of grass of sufficient width that the water must flow over it. It is desirable that the line of lowest part of the depressions be as crooked as possible in order that the gradient may be as low as possible.

Many farmers have attempted to deepen, widen, and straighten channels on the theory that such action would lead to less spoiling of meadow land. A program of this kind is fraught with great danger and should never be attempted until all conditions in the region which relate to erosion have been carefully investigated by someone competent to make decisions in such matters; otherwise more land may be lost than is gained by the straightening. The conditions which need study are the maximum flow of water, the depth of the alluvial deposits which may be eroded, the increase in gradient made by the straightening, and the protection against danger which may be given. Figure 32 shows a small valley in western Wisconsin which extends through two farms designated A and B. At one time not over a dozen years ago a shallow crooked channel was present in this valley to conduct the occasional water. On farm A this channel was so shallow that it was easily crossed by automobile. The valley was excellent pasture land and for much of the year the channel contained no water. The farm house and farm buildings of farm A are in the valley where it is crossed by the road.

The owner of farm B straightened the shallow channel where it crossed his farm. This steepened the gradient and within ten years the shallow channel in which water flowed for only a part of each year had become a deep gully which extended across both farms for fully a quarter of a mile. When this gully was seen in the summer of 1940 it was 25 to 50 feet wide and 15 to 20 feet deep. Not even a dog could have crossed the gully at most places at that time. Furthermore, it was extending itself headward at the rate of a couple of hundred feet each year. At the time of observation a flume was being constructed at its head to conduct the water from the bottom of the shallow channel which remained to the bottom of the gully in the hope of eliminating waterfall or undersod erosion at the head of the gully. Nothing was being done or contemplated to stop erosion of the tributaries into the gully. The attempt to stop the gully in this way seemed unwise.

The formation of the gully was not, however, the only consequence of the straightening of the channel. Before the straightening, the water table could not have been but a few feet below the bottom of the original shallow channel. After the gully was formed, it could not fail to have fallen to the level of the bottom of the gully which means that it was also lowered beneath the lands on both sides of the gully. Both farms lost in conservation of water and soil, and both farms, for a very temporary convenience, lost tremendously in acreage of excellent pasture land. The results were disastrous for all concerned.

Gullies should not be permitted to form. If they do form, they should be prevented from becoming deeper and wider, and, if possible, they should be made to disappear. Retardation of erosion and growth of gullies have been attempted in many ways (Mattoon, 1934; Jepson, 1939; Ireland, Sharpe, and Eargle, 1939). As previously noted, gullies grow by waterfall erosion and channel erosion. Erosion in channels may be retarded by planting of various trees and shrubs. These check the velocities of the water, may compel deposition and thus raise the bottom of the gully. The plantings should be protected against destruction by stock. This may be done by fencing the gully so as to give the plantings a chance to grow freely. Excellent plants for the purposes of this protection are hazel, sumac, elderberry, alder, wild plum, Scotch broom, black locust, blackberry, dewberry, Japanese honeysuckle, certain pines, sassafras, kudzu (Bailey, 1939), wisteria, Bermuda grass, and centipede grass (McGinnis, 1933). Every one of these plants has been used in some part of the United States with excellent results. In the northwestern states, Oregon and Washington, the Himalaya blackberry, the boysenberry, and the evergreen blackberry should serve very efficiently for this objective as they grow very luxuriantly and the thickness of their growth and their thorns repel stock. The black locust is particularly good for gullied lands as it has a wide spreading root system, and suckers grow from the

Fig. 33-A

Figs. 33-A, 33-B. Effects from construction of a drop inlet dam. (A) The gully just after completion of the dam. (B) The gully one year later. Erosion is effectively controlled. By taking advantage of geologic principles the owner has substituted construction for destruction. Photographs by Professor E. R. Jones, University of Wisconsin.

