Issued June 8, 1911.

U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF SOILS—BULLETIN No. 71.

MILTON WHITNEY, Chief.

SOIL EROSION.

BY

W J McGEE.

Expert in charge, Soil Water Investigations.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., May 3, 1910.

Sir: I have the honor to transmit herewith the manuscript of an article on Soil Erosion prepared by Dr. W J McGee, of this bureau, and recommend that it be published as Bulletin No. 71, of the Bureau of Soils.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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AGRICULTURAL DUTY OF WATER.

The soil is of three parts, one solid, another fluid, and the third gaseous. The solid part is made up of both organic and inorganic matter in fragmentary or granular condition; the fluid part is a solution consisting of water carrying more or less organic and mineral matter; the gaseous part consists of air (nitrogen and oxygen) mixed with aqueous vapor, carbon dioxid, and other gases. The solid part forms the body and the fluid part the circulatory medium of the soil on which plants grow and animals live; the gaseous part permeates the body of the soil and passes through it in a manner which is sometimes likened to breath.

As a whole the soil of a country forms a unit or entity comparable to, although less complete and distinct than, the flora or the fauna. It differs from these in that it is suborganic rather than organized, and in that it contains a larger proportion of mineral matter; it simulates organized systems in that it has its own modes of action and self-perpetuation, and also functions in accordance with its own special properties. Like the flora and fauna, too, it may be defined by special types and classified in general groups; the types comprising more or less variable unit areas corresponding somewhat with organic individuals.

The internal action or functioning of the soil goes forward chiefly through the agency of its fluid part; this may be specifically denominated soil-fluid,[a] while the solid and gaseous parts are conveniently designated soil-body and soil-gas. In the absence of soil-fluid the soil soon becomes inert or dead, losing its suborganic character; in the presence of this circulatory medium it is vitalized, and its reactions are largely connected with the growth and decay of organisms.

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[a] The fluid part of the soil has been made known largely through notable investigations by Prof. Milton Whitney, chief of the Bureau of Soils, and several collaborators. Bulletin 9, "Soil Moisture," by Milton Whitney and Ralph S. Hosmer (1897), and Bulletin 10, "The Mechanics of Soil Moisture," by Lyman J. Briggs (1897), contain the more important results of the investigations.

Thus the functioning of the soil is correlative with the functioning of the flora and fauna; the processes taking place in the soil being interdependent with those taking place in the plants, somewhat as these processes are interdependent with those taking place in animals. Much of the substance of plants is taken directly and that of animals indirectly from the soil, and the growth of soil goes forward largely through the return of substance from plants and animals in a more highly differentiated or richer form; while the chief source of vital energy in the soil is derived from the growth and decay of plants and animals. Although the interdependence extends to all the materials and powers of both soil and organisms, it operates chiefly through the peculiarly potent substance, water, of which large quantities pass into the plants and thence into animals; and the vital energy of organisms, like that of soil, is measured by the circulation of their fluid portions which consist chiefly of water.

As the efficiency of plants and animals is measured by the production of substance and energy, so the efficiency of soil may be measured by the yield of plant product; and in both cases the yield varies with the vital energy attending circulation. In most animal genera the circulation is fairly uniform throughout life, and the greatest efficiency is attained during a (secularly lengthening) period of maturity following a period of more rapid growth. Among most kinds of plants the circulation varies widely with the season, and the efficiency is at its best during the period of most rapid growth of highly differentiated substance, which occurs about the time of most active circulation. In soil the circulation depends largely on climate and season, and the efficiency in general varies with circulation, though most types of soil are capable of storing or conserving water in ways increasing and prolonging their efficiency. Other things equal, the internal work or functioning of soil is determined by its capacity for conserving water and conveying it to growing plants.[a]

The ratio of the solid and fluid parts of soil varies widely. When the soil is in good condition, i. e., when it contains its optimum of moisture, the fluid ranges from 4 to 45 per cent (even more in mucky and peaty soils) of the weight of the solid, according to texture; e. g., if the productive layer averages a foot in depth the two parts average about 2,000 tons per acre, while the fluid ranges from 80 to

[a] An excellent statement of the most acceptable modern view of the soil as an entity functioning in a fairly definite way appears in "The dynamic viewpoint of soils," by Frank K. Cameron (Jour. Industrial and Engineering Chemistry, vol. 1, No. 12, 1909). In the light of those properties of soil-fluid and other waters pointed out herein the internal work of soil might perhaps better be considered kinetic, which would be but a consistent extension of Dr. Cameron's conclusions.

perhaps 900 tons per acre[a]. The solid part is relatively stationary, but the fluid part is in constant movement (and change of state from liquid to vapor) throughout the growing season or period of soil efficiency; and the water required for the optimum moisture will not itself suffice to produce a crop, nor will it even permit any yield whatever from most types of soil, unless replaced as it is exhausted by the growing plants. If properly cultivated and watered, an acre-foot of soil averaging 2,000 tons retains efficiency for centuries; but to be even moderately productive of crop plants it must convey to these plants fully 1½ acre-feet of water, or an amount equivalent to its own weight, during each growing season. The average required for ample yield from various soils is about 4½ acre-feet, or something over 6,000 tons per year. So the nominal ratio of solid and fluid parts of the soil (i. e., the ratio reduced to the yearly basis)

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[a] The quantitative view of water, except in smaller measures, is so new to thought that familiar units are lacking. Municipal and domestic water supply is generally expressed in gallons, irrigation water in acre-feet, stream flow in second-feet (or more accurately seconds-feet), and water for certain uses in the variable and indefinite miner's inch. There is urgent need of a unit applicable to the quantities commonly used for water supply, irrigation, and various other purposes. Moderate familiarity with the metric system would render convenient as such a unit the stere (equivalent to the kiloliter or cubic meter, the virtual basis of the metric system for capacity or tridimensional measure), which roughly approximates—much as the liter approaches the quart—the cubic yard in quantity and the ton in weight of water, while the kilostere approximates 1,000 tons and an acre-foot. The kilostere is especially convenient in discussing the water supply of the United States in that it permits expression of the leading values in round numbers not too large for ready comprehension—the mean rainfall of 215,000,000,000,000 cubic feet totaling 6,000,000,000 kilosteres, and its main derivative fractions being expressible in sixths of this total. For the present cubic feet, acre-feet, and tons may be employed.

A few of the equivalents involved in the use of customary units for the measurement of water (reckoned at maximum density) follow:

1 liter=1.057 quarts=0.264 gallon=61.023 cubic inches=2.205 pounds.

1 kiloliter=1 stere=1 cubic meter=1,000 liters=264.18 gallons=35.314 cubic feet=2,204.62 pounds.

1 kilostere=1,000 kiloliters=264,180 gallons=35.314.45 cubic feet=0.8107 acre-foot=1,102.31 tons.

1 gallon=3.785 liters=230.972 cubic inches=0.1336 cubic foot=8.34 pounds.

1 cubic foot=28.317 liters=7.485 gallons=62.42 pounds.

1 acre-foot=43,560 cubic feet=1.2335 kilosteres=326,047 gallons=1,359.6 tons.

1 cubic mile=147,197,952,000 cubic feet=4,168,207 kilosteres=3,379,165 acre-feet=4,594,656,258 tons.

1 pound=27.68 cubic inches=0.4543 liter=0.12 gallon.

1 ton=2,000 pounds=32.04 cubic feet=907.19 liters=239.66 gallons.

The mean rainfall of mainland United States may be expressed as—

215,000,000,000,000 cubic feet=6,088,159,380 kilosteres=4,935,670,809 acre-feet=1,460.6 cubic miles=6,711,000,000,000 tons.

215,000,000,000,000 cubic feet±6,000,000,000 kilosteres±5,000,000,000 acre-feet±1,500 cubic miles±7,000,000,000,000 tons.

is about 1:3; but since the solid part lasts for years or centuries, while the fluid part passes away, the actual ratio is much higher. The fluid part (or circulatory medium) of the soil is not pure water, but carries both mineral salts and organic substances in solution; and the relative value of the solid and fluid parts in plant growth probably corresponds fairly with the strength of the solution, or one to several hundred. Pending exact determinations, it may be assumed that the strength of the solutions forming the fluid part of the soil and the ultimate ratio of the solid and fluid parts required to maintain efficiency are about equal and as something like 1:1,000.

The water within the soil may be or may not be efficient in circulation (or in soil functioning) according to its quantity in relation to the soil texture; for with the quantity its condition may be said to vary from (1) static to (2) dynamic; i. e.. it may be either inert or active. The full capacity of a given soil for water ranges with its texture or porosity from some 30 per cent to over 50 per cent of its volume.[a] This is conveniently called the water of saturation; it completely fills the interstices among the soil grains, displacing the soil-gas, and ordinarily moves hydrostatically under the impulse of gravitation; it impedes or prevents normal functioning of the soil and remains in a virtually static condition until the excess is removed by drainage or otherwise. The water required to form soil-fluid (or to furnish the optimum soil moisture) ranges with the texture of the soil-body from, say, 10 per cent for sand to 40 per cent for fine clay. The quantity suffices to form a film surrounding each soil grain in such manner as to permit capillarity to act throughout the mass, yet leave space for air (or soil-gas) within the interstices. Through surface tension these films tend to flocculate the finer soil particles and promote physical and chemical action both within the soil grains and between the soil-gas and the soil-body; apparently the films are the chief means of interchange between inorganic soil matter and growing or decaying organic matter, and, though subject to gravitation, the water forming them moves mainly through capillarity under stresses acting dynamically in the normal functioning of the soil. Probably the energy of internal action within the soil-fluid increases with the thinning of the films—i. e., with the diminution of the water—from the point of subsaturation at which capillarity begins to the indefinite point at which capillary contact is interrupted and the moisture becomes hygroscopic, so that functioning is most vigorous in a moist but drying soil.

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[a] Slichter computed the porosity of aggregations of spherical grains to range from 25.95 per cent to 47.64 per cent of the aggregate volume ("The Motions of Underground Waters," Water Supply and Irrigation Papers of the United States Geological Survey, No. 67, 1902, p. 20); King computed the porosity of soils to range from 34.91 per cent in coarse sand to 52.94 per cent in finest clay ("Physics of Agriculture," fourth edition, 1907, p. 124).

While the aggregate quantity of soil-fluid varies widely with different soils of varying texture, the limiting points of subsaturation and interrupted capillarity vary in a measurably corresponding way, so that an approximate estimate may be made of the soil-fluid available for plant growth in average soil. The basis of the estimate may be the 4 feet of soil and subsoil throughout which capillarity has been observed to operate freely,[a] for while ordinary annual crop plants root within the first foot from the surface, the underlying 3 feet of subsoil forms a reservoir whence they derive much of the moisture required for their growth; indeed, it is probable that under certain conditions the moisture at much greater depths becomes available. Now, the mean moisture of average soil when in good condition approaches 25 per cent, while the mean moisture when plant growth ceases by reason of exhaustion of the soil-fluid is probably less than 10 per cent,[b] and the difference measures the store of water additional to the current rainfall on which the plants may draw. This difference (15 per cent of 4 feet, or 7.2 acre-inches=816 tons per acre) may be considered as the effective soil-fluid of average soil.

Much of the fluid conveyed by soil to growing plants evaporates, this change in the state of the water produced by the power of the sun constituting the chief motor force attending growth; so that while the crops of a generation may far exceed the quantity of solid soil yielding them, the same crops form but a fraction of the quantity of soil-fluid utilized. A fair to good crop from an acre-foot of fertile soil supplied with $4\frac{1}{2}$ acre-feet of water may be put at a ton of grain and 3 tons of dry forage (including stover or stubble), or 4 tons in all, i. e., $\frac{1}{1530}$ of the weight of the season's water. The yield of grain alone is much less, as shown in the accompanying illustrative estimates in which the mean ratio is $\frac{1}{4326}$ of the water. The yield of pasturage, green forage, fruit, timber, tubers, et al., on the other hand, is much greater; the average of all crops in good farming may be put at 6 tons per acre-year, i. e., $\frac{1}{333}$ the weight of the first foot of soil (solid and liquid), or approximately one-thousandth of the weight of the water received and conserved in the soil and largely conveyed to the growing plants. This may be considered the duty of water in crop production. So the agricultural duty of water may be defined as *the production of one-thousandth part of its weight in useful plant crop.*

[a] King found that capillary lifting of water through fine sand diminished from 2.37 pounds per day at 1 foot to 0.91 pound at 4 feet, the diminution being less with clay loam ("Principles and Conditions of the Movements of Ground Water," Nineteenth Ann. Rept., U. S. Geological Survey, 1899, Pt. II, p. 85).

[b] The mean of King's determinations of soil moisture "when growth is brought to a standstill" ("Physics of Agriculture," op. cit., p. 125) was 10.93 per cent for clover and 8.92 per cent for maize.

Illustrative estimates of yields of grain with varying water supply.

Water.		Corn.		Oats.		Wheat.		Aggregate.	Mean.
Quantity.	Weight.	Quantity.	Weight.	Quantity.	Weight.	Quantity.	Weight.		
Acre-feet.	*Tons.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Bushels.*	*Pounds.*	*Pounds.*	*Pounds.*
1½	2,040	10	560	15	480	6	360	1,400	467
3	4,080	35	1,960	40	1,280	12	720	3,960	1,320
4	5,440	70	3,920	80	2,560	25	1,500	7,980	2,660
5	6,800	105	5,880	120	3,840	40	2,400	12,120	4,040
Sums..	18,360	....	12,320	....	8,160	....	4,980	25,460	8,487
Averages..	[a] 4,590	....	3,080	....	2,040	....	1,245	6,365	2,122
Ratios.....	....	....	1:2,980	....	1:4,500	....	1:7,374	....	1:4,326

[a] Equals 9,180,000 pounds.

With present knowledge, the coefficient is but a rough approximation. Measurements are vague and experiences variable; soils differ both in composition and in the texture controlling circulation; and the yield of succulent vegetables or of juicy fruits or fresh forage may be several times that of grain, nuts, or dry forage, so that while the final product (in nutrients, textiles, etc.) may vary less than the bulk and weight of the immediate product, it will probably be found needful in time to work out coefficients for particular crops, just as it is now convenient to reckon yields per acre in different averages for the several crops. Still, if scientific methods are to extend to the farm, no inexactness in the coefficient or variability with different crops can remove or reduce the need for recognizing some definite relation between the water passing from soils to plants and the crop produced by means of this circulation. Already civil engineers recognize a duty of water in the development of power, and irrigation engineers recognize a duty of water in ditches or flumes or headworks supplying a given depth of water over a given area;[a] yet it is vastly more important to the country and to the world for the farmer (or agricultural engineer) to recognize a duty of water in terms of that

[a] Powell long ago recognized the necessity for determining "the amount of water which is needed to serve an acre of land" ("The Irrigable Lands of the Arid Region," The Century Magazine, vol. 39, 1890, pp. 770–771), and described this service as the "duty" of water measurable in acre-feet; and irrigators have frequently applied the term to the measure of water rather than of the service (or duty) performed by the water—a service susceptible of useful measurement only in terms of what the water *does* or performs, just as the duty of an engine is measured by its performance and not by boiler pressure. Terms for the measurement of the water no less than of the service performed are indeed requisite. Prof. Fortier, in judiciously discouraging excessive use of water in irrigation, says, "We find that the average duty of water over two-thirds of a million acres of land was recently shown to be 4¾ feet per acre" (Proceedings, Seventeenth National Irrigation Congress, Spokane, 1909, p. 274); but it is needful to distinguish between the quantity of water required by a given soil and the service which that water renders in crop production.

production which furnishes food for man and forms the foundation for all human industries and institutions.

The water consumption expressed in the coefficient is, of course, gross rather than net, i. e., reckoned from the practical conditions of the average farm, rather than from the technical conditions and measurements of plants singly or in small groups. Such net coefficients as those worked out by King, Storer, and others for special crops and seasons are undoubtedly more exact;[a] but they would seem to be less applicable to the practical agriculture of the country at large with its incidental and generally unnoticed wastes, and with the growing need for balancing yearly use with aggregate current supply.

Naturally, the coefficient for plant yield will not apply to general farm production, including crops of meat, eggs, wool, hides, etc.; for not only do animals drink many times their weight in water annually, but they consume indirectly in their feed the equivalent of that much larger quantity required for the growth of the vegetal tissue of which the feed consists. The human consumption is still larger: In illustrative estimate, a pound of bread is the equivalent of 2 tons of water used by the growing grain, and a pound of beef the equivalent of 15 to 30 tons of water consumed by the animal both directly and indirectly through feed; and the adult who eats 200 pounds each of bread and meat in the course of a year consumes something like 1 ton of water in drink and the equivalents of 400

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[a] King, in Wisconsin, found the mean weight of water used during the growing season by barley, oats, maize, clover, peas, and potatoes in producing a ton of dry matter ranged from 270.9 to 576.6, and averaged 446.3 tons ("Physics of Agriculture," by F. H. King, 2d edition, Madison, 1901, p. 139). Storer, summarizing numerous experiments made by observers in different countries on various kinds of crops, says: "More than 300 pounds of water pass through a plant, and are transpired by its leaves for every pound of dry solid matter fixed or assimilated by the plant" ("Agriculture," by F. H. Storer, 7th edition, New York, 1906, vol. 1, p. 15). In Idaho McPherson measured the water used on an experimental farm in 1906, and obtained the following ratios of water to crop: Alfalfa, 432.78 to 1; beans, 152.9 to 1; beets, 90.7 to 1; carrots, 77.18 to 1; corn of four varieties, an average of 135.75 to 1; oats, 90.86 to 1; potatoes, 46.28 to 1; and wheat, 66 to 1 ("Third Annual Report of Alex McPherson, Director of Experiment Stations," dated Twin Falls, Idaho, Apr. 4, 1908); the measurements being made only during the growing months without allowance for accumulated ground water or natural subirrigation, and on the assumption "that the amount of water evaporated from a water-free surface, as shown by the evaporating tanks, was equal to the evaporation from the soil, the seepage, and the amount actually used by the plants"—an assumption undoubtedly rendering the figures too low. All these determinations relate primarily to the plants themselves and have little reference to the total water supply on which agriculture in the last analysis depends; they especially fail to include that soil moisture on which fitting texture of the soil depends during the nongrowing as well as the growing seasons, and of which there is generally a considerable loss through surface evaporation.

tons in bread and 4,000 tons in meat, or 4,401 tons in all—besides the use in ablution of from 100 pounds to 200 tons (12 to 48,000 gallons, or from a gill to some four barrels daily), according to habit of living. These figures correspond fairly with current experience of intensive agriculture in the arid region, in which water is measured more carefully than in humid lands; here a 5-acre farm supplied with, say, 5 feet of water, suffices for a family of five, or an inhabitant per acre (cities balancing more barren tracts); and on this basis the 5,000,000,000 acre-feet, constituting the total yearly water supply of mainland United States, would suffice for a population of about 1,000,000,000, which at the current rate of increase will be reached in some three centuries, i. e., a future span equal to that passed since the Pilgrims landed on Plymouth Rock.

THE DUTY OF SOIL.

The measure of the solid part of the soil required to produce given crops varies widely with water supply, soil type, mode of cultivation, crop type, and other conditions. In ordinary farming the common annuals are sustained chiefly by the topsoil lying within plow depth, i. e., nominally 4 to 8 inches, actually 2½ to 5 or 6 inches. Especially in dry seasons, corn and some other plants send their roots so much deeper as to impede the next plowing, while alfalfa and certain other plants adapted to arid conditions send a part of their roots down to water even many feet below the surface. On the other hand, the roots of corn and some other crops in wet seasons and in irrigated fields ramify near the surface; with dust mulching in the subhumid and semiarid regions, the roots tend to spread throughout the friable soil immediately beneath the pulverized moisture-retaining layer at the surface; and the most exuberant native flora in the United States, including the lofty firs and rank undergrowth forming a veritable jungle throughout western Washington, roots wholly within depths of 18 to 24 inches, the minor root tips turning upward and terminating where the abundant duff or natural mulch passes into the rich humus at the very surface of the soil. In a word, the rooting of crop and other plants is controlled chiefly by the distribution of soil-fluid, i. e., by the soil circulation; and this circulation is but a part of a general system which includes the movement throughout the subsoil below and the plants above no less than within the layer of soil whence the plants draw their moisture. The chief rôle of the subsoil, indeed, is that of a reservoir of soil-fluid for the supply of the topsoil by which the crop plants, or the native grasses and shrubs and trees, are chiefly or wholly sustained; and when the water supply is adequate this topsoil is rarely over 12 inches in thickness. So it is convenient to reckon soil, no less than water, in terms of acre-feet.

The apparent specific gravity of properly cultivated soil averaging about 1.5. a cubic foot weighs between 90 and 100 pounds and an acre-foot weighs some 2,000 tons. An annual yield of 6 tons of (dry) plant tissue from such an acre-foot (assuming its extensions to balance the part not fully employed) would thus equal $\frac{1}{333}$ of its weight; or (the ash being barely 5 per cent of the plant produced), say $\frac{1}{6667}$ of the solid soil matter presumably consumable by plants in time. Whether a given acre-foot of soil would endure for 70 centuries; whether its substance would be consumed and carried away; whether it would be enriched to any given degree by the differentiation of mineral constituents attending organic growth and decay; whether the material derived from water and air would counterbalance in part or in whole the loss of substance carried off in the annual crops—these are questions not to be fully answered with present knowledge. The broad facts of geology teach that the organic and the inorganic have interacted through the suborganic soil during the ages, and that in a general sense the successive floras of the world have (despite the loss of soil matter through erosion) accumulated and enriched the world's soils; yet geology has not yet yielded quantitative coefficients. Current agricultural experience commonly suggests that soils are impoverished by continuous cropping, in connection with the often neglected but appallingly large losses through destructive erosion, unless productivity is maintained by special treatment; and the impoverishment is commonly ascribed to the exhaustion of certain earth salts regarded as plant food. The more extended studies and comparisons of scientific agriculture, on the other hand, reveal a progressive increase in productivity with continued cultivation in this and other countries[a] (i. e., a trend parallel with that indicated by geology), which may be due in part to improvement in crop plants, in part to fertilizing, and in part to better methods, but is certainly inconsistent with any view of progressive impoverishment of properly cultivated soil. In any event, the foot of suborganic soil required to produce annual crops is constantly changing; it is at once product and producing agent; and if it loses toward the surface through absorption by the growing plants, it gains below in equal or greater measure by oxidation and disintegration of inorganic subsoil and subjacent rocks, so that the acre-foot of one century is not identical with that of the last and may be quite different from that of the preceding millenium. Yet, since the farm is not limited in depth, the acre-foot of soil may be considered permanent, whatever the progressive internal changes due to the internal work attending the soil-plant circulation and other processes; and its average duty may

[a] The data are summarized by Professor Whitney in "A Study of Crop Yields and Soil Composition in Relation to Soil Productivity," Bull. 57, Bureau of Soils, Oct., 1909.

be defined as *the annual production of $\frac{1}{333}$ of its weight of useful plant crop.*

This coefficient is of less consequence than that defining the agricultural duty of water, chiefly because soil efficiency depends primarily on water supply, partly because of the variability of secondary conditions. Thus, yield varies with depth of tillage, and with composition and texture of the soil; it varies also with the contained moisture of crops ranging from succulent vegetables or juicy fruits and bulky forage to grain, nuts, and fiber; though with increasing knowledge the coefficient may be standardized by reducing the measured crop to a uniform condition of dryness.

