U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF FORESTRY—BULLETIN No. 49.
GIFFORD PINCHOT, Forester.

THE TIMBER OF THE EDWARDS PLATEAU OF TEXAS;

ITS RELATION TO CLIMATE, WATER SUPPLY, AND SOIL.

BY

WILLIAM L. BRAY,
Collaborator, Bureau of Forestry.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1904.

BUREAU OF FORESTRY.

GIFFORD PINCHOT, *Forester.*

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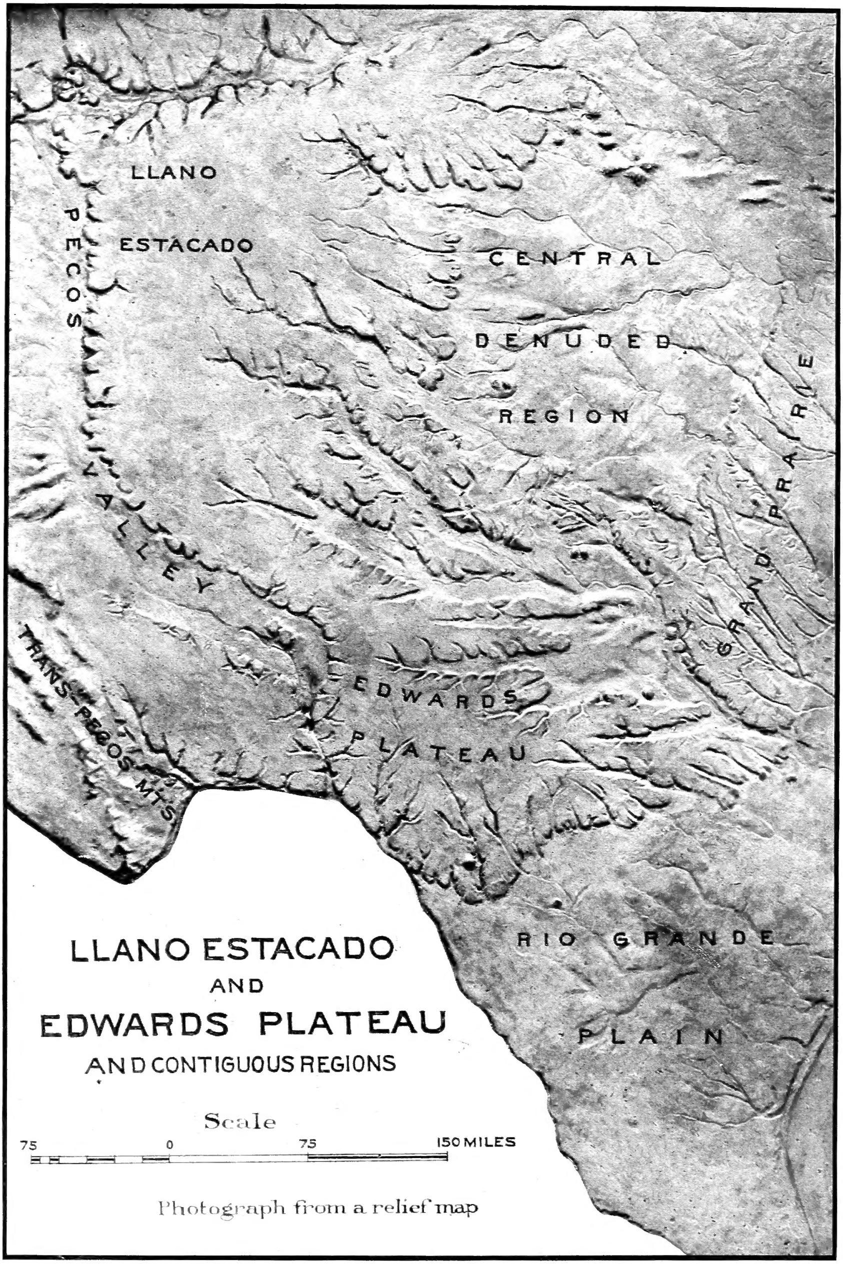

RELIEF MAP OF THE EDWARDS PLATEAU.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Forestry,
Washington, D. C., April 23, 1904.