Fig. 33-B

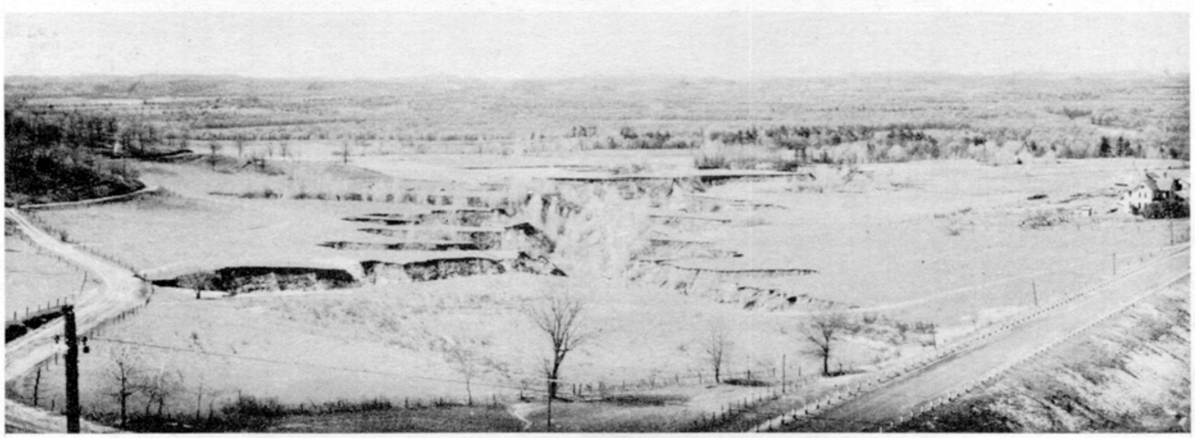

Fig. 34. A gully swallowing a farm. This large gully in the unglaciated area, west of Melrose, Jackson County, Wisconsin, originated since World War I. Waterfall erosion of the numerous tributaries, if unchecked, will ultimately result in the destruction of the entire farm. Photograph by Professor F. T. Thwaites, University of Wisconsin, about 1930.

roots and shortly give the surface a thick cover. Nitrogen-fixing bacteria which add nitrogen to the soil and thus introduce this form of fertilizer also live on the roots of the black locust.

Plantings, however, merely stabilize gullies. They may raise the channels somewhat but they do not eliminate them. That this method, however, is very effective is shown in many cases and the writer has seen a barren desert of gullies over essentially worthless land covered with grass within a dozen years through the planting of black locust.

Large and rapidly growing gullies, however, require more heroic and more rapidly effective measures than plantings, as the latter require time to grow sufficiently thick to hold sediments effectively. After gullies have become large and deep the planting method is too slow. Plants may retard deepening and to some degree widening, but erosion at the head and where tributaries enter is done through waterfall, and the plantings have little or no effect in retarding this erosion. Waterfall erosion may be prevented by construction of flumes. Gullies have been filled with brush, straw, or fodder. Posts have been constructed across gullies, wire strung to these, and brush woven to the wires. The posts may be set close together and the wire omitted. Dams of plank or rock have been repeatedly used. These methods are frequently effective, and enough sediments may be deposited above the obstructions to raise the level of the channel and prevent erosion by undermining at the head or where tributaries enter. The hazard is always faced that the waters will cut around the obstructions and bypass them. The methods may be aided by diversion channels at the heads of gullies to reduce the flow in the gullies (Jepson, 1939).

Very large gullies are being reclaimed by means of earth dams. These stop the flow and compel deposition, thus eliminating the gully. Some device must be installed in order to convey excess water over or through the dam. This is most conveniently done by means of a side spillway which, however, faces the hazard of erosion and the formation of a gully unless it is lined with plank or cement. The water is best conveyed through the dam by means of a drop inlet (Kessler, 1934). Figure 33A shows a gully just after such a dam with drop inlet had been constructed. One can easily see the damage which the gully had caused, the damage in prospect, and the strenuous efforts of the owner of the property to prevent the damage. Figure 33B shows this gully one year later. It should be noted that erosion has been stopped and the gully has been partly filled. The buildings are now safe. They were not safe before the drop inlet dam was built.