Pending a more careful reckoning of the variables, the coefficient is useful chiefly in fixing the idea that in rational agriculture, no less than in mechanics and the physical sciences, cause and effect may and should be constantly balanced by measuring or weighing in commensurable units. Intensive methods have already shown that multiplying depth of tillage is more profitable than multiplying the acres tilled, and the time is at hand for measuring production in terms comparable with both soil and cultivation. So, habitual thought in terms of any coefficient based on commensurable quantities, rather than on random ratios between incommensurable units of weight or volume and area, can not fail to be useful.

NATURAL WORK OF WATER.

The sole original source of fresh waters on the lands of the earth is rainfall, including snow. In mainland United States (i. e., exclusive of Alaska and the insular possessions) the mean annual rainfall has been shown by the Weather Bureau to average about 30 inches. The total quantity is some 215,000,000,000,000 cubic feet, or 5,000,000,000 acre-feet (6,000,000,000 kilosteres, or 7,000,000,000,000 tons); it is equivalent in volume to 10 Mississippi rivers running constantly. A secondary source of fresh water is the supply derived from former rainfall and stored chiefly in the form of ground water, partly in lakes and ponds and running streams. The water thus stored within the first hundred feet from the surface is estimated at 2,000,000,000,000,000 cubic feet (1,400,000,000,000,000 in the ground and 600,000,000,000,000 on the surface, including the American part of the Great Lakes) or some 46,000,000,000 acre-feet (or 57,000,000,000 kilosteres); it is equivalent to nearly 10 years' rainfall. The ground water alone would fill a reservoir conterminous with the entire country to a depth of some 17 feet.

Neither rainfall nor ground water is uniformly distributed; the mean annual rainfall ranges from less than 5 (locally less than 2) inches to more than 100 inches, while the soil wetness measuring the quantity of ground water ranges from the air-dry condition to complete saturation, or from, say, 4 per cent upward; i. e., from desiccation to drowning. Considered with reference to natural water supply, mainland United States may be divided conveniently into the three sections shown in figure 1,[a] viz, (1) the Eastward States, or humid section, comprising the two-fifths of the total area lying generally east of the ninety-fifth meridian; (2) the subhumid section, comprising the one-fifth contained in the Median States (North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas); and (3) the Westward States, or semiarid section, comprising the two-fifths west of the Median States, and generally beyond the one hundred and third meridian. The mean rainfall over the humid section is about 48 inches yearly,[b] or not quite enough for full productivity from average soils (the optimum being some 60 inches), aggregating nearly 140,000,000,000,000 cubic feet annually; the ground water within the first hundred feet probably averaged over 25 feet at the time of settlement, but has been reduced perhaps 5 feet through injudicious industrial development. The mean rainfall over the Median States approaches 30 inches, or 40,000,000,000,000 cubic feet yearly; it is supplemented by natural subirrigation from the mountainous country farther westward to an amount estimated at 12 inches in central South Dakota, and probably averaging 3 to 5 inches; the ground-water reservoir is sustained by this subirrigation, and is estimated as equivalent to some 25 feet in the first hundred. In the semiarid section the rainfall ranges from less than 2 to over 100 and averages about 12 inches, aggregating less than 40,000,000,000,000 cubic feet; the soil ranges from desiccation to saturation, and the ground water probably averages 5 or 6 feet in the first hundred. On the whole, the water supply of mainland United States is hardly half that required for full agricultural production, and the distribution is

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[a] EXPLANATION OF FIG. 1.—Shows mainland United States, i. e., exclusive of Alaska and the insular possessions, classified as (1) Eastward States or humid section, (2) Median States or subhumid section, and (3) Westward States or semiarid section; showing also precipitation by isohyetal lines ranging east of the one hundred and twentieth meridian from 10 inches to 60 inches, with 10 inch intervals, and west of that meridian from 20 inches to 100 inches, with 40-inch intervals.

[b] This and other figures for rainfall are somewhat in excess of the means computed from the observations at Weather Bureau stations. They have purposely been made high, because it seems preferable, in aiming for practically the first time to show that the rainfall over even the more humid parts of the country is below the agricultural optimum, to err if at all on the safe side, i. e., to give the farm the benefit of the doubt; accordingly it is assumed that the precipitation over mountainous areas where the Weather Bureau stations are fewest commonly exceeds that over lowlands, where the stations are more generally distributed.

such that about 1,000,000 square miles may be regarded as fairly well watered, while another 1,000,000 are sufficiently watered for about half the normal productivity, and the remaining 1,000,000 square miles

FIG. 1.—Natural water supply of mainland United States.

of the country are so meagerly watered as to be practically unproductive under existing conditions.

The possible crop yield over the entire country may be estimated at something less than half the possible production from half the area with the same aggregate quantity of water equably distributed;[a] or equivalent to full production from an area of say 1,300,000 or 1,400,000 square miles.

Of the total rainfall, about one-third flows into the sea through rivers and smaller streams; this is the run-off. A smaller fraction either enters directly into chemical combinations (largely through vital action) or else penetrates deeply into the earth to saturate hypogeal rocks and find its way into the sea through slow percolation; this is the cut-off. The greater fraction remaining is returned to the air by evaporation (largely after circulation through organisms), forming the fly-off; it augments the vapor-content of the atmosphere, and is partly reprecipitated and reevaporated over and over again, thereby aiding in the equable distribution of the natural water supply, though its transitions have not been fully traced or its movements finally measured.

The slight variations noticed from season to season have given rise to widespread popular beliefs that the rainfall of particular districts is increasing or decreasing; but meteorologists and geologists generally have favored the view of secular uniformity on the evidence of rainfall records for series of years. Of late the influence of forests and other vegetal cover on soil-plant circulation has received critical attention,[b] while the extent of deforested and artificially wooded areas has so far increased as to afford a basis for instructive comparisons of records, some of which seem consistent with the well-known facts that in passing from the humid section toward the semiarid section, or from any other humid district to an arid one, there is not only a decrease in precipitation, but the waterways change from comparatively steady streams into sand washes generally dry but flooded by tumultuous torrents for a few hours or days after each great storm; and that the transition is gradual and attended by progressive transformation in the character of the flora or vegetal cover. This accords with the elementary principles of geology, and also with a fundamental physical law affecting all climatic conditions whereby widening of extremes is accompanied by lowering of means,

[a] The water resources of the country are set forth in greater detail in the Report of the National Conservation Commission (60th Cong., 2d sess., S. Doc. No. 676), 1909, vol. 1, pp. 39–49; and in the Annals of the American Academy of Political and Social Science, Vol. XXXIII, 1909, pp. 521–534. The principles involved are summarized in "Outlines of Hydrology," Bulletin of the Geological Society of America, vol 19, 1908, pp. 199–220. A fuller discussion of the normal relations between water supply and productivity is reserved for later publication.

[b] A recent and noteworthy contribution to knowledge of the subject has been made by Prof. L. C. Glenn, "Denudation and Erosion in the Southern Appalachian Region and the Monongahela Basin," U. S. Geological Survey Professional Paper 72, 1911.

and vice versa.[a] Accordingly, since the rainfall in the humid section (averaging barely 48 inches) is below the optimum for vegetal growth, any such diminution as is shown by the records can only be regarded as indicating progressive desiccation of both the air above and the soil below the natural vaporizer formed by the vegetal cover, and hence as marking a stage in transition from fair productivity toward desert conditions. Over the Great Plains, once open prairie but now partly wooded, a converse transition is frequently suggested; but the records thus far disclose no perceptible increase in rainfall since observation began.

In the state of nature existing before settlement of the country, the three fractions of the natural water supply (fly-off, run-off, and cut-off) were closely balanced not only among each other but with the natural cover formed by the flora—indeed neither the whole world nor the marvelous balance between the heavenly bodies of sun and planet and satelite reveals any more delicate harmony than that arising in the interrelations between the movements of the waters and the features of the lands. The inorganic interrelations are relatively simple; they form the foundation of dynamic geology. Lyell long ago, and Powell later, proved that nearly the entire earth face, down to the minutest lineaments, was sculptured during the ages by running water, and that the same water carried the waste into seas to build later formations eventually forming newer lands. Except in the glaciated region and a few volcanic districts and inclosed basins, the land forms of mainland United States were shaped predominantly by running water; and even in the exceptional regions the final configuration was generally given by the same agency. When the slopes are steep the water works rapidly and chiefly on the surface; when the inclination is gentle it works slowly and largely beneath the surface; in the one case the rainfall runs off quickly, in the other case it either lies long for evaporation or sinks into the soil to reappear as springs and seepage. So the hills are cut down, the valleys are deepened more slowly, the plains are lowered more slowly still, and sometimes caverns and sinks are produced by subterranean flow.

The general process is erosion; it involves (1) corrosion or weathering of the surface, (2) corrasion or scouring of channels, and (3) sapping or undermining of banks and strata, with (4) transportation

[a] The empiric law was brought out in a discussion of "Maximum Synchronous Glaciation," Proceedings American Association for the Advancement of Science for 1880 (vol. 29, 1881), pp. 469, 482–485. Although it may be formally explained as among the many cases of arithmetic means of geometric variables, the relations undoubtedly express innate properties of water as a temperature-controlling agency.

or removal of the materials in (*a*) solution, (*b*) suspension, and (*c*) saltation.[a]

The rate of erosion varies in a geometric ratio with the declivity or slope of the surface, so that it is many times more rapid in mountainous and rolling regions than over smooth plains; it also varies geometrically with the size and swiftness of streams, so that by far its greater part attends storms. The secular rate of erosion of the lands of the earth commonly accepted by geologists ranges from $\frac{1}{2500}$ to $\frac{1}{6000}$ of a foot yearly, or a vertical foot in from 2,500 to 6,000 years; the latest estimate for mainland United States, made by R. B. Dole and H. Stabler, of the United States Geological Survey, for the National Conservation Commission, is $\frac{1}{9120}$ of a foot ($\frac{13}{10000}$ of an inch) yearly—the amount of material removed being computed at 783,000,000 tons annually.[b] The several figures give some indication of the rate at which the earth face is sculptured into hill and dale, butte and gorge, knoll and swale, and all the varied forms of landscape and countryside. All have been carved out of older earth-forms during the ages by the removal of hundreds, thousands, and even ten-thousands of feet of rock above the present surface; and the work goes on and on.[c]

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[a] The several processes are described and the last-named is defined somewhat fully in "Outlines of Hydrology," op. cit., p. 199, where it is suggested that the movement of the finer no less than the coarser sediment, and even of the water particles, is saltatory.

[b] Op. cit., vol. 2, p. 130. Although lower than earlier estimates, this determination, resting as it does on extended observations and measurements, is undoubtedly the most trustworthy thus far made. Still it should be noted that since it is based on measures generally made under average conditions, and is hence an arithmetic mean of geometric variables, it is probably too low. Other factors corresponding, the erosion of a vertical foot in 6,000 years would give 1,190,000,000 tons, and in 2,500 years 2,856,000,000 tons, of material removed yearly. Doubtless the discrepancy is due to the making of earlier measurements in flood, during which more sediment may be moved in a few hours than at ordinary stage during the rest of the year. In any event, the recent determination may not be regarded as indicating progressive diminution in erosion, which is known through common observation to increase with settlement and injudicious cultivation.

[c] Current knowledge concerning the development of land forms was gained chiefly through the work of the Geological Survey in conjunction with a number of State surveys and several universities, notably Harvard, Wisconsin, and Chicago. The interpretation and definition of land-shaping processes ranks as the most important work of the federal survey, if not as America's greatest contribution to systematic knowledge; indeed, it marks an epoch in scientific progress. The data are distributed through hundreds of publications, are incorporated in text books and taught in schools, and are rapidly entering into common knowledge. Perhaps the most convenient summary is that recently published by the Geological Survey as Professional Paper 60, "The Interpretation of Topographic Maps," by R. D. Salisbury and W. W. Atwood. While the researches and publications form a firm foundation on which the art and

Resting on the sure foundation of dynamic geology, the more intricate interrelations between land forms and natural or artificial cover become clear; and here geology and agriculture meet. As the slopes of the land flatten under secular erosion vegetation appears and spreads in ways eloquent of the pertinacity and persistence of vitality, gradually forming soil; and thenceforward vegetal cover and suborganic soil cooperate to check erosion, convert free run-off into fly-off and cut-off, and utilize the rainfall for the maintenance and increase of living things. With the advent of organisms and soil the physical laws of land sculpture are modified or masked, if not nearly nullified; for once a region is mantled with soil covered by a flora, mechanical reaction to external force is largely replaced by chemico-vital interaction responsive to the internal forces manifested in circulation and growth. The efficiency of different plant forms (themselves reacting primarily to water supply and secondarily to soil) varies widely; sage and greasewood and other arid plants barely hold ground against wind and storm; the grasses form sward shielding the soil against rains and rivulets on gentle slopes though not on steep; while dense forests and close shrubbery break beating rains into mists and lead the trickles through a carpet of mulch into topsoil and on into subsoil over steeper no less than flatter slopes. It is in this final relation that the fullness of natural harmony attains perfection, and the organic and suborganic and inorganic are, as it were, attuned to a common measure of which the theme is the thrill and throb of life on the land—a harmony no less delicate and far worthier of appreciation than that of the cosmic spaces. And so practical is it that the trained eye of the geologist (or geomorphist, in stricter definition) sees at a glance whether the lines and contours of the fields before him were originally wooded or grassed or sheltered only by scattered shrubbery; for the slopes reveal not merely the work of the waters during the ages but the modification of that work first through the varying forms of plant and animal life and finally through the soils produced by the organic interactions.

While a fuller analysis of the normal rôle of water in the functioning of soils remains for later publication, it is needful to note the primary relations between (1) moving water in its three forms, (2) the soil and subsoil accumulated during the ages, and (3) the vegetal cover; for the cover is the natural or artificial crop grown

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the science of the farm may forever rest secure, the leading applications have thus far run chiefly toward mines and mining; yet it is reasonable to forecast that as the applications are turned toward farms and farming they will be found still more useful, perhaps in even higher ratio, than that of agricultural production to mineral production, or as more than 4:1.

from the soil through the work of the water. Stated in terms of active work (or function), the leading relations are:

(1) It is the proximate function of water, as the chief agency of geologic process, to grade and shape the lands of the earth.

(2) It is a function of plants (in cooperation with other organisms) to decompose and disintegrate the inorganic rocks of the earth, thereby producing soil with its complex mineral salts and organic compounds available for plant food.

(3) It is the function of soil (in cooperation with organisms) to sustain plants, and especially to conserve water for their use and supply it as needed for their growth.

(4) It is the mediate function of water to initiate and maintain the vitality and cumulative power of organisms by means of circulatory systems—systems at once extending through soil and plants, involving change of state from liquid to vapor, and accompanying stresses (both tensile and compressive) sufficient to accelerate or retard, if not to cause or prevent, the reactions involved in organic growth and decay.

(5) It is the ultimate function of water to regulate the temperature of the earth by means of its own distribution and changes of state in a comprehensive circulatory system (at once secular and telluric) including its own movements and changes of state no less than the shapement of the land and the development of both organisms and the suborganic soil.

Of these functions the second, third, and fourth are directly involved in the current work of water in the form of soil-fluid throughout habitable lands; the first and fifth are involved indirectly and more remotely. Now, in a state of nature the functions are coordinated, or adjusted one to another, in such manner that throughout lands lying at moderate height above the sea nearly all (in arid regions all) the water supplied by ordinary rainfall is used in the growth of plants and related organisms, in tempering the air by means of aqueous vapor, or in producing and enriching soil—or in two or all of these processes combined. With the normal balance found in a typical forest or on a well-grassed plain, the vegetal cover holds the storm water until it sinks into the duff or mulch and on into the soil and enters the soil-plant circulation; save in extraordinary storms the streams run clear because supplied rather by springs and seepage than by surface run-off; while the seepage water percolating through the topsoil and subsoil serves partly as a reserve against drought and partly as an excretory vehicle to carry off injurious by-products (such as growth toxics and the excessive alkalis of ill-drained areas) and sweep the worst of them through the streams into the sea. So the natural valley or drainage basin, from upland rim to lowland channel, is in proper sense a complete water system, involving supply, distribution, use, and sewerage. In the final balance toward which nature works, both gentle rains and ordinary storm waters are utilized in organic growth and in soil making, and only the slight excess required for sewerage flows seaward; each acre takes care of its own, both in water and in life; and all the acres cooperate in using all the rainfall, and in the use transform much of it into vapor for the benefit of all. This ideal balance may seldom be attained: yet it is often approached—as it was in much of the Mississippi Valley before the relations were disturbed by settlement.

WORK OF WATER IN AGRICULTURE.

The basis of agriculture in mainland United States may be considered as the first foot of soil over an area of nearly 2,000,000 square miles, or about a billion and a quarter acres; it weighs fully 2,500,000,000,000 tons; and it is capable, when adequately supplied with water, of yielding perhaps 7,500,000,000 tons yearly of plant product (including the field staples and also the woods, nuts, berries, pasturage, browse, mast, and mulch of woodlands), i. e., many hundred times the current useful yield. Such a yield would suffice for a population averaging 500 per square mile over the 2,000,000 square miles of productive area, or 1,000,000,000 in the aggregate, or all the water supply could sustain at present standards. This soil and yield form the agricultural capital of the country, the primary source of food and apparel and industrial growth.

The processes of agriculture supplement and extend the processes of nature. They progressively reconstruct the natural cover and modify the soil, and thereby initiate changes in the natural forms of the land which affect the natural balance established by the running and circulating waters. The processes are often injurious to the soil; though when conducted judiciously they may easily be made beneficial.

In primitive agriculture the natural balance of land forms and soil and cover is disturbed but slightly and slowly. Most of the American aboriginal tribes were agricultural in that they seeded and harvested sufficiently to supply a considerable part of their provender and apparel; yet they neither plowed the ground nor cultivated the crop in proper sense, merely planting local patches in a manner generally simulating natural arrangement and leaving the production largely to natural processes—pursuing the methods of *hackbau* rather than *ackerbau*, as expressed by German students, or of hoe work rather than fieldwork. True, corn and tobacco and some other plants were so completely artificialized during the centuries of aboriginal cropping as to find their way into use in foreign countries soon after Columbus and Cortez came into the New World; yet the chief process was selection of seed rather than cultivation of the soil or protection of the plants. So the aboriginal agriculture had little effect on the natural harmony.

Certain customs of the hunting tribes were of greater effect, notably the burning of woodlands often ascribed (albeit erroneously) to a design of enriching the range for game by extending the prairies; as a matter of fact the aboriginal huntsman neither reasoned from cause to effect nor exercised the inventive faculty, since he had not reached the stage of development to which these powers pertain; but with animistic faith instead he invoked the power of fire as a deific agency to aid in the chase, and in hunting orgies akin to the warpath obsession he slaughtered ruthlessly the game animals crazed by the flames—whereby the prairies were indeed extended, though the areas were generally reduced in game-bearing capacity. This aboriginal fire clearing was hardly less shortsighted and recklessly destructive than that of later agriculture at its worst, in that its motive was extravagant feasting for the day without thought for the morrow's famine; over considerable tracts it indeed removed the natural cover, yet the burned areas were not extensive enough to affect materially the natural balance between the rainfall and the slopes and soil and cover of the country as a whole—for the pre-Columbian population of what is now mainland United States was not over 2,500,000 (perhaps not more than 1,250,000), or much less than one per square mile.

In the effective agriculture following white settlement, the natural cover and surface were progressively artificialized. At the outset and for long after there was little effort to define or measure, much less to modify or improve, the delicate balance between those natural factors involved in shaping the surface and forming the cover; lands were chosen for clearing and breaking largely on the evidence of fertility seen in luxuriant growth, partly on account of smoothness or other qualities indicating suitability for plowing and seeding and harvesting; and since the smooth and fertile lands were relatively little affected by the artificial change, the natural balance was not seriously disturbed. So the liquid and solid parts of the soil remained about as before, the soil-plant circulation extended through the vascular systems of the artificially chosen plants much as it did through those selected by nature through survival of the fit, and the plow-stirred topsoil took partial place of the natural mulch as a sponge for retaining rainfall and reducing run-off. The chief immediate change was the forcing of a land naturally bearing a fine flora to yield still finer products—two heads of grain were grown where a blade of grass grew before, luscious fruits or pliable fibers were substituted for bitter shrubs, and the profitless acres were made to teem with material for food and clothing; and under irrigation a hundred heads of grain replaced the blade of buffalo-grass, and a hundred head of kine grazed where an antelope or two wandered before. Meantime unnoticed changes in the natural balance were advancing cumulatively, especially in the long-settled districts; and as the heavily wooded and more rolling lands were cleared, the disturbance became more and more manifest—and this in several ways:

(1) With ordinary plowing and common crops the natural mulch soon disappeared and the humus diminished, so that the soil grew harder and poorer; and when storms came there was more surface run-off and less water soaked into the topsoil and on into the subsoil below.

(2) With crops covering the surface imperfectly and for but part of the year, the soil was subjected to evaporation directly rather than through the growing plants; and some of the soil-fluid, the very life-blood of the farm, was sacrificed.

(3) When the meager and temporary cover of common crop plants replaced a luxuriant and perennial forest cover, the unbroken rain-drops smashed the soil into slime at the surface and tamped down the earth beneath; and as the natural sponginess diminished, more water ran off the surface, bearing a burden of sand and silt, whereby it was enabled to corrade rills, quickly widening into gullies.

(4) When snows came they lay on bare surfaces (despite the slow bottom melting which normally absorbs snow sheets on ground to which they are naturally adjusted) until thawed by warm winds or rains,[a] when the thaw water went off in destructive freshets instead of soaking into and softening the thawing soil as in that state of nature wherein melting at the bottom is supplemented by the melting through the reflected rays from trunks and shrubs and leaves.[b]

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[a] A recent observation by Prof. J. T. Rothrock, made in Chester County, Pa., during a thaw following a heavy snowfall and hard freeze, is typical: "In the woods, where leaves covered the ground, I found that it was possible to thrust an iron-shod cane without difficulty to a depth of 18 inches into the earth, unless it was stopped by a root or stone. * * * On the open ground, whether the snow still remained or had drifted away, the resistance to the thrust of the cane was solid, almost as if I had struck a rock. To this there was but one exception, where there was an unusually dense covering of long grass. Under a matted surface of this kind I could still thrust my cane into the ground of an open field." (American Forestry, Vol. XVI, 1910, pp. 349–350.)