Sir: I have the honor to transmit herewith a report entitled "The Timber of the Edwards Plateau of Texas; Its Relation to Climate, Water Supply, and Soil," by William L. Bray, collaborator in the Bureau of Forestry, and to recommend its publication as Bulletin No. 49 of the Bureau of Forestry.

The map and five plates which accompany the report are necessary for its proper illustration.

Very respectfully,
Gifford Pinchot,
Forester.

Hon. James Wilson,
Secretary of Agriculture.

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THE TIMBER OF THE EDWARDS PLATEAU OF TEXAS; ITS RELATION TO CLIMATE, WATER SUPPLY, AND SOIL.

INTRODUCTION.

That a forest or other heavy growth of vegetation exerts an important influence in conserving the water supply, in preventing or checking floods, and in resisting the erosion of soil, scarcely requires demonstration in these pages. Most Texans, at any rate, have had abundant opportunity to observe how a heavy growth of grass on prairie slopes will hold the soil at the time of a heavy cloudburst, which, on denuded soils, plows out great gulches and carries away thousands of cubic yards of earth. Or those living in the rough, mountainous region of south-central Texas may have noticed how, after a violent downpour of rain, the water rushes down the sides of bare, steep hills with a power which carries not only any remnants of soil, but the fragments of rock as well, and scoops out the bottom of the gorge down to a solid rock bed; whereas when the sides of the gorge and perhaps the hills above are heavily timbered, the organic débris drinks up and detains the water, so that not only is this heavy covering of leaf mold not washed away, but the water does not acquire momentum and volume sufficient to sweep out the channel of the gorge itself.

Older communities, after costly experience with floods, with the failure of springs and streams, and with the destruction of valuable farming areas, acknowledge that there are some areas from which forest covering must not be removed. It is quite within experience that the difference between two similarly located regions, one of them abounding in fertile farms and orchards and pastures, the other a bare waste of naked hills and water-washed lowlands, may be due to the treatment given to the native forest vegetation which, to begin with, covered the hillsides. Our neighbors of the older States of the South who live in the Coast Plain forest belt of sandy clay soils (the same as the Lignitic Belt of Texas) realize, after the loss of whole farming areas by erosion, that, within this region at least, certain portions must be left timbered for the protection of farm lands. It is a familiar fact that in the south of France, when the short-sighted policy of selling the Government forest lands and permitting their denudation was adopted after the Revolution, whole regions were reduced from fertile farms and vineyards to barren wastes, and that within recent years the policy has been pursued of reclaiming these lands by reestablishing the forest covering, though at an enormous expense. Some of the same conditions and possibilities exist in the region which we are to consider in this bulletin.

THE EDWARDS PLATEAU AS A SOURCE OF WATER SUPPLY.

The water supply furnished by the rainfall of the Edwards Plateau is important not only for its own area, but especially for the coast plain lying to the southeast and south of it. The plateau is a vast receiving or catchment area for water, the major portion of which is given up to the plain, either immediately, in the form of destructive floods, or gradually, in the form of steadily flowing or intermittent streams or artesian water. The great Rio Grande Plain from the Colorado to the Rio Grande is a level, irrigable area, whose richness of soil and mildness of climate mark it as one of the endlessly resourceful and productive regions of the country, if only it can get water enough. Its relation to the interior highlands of the Edwards Plateau (see relief map, frontispiece) is therefore one of extreme importance. While no pretension is here made to such a treatment of this subject as would fall to a hydrographic engineer, it is nevertheless possible to point out how the forest growth of the plateau affects the supply of water, and how through its agency the supply may be improved.

DESCRIPTION OF THE REGION.

The Edwards Plateau is the southernmost province of the Great Plains region, which comes to an abrupt termination in the escarpment known as the Balcones escarpment—a line of cliffs formed by a gigantic downthrow or faulting. These cliffs constitute the front line of the hill region one sees so clearly marked from Austin to San Antonio, and thence westward to Del Rio. Strictly speaking, the plateau is arbitrarily bounded by the canyon of the Pecos River on the west, and on the northeast by the escarpment overlooking the central denuded area (the Granite country, etc.); but in this bulletin the discussion includes as well all of the adjacent area of the Central Denuded Region and the rougher eroded and timbered parts of the Grand Prairie from the Colorado northward, since they have the same relation to water supply as the more limited plateau proper.