Figure 34 shows another gully in western Wisconsin which was formed after the first World War. The picture was taken about 1930. The gully was thus formed in 10 to 15 years. The picture shows that many acres have been spoiled and that the spoiling of many more acres is in prospect. It would seem that the only way this land can be saved and restoration of the ruined land be made is by means of dams, preferably those with drop inlets,

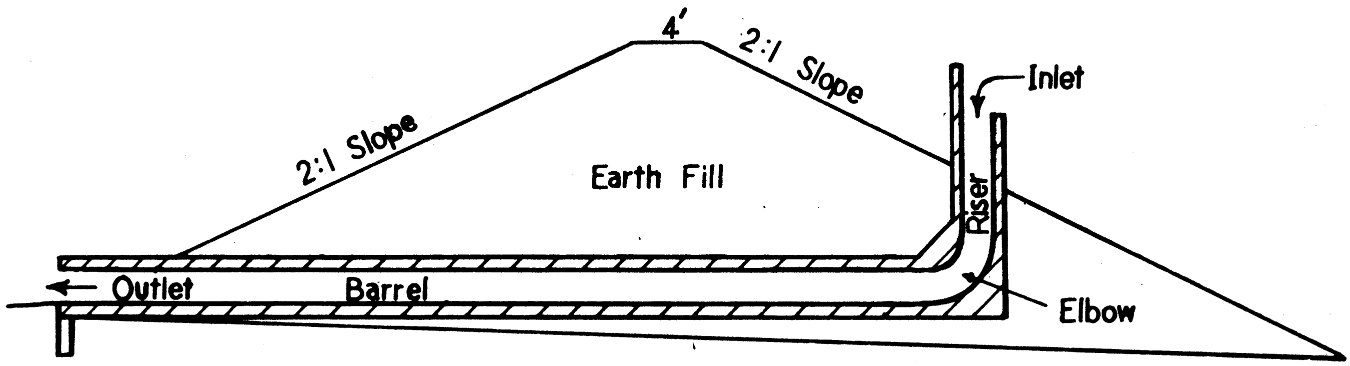

Fig. 35. Diagram of a drop inlet dam. The water rises in the reservoir to the top of the inlet. The sediments are deposited in the gully to be filled. The energy possessed by the water at the top of the inlet is neutralized in the conduit so that it emerges with little ability to erode. The barrel should have a minimum slope of 1 foot per hundred feet of barrel. (Redrawn after Kessler.)

across the gully. As the gully seems to have considerable gradient it would seem that several dams would be necessary.

A drop inlet dam is usually composed of earth with a cement conduit beneath it at about mid-length. This conduit conducts the water underneath the dam and at the same time deprives the water of its energy. Figure 35 shows the construction of the conduit. The water must rise to the level of the drop inlet before it can flow beneath the dam. This compels the water to lose velocity and any load of sediments is largely dropped. These sediments raise the bottom of the gully ultimately to the level of the drop inlet. The water enters the conduit at the top of the inlet and drops to the bottom. This deprives it of its energy and when it flows from the outlet on the downstream side of the dam it has been deprived of its power to erode. The growth of many gullies has been stopped and lands reclaimed by means of drop inlet dams.

There are other consequences of conservation of water and soil. The improvement in the flow and constancy of springs has been noted. This means pools for fish, water for stock, and raising of the water table beneath the bottom lands bordering creeks. Surface wells, now too often perennial, become more constant in production of water. Prevention of runoff reduces the hazards of flood which always are due to rapid runoff; floods then become possible only where adequate protection of soil cannot be given. Experimental studies have shown that most floods are preventable. (Soil Conservation Service, 1939) Three birds are here killed with one stone; namely, conservation of water for the welfare of man, prevention of destruction of the rock mantle, and prevention of the dangers and losses arising from flood.

Summary

The foregoing considerations show how geologic processes can be made to work for, instead of against, man; how the water can be made to conserve and not to destroy the soil. Thus, the geologic processes become the friends and not the enemies of man.

Outstanding facts in the erosion problem are that our nation has lost vast areas of some of the best of its tillable land and that the losses are continuing at the rate of about 100,000 acres each year. There still prevails among our people a smug complacency respecting these losses that does not augur well for the nation's future. Great segments of the people are completely unaware of the danger. Destructive farming is still too extensive and too few farms have taken the necessary steps to preserve their lands. An informed and appreciative citizenship is essential to combat the danger and to save the soils which are not yet lost. The education must not be confined alone to the farmers, but must be given to working, business, and professional men and women. The education must be hastened; delay is dangerous.

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