[b] The practical aspect of the diathermancy of snow and ice, long ago demonstrated by Sir John Tyndall (Heat as a Mode of Motion, Lecture IX, Mar. 20, 1862; edition of 1871, pp. 322–325), is too little understood. Ordinarily the sun is without appreciable effect in melting snow or ice, for all of the solar rays capable of affecting H_2O in the solid form are, as it were, sifted out by the H_2O in gaseous form (or aqueous vapor) diffused through the circumjacent atmosphere. In order to become effective the rays must first impinge on some other substance, whereby they are broken up and rendered capable of absorption by water in its three forms. It is by reason of their diathermancy to solar rays that snow and ice seldom even soften at the surface in cold and dry

(5) With the increase of run-off and fly-off, less of the water furnished by rains and snows sank into the soil, the natural drainage and sewerage effected by the ground water was impaired, and the accumulated reservoir of ground water was progressively reduced.

The general result of these specific tendencies is well known. Most pioneer homesteads were located by springs, of which by far the greater part have failed; in the next generation the households were supplied by shallow wells, of which most have gone dry unless greatly deepened; well-remembered trout brooks have ceased to exist, while many tamarack swamps and hundreds of prairie sloughs have shrunk or disappeared; numberless bosky dells and shady reaches of clear river are gone, leaving in their stead freshet-swept gorges, running dry in summer; in certain districts old-field slopes are gullied, and even the new-cleared patches wash quickly, and often the soil soon turns hard and lumpy. It is estimated that throughout an area of some 500,000 square miles in eastern United States the natural level of water in the ground has been lowered 5 to 30 feet since the country was settled; and that the depletion of this natural reservoir can hardly be less than 700,000,000,000,000 cubic feet of water, equivalent to more than 3 years' rainfall for the entire country or fifteen years' rainfall over the area depleted; i. e., an immense capital has been squandered thoughtlessly.

The artificial disturbance of the natural balance between cover, soil, and slope with given rainfall brings out clearly the normal rôle of water in agriculture, which is precisely parallel to that enacted in nature. The ordinary practice of the farm is measurably to reinstate the mechanical conditions of land sculpture existing before the advent and extensions of organisms, under which conditions the running water tends to erode the slopes, cut down the hills, clog the valleys, and generally flatten the land surface to that natural hydraulic grade known in geology as the base-level of erosion.[a] At

air, however strong the sunshine, though they quickly melt under a warm wind or rain (perhaps to refreeze and form a crust during the night); while the rays penetrate the mass to the dark earth below, which warms quickly and then by conduction and radiation thaws both snow and frozen soil. It is for the same reason that leaves and twigs lying on snow and ice soon sink deeply in pits, preserving their outlines; that tree trunks melt the snow about them until they rise from wells sometimes several feet deep; and that under natural forest conditions the heaviest snow seldom forms freshets, but thaws progressively at bottom and about the trunks and along fallen stuff in such manner as to soak into the mulch and hasten the melting of the frost in the ground below.

[a] In dealing with the natural distribution of water it is necessary to recognize three natural levels or horizons. The first of these is the natural surface of the continent, including both the lands and the inland waters. The second is the "base-level of erosion" recognized and defined by Powell in the course of his classic work on the geology and geography of the Rocky Mountain region; it applies to each and all points at which the altitude is such that while water

the same time this short-sighted interference with natural relations emphasizes nature's lesson, and indicates ways in which methods may be so modified as to keep the mechanical conditions and powers under complete control.

Summarized in a preliminary way, the requisites are (1) to retain mulch and humus, partly to hold the waters of rains and snows, partly to temper and so increase the friability and sponginess of the soil; (2) to till deeply in order that the soil-body may be kept open to free circulation of the soil-fluid; (3) to select crops partly for the sake of affording cover for the longest practicable portion of the year, especially on steeper slopes; (4) to rotate crops partly for the sake of alternating long and short seasons of cover and so checking any erosion started by defective cover; (5) in the dearth of vegetal mulch, to maintain a dust mulch tending to check evaporation from the surface and thus to promote circulation through the crop plants; and (6) on all steeper slopes to plow and plant on contours, thereby closing gullies and channels and retarding run-off.

These and related devices suggested by the natural balance between cover, soil, and slope as connected with rainfall lie at the foundation of judicious agriculture. Properly developed and applied, they may be made to preserve and perfect organic control of the inorganic, to maintain the interadjustment of the solid and fluid parts of the soil, to obtain the full agricultural duty of water, and to prevent waste of the natural water supply with the attendant direct loss and indirect injury. The end of effort in the artificial applications agrees with that toward which nature works; when each acre retains and makes good use of its entire rainfall, then and then only is the adjustment perfect.

ABNORMAL WORK OF WATER IN AGRICULTURE.

Since it is the function of soil-fluid to circulate through the interstices of the soil-body and the vascular structures of plants, any water

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will flow along its natural lines leading seaward, the slopes are too low to give velocity sufficient for erosion (i. e., along the seashore it coincides with sea level and thence slopes upward inland at a rate varying with the size and distribution of the rivers and minor lines of drainage); so that the base-level of erosion may be conceived as a surface within the earth, generally lying considerably below the natural surface, but conforming broadly with its irregularities. The third horizon may be denoted the ground-level of water; it is the upper level or surface of the natural ground water, sometimes called the water table, i. e., the level at which the earth is normally so saturated as to supply well water and springs or seepage. In clear streams or points supplied by seepage the three surfaces coincide; generally the ground-level of water lies somewhere between the natural surface and the base-level of erosion; although in arid regions the ground-level may be discontinuous or absent, while the base-level is determined by lines of flow leading not to the sea, but to loci of natural balance between storm flow, evaporation, and soil absorption.

in the soil departs from its normal function and works abnormally (1) when it evaporates from the ground, whether or not it carries up earth salts to be precipitated at the surface; (2) when it evaporates through weeds or noxious plants; (3) when it accumulates in quantities so excessive as to prevent circulation; (4) when it drains quickly downward to depths beyond the reach of plants; and (5) when by reason of hardness of the ground and steepness of the slope it fails to permeate the soil-body and runs off at the surface.

Of these abnormal tendencies the last is by far the most common. It is also the most serious, not only because of wider extent, but by reason of far-reaching consequences. The chief consequence is destructive soil erosion, one of the gravest evils confronting the American farmer. It was shown by the National Conservation Commission on the basis of estimates received from 30,000 farmers, representing every county in mainland United States, that 16,597 square miles of farm land have been abandoned, and that 6,076 square miles, or 0.2 per cent of the entire area, have been devastated by soil erosion.[a] It was pointed out that—

> In districts liable to extensive soil erosion the abandonment of fields is disastrous; in some cases the old-field erosion not only removes the soil proper, but carries away the subsoil, and even the surficial deposits, exposing bare rocks or intractable formations, over which soils naturally redevelop with extreme slowness, and can not be extended artificially except at large cost. The fact that over 6,076 square miles, or 3,888,640 acres, of our abandoned fields have been destroyed in this way is appalling. Not only would the area form nearly 100,000 farms, capable of sustaining a population exceeding that of any one of our 12 least populous States, but each gully starts others in such manner as continually to extend the devastation. The evil should be remedied without delay. Communities and States should be awakened to the sacrifice of public interest through old-field erosion. First, in connection with abandoned fields, and progressively in cultivated fields, soil wash should be considered a public nuisance, and the holder of the land on which it is permitted to occur should be held liable for resulting damages to neighboring lands and streams.

It was also shown (as noted above) that the rivers annually discharge into the sea over 70,000,000,000,000 cubic feet of water, carrying in solution and suspension no less than 783,000,000 tons of sediment, of which a great and rapidly increasing part is derived from the erosion of farm lands; and the annual loss due to this cause was estimated at 7 to 10 per cent of the product of upland farms.

Considered with special reference to the farm, destructive soil erosion comprises (*a*) comminution (including both disintegration and decomposition) of organic and inorganic material in excess of the rate required for production, (*b*) leaching or solution of such material beyond the norm of soil-plant circulation, and (*c*) washing

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[a] Report of the National Conservation Commission (60th Cong., 2d sess., S. Doc. No. 676), 1909, vol. 1, p. 79.

of the material comminuted or leached (the three minor processes forming the corrosion of the general process defined on p. 20), together with corrasion, in which firmer materials are scoured and crushed or dislodged by the impact of solid particles dropped or driven by moving water, and the transportation of all the materials down the slopes and toward the sea. The several processes are largely interdependent, and cooperate in a cumulative way; clear water will not corrade, and the capacity of silt-laden water for corrasion (e. g., in gullying) increases, other things equal, in a geometric ratio with the sediment carried; washing is of little effect without comminution and leaching, and generally increases geometrically with the material supplied in these ways; while leaching and comminution doubtless interact, each aiding the other, and each aided, first, by the washing, which lays bare the surfaces of particles, and then by corrasion, which lays bare larger surfaces.

The cumulative character of these processes is clear to any observer of old-field erosion during a storm. When the rain begins to fall the drops patter on the surface, breaking into spray at first absorbed by the air-dry earth; as the surface moistens the spray gathers in a film surrounding and softening the external grains, and the continued patter disintegrates the softer particles and quickly converts the watery film into thin slime. Now, if the surface is level or rough the slime lies stationary until the water soaks into the soil and the ground below; but if it is inclined and smooth the slime slips slowly down the slope, soon gathering in rivulets gaining swiftness as they run. Here the action changes according to the aridity or humidity of air and earth; in the arid region the water is absorbed or evaporated more rapidly than it gathers sediment, so that the rivulets are quickly dammed by their own débris and the flow is rediffused into a sheet-flood of slime,[a] while in humid lands the absorption and evaporation are so much less that the rivulets enlarge and gather larger granules to grind against the bottom and sides and cut rills of rapidly increasing width and depth. Then rill joins rill and the swifter flow and scour quickly cut gullies, and within a few minutes after the beginning of a brisk rain the surface may be flooded by a muddy slime gathering in gullies and carrying literal tons of soil matter for each acre of ground. The flow in slime film and rill and gulley varies geometrically with the slope; when the slope is doubled the rate of flow is more than quadrupled, while the amount of soil matter carried, itself increasing geometrically with the velocity, may

[a] The sheet-floods of arid regions and their work are discussed in "Sheet-flood Erosion," Bulletin of the Geological Society of America, vol. 8, 1897, pp. 87–112. The destructive erosion of humid regions is described in "The Lafayette Formation," Twelfth Annual Report of the U. S. Geological Survey, 1891, pp. 373–374.

be more than octupled. Where gullies meet on increasing slopes, falls are formed and the floods descend inches, or feet, or even yards in roaring, foaming, churning cataracts; each cataract scours a pool at its bottom, in which the whirling waters sap the sides and undermine the rim, eating their way upstream and generally increasing the height of the fall; here the waste is worse than on uniform slopes, for each fall marks a locus of retrogressive erosion[a] where the energy of the flood is concentrated, while the lateral sapping initiates sloughing of the banks, and great masses of the soil and subsoil slide into the channels. So the waste, which may be trifling on level land, may on a steep hillside become enormous—a single storm may sweep away the entire soil accumulated through decades or even centuries of organic interaction, and then dig deep ruts and channels far into the earth beneath.

Largely because of the geometrically increasing efficiency of the water with slope, partly because of nature's device of protecting the surface with root-bound sward, the worst havoc is wrought where gullies and falls last from one storm to the next as ways for progressive devastation. The careful observer, standing on an old-field slope already denuded of soil and rent by gullies, and watching the work of a single heavy rain, sees the storm water gather in rivulets guttering and roaring down the old channels and cataracts, sapping the banks at every bend, and so both deepening and widening the trenches and undermining any protective sward on either side, yet always pushing most rapidly upslope. Each gully forms an open line of attack, occupied by a growing body of rushing, crushing, rending, grinding, scouring, sediment-bearing water; each water body is a monster of two-score arms each ended in a hundred wriggling fingers clawing into the humus, under the bordering sward, through the softening surface, slashing the soil into bits and separating these into the sand and the soluble and solid semiorganic grains of which the soil bed consists. Finally, the débris is sorted and

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[a] Retrogressive ("rückläufige" or "retrogradern") erosion was recognized in Persia by Emil Tietze in 1877 in its geologic aspects ("Bemerkungen über die Tektonic des Albursgebirges in Persien," Jahrbuch der K. K. Geol. Reich., XXVI. Band, Wien, 1877, S. 375, et. seq.; ibid., XXXIII. Band, 1882, S. 742; and elsewhere). In this country it was recognized in its relation to the current work of streams as part of a process of varigradation under which running water tends to depart from uniform inclination ("Pleistocene History of Northeastern Iowa," Eleventh Annual Report of the U. S. Geological Survey, 1891, p. 269). The first result of this tendency is the formation of falls; the second is the retreat or retrogression of the falls upstream, with the continual sapping of the earth by the swirling waters of the pools which the falls form at their bases. The tendency appears in all streams, but is most pronounced in storm rills on steep slopes; it forms a phase of that autogenetic sculpture which gives form to the major part of the lands of the earth (ibid., p. 245).

scattered; the coarse sand is spread over the near-by bottom land and the fine sand is dropped in the stream channel, the silt is dumped in the neighboring river, and the slime and soluble salts and organic matters are swept on toward the sea, muddying and befouling the waters on the way. If willing to risk engulfment in near-by gullies, the observer may watch a single storm destroy a tenth of the soil within a radius of 50 yards from where he stands; or as the storm passes he may trace the destruction of literal acres in a rolling 80-acre old field; and he can hardly fail to see that each acre of upland devastation ruins from an eighth to a quarter of an acre of fertile bottom by the overwash of sand and silt. And where destructive erosion is once well started, each passing season sees the streams impaired hardly less than the soil; more water goes off in local freshets and less in springs and seepage, while the low waters are lost in the sand washes, and many old-time springs and smaller streams go dry; so that (even apart from any diminution in rainfall due to reduced local evaporation) every season of neglected soil erosion sees the section carried a stage nearer desert conditions. The facts are common knowledge in regions of old-field soil wash, the effects are abundantly recorded by the camera, and both processes and results are of the highest scientific and economic significance.

REMEDIES FOR SOIL EROSION.

PRINCIPLES OF TREATMENT.

When the soil is viewed as a suborganic structure exercising normal functions connected with its own circulation, it is easy to see that destructive erosion and other abnormal processes affecting the soil are analogous to the diseases affecting animals and plants, and that, like most diseases, they may be counteracted by treatment tending to retain or restore normal conditions—and, as proverbially in other disorders, an ounce of prevention is better than a pound of cure.

The practical treatment for soil erosion involves both prevention and remedy, and while the special means may vary widely with natural and artificial conditions affecting the soil the best preventive and remedial measures are much alike. In every case the key to the treatment is the same—maintenance of normal balance between slope, cover, soil, and water supply.

Of the four prime factors the slope is most considerable, largely because the movement of water on the surface varies in a geometric ratio with its declivity, and the chief modifications in treatment are those growing out of variability in slope. Next in influence on disorder and treatment comes the cover, largely because agriculture necessarily involves more or less complete transformation of the natural flora and fauna; and special cases arise to demand treatment on account of varying degrees in this transformation. The soil is usually the least variable factor and the one most susceptible of control; with it the general course of treatment begins and in most cases ends—for only over a minor part of the agricultural land of the country is it necessary to undertake special control of cover or of slope, much less of water supply, to prevent or remedy destructive erosion. Commonly the last factor requiring consideration is that of water supply, whether derived from direct rainfall or depending either on natural inflow or on irrigation; the variability in supply in the humid region is much less than the inevitable variations in slope and in cover, while the natural supply in arid regions affects erosion chiefly in connection with storms and floods. In every case the treatment has for its keynote the end toward which nature wrought during the ages of land sculpture and plant development, i. e., making each acre take care of its own rainfall.

TREATMENT OF THE SOIL.

The first requisite is to keep the soil and subsoil in such condition that its range in moisture capacity between (*a*) air dryness and (*b*) saturation is large, for when this is done the ground will absorb much water without drowning, while the abundant water modules[a] in the interstices tend to remain in contact, and hence in free movement—i. e., in normal circulation. Commonly this condition is attained when the soil is granular and open-textured or friable to a considerable depth; but it is promoted (*a*) when the particles or grains are variable in size and texture,[b] (*b*) when the inorganic particles

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[a] The natural particle of water is postulated as a module, or a group or aggregation of molecules large enough to pass readily with change of temperature through the three stages in which water exists—i. e., to form a spicule of ice, a droplet of water, or a unit of vapor, according to the rapidity and amplitude of its own molecular undulations. The water module is discussed in "Outlines of Hydrology," op. cit., pp. 206–210.

[b] It is well known that the glacial soils of northern United States are much less subject to erosion, other things equal, than the residuary soils found over the greater part of the country, and concurrently that the streams in the glaciated region are on the average much clearer than those beyond the glacial limits, despite the fact that the topography is youthful in the former case and mature in the latter. Of course, certain factors are seldom equal; rains are more largely torrential in both the more southerly and the more arid portions of the country; the effect of winter freezing (which may be viewed as nature's plowing) is greater in the northerly regions; grasses and some other forms of low cover flourish best on the glacial soils; and to these and related causes the difference in erosion of glacial and residuary soils has commonly been ascribed. Yet an important factor undoubtedly resides in the heterogeneity of the glacial soils: the particles composing them range in dimensions from finest rock flour (below 0.005 mm. in diameter, and hence classed as clay in the mechanical analyses) up to pebbles and cobbles or bowlders, while the materials are no less variable than the dimensions. This heterogeneity on the whole diminishes the interstitial space occupied by the contained water, but serves to promote

are intermixed with organic particles, (*c*) when the humus or organic particles are abundant, (*d*) when the chemical state of the soil-fluid tends to facilitate flocculation of particles, and (*e*) when other less important relations are favorable. In nature the condition is brought about spontaneously through the interaction of organic and inorganic forces; in advanced agriculture it may be brought about and maintained by various devices, notably the following:

(1) *Deep tillage.*—Inorganic particles lying in contact tend to cohere and finally to unite, in a way resembling the spontaneous induration of rocks, whenever the interstices and so the capacity for soil-fluid are reduced. In nature this is counteracted by the action of humus, by the impenetration of roots, and also by the heave of freezing, and other factors; in agriculture it is best counteracted by plowing and other forms of tillage which mechanically separate the particles and throw them into new and less compact arrangements. Thus, when a well-tilled field is properly plowed to a depth of, say, 6 inches, the average surface is raised an inch or more—which means that the interstices among the particles average 15 per cent to 20 per cent larger or more numerous than before the plowing. In addition, the overturning of the surface carries the stubble, litter, mulch, and any other organic matter down to decompose and form a richer topsoil, the organic particles themselves adding materially to the moisture capacity.

(2) *Mulching.*—Organic substances are commonly porous and capable of carrying considerable water; and, especially when protected from sun and air and so kept moist, they undergo fermentative and other changes liberating gases or solutions which react on contiguous mineral substances. In nature the surface is littered with leaves, twigs, bark, and other waste which holds storm water for a time and then sends it into the soil charged with organic and inorganic substance in solution, while the root systems are generally larger than those of crop plants and on their decay leave their abundant substance in the soil; in agriculture corresponding benefits may result from surface litter, whether accumulated naturally or applied

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both absorption and circulation; at the same time it seems to facilitate the impenetration of roots and the charging of the earth with organic matter. When glacial soil is exposed to an eroding rill the work of the water is constantly impeded by particles, too large or too dense for suspension or saltation, which obstruct the flow and occasion grounding of a part of the finer load; and the finer material thus tends to line the bottom and sides of the rivulet and in turn protect the coarser and intermediate particles. The residuary soils, on the other hand, are more homogeneous not only in texture, but especially in the size and material of the constituent particles; and a rill once formed finds little obstruction to the successive removal of particles corresponding with those adjusted to the slope on which the flow begins, for as the rill grows in volume it increases in velocity, and hence in capacity for both carrying and corrading.

purposely—for although the quantity is generally less, its efficiency is increased through the better admixture secured by tillage.

(3) *Fertilizing.*—The physical effects of manures and other fertilizing materials simulate those of organic mulch and humus; their solid particles mix with those of the soil, increasing that heterogeneity which in turn augments the capacity for moisture, while certain soluble materials yield solutions promoting flocculation or granulation, and thereby again increasing moisture capacity and aiding circulation. The effects of fertilizers are by no means uniform—indeed as shown by Professor Whitney they are so uncertain as to elude prediction.[a] In some cases the application induces changes narrowing the range between (*a*) the drought limit and (*b*) saturation, so that the soil is more prone to drown or bake after fertilizing than before; when obviously the effect is injurious in so far as the mechanical conditions of soil circulation are concerned, and so of diminished benefit at the best.

(4) *Seasonable plowing.*—Although the condition varies with climate and other circumstances, it is quite frequently preferable to leave the cropped surface undisturbed throughout the ensuing autumn and winter. This is especially true of the middle latitudes, in which the ground alternately freezes and thaws and in which snow falls usually or occasionally, yet does not commonly lie long. Generally evaporation is less from the cropped surface than from plowed land, partly because the stubble and litter form more or less of protective mulch so that a larger share of the soil-fluid is retained. This retained moisture in turn facilitates freezing (for it is not the solid part of the soil but only the fluid part filling the interstices that congeals) with the consequent expansion of the soil, which tends to remain open-textured after thawing; and there is generally less evaporation of the ice itself from under the litter and stubble than from the surface exposed by plowing. When snow falls the difference is still greater; usually the stubble impedes the movement of the wind so that the snow lies deeper, softer, and more uniform over the cropped field than over the plowed land, while the bleached surfaces of the stubble and mulch and weathered ground neither absorb nor dissipate heat so vigorously as the black soil newly turned up by the plow, so that on the average the snow lies longer on the unplowed surface than on the plowed land. Now, snow is highly beneficial to soil. The farmer who declares that a foot of snow is better for his field than a heavy top-dressing is not without reason, for not only is a foot of snow equivalent to fully an acre-inch of

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[a] Fertilizers for Cotton Soils, Bureau of Soils Bulletin 62, 1909, especially tables on p. 10, showing certain cases of decrease in production following applications of fertilizer. Similar relations are still more strikingly shown for other crops in bulletins of the same series.

water (or over a ton to the acre), but it equalizes temperature in the ground beneath, facilitates the few freezings which open the texture rather than the manifold freezings and thawings which break up the granules, and in the normal thaw produced by warm wind and sunshine it softens the soil beneath in advance of the melting so that most or all of the snow water is absorbed. The result of, say, 18 inches of frost in the ground, protected and finally removed by a foot of snow, is to raise the average level of the surface fully an inch (as may be measured on a deeply planted post or partly buried bowlder) and not only add over 10 per cent to the interstices in the soil, but leave this space filled with water ready for circulation immediately on the sprouting of seeds and springing of plants; if not equivalent to given tons of certain fertilizer, it is at least partly equivalent to a deep and thorough plowing; and the subsequent actual plowing is not only rendered easier by the softness of the ground, but may be shallower than would otherwise be needful. In regions of winter rains it may sometimes be preferable to sacrifice the water of excessive evaporation from the newly plowed field in order to save loss through erosion; but generally the crop litter can be made to serve the same end with less waste. In other cases the growing of winter wheat or other fall-sown crops may require fall plowing; but even in this case the subsequent harrowing (with rolling, if used) produces more or less dust mulch and so leaves the surface in much better condition for resisting excessive evaporation and snow melting than that of freshly plowed land. In any event, the advantages of spring plowing should be reckoned thoughtfully, for not only does it conform to the natural order of things which led to the development of land forms and soils and floras (in which the winter frost is as nature's tillage), but it affords what is in some cases the most effective means of counteracting the destructive erosion of hilly fields through vernal thaws accompanied by spring rains.