According to Hill[a] the Edwards Plateau proper includes all of Crockett, Valverde, Edwards, Sutton, Schleicher, Kimble, Kerr,

[a] Hill and Vaughan. The Edwards Plateau and Rio Grande Plain (p. 205), Eighteenth Ann. Rpt. U. S. Geological Survey, Part II.

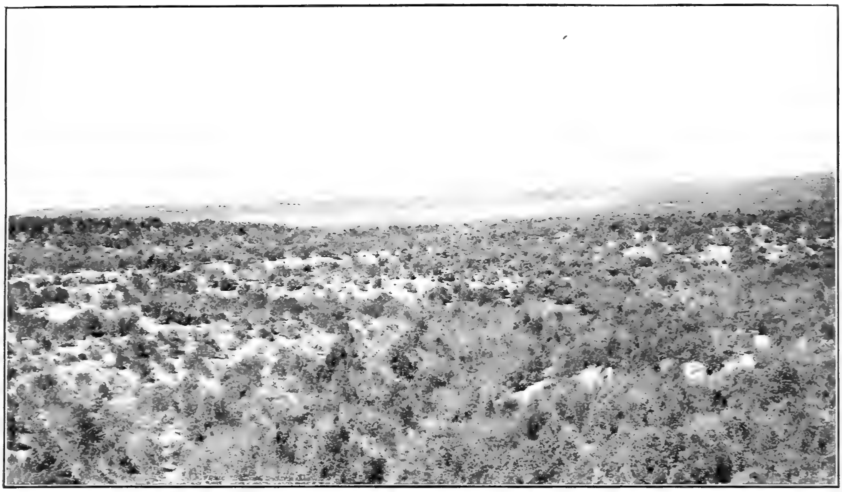

FIG. 1.—VIEW OF TIMBER (MOSTLY CEDAR) ON WHITE, CRUMBLY LIMESTONE; HIGHER REMNANTS OF PLATEAU IN DISTANCE.

No soil accumulates except under clumps of cedar. Colorado breaks 10 miles north of Austin.

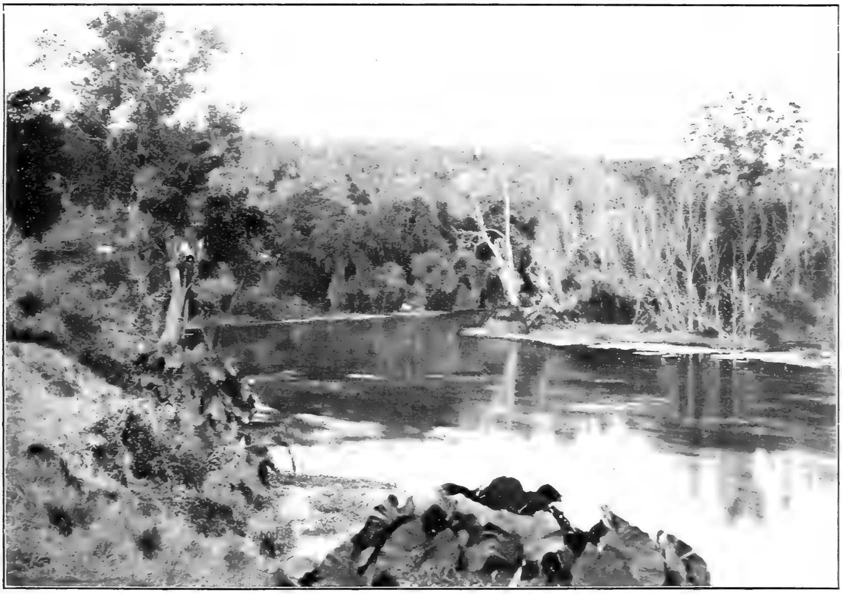

FIG. 2.—COMAL RIVER AT ITS SOURCE—ESCARPMENT TIMBER.

FIG. 1.—CHARACTERISTIC VIEW OF THE EDWARDS PLATEAU FOREST, ON THE COLORADO RIVER, 10 MILES ABOVE AUSTIN.

Mostly cedar on the summits here. Mountain oak lower down the sides of the gorge. This timber prevents rapid run-off and erosion after rainfall.

FIG. 2.—HILL NEAR AUSTIN COVERED WITH PURE STAND OF MOUNTAIN OAK.

On the left the timber has been cut clean for fuel. Such clearings show rapid renewal of timber.

Bandera, Gillespie, Kendall, and Blanco counties, as well as half of Crane, Upton, Tom Green, Irion, Concho, Menard, Travis, Hays, Comal, Bexar, Medina, Uvalde, and Kinney counties. This area is a part of the great limestone region which constitutes the southern province of the Great Plains. To the northwest it is continuous with the Staked Plains, and is a typical open, level plains country. Farther southward, however, the area is far advanced in the process of erosion, being deeply dissected by streamways flowing southeastward and cutting the margin into long, narrow tongues of the former plateau mass. In the dissected border are also hundreds of remnantal buttes or hills, like Mount Bonnel and Lone Tree Hill at Austin, Long Mountain, Post Mountain, Pack Saddle, etc.[a] (See frontispiece and Pl. I, fig. 1.)

The Edwards Plateau (Eighteenth Ann. Rpt. U. S. Geological Survey, p. 206) presents three simple topographic elements: (1) The flat-topped summits of the decaying plateau (the divides); (2) the breaks and slopes of its crenulated borders and canyoned valleys ("the mountains"); and (3) the streamways or rivers and their branches.

The escarpment front rises to an elevation above the Coast Plain of from 400 feet at Austin to 1,000 feet in Uvalde County, while the northwest is a high plain 2,400 feet above the sea. Naturally, it is chiefly in the eroded or mountainous portion of the plateau that a protective timber growth is needed.

For our present purpose the important considerations concerning the Edwards Plateau are, that it is a vast receiving area for rainfall, and that its structure is such as to give special significance to the behavior of water after it has been precipitated.

STRUCTURE OF THE EDWARDS PLATEAU AS A CATCHMENT AREA.

Until the report by Messrs. Hill and Vaughan was published there seems to have been no general recognition that this limestone country played a rôle of consequence as a receiver of precipitated water. The report showed, however, that, as a matter of fact, its capacity to take up water is of the first importance; and that this is possible not only because of the specific absorption capacity of the limestones themselves, but also by reason of the favorable exposure (by erosion and normal outcrop) and the tilting of the strata, and especially by reason of the very extensive systems of fissures and caverns, which contribute remarkably toward rendering the formation receptive of water.

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[a] Hill and Vaughan. Artesian Water of the Edwards Plateau, etc., Eighteenth Ann. Rpt. U. S. Geological Survey, Part II.

The above report has been used freely in the preparation of this bulletin, and grateful acknowledgment is hereby made of the author's indebtedness to it.

STRUCTURE OF THE EDWARDS PLATEAU AS TO INFLUENCING THE BEHAVIOR OF THE PRECIPITATED WATER.

We have just seen wherein the structure of this formation renders it an efficient catchment area. The same structure operates to convey a large part of the water to the deeper strata, whence it reappears as spring water to feed the rivers flowing from the region.

The topography has, however, from our present point of view, an even more important bearing; since by it are determined in large measure the rapidity of run-off and the percentage of precipitated water lost in this way. Since the border region of the plateau is very rough and deeply dissected, the water will flow off after heavy rainfall before it has had time to enter the limestone formation; and with such volume and velocity as to cause swift and destructive floods, unless detained by some agency other than the limestone structure of steep hillsides. This is exactly the function which a timber or heavy grass covering performs (Pl. II, fig. 1).

CLIMATIC CONDITIONS OF THE REGION.

The climatic conditions are of significance in this discussion: First, because they determine the actual amount of rainfall and influence its behavior after falling, e. g., its rate of evaporation; second, because they determine very largely the character of the vegetation, with whose efficiency as a water conserver we are mainly interested.

RAINFALL.

The region under consideration lies in the belt of transition from moderately heavy rainfall to arid climate, with a very pronounced difference between the eastern and the western borders. Thus, at Austin, the average is nearly 33 inches annually, while on the Pecos side it sinks to about 15 inches. But the more important part of the area for our purpose receives an average annual rainfall not much below 25 inches, which, if well distributed and available, would be ample for agriculture.