(5) *Draining.*—Paradoxically, the circulation of the soil-fluid is diminished by excessive wetness of the soil; and this abnormality can best be counteracted by drainage, preferably by tile drains laid at considerable depth beneath the surface. When soil is saturated several consequences follow: In the first place, the water ceases to circulate except as the evaporation at the surface is balanced by capillarity immediately beneath; again, the reactions of humus are modified and the normal activity of the functioning proper to the soil is thereby retarded; likewise, the air necessary for the functioning of the root tips and for the complete soil-plant circulation is excluded, and the impenetration of roots is obstructed; at the same time slow fermentation is often engendered, and acids are generated and (in the absence of circulation) retained in such quantity as often to sour the

soil; furthermore, the granules deflocculate until the suborganic mass settles like leavenless dough, becoming no less sodden than sour, and under its own weight tends to indurate after the manner of inorganic materials—so that finally on drying it bakes, and when turned up by the plow forms intractable clods wholly unsuitable for soil circulation and for the plant growth dependent thereon. Now, the absorptive capacity of baked soil, whether in mass or in clods, will not suffice for the taking up of an ordinary rain; while some of the water is sucked in through the hygroscopic surface, the interstices are too small and irregular for capillarity, so that most of it is shed as from so much solid rock to flow off in corrading rills quickly growing into gullies. Commonly the condition of such soil can be alleviated by the application of chemical fertilizers, such as slack-lime or limestone powder on superacid tracts, which tend to induce reflocculation toward the normal granular condition; but the only permanent remedy lies in systematic drainage—preferably underdrainage. After a drain is so laid as to carry off the excess of water from beneath, aeration and flocculation occur spontaneously and gradually extend laterally on either side of the drain, sometimes actually raising ridges 1 to 3 inches high which steadily widen until they merge with those of neighboring drains—the uplift measuring the increased porosity of the soil, including, of course, its capacity for absorbing rain and maintaining normal circulation.

(6) *Dust mulching.*—As commonly practiced, dust mulching (the essential feature of "dry farming") is designed to produce a superficial layer of finely divided soil matter so loose in texture as to intercept capillary movement and hence prevent evaporation of moisture from the damper soil beneath the surface; and in fact the method is most effective in districts of natural subirrigation, such as considerable parts of the Great Plains and certain valleys and piedmont slopes farther westward. Yet it should be noted that the dust layer may under favorable conditions extract aqueous vapor from the air and distill it into the cooler earth below, and thus render it available for soil-plant circulation; the process being analogous to that of dew formation, though the product may be imperceptibly small. In subhumid or arid regions and at seasons suitable for vegetal growth, the strongest hold on the water appears to be that of the plant, the next that of the soil, and the weakest that of the air; so that in time of drought (with a moderate quantity of aqueous vapor present in the atmosphere) growing plants are actually able to extract water from soil nearly or quite air-dry, while the dry soil with its hygroscopic dust skin absorbs water from the air until its aqueous content is considerably the greater. It can hardly be doubted that this ability of finely divided soil to seize and hold water from the adjacent air and convey it to plants is the chief physical foundation for that dust

mulching pursued empirically for centuries in Arabia and Egypt and applied scientifically of late in "dry farming" in this country; though it is equally indubitable that the decomposition of any organic matter containing cellulose and starch intermixed with the soil must yield some carbon dioxid and water, the former available for absorption by the plants and the latter for use in the soil-plant circulation (much as seems to occur within the tissues of cactus and other desert growths during prolonged droughts). Now, in well-balanced dust mulching, the fine surface layer overspreads the friable soil through which the rootlets ramify, both for mechanical support and for material sustenance; the moisture of this soil, whencesoever derived, is conserved by the noncapillary dust; normal circulation proceeds through capillarity in the soil and through the capillarity and osmosis extending from root tips to plant tops, and is kept up largely by evaporation from the stomata of leaves and other structures of the growing plants;[a] while in case of rain at any season the

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[a] Soil-plant circulation can hardly be elucidated save in the light of a virtual autonomy (or self-activity) of water, well exemplifying that fundamental attribute of matter described by Spencer as the "instability of the homogeneous;" for although so common H_2O is one of the least-understood substances within the purview of ordinary experience, and its properties (while partly known empirically) are seldom defined systematically or in such wise as to throw light on the circulatory mechanism. Pending fuller synthesis, it will suffice to note two properties of water which seem measurably reciprocal, and in their interaction apparently control the aqueous circulation, not only through soil and plants, but generally throughout those portions of the planet known technically as atmosphere and hydrosphere and lithosphere. These properties may be denoted (1) *latency* and (2) *diffusivity.* (1) By far the greater part of the water of the earth exists in that liquid state which constitutes the hydrosphere, and which may be deemed its normal or optimum form, not only because it is the predominant one, but because it is that in which its several characteristics (including the "instability" of liquidity) are most typically displayed. Viewed in the large aspect, liquid water vigorously resists change into the other forms except in automatically limited quantity; technically, it possesses high specific and latent heat which tend to maintain that form; practically, it will not solidify without giving up "latent heat of water" in sufficient amount to lower a corresponding volume 143°, which thermal equivalent in nature tends to raise the temperature of contiguous air, and water, and earth, and thereby limit the freezing; nor will it gasify without taking up "latent heat of steam" sufficient to raise a like volume 967°, and this thermal equivalent is in nature taken from adjacent air, or water, or earth, in a manner tending to lower their temperature and thereby reduce or limit the vaporization; furthermore, while neither the ice nor the vapor will resume the liquid form until after taking in or giving out the corresponding thermal equivalents, in nature the ice tends to move toward lower altitudes and latitudes in which warmth abounds to replace that lost in solidifying, and the aqueous vapor normally moves toward altitudes or latitudes in which coolth prevails and is ameliorated by its condensation—whereby the terrestrial water continually equilibrates the temperature of the earth and maintains it mainly within the temperature range of its own normal, or optimum, or at least predominating,

thin dust layer is quickly saturated, and the spongy soil below absorbs the excess of water and forestalls that surface run-off to which erosion is due.

The several devices for controlling erosion through treatment of the soil may be held to stand for nothing more than those of good farming. They are, indeed, nothing more; but this is only another way of saying that under ordinary conditions of cover, slope, and water supply, good farming may be depended on absolutely to prevent destructive soil erosion. Even where the slopes are high, the cover inadequate, and the rain liable to come in devastating storms, good farming palliates where it fails to prevent the evil; and whether used as palliative or preventive, the special merit of good farming lies in this, that under all ordinary economic conditions the remedy is not only effective, but pays more than it costs in the way of progressively increasing returns for progressively decreasing expenditure. All the devices tend toward that intensive agriculture which

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form. In the minute aspect (such as that revealed in soil-fluid) the force often described as molecular attraction, and in some phases known as surface tension and the spheroidal condition, restrains disruption of small water bodies; while the substance is so far inert chemically as to remain stable (in the liquid form) in strikingly pertinacious manner and degree. However interpreted, the tendencies of water revealed in both the large and minor aspects to persist in or return to the liquid state are most conveniently generalized as a sort of inertia or molecular harmony; and in all its aspects these tendencies take a leading rôle in conserving and distributing over the globe the heat received originally from the sun. (2) Conversely, H_2O diffuses vigorously with atmospheric and other gases, passing into vapor from both solid and liquid states, and absorbing heat with extraordinary avidity in so doing, until a thermal balance is approached; it also passes no less vigorously in the liquid form over the surfaces and about the constituent particles of various substances in ways commonly described as hygroscopicity of these substances, and in some cases this diffusion develops (or is attended by) enormous stresses in film pressure, etc.; and it similarly diffuses vigorously through and even penetrates certain organic structures—as in the capillarity and osmosis involved in plant circulation—in such wise as at least to contribute materially to the vital action of the organisms. Thereby H_2O tends in so extraordinary degree to diffuse its own substance that in a state of nature it impenetrates virtually all other terrestrial substances and affects their properties in a manner on the whole supplementing its direct agency as a conservor and distributor of the energy of insolation—the details being far too many for present mention. So effective are the combined properties of latency and diffusivity in the reciprocal relations manifested by water in contact with earth and air and organisms that they serve to render the surface of the land (with its infinitely complicated extensions into the soil below and the vital forms above) the theater of perhaps the most intense continuous energizing on the planet—energizing due initially to the power derived from the sun yet rendered operative essentially through the inherent properties of water. Seen in detail, whether in nature or art, every phenomenon and each tendency is automatic, or a phase in a process passing from antecedent cause to consequent effect; while viewed in general the phenomena and tendencies and processes seem to fall into a perfect autonomy in which the innumerable sequences in every country grows more and more necessary with increasing density of population, and which is the sole ultimate hope of every agricultural land.

TREATMENT OF COVER.

The chief functions of the natural or artificial cover are (1) *protection of the soil*, (*a*) by shielding it from direct rain beat, (*b*) by dissipating heavy rains into mists and trickles soaking easily into the surface, (*c*) by accumulating débris to form mulch, and (*d*) by shading and sheltering the surface from sun and wind and so reducing evaporation except from the cover itself; (2) *promotion of soil-plant circulation* by (*a*) catching and retaining rain and snow water, (*b*) retarding or preventing surface run-off, (*c*) keeping the soil moist and open, and (*d*) allowing the root tips to ramify near the surface; and (3) *enrichment of the soil* by (*a*) amassing mulch, (*b*) facilitating impenetration and spread of rootlets, (*c*) decomposing inorganic substance by the liberation of carbonic acid in growth and decay, and (*d*) conserving humus and other organic matters.

These functions are exercised in somewhat different ways and degrees by different types of cover. In nature the leading types are those of forest, prairie, and desert; or, described in detail, close forest, open forest, shrubbery, grass, and scrub (the last including tufted and scattered grasses, cactus, mesquite, sage, greasewood, creosote, rabbit brush, bunched chapparal, and other partial cover in the subhumid and semiarid regions). With that agricultural transformation which opens the way for soil erosion, the types of cover may be described as those of (*a*) close forest, (*b*) open forest generally available as range, (*c*) pasture or meadow grass, (*d*) field crop, and (*e*) scrub sometimes available as range. The types are fixed primarily by water supply and secondarily by character of soil, and are affected incidentally or materially by slope, temperature, and

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of cause and effect are unified in the primary disposition of H_2O to persist chiefly in the liquid state, and to pass into other forms only in sufficient measure to maintain that normal or optimum. In more humid sections these inherent properties of water may seem of little immediate consequence; but in subhumid and semiarid districts, where air and soil and organisms seem joined in ceaseless strife for water, the primary strife is that of the water itself for its own normal state on which even the plants are dependent—and any human effort to regulate the soil-plant circulation must be adjusted to this condition, just as the structures and functions of desert plants have been during the ages adapted by nature to the same condition. (The natural adaptations of desert floras and faunas and human populations to their environment, which have exercised a controlling influence on the development of civilization, are discussed somewhat fully in "The Beginning of Agriculture," American Anthropologist, vol. 8, pp. 350–375, and "The Beginning of Zooculture," Ibid., vol. 10, pp. 215–230—both recently reprinted by Prof. William I. Thomas under the title, "Influence of a Desert Environment," in his "Source Book for Social Origins," pp. 55–73.)

minor factors; within limits they are subject to artificial control through selection of plants and other means.

Now, cover can best be used to palliate or prevent soil erosion by making it conform to the natural functions of protecting the surface, promoting the soil-plant circulation, and enriching the soil, which functions are normal to all plant growth in greater or less degree, and in themselves express the fundamental laws of life on the land. Yet since crops are selected and cultivation is pursued primarily for production and only incidentally to prevent erosion and other waste, it is commonly necessary to sacrifice part of the natural functions and to modify others so that the whole will be redirected toward the end of human welfare rather than that of natural balance. The means are many and are increasing with every advance in agriculture. Some of them are as follows:

(1) *Tree planting.*—When gullying once begins (especially in rolling lands formerly wooded and hence too steep for stability in field or pasture) the erosion tends to increase cumulatively and devastatingly; but usually it can be checked by planting locust or other hardy trees or shrubs adapted to the soil and climate. If the destruction is advanced and storms are frequent, it may be necessary to start the planting above dams of logs or brushwood or stakes, perhaps reenforced with straw or other litter affording a temporary mulch. With ample humus, an occasional patch or thicket may serve to protect the field; but where the topsoil is thin or poor and rests on intractable subsoil it may be necessary to extend the planting throughout the length of the gully and well into the undisturbed soil on either side. So, too, if the case is a light one (that is, if the gullying is slight), the treatment may be temporary only, and after a few years the shrubbery or timber may be cleared away and the new soil accumulated and held by the roots may be put under cultivation and kept available for permanent cropping; but if the case is grave it may be necessary to replace the forest cover and preserve it permanently—of course, taking out the mature timber for fencing or fuel. Trees and shrubbery planted in gullies tend to form belts on lines along which the drainage runs naturally or may be turned; they are less serviceable in controlling surface run-off than belts of trees or shrubbery extending across the natural lines of drainage, since such transverse belts tend to catch the storm flow and convert it into seepage and ground water. So, when the nature of the soil and the methods of cultivation are unfit and the fields reveal premonitory symptoms of erosion (i. e., if the humus disappears and the topsoil turns yellow or red, if the soil hardens and grows intractable, or if the yield runs light on knolls), it is best to adopt vigorous preventive measures by setting timber belts transverse to the drainage lines before the gullying begins. When the larger ravines are occupied

by spring-fed or seepage streams during most or all of the year these should be preserved, partly as source waters of rivers and partly as safeguards against destructive floods in case of exceptional storms; in nature streams are commonly protected by bordering shrubbery or timber belts; and in thorough agriculture they may be maintained and improved by continuing and extending the border growth, which serves to strain the sediment from such surplus waters as may escape the fields, and thereby maintain the clarity and diminish the erosive power of the stream water, while the cream of the soil carried by the surface run-off is at least saved to the farm (albeit lost to the field); while the water-side woods may be made no less profitable than the cleared acres through crops of grapes, nuts, small fruits, and berries, in addition to timber for domestic use.

The cases in which tree planting is indicated are endlessly variable and too numerous for listing; and they are constantly increasing, not only with extension of agriculture into previously unbroken tracts, but with that growth of intensive methods which best marks agricultural advancement. The method is indeed nothing more than the artificial application of nature's process, for under natural conditions (wherever soil and climate are favorable to tree growth) the gullies and scarps breaking the surface are soon invaded by pines, locusts, old-field plums, or other trees, tending to shelter the surface, hold the soil with their roots, and form mulch with their waste. In any event, the sufficiency of the treatment is shown by the results; if narrow timber belts either along or across the gullies and along the streams serve to stay the surface run-off and prevent scouring the remedy suffices; if they fail at first (other devices being inapplicable) the belts should be widened until they work well, even if it be necessary to plant the entire surface—a necessity only proving that the land is unsuitable for farming and fit only for forest.

(2) *Grassing.*—Over gently rolling plains, whether prairie or woodland originally, erosion is commonly preventable by proper treatment of the soil itself; yet, since cultivated soil is less resistant than sward, scouring may begin either in gullies or over broader surfaces and, proceeding cumulatively by retrogressive erosion, may require vigorous remedial treatment. While severe cases may demand tree planting, the seeding of the scoured surface with grass commonly suffices. If the topsoil is already gone before treatment begins, it may be necessary to scatter litter or apply top-dressing to form mulch in which the seed may sprout, or if the land is valuable it may be sodded. Especially in the subhumid and semiarid regions the natural sward is frequently broken in consequence of overclose pasturage, particularly by sheep, partly because the animals like to stand level and walk on contours and thus wear paths into the subsoil; such cases are best treated (when the value of the land suffices)

by regrassing and withdrawing the stock until the sward is restored. The grass to be selected varies with climate, character of the soil, and other factors. In southeastern United States Bermuda grass and Johnson grass are especially effective by reason of that length and strength of root which render them objectionable in some situations. In general the preferable grass is some introduced variety found specially applicable; for, under the natural tendency underlying such plant invasions as those of the English daisy and Japan clover, well-adapted alien forms flourish greatly and perform their office quickly in the new environment.

Whether in scattered spots or strips or over entire meads the grassing designed to control the water and save the soil should be done with a view to early returns in hay or pasturage; generally it should form part of a system of crop distribution and rotation adapted to the locality; and frequently the grass first sown may be replaced later by more profitable varieties. As with timber, so with grass, the suitability of the treatment is shown by its success. Some tracts are quite stable under sward, but not at all under plowing, and these should be grassed permanently and made profitable to their capacity through forage or grazing, while certain bottom lands adjacent to streams, either timber-bordered or not, are best kept in meadow to catch excessive wash from neighboring hills, prevent river pollution, and store in soil and subsoil the source waters for steady seepage into the permanent waterways; for in well-balanced farming the general benefit to the water supply of the country is equaled or exceeded by the special benefit of keeping the soil on the farm, coupled with the current profit of ample yield in a crop so richly responsive to moisture and fertility as hay.

(3) *Nurse cropping.*—While nurse crops are commonly sown primarily to shield seeds and shoots from destructive alternations in moisture, from withering winds, and perhaps from frost, they at the same time protect the soil, and frequently they perform their chief function in maintaining that normal soil-plant circulation required both for the greatest soil efficiency and for the largest content of soil-fluid—the precise conditions which, other things equal, most directly counteract soil erosion. So the device is commendable in general, and is especially worthy of testing whenever slopes are steep enough to permit free run-off.

(4) *Cover cropping.*—The effect of grassing in orchards or vineyards, as in meadow or pasture, is to form a sward serving to hold the soil against storm wash, and at the same time to produce mulch and humus and maintain normal soil-plant circulation; and the same thing is true of grasses or legumes planted partly to protect the soil from desiccation during the period of growth, though designed also to make mulch when plowed under. Grain or cultivated growths in

orchards, intended either to keep down weeds or to form by-crops, aid in maintaining the normal condition of the soil, thereby increasing its absorbtive capacity and checking run-off, with consequent erosion; accordingly they may serve a useful purpose both directly and indirectly. In special cases Bermuda grass and Johnson grass or other growths in corn and cotton fields serve a useful purpose in holding the soil on unstable slopes during the late summer and ensuing winter, and so may be worthy of encouragement despite their weed-like character and their obstruction of plow and cultivator, especially when they afford grazing for sheep or swine in the non-growing season. Cover cropping and nurse cropping alike imply both soil-fluid and plant food in such abundance that the supply may be divided without material loss to the main crop, a condition existing only where the water supply is abundant; otherwise the useful production may be so far reduced as to counterbalance the benefit of diminished erosion. Especially in the subhumid and semiarid regions dust mulching should be considered an alternative and generally preferable device.

(5) *Eradication of weeds.*—The weed is the sign and symbol of slack farming, and still more of failure in that complete command over the materials and forces of nature forming the aim and the end of human effort—it reveals not only imperfect work, but imperfect thought. Typically, the weed is useless, in that it contributes nothing to human welfare; it is injurious, in that it consumes water and plant food which would otherwise enrich useful plants; it is noxious, in that it chokes the innocently good by means of its own gross luxuriance and by means of the toxic substances left in the soil; and it is malignant, in that through unwitting human help it has acquired a better constitution, giving greater pertinacity and stronger persistence than that possessed by the ordinary plant. So wild artichoke and ambrosia not merely overshadow the corn but rob it of sustenance, foxtail steals plant food from the wheat, and in the subhumid region the wild sunflower draws the scant ground water away from the oats and the barley, leaving them to wither in half-headed weakness, while the futile farming that permits only the toughest weeds to survive and yield seeds for a still hardier generation renders the tale of each year worse than the last. True, weeds, like useful plants, maintain soil-plant circulation and contribute humus, so that they tend to preserve the natural balance between soil and land form, albeit no more effectively than the useful plants they displace; yet their presence almost invariably marks a lapse from those standards of thorough and thrifty treatment which best counteract erosion. In general the gravest single cause of soil devastation has lain in the abandonment of fields to weeds, either indolently or in the vague expectation that shrubbery and forest would follow in natural course;

for while the old fields do reset slowly with pine and hardwoods, the gullying during the period of growth often removes from entire acres the humus accumulated during centuries. As a device for counteracting erosion, weeds are in every case—whether on the old field, over the producing acres, or in the orchard—unsatisfactory and unprofitable, if not a delusion and a snare. And whatever other device be adopted, it should end, if it does not begin, with the eradication of weeds—indeed with the elimination of everything not contributory to human welfare and subject to artificial control.

(6) *Rotation of crops.*—Shaped during the ages under a natural cover of forest and sward, most of the soil of the country is more or less unstable after removal of this cover; and in retrogressive erosion the scouring initiated by any storm tends to increase cumulatively with each recurring storm from season to season and from decade to decade until the entire surface is reconstructed in harmony with the reduced cover of the farm—indeed the conspicuous feature of any eroded landscape is the flattening of the slope. While any season's injury may be unavoidable, the cumulative tendency may often be stopped merely by changing the crop—e. g., if scouring begins while the field is in corn, its course may be interrupted by sowing small grain next season, and would almost certainly be checked by seeding to clover or alfalfa. Although in a broad way each field has its own coefficient or measure of erosivity (depending on soil type, texture and depth of the humus, capacity for soil-fluid, and slope of surface), the coefficient varies with crops, each of which reacts on the soil in its own way not only as cover but in effect on circulation, and this for its own special part of the year. So in land subject to erosion, crop rotation may have an office additional to those commonly recognized in the way of counteracting the exhaustion of plant foods and the intensification of growth toxics; and with progress toward intensive cultivation the full uses of rotation should be combined and worked out in a complete system adapted to each locality.