The manner in which the rainfall comes is next in importance to the total quantity of it, because of its relation both to the percentage and velocity of run-off and to the checking power which a forest covering could exert. It happens that the Edwards Plateau region is in a zone of fluctuation as regards the type of rainfall; so that when, for example, the Eastern Gulf type prevails, as during the winter of 1902–3, a very heavy season of rainfall may occur entirely unaccompanied by destructive floods, while, on the other hand, an equally heavy season's rain may fall in a very few heavy downpours between April and July. An example of the latter was in 1900, when repeated destructive floods occurred. The amount of percipitation within a brief period may be extraordinary. Thus, at Fort Clark, toward the western border of our area, the June rainfall of 1900 was 22.32 inches, of which over 16 inches fell within twenty-four hours. During the same month, in 1899, occurred the great Brazos River flood, in connection with which the rainfall of a period of three or four days at Waco exceeded 18 inches.

Mr. Hill, in The Physical Geography of Texas (p. 11), calls attention to the recurrence of flood periods:

> This combination of overlapping conditions in the provinces mentioned, and the accompanying meteorologic phenomena, produce peculiar climatic conditions productive of erratic floods, which have an important bearing on the agricultural interests, and have, no doubt, been a factor in the peculiar erosion of the denuded central province.

ATMOSPHERIC MOISTURE.

The relative humidity and the evaporation capacity of the air have significance, also, both for the behavior of the precipitated moisture as affected by its rate of evaporation and for the occurrence of a protective vegetation; since the drier the air the more open and stunted the timber or other growth.

During most of the year the Edwards Plateau climate is dry. Even at Austin the average number of actually humid days during the year is small. From Burnet, Fredericksburg, and San Antonio westward the dryness of the air is notable—so much so that invalids requiring dry atmosphere resort thither—while in the Devils River country the air has the dryness and, in the summer, the parching heat of the desert. On the average, the evaporation capacity of the air over this region is sufficient to remove annually a free layer of water over 50 inches deep; which means that if the water which falls over the area were continuously and freely exposed as the surface of a lake, this thirsty air could drink it up twice over in one year.

We shall see later how a heavy timber covering operates to check this loss of water from the soil.

WATER SUPPLY OF THE EDWARDS PLATEAU.

This vast limestone country is the receiving area for an annual rainfall sufficient to cover its entire 15,000 square miles of territory with a sheet of water 2 feet deep. The important question is, what becomes of this water? If most of it runs off speedily it is, of course, lost to the region and its adjacent coast plain, so far as benefiting the growth of vegetation is concerned. If, on the other hand, it is detained to be doled out gradually by the limestone formation, its possibilities for plant life are enormously multiplied. As a matter of fact, the quantity lost by a rapid run-off no doubt materially exceeds that retained by the earth strata. But this, we have seen, is dependent upon certain conditions; especially upon the manner in which the rainfall comes, the topography of the area (the run-off being greater in the country of steep slopes and deep canyons than on the level uplands, unless it should happen that here the rock strata are flat, unbroken, and impervious), and upon the presence of hindrances to rapid run-off which detain the water until more of it sinks into the earth. The physical action of this flood water has been the principal agent in causing the dissection of the ancient plateau into its present aspect of hills and canyons. The drainage channels cut by the run-off waters constitute the present river systems of the area. (See frontispiece.)

RIVERS.

Two classes of streams are to be distinguished: (1) Those having their origin within the plateau area and cutting deep canyons in it before emerging upon the Coast Plain; (2) those which rise at the base of the escarpment, and which consequently, although owing their water supply to the plateau region, are structurally features of the Coast Plain.

Of the former class the Colorado is the foremost; for, although it heads in the Red Beds and Staked Plains, it is to be regarded in the main as a drainage system of the Edwards Plateau, from which it receives not only its major branches, the San Saba, Llano, and Pedernales, but also several important minor ones, like Beaver, Sandy, Spring, Cypress, Barton, and Onion creeks. Next in sequence westward come the Blanco, the San Marcos, and the Guadalupe, of which the last two receive strong reenforcements from the San Marcos and Comal springs, respectively, as they emerge from the plateau. West of San Antonio come, in order, the Medina, Hondo, Sabinal, Frio, Nueces, and Devils rivers. In the case of all of these except the Colorado, Guadalupe, and Devils rivers, while there are constantly flowing springs and water holes within the plateau area, the water, upon emerging from the escarpment, especially during dry seasons, often entirely sinks out of sight in the broken limestone bed, reappearing farther toward the coast. In the three exceptions named there is a flow which, though subject to fluctuations with the season's rainfall, is at all times relatively strong.

Of the second class of streams are the San Marcos, as reenforced by San Marcos Springs; the Comal, fed by Comal Springs; the San Antonio, fed by a series of springs; Los Ulmos, heading in the springs at Fort Clark; and the San Felipe, heading at Del Rio in the San Felipe Springs. In all these rivers the flow is remarkably constant, though naturally fluctuating somewhat with longer periods of drought or excessive rainfall. The quantity of flow will be found in the table of flow of springs on page 14.

All of these streams, but more especially the first group, which cut through the plateau, are channels for the flood waters of the region, which frequently descend with great volume and velocity, causing serious losses. Their permanent flow, however, is sustained by the springs of the region, which are fed by the retained waters. This leads us next to an inquiry as to the water-receiving capacity of the Edwards Plateau limestones. We have seen above that not only are the edges of the successive strata exposed either by normal outcrop or by erosion, but that the strata are much interrupted by clefts and fissures, minor faultings, and caverns, until the entire area possesses a very large capacity to take up the precipitated water. The magnitude of these fissures may be appreciated when one observes such volumes of water as that which flows from Kickapoo Springs suddenly disappear in the limestone bottom of the creek bed—a phenomenon also to be observed in the Nueces, and, indeed, in most of the minor tributaries of the region indicated above where they emerge upon the Coast Plain.

SPRINGS.

Some of the water retained by the limestones and their superficial soils is removed by evaporation, of whose intensity we have already learned. Some of it sinks to subterranean reservoirs and does not reappear unless the reservoir is tapped, when either nonflowing or artesian wells result. The rest reappears in the form of springs, of which Hill and Vaughan (p. 307) distinguish two types—gravity springs and fissure springs.

GRAVITY SPRINGS.

These springs are characteristic of the region itself, and are simply the flow of water from exposed rock strata in the natural course of seeking its level. Such springs form the heads of the various streams of the region. The famous Kickapoo Springs at the head of the west fork of the Nueces are an example.

FISSURE SPRINGS.

On the southern and eastern margin of the plateau is a line of springs which extends from Del Rio to San Antonio, and thence along the escarpment border to Austin and northward. These are fissure or artesian springs, whose flow is due to hydrostatic pressure. The water is forced up through the fractures caused by the gigantic down-throw or faulting which caused the escarpment itself. So great is the flow from some of these springs that full-fledged rivers boil from the earth within the space of a few square rods (Pl. I, fig. 2).

An approximation of the run-off from these springs may be had from the table following, taken from the geological report of Hill and Vaughan (p. 311).

TABLE I.—*Discharge of spring rivers arising from fissure springs.*

Date.	Streams.	Discharge per second.	Discharge per 24 hours.
1895.		*Cubic feet.*	*Gallons.*
December 18	Barton Springs	25	16,157,921
December 18	Dam Spring–Austin	4.3	2,800,000
December 19	San Marcos River	89	57,522,200
December 20	Comal River, New Braunfels	328	211,981,952
December 21	San Antonio River	42	27,145,308
December 21	San Pedro Springs, San Antonio	9	5,816,852
December 24	Los Moros Springs–Fort Clark	21	13,572,653
December 24	Del Rio Ditch	19	12,280,021
December 24	San Felipe Springs–Del Rio	80	51,705,350
	Guadalupe River, before junction with Comal	48	31,023,210
December 23	Sabinal River	0.6	387,790
December 23	Leona River	11	7,109,486

THE VEGETATION OF THE EDWARDS PLATEAU.

GENERAL DESCRIPTION.

The character of this vegetation is very clearly a product of climatic and geologic conditions. These combine to give it the stamp befitting an arid or at least a semiarid environment. Its structure and habits indicate that it is a xerophytic or dry climate vegetation; but though this is true of it as a whole, conditions vary enough to give in some places, as in well-watered and sheltered canyons, a relatively luxuriant growth, while in other situations, as upon stony arid slopes, there is the scantiest vegetation, by no means sufficient to hide the white glare of the chalky soil (Pl. III, fig. 2). On the western border of the region the vegetation bears a markedly desert aspect.

TRANSFORMATION OF PRAIRIE INTO TIMBERLAND.