The devices for palliating or preventing erosion through control of cover are akin to those operating through treatment of soil in that they are merely those of good farming. They will not always suffice in themselves, but they will always be found compatible with other sound remedial measures; and at the same time they have the merit of paying as they go.

TREATMENT OF SLOPES.

Throughout inorganic nature the slope of the land is the passive resultant of forces operative during the ages; but in organic nature the slope enters into active relation with the suborganic soil and organic cover, and exercises a normal function—which is that of removing the excess of rainfall. Now the quantity constituting "excess" varies widely with the efficiency of the cover and the capacity of the soil, together with the susceptibility of the subsoil and underlying rocks to seepage; and accordingly the normal slopes of the land before settlement are variable within wide limits, ranging from imperceptible inclinations to grades approaching 100 per cent or 45° (i. e., having a rise of 100 feet in each 100 feet in distance). In general the slopes of prairie land seldom exceed a 10 per cent grade (or 10 units of rise for 100 of distance), though they average a little too steep for stability under the plow, and hence are subject to destructive erosion unless protected by appropriate treatment of the soil and cover; actual reconstruction of the slopes being seldom required save where the soil is exceptionally sandy or the subsoil exceptionally insusceptible to seepage. Woodland slopes, on the other hand, run much steeper, frequently reaching grades of 20 to 25 per cent; and although some bottom lands are wooded the greater part of the woodlands of the country are rolling. This country includes probably 500,000 or more square miles of originally wooded arable land, otherwise available for agriculture, in which the natural slopes are too steep for stability under the plow. Throughout this area destructive erosion is imminent so soon as the land is cleared and broken: and while some of the land lies flat enough to be protected by treatment of soil and cover, several hundred thousand square miles of original woodland remain, together with a small part of the original prairie land, which can be protected and made permanently productive only by appropriate treatment of the slopes. While the modes of treatment required in particular cases vary with the texture and other conditions of the soil and with the character of the crops, the keynote is always the same—it is to regulate or prevent surface run-off. The chief devices are contouring (or contour cultivation) on moderate slopes and terracing on steeper slopes, both of which tend toward a gradual reconstruction of the slope into what may be considered the agricultural angle of stability; and when judiciously designed and carried out they may be made to attain this end without impairing production or involving prohibitive cost. These and related devices are as follows:

(*1*) *Contouring.*—On level ground it is convenient to plow and lay out crop rows in straight lines; and on moderately rolling land it is commonly preferable to run furrows and rows in lines straight on the ground, even though they curve considerably up and down with the undulations of the surface. On steeply rolling or hilly ground, on the other hand, labor of men and draft animals is saved by laying out the furrows and rows on level lines curving on the ground to fit the conformation of hills and draws. Such curved lines correspond with the contours, or lines of equal altitude, on a topographic map; and cultivation along such lines on the farm may be denoted contouring.

In addition to saving labor, contouring saves the soil. Straight furrows and rows running up and down the slope form ways for the surface run-off during storms which, even when not developed into gullies, aid in the wash of humus and other soil materials down the slopes and away from the fields into neighboring ravines or streams; while the ridges of contouring obstruct the surface run-off and the intervening troughs hold the storm waters for seepage into the ground, thereby preventing instead of aiding erosion. Except on slopes so steep as to compel the use of sidehill plows or other means of throwing the soil in a single direction, contouring also tends to retain the soil substantially in place on the slopes; for as the plow moves on level lines the earth is thrown up or down the slope largely at the will of the operator, while in plowing uphill or downhill in linear cultivation the greater throw of the soil is always downward.

In contouring, the first requisite is to lay off the land. With moderate slopes or with soil of such texture that the land approaches stability, a high degree of accuracy in leveling is not necessary, and the opening or "dead" furrows may be laid off by the eye; on more rolling ground or sandy soil greater accuracy in leveling is required, and the opening furrows should be located with the aid of a suitable instrument—what is of late made and known as a farm level, or an engineer's or Y level, a surveyor's transit, a theodolite, a hand level, or some improvised apparatus, perhaps utilizing a carpenter's level.[a]

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[a] During the fifties Thomas Skinker, of St. Louis, County, Mo., recognizing the need and the practicability of preserving the soil of what was afterwards by reason of its continued productivity well known as the "Skinker Farm" (the tract occupied in part during 1903–1905 by the Universal Exposition), improvised an apparatus, using a plumb line instead of a level. It comprised a simple framework of three narrow boards connected in the form of a flattened letter A, with the plumb line dropping from the apex past an index mark at the center of the horizontal board; this apparatus was either "walked" over the field (the span between the feet being about a rod) and leveled by moving the forward foot up or down the slope until the plumb line fell over the index, or used by sighting along the horizontal piece; and the curved line so laid out was marked with sufficient frequency to guide the opening furrows. In the later sixties and early seventies the late Professor Hunnicut and Mr. H. H. Parks (now of Grandfield, Okla.) began terracing their farms in Coweta County, Ga., with the help of an improvised apparatus consisting of a high trestle, modeled somewhat after a carpenter's bench, supporting a carpenter's level; after bringing the beam of the trestle to a level by moving the legs, it was used for sighting points on the ground, with the help of a rod carried by a flagman; and when sufficient points were located the opening furrow was cast through them. A serviceable device consists of a glass tube, say 30 inches long, with the ends turned up at right angles in the same line (which is easily done after softening the tube, preferably after filling with sand, by holding it in a flame for a few minutes), so as to form a greatly flattened U; this is nearly filled

The chief difficulty in the way of laying off the field on contours arises in the "lay of the land," i. e., in the endless variability of slope, which is commonly such that two or more opening furrows, each lying level, are not equidistant on the ground; so that the number of crop rows on one side of a knoll may be two or three times the number that may be accommodated on the steeper side. With moderately variable slopes the inequalities in width may be adjusted partly by varying the width between rows, partly by some sacrifice of accurate horizontality in the lines of cultivation; and on steeper slopes the methods may merge into those employed in terracing.

In every case contouring should be adjusted to both soil and cover, and also to other methods of counteracting erosion. In most soil types deep plowing is especially necessary, in order to provide a surface sponge capable of holding the water supply not merely of an ordinary rain, but (so far as may be) of exceptional storms or series of rains; for with shallow tillage over intractable subsoil the entire topsoil is liable to melt into mud and slough or slide down the slope bodily, not only impoverishing the field, but ruining adjacent lands and streams. In all types, unless conditions render it needful to move the soil upslope in tillage, it is sure to work downslope slowly; while despite any effort to the contrary the circulating soil-fluid and the wash of humus always tend to move downward, with the result of relatively impoverishing the knolls and divides, though generally at a much slower rate than with linear cultivation—which natural tendencies may be counteracted by more thorough cultivation (mulching, top-dressing, and fertilizing, no less than tilling) and more careful attention to cover at the higher levels. Commonly the devices should be directed to maintaining and increasing immediate productivity rather than maintaining the original slope; for, in the natural course of things, it is the fate of the rolling field to flatten from year to year by the progressive removal of material from upland to lowland in such manner as to develop an artificial, rather than a natural slope—the agricultural angle of stability, in lieu of that normal to the native flora and land-form.

(2) *Terracing.*—When slopes are too steep for stability of the soil under contouring, they may be reduced to practicable grades by systematic terracing. Where the land is of sufficient value to warrant the expense, as in cities and sometimes in suburbs, this can be done

with water rising mid-height of the upright portions; and when held in the hand or rested on a staff the two water surfaces are easily brought in the line of vision, when they cut points level with the eye of the user, which can then be marked to locate the opening furrows. Many other devices have been improvised, but except for emergency or merely experimental use, the farm level or hand level (obtainable from any instrument dealer) saves times and trouble.

quickly by engineering methods; but where the land is of value solely or chiefly for current agricultural production the only practicable process is one whereby nature works and man merely directs the work, i. e., one wherein the farmer or agricultural engineer does little more than lay out the terrace system in connection with customary agricultural operations, leaving the upbuilding and final shaping to the natural movement of the surface waters and soil-fluid and solid soil as they occur normally under these operations. In other words, man but starts while nature carries forward a progressive process of reconstructing the natural slopes.

Terracing differs from contouring rather in degree than in kind—the leading principles are identical; the chief difference lies in this, that in terracing the opening furrows are permanent, forming balks or breaks which gradually rise into banks separated by belts of plowland. With medium slopes the balks are best started by opening or "dead" furrows (the first laid to throw the earth upslope and the second to throw downward), subsequently seeded with some sod-forming grass, while on still steeper slopes any native sward may be left on a somewhat wider belt to be either grassed or set with shrubbery; thereafter plowing should be on contour lines, preferably with a hillside plow, throwing the earth downslope; the crop rows, too, should run on contours, when all the normal soil movements will be downslope to the balk, of which the upper part will gradually grow by accretion while its base will be lowered and its slope thereby steepened by the successive plowings and other movements of the soil below. In time the balk will become a steeply sloping bank or glacis[a] standing at the angle of stability fixed by the strength of the sward or the hold of the shrubbery. Ordinarily its height should not exceed 5 to 8 feet, and the width of the belt of plowland it sustains, which is to be estimated when the terraces are laid out, should be so adjusted to the original slopes as to take the agricultural angle of stability when the terraces assume final form. So each slope ultimately becomes a series of steps—a giant stairway in which the "risers" are steep banks of tough sward or strong shrubbery and the "treads" are flat-lying belts of fertile field. In ordinary or extensive farming and on moderate slopes the glacis should be kept in tractable grass available for forage when cut by

[a] The English language lacks terms distinguishing the horizontal and inclined elements of terraces. In geology, as in ordinary usage, the term "terrace" is generally applied specifically to the essentially horizontal element in contradistinction from the more or less nearly vertical face below, while in military nomenclature the term "glacis" (either French or, preferably, anglicized) is applied to the slope sustaining a parapet in fortifications and to the similarly sloping part of the armament of warships. It will be advantageous to adopt and apply the latter term to the terrace face, i. e., to the sloping element of the terrace.

a properly designed mower or for pasturage in the off-crop season, i. e., it should be treated as an integral part of the farm merely devoted to a special use and should not be permitted to become a nursery of weeds and brambles pushing ceaselessly into the adjacent plowland; and as in contouring the higher portions of the terraces should receive special care, with a view to keeping up current productivity. With intensive cultivation and on higher slopes requiring stronger support than that of sward, the banks may be held by perennial shrubbery, which should be made at least partly productive—perhaps by a strong hedgerow at the top, with berry bushes or vines below; for not only will the yield contribute to the yearly profits, but the cropping will direct toward the banks that continuous attention necessary to insure them against falling into neglect and gradually impoverishing the farm.

As in contouring, so in terracing, laying off the land is the critical step; and on slopes steep enough to demand this form of protection the process requires intelligence and skill—it forms, indeed, one of the most difficult lines of agricultural engineering. The plans for terracing the field or the entire farm should be worked out in advance with reference to (*a*) original slopes, (*b*) texture of soil and earth or rock beneath as bearing on the agricultural angle of stability, (*c*) nature of prospective crops and of sward or shrubbery for protecting the glacis, (*d*) nature of subsoil and depth of rock, and (*e*) relative dimensions of terrace and glacis required for stability of the entire system. Here, too, the difficulty arising in the "lay of the land" (or variability of slope) enters; it is seldom practicable to lay off a large field into belts or zones of uniform height, since they would be too variable in width; generally it is better to plan for banks of varying height protecting terrace plots of convenient form and dimensions, so that the field is separated into a combination of curved forms (annuli, crescents, lunes, etc.) with the banks running out on gentler slopes but rising high or merging with others on steeper ground. In practice the combinations of form, slope, and material are too variable for description; they are fully developed only by actual experiment, and can be pictured only through projects already carried out. The combinations are, indeed, so various and so totally unlike those produced in rectilinear agriculture that they involve distinct standards, both practical and esthetic, and distinct habits of both thought and work.

When the plans are perfected for laying off the field or farm, the lines of the prospective banks should be located with the aid of suitable apparatus. Unless detail surveys and plats are contemplated, the best instrument is a Y level mounted on a tripod or Jacob staff and used with the help of a flagman and target rod. Usually the instrument can be set up on a spur affording a view of a considerable area; after it is brought to a level the flagman sets his target at the height of the cross hairs, then moves off to a paced distance of 20 to 200 yards (according to the slope), when the level man waves him up or down the slope to a point at which the center line of the target is cut by the cross hairs, where he leaves a stake or other mark (switches or stalks easily plowed under are convenient), and then passes on to other stations at greater distances. The plowman follows, casting his opening furrow through the marks and along the same horizontal line as measured by the eye between, first throwing the earth upward and on his return throwing downward in such manner as to form a ridge. The initial line may be extended by resetting the level, and the other lines for additional banks at higher or lower levels are laid out in the same way. In ground not before broken and retaining some sward, the return furrow may well be far enough from the first to leave a belt of the original surface, when the further breaking should be by a hillside plow throwing downward, in order that the terrace may be somewhat reduced in slope at the first operation. In ground already under plow (new ground previously wooded is usually friable enough and rich enough in humus to resist erosion for at least a year or two) it may also be found preferable to leave a belt for the prospective glacis and seed it in grass or set it in shrubbery, as the steepness of the slope may require.

In the absence of a Y level, or when a horizontal survey and plat are desired, a surveyor's transit is the best instrument for laying out the lines, while an architect's level will serve admirably; though for all ordinary purposes a simple farm level will suffice—and especially if made with an attachment for determining grades, it is more convenient than any other apparatus (fig. 2[a]). The least expensive

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[a] EXPLANATION OF FIGURE 2.—Shows approved type of farm level, seen from above in outline (in upper part of drawing), and in horizontal section (in center of drawing), with attachments and adjuncts. The essential part is a metal tube carrying a perforated eyepiece at one end and a cap supporting fine metallic cross hairs at the other end, which is open and covers a considerable field of vision about the intersection of the cross hairs. The tube is mounted on an accurately turned turret, with adjusting screws by means of which its horizontal axis can be kept parallel with the planes of the upper and lower rims of the turret. Within the turret and parallel to the tube there is also mounted a metal case containing a spirit-level vial; this case, too, being adjustable by means of screws to parallelism with the planes of the turret, and so with the axis of the tube. The turret rests and rotates horizontally in an accurately turned seat in the uppermost of a pair of parallel planes, of which the lower is reduced to triangular form and provided with three leveling screws (as in modern field instruments of American make generally). The lower plate is fitted to a tripod head and supported in use by a tripod. In use the tripod with the parallel plates attached is first set and approximately leveled by the eye; then the turret with its tube is placed in its seat, and the final leveling is effected by means of the screws. A target rod is then set up in front of the

instrument of sufficient accuracy for ordinary leveling is what is known as a hand level (fig. 3 [b]), which may be used with an im-

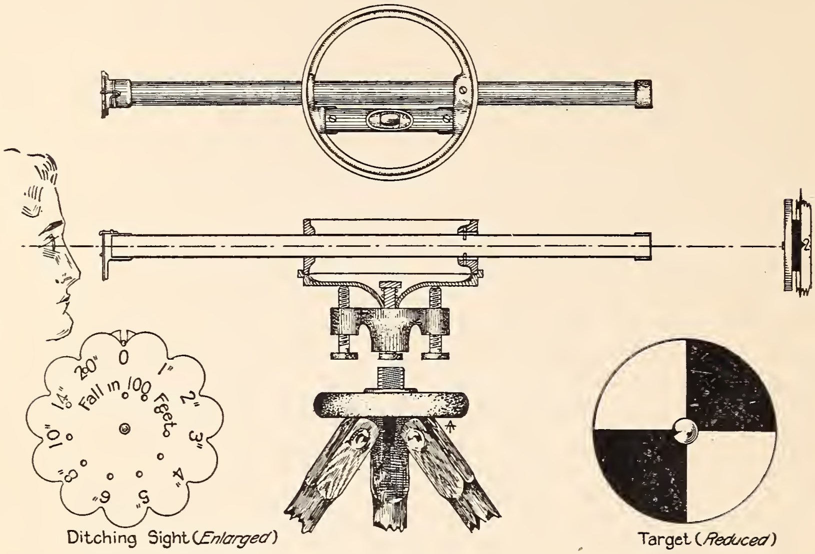

FIG. 2.—Farm level.

provised target; with careful work its error need not exceed 3 to 6 feet per mile, or a third of that on a 40-acre field—a probable error

instrument, and the target is adjusted to its height by bringing its quadrants into coincidence with the cross hairs; thereafter the target rod is carried to measured or paced distances, and shifted up or down the slopes by the signals of the levelman until the cross hairs again coincide with the quadrants, when the ground at the foot of the rod is on the same level with that beneath the instrument. With the aid of a graduated extensible target rod, the instrument may be used for measuring heights or grades, just as with an engineers' level. While in its simple form designed only for leveling, the instrument can easily be adapted to surveying with sufficient accuracy for farm purposes, and also to laying out grades—e. g., for ditches or for terrace inclines designed to carry storm waters from steeper toward gentler slopes. It may be converted into a surveying instrument merely by inscribing an index on the turret in line with the vertical axis of the tube, and graduating the rim of the upper parallel plate immediately outside of the turret seat; and it is adapted to grading by replacing the eyepiece with a patented contrivance consisting essentially of a rotating disk with perforations adjusted to varying departures from horizontality in the line of sight through the tube (in the illustrative disk in the drawing the apertures are adjusted to grades of 1, 2, 3, 4, 5, 6, 8, 10, 14, and 20 inches in each hundred feet of distance). Imperfect adjustment of either the leveling tube or the spirit vial is easily detected and corrected by inverting and reversing the turret and setting the screws in a manner similar to that employed in the engineers' level; if adapted to surveying, any error of adjustment is constant and negligible; and when adapted to grading, the error for each aperture is independent and constant and should be determined by accurate measurement and recorded as a constant correction.

[b] EXPLANATION OF FIGURE 3.—Shows longitudinal and transverse sections of an acceptable type of hand level. The essential part of the instrument is a

far less than that of the plowing, and one negligible in comparison with slopes steep enough to require terracing.

Terracing, unlike contouring, tends rather toward local reconstruction of slopes than general flattening of grades; and especially where the soil is merely a thin mantle over rock or where it is but a talus at the base of a steeper slope above, the amount of soil matter removable without impairing production is limited. In such cases

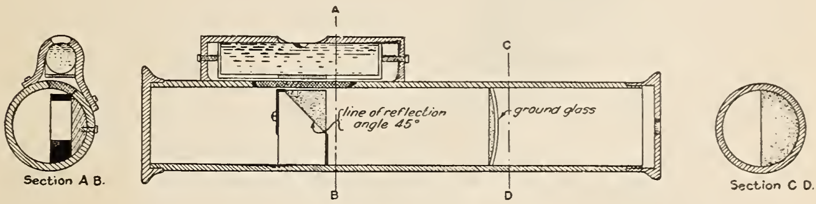

FIG. 3.—Hand level.

particularly the treatment of soil and cover should be carried forward in connection with the treatment of the slope; mulching, and in case of need fertilizing, should be used on the upper part of the terrace, and cover crops should enter freely into the scheme of rotation. In less favored countries actual soil is sometimes added, but ordinarily in the United States this can be made profitable only under special conditions of crop and market.

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metallic tube, closed at the ends with caps fitted with plain glass discs (that at the eye end small, and that at the outer end large enough to take in a considerable field of vision); to it is attached a metallic case carrying a spirit vial with a small bubble, the tube with its appendages and the level being permanently adjusted in the factory. The upper part of the tube (as placed when in use) is perforated, as is the lower part of the outer case carrying the spirit vial, and within the tube, immediately beneath the center of the vial, is an inner metallic case carrying a small mirror placed eccentrically, one edge marking the (vertically) middle line of the tube; this mirror is inclined 45° to the axis of the tube (and spirit vial), so that to the eye at the eyepiece it reflects the bubble moving apparently in a vertical direction. Midway between this inner case and the eyepiece the tube contains a ground glass semidiaphragm, so placed as to screen the mirror from the eye at the eyepiece and also cut off the left half of the field of vision (which is also cut off by the mirror); it is made lenticular to magnify somewhat the image of the bubble as seen in the mirror. A fine metallic cross hair (not shown in the drawing) is so placed in the aperture in the upper part of the tube as to be reflected from the mirror to an eye at the eyepiece in the exact horizontal axis of the tube, where it crosses the vertical axis defined by the edge of the mirror. In use the instrument is brought to the eye by the hand (perhaps steadied by a staff or other rest) and leveled tentatively; and when the horizontal cross hair cuts the center of the magnified image of the bubble, its intersection with the edge of the mirror marks a point in the field of vision on the same level with the eye of the user. In the best type of instrument the tube is made extensible by a telescope construction toward the eyepiece.

(3) *Vineyarding.*—On slopes too steep for the plow vines may be set out on level lines raised partly by mulching and partly by the natural movement of the soil as aided by hand cultivation, and whole hillsides may thus be made productive. The principles are essentially similar to those involved in terracing, while the processes may easily be extended to other crops, especially berries and small fruits.

(4) *Retain-walling.*—Where intensive cultivation prevails and proximity to market gives special value to high-grade products, the sward-protected glacis of ordinary terracing may be replaced by a retain wall of stone or brick or concrete, and this may be raised in a parapet completely protecting the soil of the terrace. The risk of failure through accident or otherwise, and also the cost attending this device, increase geometrically with the height of the wall, so that, other things equal, lower structures and narrower terraces are preferable. Retain walls should never be vertical, but should be built with a batter sufficient to counteract the cumulative effect of frost heave and of the hydrostatic head of the ground water combined, i. e., the angle of stability of the wall should be determined no less carefully than that of sward-bound glacis or plow-land soil.

(5) *Annular forestation.*—Commonly terracing, like contouring, is best adapted to slopes of only moderate length and of steepness diminishing upward, i. e., to rolling country rather than to foothill and mountainous country; for on long slopes increasing in steepness upward into foothills or mountains cloud-bursts or cataclysmic thaws are liable to form floods so great as to sweep away all ordinary protective devices with a violence only the greater for the temporary retardation of the waters. Accordingly, long slopes should be guarded more effectively than is necessary on shorter slopes of like grade; and this may best be done by transverse belts of woodland, widening as the slope steepens and narrowing as it flattens, in which even the extraordinary storm-born flood or thaw freshet will lose its force and lag amid the trunks and undergrowth until absorbed by mulch and soil. Such forest belts should, of course, be designed for production no less than for protection; for so much of the native forests have been cut that silviculture is bound to become an adjunct to farming, and wood for home use and market no less a crop than grain or meat, milk or cotton.

(6) *Grading.*—Where land is dear and labor relatively cheap (as in cities and some suburbs, or wherever the soil forms gardens rather than farms) and where capital abounds, it may be profitable to undertake complete reconstruction of the natural slopes by extensive grading operations. Such operations pertain rather to engineering than farming, and can seldom if ever be made to meet the prime requisite of the farm—that of paying their own way by increased production within a reasonable period.

While the treatment of soil and cover and slope should be carried out jointly, the last differs from the others in that, whatever the methods employed, it is essentially a process of reclamation of lands not adapted to agriculture in the original or natural condition. The treatment of soil and cover is applicable to all lands, looks to the present, and should pay for itself annually through increased yield of each ensuing crop; while the treatment of slope is applicable only where rendered necessary by unfavorable natural conditions, looks to the long future rather than the present, and can seldom be expected to do more than prevent impairment of current production, as the tax of labor is capitalized in growing value of the land—a normally increasing capital which can be made secure only by continuous and consistent carrying out of the treatment until the land is wholly reclaimed, i. e., re-formed in a manner adapted to agriculture. As a process of reclamation, the treatment of slopes by terracing or otherwise affects agricultural communities no less than individual farmers; for although an occasional farm may be so situated that it can be terraced without regard for neighbors, most farmsteads are so placed with respect to the natural slopes that the terracing of one affects those adjoining; and in any event the control or neglect of run-off on any farm in rolling country reacts on neighboring farms. Thus the interdependence of farms and farmers in broken country may approach that arising in arid regions, where entire communities take their water supply from a single source; and thereby opportunity is opened for associations of citizens and for action in the common interest by townships or counties or even States. Similarly, a way is opened for collective operations in acquiring and reclaiming lands too broken for reclamation by individual effort and capital, in a manner analogous to that in which both dry and wet lands are reclaimed by collective or state action in the common interest.

While the reclamation of rolling lands by treatment of slope is essentially investment or capitalization, the best medium is not so much money, or its equivalent in labor, as intelligence—intelligence applied in so directing natural agencies and processes that they will of themselves re-form the land. Now in all natural processes, time is a large and often controlling factor. Especially in contouring and terracing, the translocation of material must proceed slowly else the natural processes will become destructive rather than constructive. The proper rate can not be worked out in advance or expressed in equations; it is best measured in terms of current yield of crop: So long as (other things equal) the yield increases, the rate may be hastened; when it decreases, the rate is too rapid; and when it holds its own, the rate is about right.

Whether the translocation of material is destructive or constructive, it always works cumulatively; in the one case it robs the soil and in the other enriches it, at rates increasing from season to season, up to limits hardly to be foreseen, except, perhaps, in the light of object lessons in older countries ranking among the most impressive in the history of the world. The present wastes of Palestine and western China and parts of Greece and Spain where once the soils were fruitful, are due to cumulative robbing, at first so slight as to pass unnoticed, but later so swift as to defy regulation by human power. On the other hand, the wall-held vineyards rising tier on tier up the steep hill slopes of southern Europe show what regulation will do when started betimes, while the terraced rice fields of eastern China and Japan and the Philippines are not only marvels of successful agriculture (despite the crudeness of the methods), but illustrate forcibly the cumulative character of constructive processes. At first sight the terraced plantations, like the tiered vineyards, are commonly thought to be the outcome of elaborate engineering work, in which each feature was laid out with a technical skill and foresight exceeding those of modern science, though in truth the great systems are little more than products of natural growth. The primitive tiller simply adjusted himself to that which lay nearest at hand, and with little labor and less thinking leveled a tiny plot in order that his few plants (often known individually and even named like the sheep and cattle of a small herd), might have standing room safe from flood; and as he broadened the narrow terrace he naturally built up his glacis, though always with the least possible labor of hands or effort of mind, yet generally in such wise that the next storm helped rather than hindered the enlargement of his plot. Where good fortune rather than skill favored, the natural translocation diminished cumulatively and gave each tiller a wider vital margin, so that communities grew and the terracing extended; while if chance—the adverse fate so large in primitive faith—frowned, the first incipient terraces were swept away, the tiller and his family were impoverished, and the community was cut off. The power of invention had not yet arisen among human faculties when these terrace systems of the Orient began, and the people and the terraces merely grew up together; and now that the faculty of invention has grown common and the habit of reasoning from effect to cause and from cause to effect has become fixed, these terraced hillsides point the way toward a more effective reclamation of the rolling and broken lands forming a considerable part of this country.

TREATMENT OF WATER SUPPLY.

The several modes of treatment designed to remedy or prevent soil erosion are alike in principle—all operate through regulating the movement of water. The primary object is conservation of both solid and fluid parts of the soil through a balanced distribution of the water supply. The ideal distribution is attained when all the rainfall or melting snow is absorbed by the ground or its cover, leaving none to run off over the surface of field or pasture; in which case the water so absorbed is retained in the soil and subsoil until utilized largely or wholly in the making of useful crops, while any excess either remains in the deeper subsoil and rocks as ground water or through seepage feeds the permanent streams. Although this ideal distribution can commonly be brought about by proper treatment, it frequently fails on account of (*a*) inequality of supply, (*b*) catastrophic storms, (*c*) defective drainage, and (*d*) thriftless farming. In these cases the evil may be palliated rather than prevented, and by collective rather than individual action.

Inequality of supply (commonly due to variable rainfall) is a menace, especially where men fall into the besetting tendency to follow standards set below rather than above the mean; for the efficiency of flowing water (including its erosive power) increases in an extraordinarily high geometric ratio with the slope and its own volume.[a] It is for this reason that both the destructive and the constructive work of water is cumulative in so high degree, that gullying and retrogressive erosion generally proceed so rapidly when once started, that the single storm may work greater devastation than the ordinary storms of a decade or a generation, and that the quantity of sediment carried by streams is nearly always underestimated—since the load carried during an exceptional day may exceed that carried during an ordinary year. It follows that the flood from an unusually heavy rainfall or sudden thaw is liable to break over the contoured crop rows or root-bound terraces or other devices for retaining run-off—and then to sweep and gully the surface so savagely as not only to leave the land in worse condition than before the treatment began, but to bury neighboring lands and dam nearby streams. So the plans for contouring or terracing, or for otherwise holding the water on the land, should be adjusted to the extreme rainfall rather than the mean; and until the artificial reconstruction is so perfected that the heaviest rain can be kept where it falls, means should be provided for carrying off the excess with the least possible injury. To this end (and also to counteract soil-cap movement and settling) it is well to work the level crop rows and terrace banks somewhat upward on the steeper slopes, thereby giving the furrows a slight in-

[a] The *velocity* of flowing water varies in some geometric ratio with the declivity of slope; the *competence* of running water (or its ability to move particles of given size, varies as the sixth power of the velocity; the total *capacity* of streams for load varies as something like the seventh or eighth power of the declivity; while the *efficiency*, or total working power of the stream, is estimated to vary as the square of the capacity, or, say, as the eighth or ninth power of the declivity: "Outlines of Hydrology," op. cit., pp. 201–2.

clination toward the gentler slopes where any surplus water will have greater chance of absorption, while the damage in case of outbreak will be diminished. In some cases this may be done within a single field or farm; but since boundaries and line fences seldom follow the configuration of the land, it will generally be found needful to carry the surplus water from farm to farm in a manner involving cooperation between neighboring owners and coordination of their systems of contours or terraces.

In general the coordinated plans should extend from the divide or water parting to the stream in which the excess waters gather; and the aim should be gradually to fill all ravines or swales except those carrying channels into which the ground water seeps with such freedom as to form permanent streams. In certain cases, depressions may be maintained in the lower grounds to catch any surplus storm waters and store them for stock (as in the tanques of Mexican rancheros); but generally this is little more than a temporary makeshift, since the ponds soon silt up, while it is easy not only to store an equal supply but keep it from contamination in the form of ground water. The capacity of ordinary ground for water is seldom appreciated; soils readily carry 10 to 40 per cent, and subsoils will generally take up from 20 to 30 per cent of their weight in water, and the capacity of the underlying rocks is often nearly as great. Derived from the rainfall on the surface of the land, this ground water distributes itself according to the slope and the texture of the earth matter containing it; it is not limited by farm boundaries or restricted by civil lines, but is the common possession of the community or district containing it, and the primary source for wells and springs and streams, no less than an emergency supply for the soil in time of drought. Just as complete reconstruction of the surface in accordance with the interests of the community may be made to guard against excessive water supply, so may the reservoir of ground water be made to provide against the other extreme; and in both cases the interests are those of entire communities, and the usage should be regulated by community action. In law and custom, the soil belongs to an owner entitled to its full use, while the water pertains to the community, and each land owner is entitled to the usufruct rather than full use.

While cloudbursts or other catastrophic storms are commonly thought equally liable to happen anywhere, their distribution is, in fact, measurably limited to certain meteorologic districts not yet fully defined, and in general the probability of their occurrence may be inferred from any local series of weather records covering a series of years—the longer the better. In other words, catastrophic storms and also excessive droughts are merely extreme manifestations of what may be considered the normal inequalities of rainfall. In the broadest and most general terms, it may be said that all those inequalities in mainland United States tend to culminate where volumes of vapor-laden air either meet similar volumes from other sources or encounter decided obstruction to free movement in strong geographic features, so that there is a zone of liability to cloudbursts approximately parallel to the Pacific coast, another stretching northward into the Great Plains east of the Rocky Mountains where the air drifts from Pacific and Gulf meet, and a third in the southern Appalachian region, where the continental air drift is liable to meet Atlantic currents. In these regions, and wherever else the weather records indicate exceptionally wide inequalities in precipitation, the modes of controlling the water should be made especially effective, and in case of doubt as to their sufficiency the land should be left in that primal condition whereby (in two of the belts at least) nature maintained the balance between variable rainfall, soil, slope, and streams before settlers came to disturb it.

Generally throughout mainland United States, the soil can not be considered safe from erosion unless its texture, cover, and slope are such that it will absorb an inch or more of water within a few hours after the last wetting; in districts of highly unequal rainfall its capacity should be increased to three or more inches. Some cases may require provision for open ways to carry the surplus flow toward larger streams or rivers and on to the sea, but better results will generally follow such treatment of the soil throughout each district that the waters of even the catastrophic storm will be held in check and compelled to move so sluggishly as to sink into the soil and the earth below and thereby increase the reservoir of ground water. The possibility of retaining the water of even the catastrophic storm is well shown in the arid region, in which the floods tend not to gather into streams, but to spread over extensive surfaces in sheet-floods, which perhaps wreak destruction here and there, but generally soak into the ground to serve as soil-fluid for ensuing months or years and also supply the neighboring springs and valleys through steady seepage. Especially where the range in precipitation is wide the treatment designed to save the soil from erosion will also save the water; yet it will commonly involve the combined action of entire communities.

While rolling and broken lands generally rise high enough above the base-level of erosion to facilitate the distribution of the entire water supply by gravity, it sometimes happens that the ground-level of water lies too near the surface to give the seepage required both for normal soil circulation and for disposing of surplus waters. Especially where it prevails over any considerable area, this condition can be remedied only by systems of artificial drainage, more or less like those required for the reclamation of swamp and overflow lands, and thereby involving community action, extending at least to cooperation of owners and coordination of plans.

Ordinarily the chief obstacle in the way of so controlling the natural supply as to remedy or prevent soil erosion lies in the negligence of shiftless owners and the indifference of renters concerned with little beyond the season's crop; and where conditions demand broad plans for distributing the waters over considerable areas, this obstacle may become insurmountable save by community action. The first requisite is an intelligent and enlivened public sentiment; the second is proper organization under legal sanction. In several States levee districts, drainage districts, and irrigation districts have been organized and work well; and their example is worthy of consideration wherever soil erosion occurs or impends, more especially when extensive contouring or terracing is required. The guiding principle should be that recognized throughout American history: The greatest good for the greatest number—and that for the longest time. As recommended by the National Conservative Commission, "First in connection with abandoned fields, and progressively in cultivated fields, soil wash should be considered a public nuisance, and the holder of the land on which it is permitted to occur should be held liable for resulting damages to neighboring lands and streams." With growing knowledge of the relations between natural water supply and productivity of the soil, such a practice is bound to arise, and in time extend to the regulation of moving waters; for since the water is paramount to the land in producing value it can work no eventual hardship on any for each to so use his own as not to injure others. At the same time the plans for avoiding waste and making the best use of waters in each community should be adjusted to the needs of other communities and, indeed, other States; for the waters, unlike the land, are essentially mobile and transitory, and as sources of interstate rivers are subject to joint administration for commercial and other uses adjunct to those arising on the farm.

PLATES.

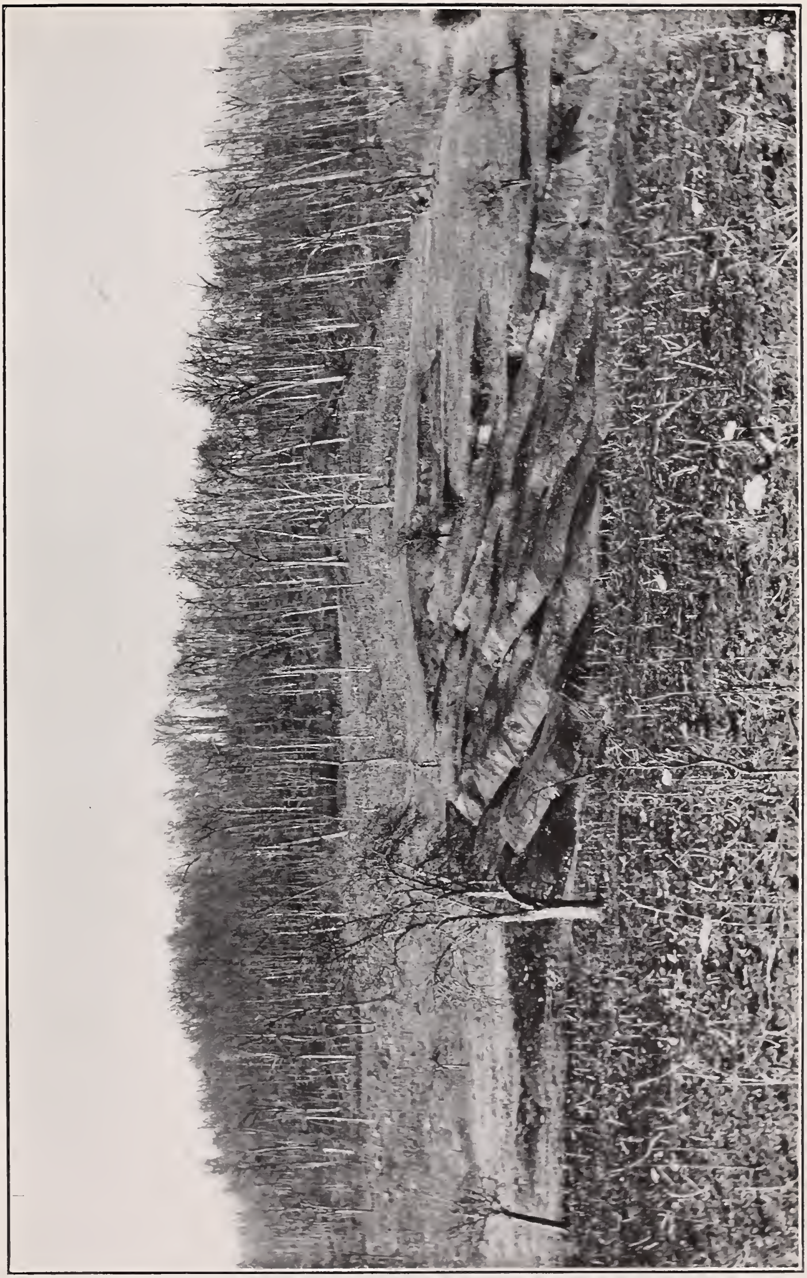
Description of Plate I.

Shows effect of removal of natural cover on moderately rolling land of sandy soil. The gentle slopes were stable under forest, although somewhat too steep for stability under sward. The sward serves to protect the surface except where broken by stock trails or roads, or by run-off concentrated in the natural lines of drainage, when gullying begins and extends rapidly under retrogressive erosion. (West of Grand Junction, Tenn.)

RELATION BETWEEN SLOPE AND COVER.

Description of Plate II.

Hilly land, partly wooded, partly cleared, and partly cultivated; illustrating the tendency toward flattening of slopes by destructive erosion attending removal of the natural forest cover. The entire surface was stable under forest, and even the steeper portions remain stable where this natural cover is retained; but over the cleared ground erosion has started on the intermediate slopes, grown into gullying, and extended somewhat into gentle slopes—the field in the foreground lying flat and thus far deriving benefit rather than injury from the adjacent waste, though it is foredoomed to destruction as the wash increases. The eroded surface soil is devoid of humus or other water-holding material, and the subsoil is baked hard, so that most of the rainfall is lost as run-off, leaving the ground too dry for productivity. (Yancy County, N. C.)



DEPENDENCE OF SLOPE ON COVER.

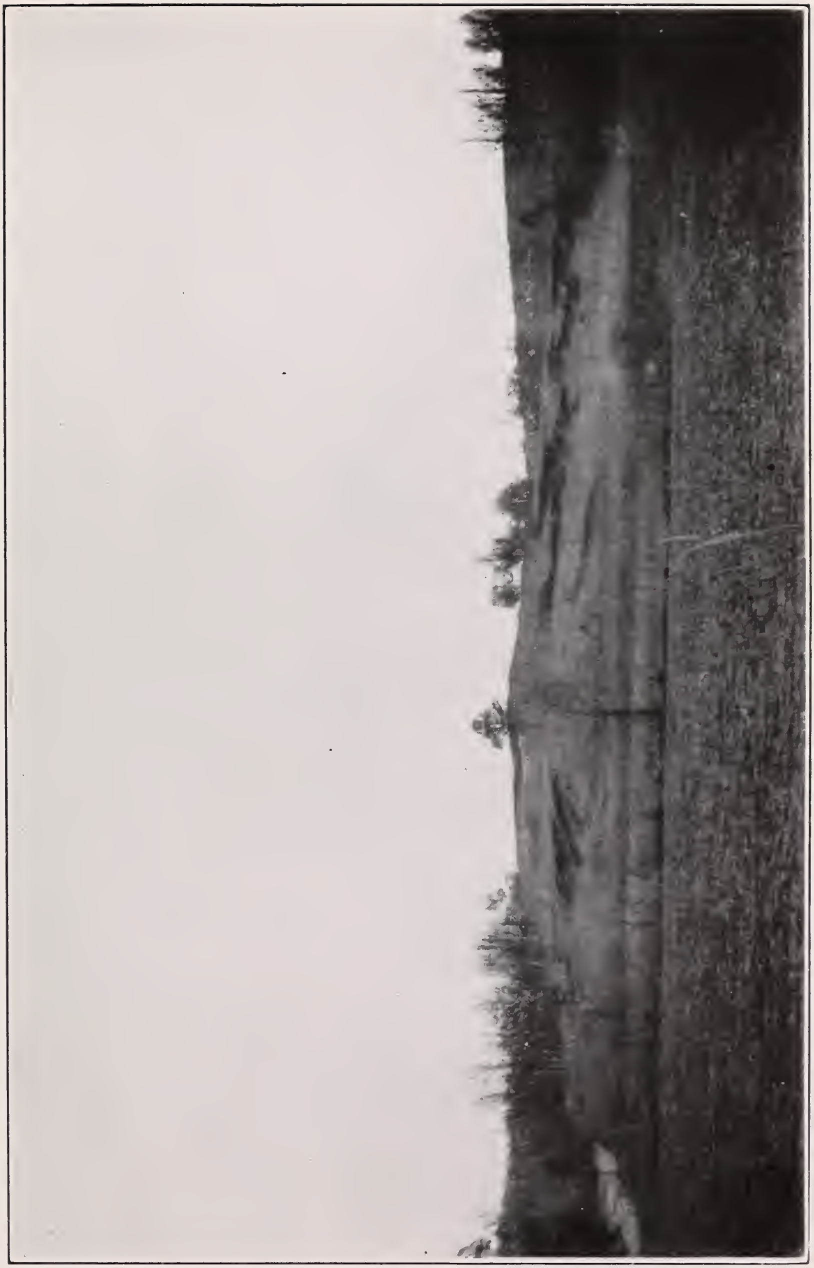
Description of Plate III.

Near view of a typical gully in homogeneous soil and subsoil. The sward suffices to hold the comparatively smooth surface until gullying begins, when it forms a slight glacis or scarp defining the margin of destructive erosion. The main gully and its tributaries with each storm retrogress farther and farther into the sward; on steeper slopes the topsoil is removed and the subsoil baked, so that most of the rainfall is lost as run-off, leaving the surface dry and sterile during the greater part of the year. In general, the erosion tends to flatten the slopes by translocation of material from higher to lower levels. The pebbles in the subsoil washed out during storms gather in depressions or pools in the course of the gullies, measurably checking corrasion at these points (thereby illustrating the tendency of heterogeneity in the soil to diminish erosivity). The view shows also the spontaneous spread of plum, locust, sumac, pine, and other shrubby and woody growths in a manner tending to retard the surface wash and eventually produce a natural cover under which the slope will again become stable. (Near Oxford, Ga.)

GULLYING IN AN ABANDONED FIELD.

Description of Plate IV.

Typical landscape in rolling land of sandy soil, showing characteristic development of old-field gullies and (toward the left) the clogging of channels with sand washed from the gullies. The moderate slopes were stable under the continuous forest cover; when cleared and put under cultivation the surface wash impoverished the soil; and when the fields were abandoned a sward formed, but remained too weak to prevent washing and gullying on steeper inclinations. The destructive erosion is extending rapidly into gentler slopes, and within a few years (as shown by neighboring examples) will remove the entire soil and fill the ravines, thereby flattening the entire surface to fit the reduced cover. The destruction here is increased by the fact that the surficial formation (including soil and subsoil) is a moderately tenacious loam, while the underlying formation is a less coherent sand. (Three miles south of Oxford, Miss.)



FLATTENING OF SLOPES WITH REMOVAL OF COVER.

Description of Plate V.

A landscape of gently rolling and sandy land deforested within a few years. Under the forest cover the slopes were quite stable, and both trees and undergrowth were luxuriant, while the surface was carpeted with duff; but wherever clearing has extended washing has begun, and about the heads of swales and brows of hills gullies have gone down to the local base-level and are retrogressing up the slopes in such manner as to threaten the removal of the entire surface. Wherever conditions favor (i. e., wherever the slopes are moderate and fires have not spread) pine trees and plum thickets are starting, and both promise at least partial protection with further growth, the former yielding an abundant and peculiarly effective litter of fallen needles and the latter binding the base of the sward with a mat of roots. (Two and one-half miles south of Oxford, Miss.)

TYPICAL EFFECT OF DEFORESTATION.

Description of Plate VI.

Landscape illustrating the development of gullying on the steeper part of a relatively gentle slope, i. e., at the brow of a low hill. The entire surface was stable and rich in duff and humus under the original forest cover. After partial clearing the sandy soil was impoverised by washing and the field was then abandoned except as pasture; but the sward (rendered feeble by annual burning and excessive grazing) was too weak to hold the soil on slopes exceeding, say, 5 per cent. and allowed active gullying to begin in stock trails or storm runnels and extend into the flatter surface in such manner as to threaten entire removal of soil and subsoil down to base-level; i. e. to a depth averaging more than 10 feet below the natural surface. A typical example of old-field erosion in northern Mississippi and neighboring States. (One mile southwest of Oxford, Miss.)

TYPICAL GULLYING AT BROW OF HILL.

Description of Plate VII.

Near view toward left of preceding, showing forms of autogenetic sculpture produced by retrogressive erosion extending to base-level in such manner as to reduce the slope to fit the reduced cover. The sandy surface in the foreground is growing up slowly in sedge and plum. The surficial deposit is brown loam to a depth of 2 or 3 feet; below lies stratified sand identified with the Lafayette formation. The scattered hardwood trees on the old surface are quite insufficient to afford protection, though their duff and root-mats retard the wash so that (as shown by neighboring examples) they form peninsulas and islands of the old surface sometimes persisting for years.

TYPICAL OLD-FIELD GULLY.

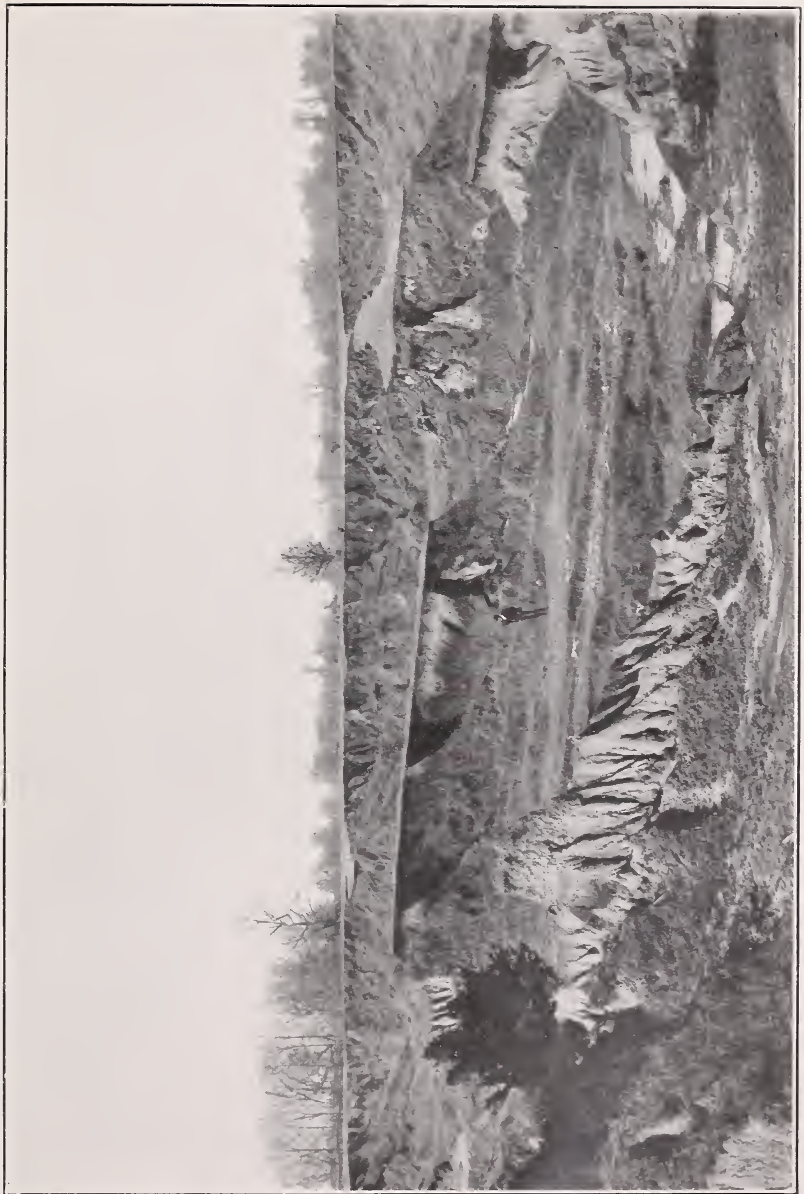
Description of Plate VIII.

Development of erosion beginning on steeper slopes in rolling land of sandy soil. The entire surface was originally wooded, and was practically stable in the natural condition; but on clearing and cultivation the erosion beginning on the steeper slopes extended into the upland, leaving only scattered patches of the old-field surface. Several acres of the hill in the right middleground have been carried away to a depth of over 50 feet, while the valley in the foreground has been so completely clogged with débris as to ruin the bottom-land farms. (One mile south of Oxford, Miss.)

EROSION OF STEEPER SLOPES ON REMOVAL OF COVER.

Description of Plate IX.

A gently rolling landscape, originally wooded and stable, in which the moderate slopes were rendered unstable by clearing and cultivation. When the field was abandoned to pasturage a sward formed and grew strong enough to hold the soil, except where invaded by gullies; but the gullies, beginning on the steeper slopes (as shown in VI and VII), have undermined this feeble cover, carrying away the soil and subsoil to a depth of over 15 feet and leaving a new surface gradually weathering flat and becoming stable through natural growth of grasses and shrubbery. (Six miles southeast of Yazoo City, Miss.)



ADVANCED OLD-FIELD EROSION.

Description of Plate X.

Gullies, started by roads descending brow of hill, extending into level fields. A typical illustration of destructive erosion along the line of low bluffs bordering the river and the delta country in Mississippi and neighboring States. Originally these bluffs, like other parts of the surface, were well wooded, and the soil was practically stable; but with settlement and the destruction of the luxuriant underbrush and cane and larger trees of the natural cover the soil broke easily along trails and roads, forming gullies pushing retrogressively into the uplands, leaving temporary tongues and islets of the old-field surface (one well shown in left middle ground), themselves gradually crumbling as their protecting trees and brambles die out on the sun-baked soil. The surficial deposit is brown loam, with stratified Lafayette loam below. (Near Rocky Springs, Miss.)

ADVANCED HILLSIDE GULLYING.

Description of Plate XI.

Landscape showing complete removal of a surficial formation through the flattening of slopes due to removal of natural cover. Under the original forest cover the entire surface was stable; with clearing the gently rolling surface washed enough to impoverish the field, which was then abandoned to pasturage—when gullying started by cattle trails and roads extended in such manner as to remove the soil and subsoil (of brown loam) to a depth averaging some 8 feet. In this case (as frequently along the lower reaches of Big Black River) the lower limit of corrasion is determined not so much by the base-level as by the greater porosity of the underlying deposits (loess), permitting it to absorb so much of the run-off as to diminish the efficiency of the flow in a manner analogous to that observed on arid plains where sheet-flooding prevails. The final effect is a decided flattening of the original slopes. (Three miles west of Edwards, Miss.)

SKINNING OF THE LAND.

Description of Plate XII.

The manner in which country roads are cut down under travel to such depths as sometimes to control storm run-off and initiate gullies invading adjacent fields. The surface here is gently rolling in general, running into steep bluffs toward larger streams; the soil and subsoil are of Memphis silt loam (i. e., loess) to a considerable depth. (One and one-half miles southeast of Natchez, Miss.)

TYPICAL ROAD IN SOUTHWESTERN MISSISSIPPI.

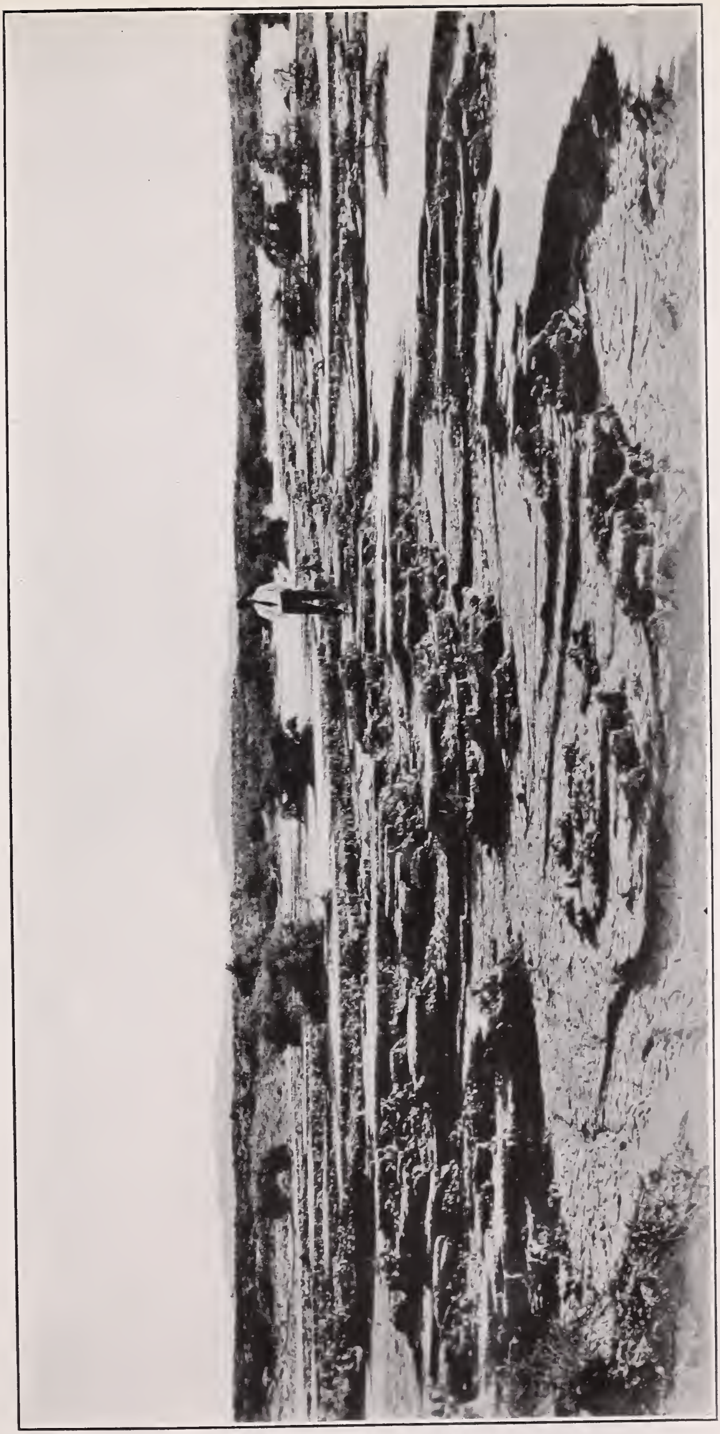
Description of Plate XIII.

Manner in which the loess generally stands in nearly vertical walls while the roadway is worn down to depths of many feet or yards, yet occasionally yields in such manner as to initiate devastating gullies. The entire surface was originally rolling but rendered stable by the luxuriant forest growth. The breaking of the surface was inaugurated primarily by clearing and cultivation. (Three miles southeast of Vicksburg, Miss.)

TYPICAL ROAD OF WESTERN MISSISSIPPI.

Description of Plate XIV.

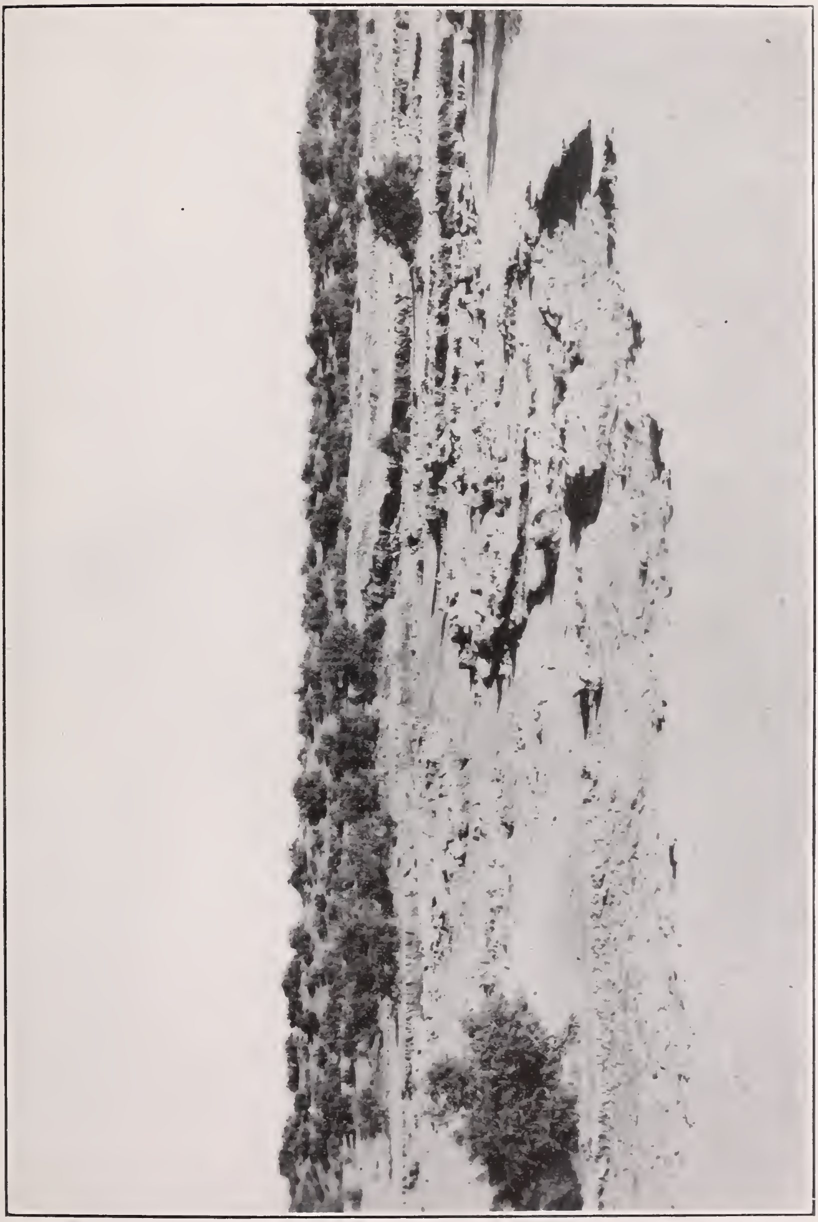
Typical valley bottom in the arid region, in which the natural balance has been disturbed. Wherever sheet-flooding prevails, the débris gathered chiefly from footslopes and buttes and sierras is washed into the valleys, whose depths are eventually lined by the finest part of the sediment. Within the storm and thaw waters accumulate, forming temporary lakes or "sinks;" during drier months the water evaporates, leaving mud-flats or playas with surfaces sometimes incrusted with mineral salts. While the playas seem level, their margins really rise gently and merge with the surface of the valley plain, bearing its characteristic flora growing in sparsely scattered tufts and colonies; and when the balance is disturbed by over-grazing of the slightly undulating valley surface or otherwise, the floods run off more quickly and corrade deposits previously accumulated about the playa margin. The initial gullies commonly retrogress and erode the surface extensively, the débris moving farther down the valley, either into lower playas or into streams flowing to the sea. Even when the natural balance is disturbed beneficially by the bringing in of water for irrigation, the excess of water may initiate erosion similarly, unless the soil is so treated as to prevent. (Near Fallon, Nev.)



INTERDEPENDENCE OF SLOPE, COVER, AND WATER SUPPLY.

Description of Plate XV.

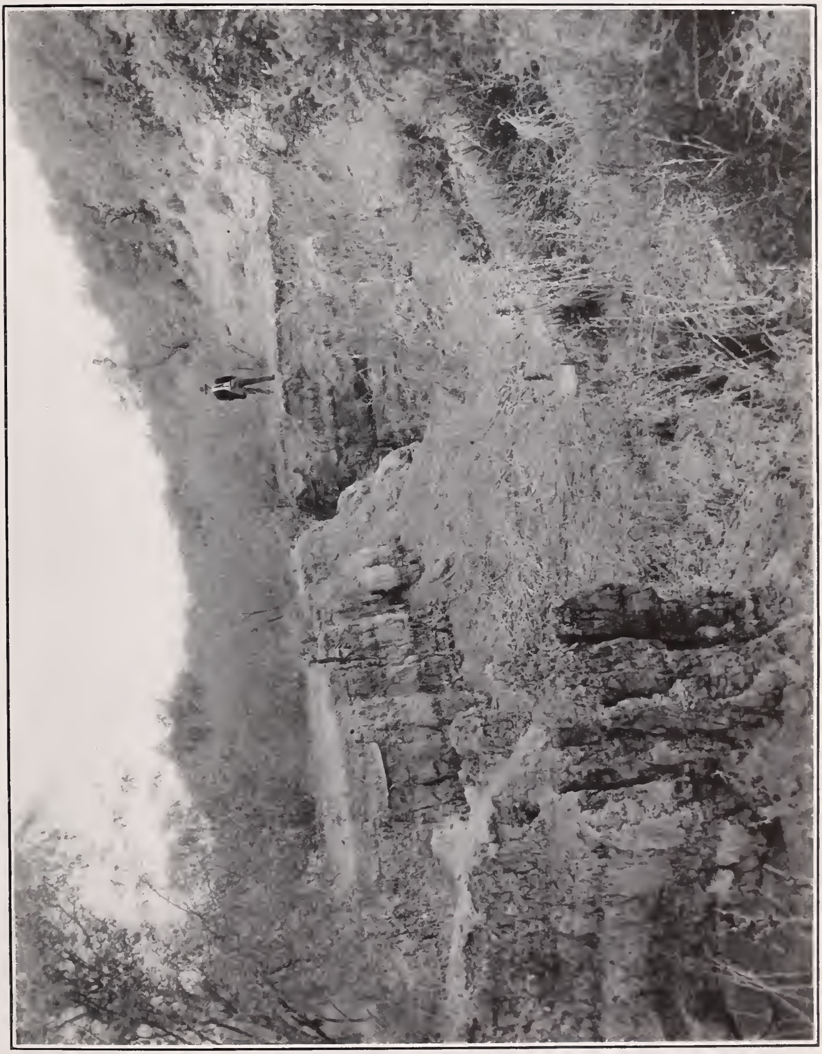
Erosion invading a characteristically distributed arid-land flora where the accumulation of surficial deposits lining the valleys has been effected by the joint action of water and wind. Material translocated by wind has accumulated in such quantity as to raise the level of the valley somewhat above the plane of stability for water-laid deposits; and erosion initiated by a freshet has retrogressed up the main and tributary channels for the storm waters, except where the deposits are held by the scant growth. (Near Fallon, Nev.)



TYPICAL ARID LAND EROSION.

Description of Plate XVI.

Effect of an exceptional flood in deepening storm channels and initiating gullies in arid districts. After accumulating valley deposits by ordinary floods for years, Rio Santa Cruz suffered exceptional floods in 1908 and 1909; these first overspread the valley to great width and coated it with slime like the traditional Nile mud, and then as the flow subsided corraded the main channel to a depth of several feet. During the height of the flood the stratified deposits were saturated, and with the lowering of the base-level by the new channel the vally was drained, not only over the surface in such manner as to open surface gullies, but sometimes subterraneously through the more pervious strata in such wise as to produce slumps or sinks; and eventually the surface and subterranean flow joined in irregular chasms of considerable depth. (Four miles southwest of Tuscon, Ariz.)



GULLYING DUE TO SUBTERRANEAN FLOW.

Description of Plate XVII.

Invasion of a gently rolling field by gullies starting on somewhat steeper slopes. The sward might be sufficient to protect the surface if the gullying were prevented, but does not resist undermining by the numberless rills in which the storm waters gather. Beneath the surficial brown loam forming a fertile soil lies the sandy loam of the Lafayette formation, containing ferruginous nodules and crusts, baked so hard by the sun as to shed the storm waters, leaving little to soak into the ground; while the ferruginous concretions gathered in the channels retard corrasion and give starting points for sedge and other grasses and shrubs, whose spontaneous growth indicates ways in which the destruction might be checked. (Near Grand Junction, Tenn.)

TYPICAL OLD-FIELD EROSION.

Description of Plate XVIII.

Rear view of Branch (State) Experiment Station, Holly Spring, Miss. Erosion is so far advanced as to threaten the entire homestead, including aged oaks, century-old cedars, and the residence of the superintendent. A characteristic landscape of one of the largest counties in Mississippi, in which the surface was originally wooded luxuriantly and so well watered that the ground-level of water approached the surface and supplied abundant springs. Through clearing and cultivation the sandy soil was rendered unstable, and it is estimated that a third of the area of the county has been devastated as shown, while the ground-level of water has been so far lowered that most of the springs have failed. The soil and subsoil are of sandy loam resting on stratified sands identified with the Lafayette formation; the photograph was taken when a light snow in the gullies brought out the relief. The devastated hillside was subsequently reclaimed and made productive by a combination of hand and plow work in deep cultivation and contouring.

OLD-FIELD DEVASTATION.

Description of Plate XIX.

Shows in detail part of a landscape originally stable under forest cover, but invaded by erosion on clearing and cultivation; the destruction now pushing retrogressively into the grove maintained about the residence (of which a glimpse appears at the right), and threatening to remove the entire hilltop. Plum and other shrubs shown in the foreground are beginning to form a new cover for the freshly exposed surface. The soil and subsoil are brown loam to a depth of some 4 feet, resting on the Lafayette formation. (Three-fourths mile southwest of Raymond, Miss.)

OLD-FIELD EROSION PUSHING INTO A GROVE.

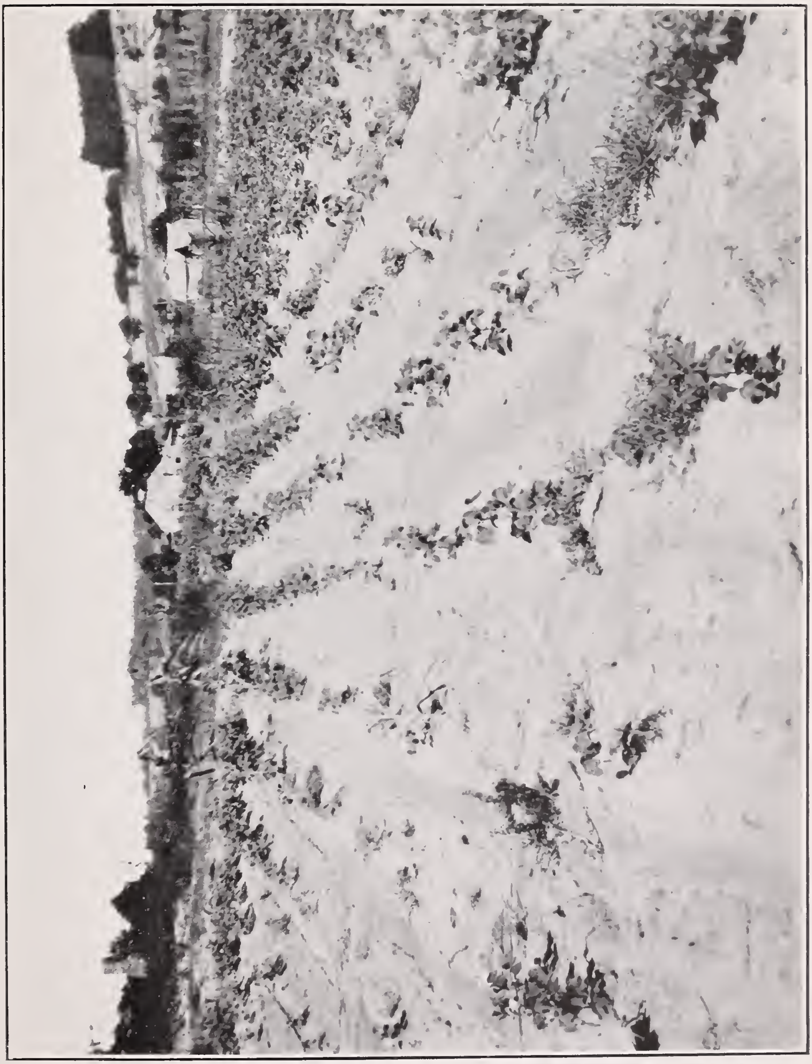
Description of Plate XX.

Another view of part of the landscape shown in Plate XIX, indicating the manner in which (provided burning be prevented) upland sedge, plum, pine, and locust spring up on surfaces exposed by erosion, even extending into the gullies and along the scarps, gradually checking the devastation by restoring that natural balance in which the cover protects the slope. The roots of the sedge form a sward and its stems collect litter, holding the storm waters; the roots of the plum and locust form a mat supporting the sward, and especially during summer provide a low cover, while in winter the fallen foliage forms moisture-holding and soil-protecting duff; the plum yields annual crops of fruit and the locust furnishes fence posts in three to five years; the pine is particularly effective, since it shelters the surface at all seasons, while the fallen needles form a heavy carpet, retaining storm water and keeping the soil so soft and friable that the water is readily absorbed and the run-off thereby reduced.

OLD-FIELD EROSION CHECKED BY NATURAL GROWTH.

Description of Plate XXI.

A common result of linear cultivation (i. e., plowing and planting in straight lines) where the slope exceeds the agricultural angle of stability: storm rills form and, running both along and across the rows, ruin much of the crop and remove the richer portion of the soil. (Near Holly Springs, Miss.)



EFFECT OF LINEAR CULTIVATION ON ROLLING LAND.

Description of Plate XXII.

A field in moderately rolling land of loamy soil, in which the slopes were stable under the natural forest cover but are unstable in the steeper portions under ordinary cultivation. The upper and flatter portion of the field is sufficiently protected by plowing and planting on contours; the lower and steeper portions are partly terraced. The contours and terraces are laid out roughly with little regard to accurate leveling, or to maintaining maximum productivity on every part of the field, so that the photograph illustrates a common rather than a model treatment of slopes. (South of Raleigh, N. C.)

A CONTOURED AND PARTLY TERRACED FIELD.

Description of Plate XXIII.

Moderately rolling land, quite stable under forest, wholly unstable under linear cultivation, and fairly stable under contouring. Both plow furrows and crop rows run on approximately level lines, while the slope is broken by balks not utilized as part of the farm but allowed to grow up naturally in weeds and brambles, so that the example can not be considered a model. The slopes throughout the field are so nearly uniform that the balks are approximately equidistant. (Near North Garden, Va.)

CONTOURING WITH PARALLEL (OR CONCENTRIC) BALKS.

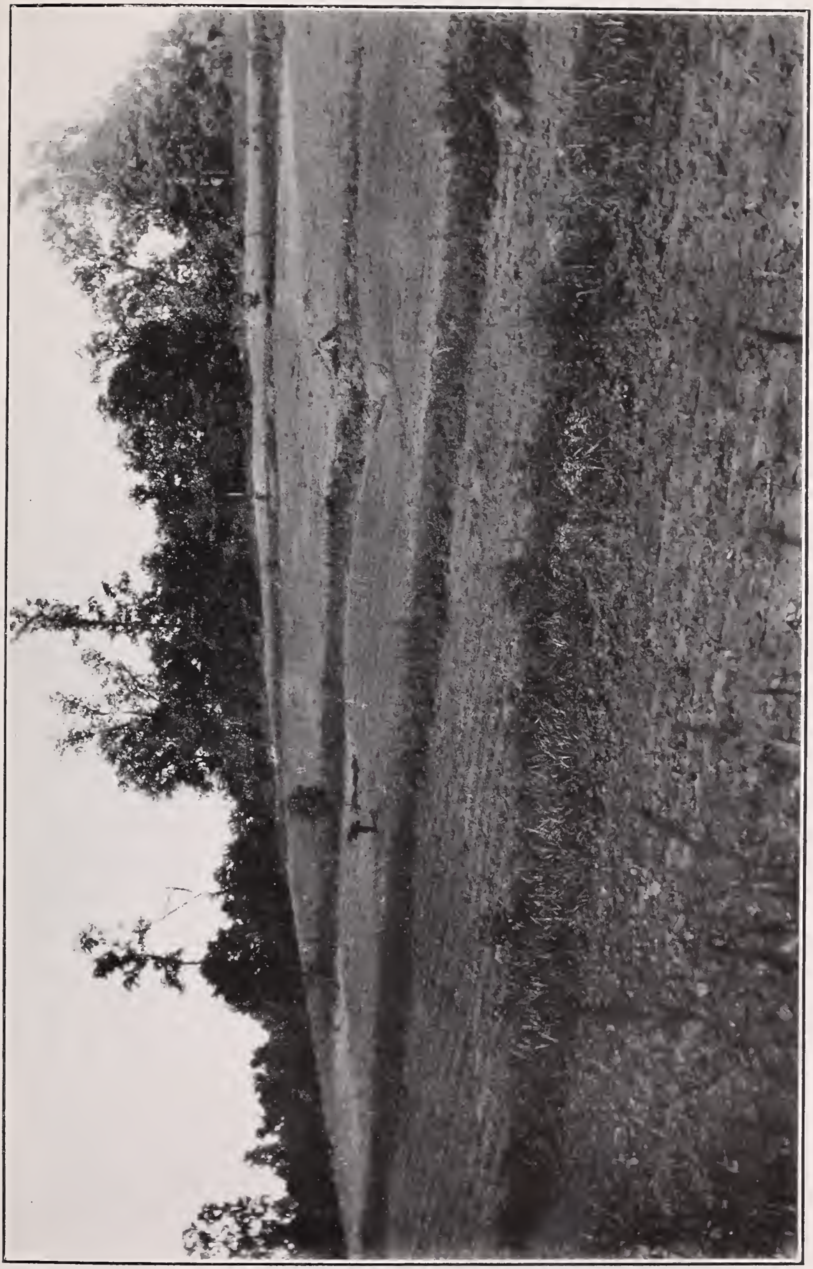
Description of Plate XXIV.

Gently rolling land, quite stable under forest, but liable to both surface wash and gullying under cultivation. The field in the middle ground is cultivated on contours adjusted to well-designed balks so curved as to conform approximately to the "lay of the land" and yet remain substantially equidistant; they are allowed to grow up naturally in grass and weeds, and hence to form waste land. (One-half mile northwest of Abbeville, S. C.)

CONTOURING WITH MEANDERING BALKS.

Description of Plate XXV.

A field of slope too steep for stability under linear cultivation (though stable under forest), in which the surface wash and gullying have been partially checked by contouring and balks. The balks have been left to natural growth rather than artificial selection and planting, and are hence only moderately effective—that in the middle ground (running out in both directions on gentler slopes) being too narrow and too imperfectly covered to retain completely the run-off and close the runnels, which threaten to grow into devastating gullies. (Eastern Mississippi.)



Contouring with Inadequate Balks.

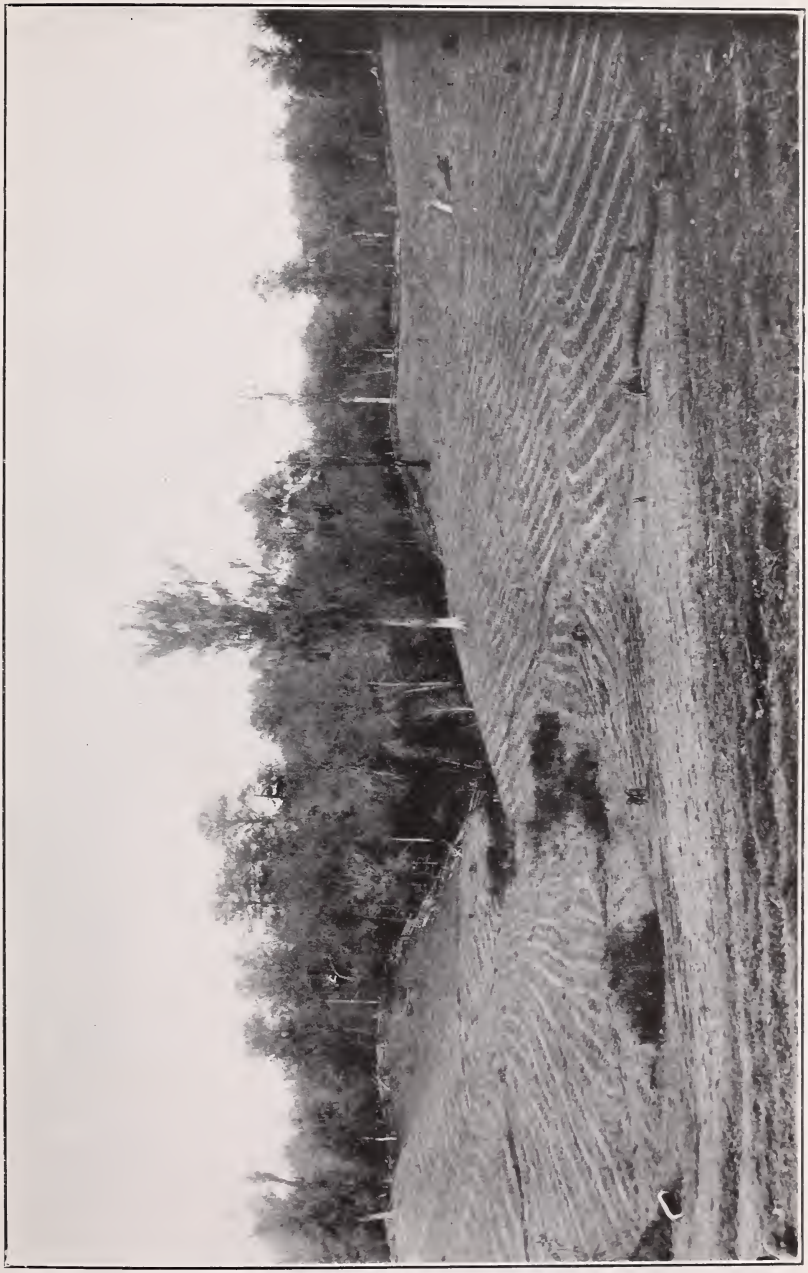
Description of Plate XXVI.

Contouring supplemented by a balk laid out with insufficient regard for slopes varying with the "lay of the land." While the lines of cultivation are curved they are not level, so that the storm waters gather and cut rills, as in linear cultivation, running both along and across the furrows, thereby promoting rather than preventing run-off, and allowing the waters to gather in sufficient volume to overflow and cut through the balk and gully the adjacent plow land. (Eastern Mississippi.)

AN ILL-DESIGNED BALK.

Description of Plate XXVII.

Rather steeply rolling land, practically stable under forest cover but liable to surface wash and deep gullying after clearing. The cotton rows are curved in such manner as to save labor in cultivation and reduce the run-off, but are not carefully leveled and adjusted to the "lay of the land," so that gullying has started at several points. While the slopes are not so steep as to require terracing, the entire field might be protected by introducing, say, two carefully leveled balks, the first some 25 feet higher than the bottom of the ravine in the middle ground and the second some 25 feet higher still (the two averaging about 200 feet apart), and adjusting to them the intermediate furrows and rows. (Northern Louisiana.)



ILL-DESIGNED CONTOURING.

Description of Plate XXVIII.

View of a field in gently rolling land with sandy soil, stable under natural cover, but liable to surface wash and also to gullying (as shown in the foreground) under cultivation. The terracing comprises horizontal balks allowed to grow up naturally in grass and shrubbery in such manner that each forms a low glacis protecting the narrow terrace above; it is experimental merely, and might be improved by planting alternate balks in permanent shrubbery or bushes yielding berries or other crops, and with the growth of these allowing each intermediate balk to merge gradually with the terrace surface and disappear. The gullying in the foreground, outside of the line fence, illustrates the interpendence of adjacent fields and the consequent necessity for coordination of plans and cooperation between neighbors. (One-half mile northwest of Abbeville, S. C.)

A TERRACED FIELD.

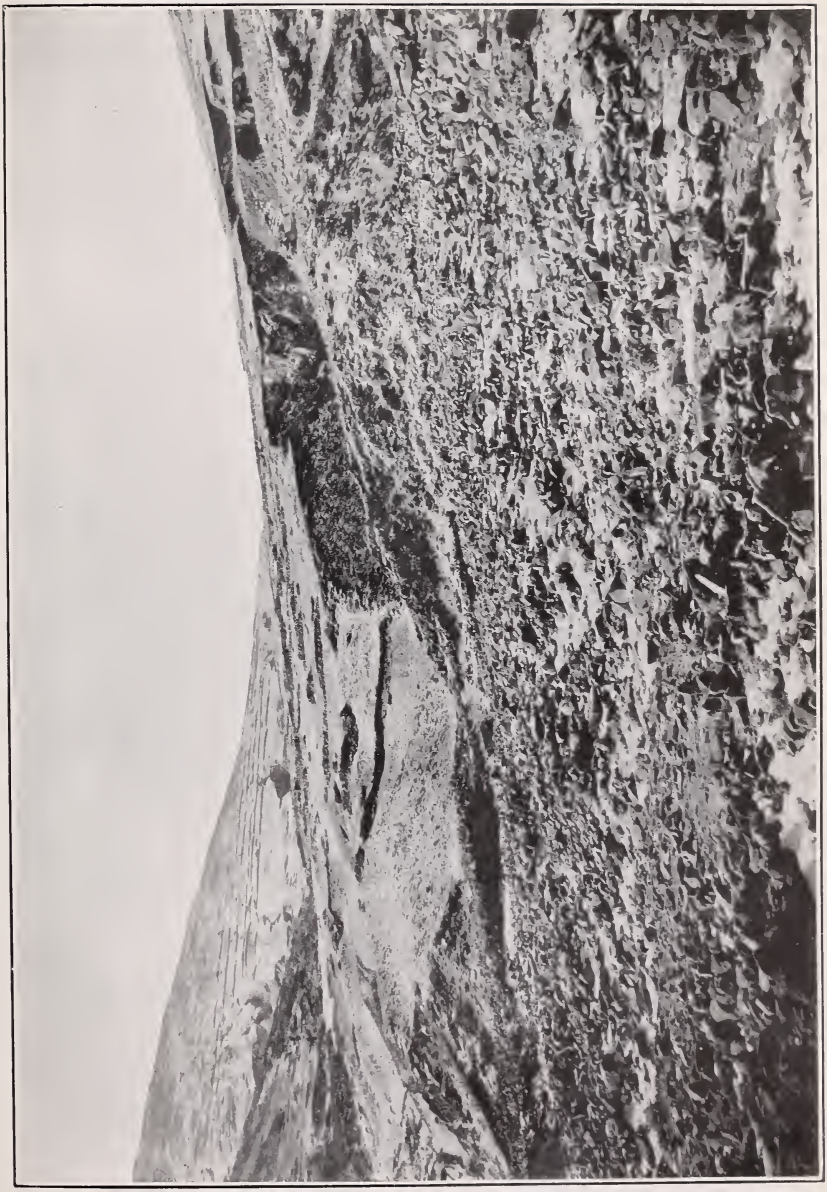
Description of Plate XXIX.

Illustrates protection of a park by breaking the slope into a series of simple terraces. The region was stable under forest, but after clearing became subject to devastating erosion through retrogressive gullies, sometimes expanding into "gulfs" 100 or more feet deep, with precipitous walls; the soil is loess (Memphis silt loam), extending to a depth of 20 to 50 feet, and grading into gravel or sand which in turn often overlies Port Hudson clays. The terraces average about a rod in width and some 5 feet in vertical height; and on their level surfaces the storm waters (including the drainage from the glacis or the upland above) lie until absorbed into the pervious soil and subsoil, whereby both surface wash and gullying are practically prevented. The stability of the glacis is due largely to the properties of loess; with other soil and subsoil the steeper slopes would require stronger sward or the root mats of shrubbery. (Southeastern outskirts of Natchez, Miss.)

A TERRACED PARK.

Description of Plate XXX.

A typical Chinese landscape, in which the rolling surface was stable under the original forest cover, but on deforestation became subject to devastating erosion, the gullies extending retrogressively and the topsoil washing away, often laying bare the stony subsoil, as shown in the foreground. A part of the area has been reclaimed by terracing, as shown in the background, the terraces being held in place largely by walls of rubble, as shown more clearly in the middle ground.



EROSION STAYED BY TERRACING IN CHINA.

Description of Plate XXXI.

A steeply rolling Chinese landscape largely devastated by erosion due chiefly to deforestation. Originally wooded, the surface was fairly stable, despite the steepness of the slopes, and was drained by a fairly uniform stream flowing at the bottom of a rocky gorge. As cutting of the timber thinned the natural cover the soil was progressively eroded until the steeper slopes grew sterile and the floods became destructive even on the gentler slopes; meanwhile the coarse débris washed from the hills accumulated in the gorge to form a broad sand wash, completely overflowed by destructive floods after storms and thaws, but running nearly or quite dry between, the meager flow of the dry season sinking largely or wholly into the sand, as in the arid districts of this country. Portions of the surface have been reclaimed, partly by terracing and partly by vineyarding on contours; for even on the relatively steep slopes and rocky subsoil these devices so far hold the rainfall as virtually to prevent run-off and consequent erosion.

CONTOURING AND TERRACING IN CHINA.

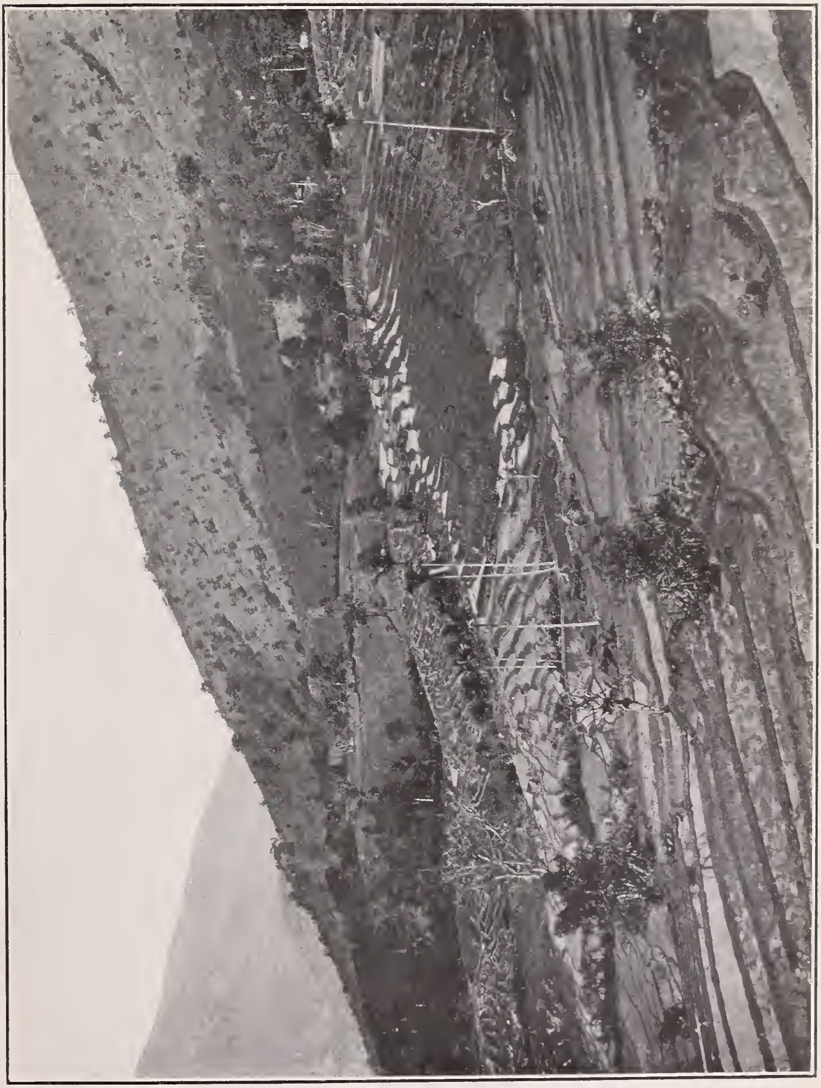
Description of Plate XXXII.

A typical landscape in the loess region of China. Originally the rolling lands were wooded and the surface was fairly stable, but with deforestation gullying developed on a stupendous scale, the fine sediment overloading the great rivers and even coloring the waters of the "Yellow" Sea. Locally the devastation was checked and the land largely reclaimed by extensive terracing, the efficiency of which depends chiefly on the pervious character of the loess in conjunction with its capacity for standing in vertical walls so long as these are protected from running water. The terracing is supplemented by contouring and sometimes by vineyarding, and in some cases habitations are partly excavated and partly built into the vertical walls.

RECLAMATION BY TERRACING IN CHINA.

Description of Plate XXXIII.

A hilly region originally wooded but now mainly deforested and hence unstable in slope, despoiled of humus and topsoil, and subject to surface wash accompanied by gullying down to the underlying rock. The foot slopes have been reclaimed by terracing. The terraces are narrow and irregular, but closely adjusted to the "lay of the land;" for the first requisite in growing the upland rice is so perfect horizontality of the surface that water will stand until evaporated or absorbed (the white terrace surfaces shown here and there are due to standing water). Each terrace is sustained by a glacis of rubble and puddled earth rising into a low parapet sufficient to retain the water of both irrigation and storms and prevent surface run-off. Such paddy fields represent continuous cultivation for centuries, with full utilization of the entire water supply, including (in the best examples) the run-off from the higher slopes with its wealth of salts and other earth matter carried in solution and suspension.



TERRACED PADDY FIELDS IN CEYLON.