It is of fundamental importance to note that the type of vegetation in this region is undergoing a change. This change, broadly indicated, consists in a transition from grass to woody growth. This transition is very apparent even to the casual observer. Everyone has observed how the mesquite captures the open pastures (Pl. IV, fig. 2), and many have watched the scrub oak timber occupy uplands that formerly were open prairies.

Some of the causes of this are reasonably evident. In the first place, dissection of the old plateau surface by the process of erosion has favored the establishment of forests in the rougher parts. Progress due to this cause, however, is too slow to be apparent. The presence of trees upward of 500 years old in some of the canyons is an index to the length of time forestation has been in progress. As one passes from the canyons and hills to the level plateau divides, the timber gives place more and more to open prairie, which, until within recent years, was free from woody growth of any kind. But these ranges have been overpastured, and the grass has consequently not succeeded in maintaining a continuous sod, and so has become unable to wage an equal fight against the shrubs which form the vanguard of the timber vegetation (Pl. IV, fig. 2). Again, settlement has stopped the periodic burning off of the grasses, which, while it left these in a condition to recuperate effectually, drove out the shrubs and prevented the timber from gaining on the prairie.

Nevertheless, in general, the Edwards Plateau is a timbered region only in the deeply eroded portions, becoming priarie on the level uplands, and finally passing into the great grass plains which stretch northward into Canada. One must, however, distinguish many degrees of forestation, according to the relative amount of available moisture. Through a gradual dwarfing and thinning out the timber passes from the big, heavy growth of the watered canyons to the stunted though continuous forest of the hills and bluffs (Pl. II, fig. 1) and the scant tree growth of the loose, stony slopes in the eastern part of the area (Pl. III, fig. 2), until at the west there remains only scattered chaparral, and finally the unique vegetation of the Sotol Country, in which the sotol, cactus, yucca, and agave reign supreme.

THE SPECIES OF TREES AND THEIR GEOGRAPHIC AFFINITIES.

The trees which make up the forests of central Texas—the personnel, so to speak—belong chiefly to the Atlantic type of forest, although Rocky Mountain species and semitropical Mexican species occur also, and in increasing numbers and importance as one goes farther west and southwest. The Atlantic type is represented by elms, live oak, post oak, black jack oak, overcup oak, and basket oak, black cherry, black walnut, pecan, sycamore, green ash, hickory, soapberry, and others. From the southern Rocky Mountain region are the piñon pine, two or three cedars, and several oaks, and from a more southerly range the mesquite, madroña, anaqua (knackaway), lignum-vitæ, and others.

Many of the trees of this region are its own peculiar product. Thus, the most abundant species of all, the mountain cedar (*Sabina sabinoides*), is practically confined to the central Texas limestone country. So also in the case of mountain oak, Mexican persimmon, and so on. Further, while these species are peculiar to the region, they are after all representatives of species ranging farther east in moister climate, and they indicate how the new and more trying environment has practically given origin to new species. The eastern red cedar becomes here the mountain cedar; black walnut is represented by the Mexican walnut, whose nuts are tiny balls scarcely half an inch in diameter. Texas oak becomes mountain oak. The common live oak becomes a new form in its mountain habitat. The common persimmon is represented by the Mexican persimmon, whose fruit is a dark blue-black; Canadian redbud is here also a characteristic "Judas-tree," but of a different species. The same is true in the case of buckeye, mulberry, hackberry, and still others.

DISTRIBUTION AND CHARACTER OF THE FOREST STAND.

It is not to be inferred from what has been said about the timber vegetation of this region that the Edwards Plateau is covered with continuous forest, even in its rougher parts. On the contrary, the timber is very much interrupted by open, grassy uplands. The present trend, however, is toward a continuous timber covering, and this fact has significance for the future water supply. Recalling the three simple topographic elements comprised in the structure of the region, viz, remnants of the plateau summit (or buttes and divides), mountains, and canyons, we have the basis for classifying the vegetation which forms a covering. This we may now consider more in detail.

TIMBER OF THE CANYONS AND STREAMWAYS.

The tongues of luxuriant forest growth which follow the streamways into the central limestone region are largely extensions of the forests of the Atlantic Plain. In deep, well-watered and sheltered canyons this timber attains large dimensions, and is a thick-canopied, shady forest, under whose protection many shade-loving shrubs and herbaceous plants from the moister Eastern States have established themselves. Thus is constituted a floral community altogether unlike that characteristic of the country roundabout; so that, in a floral zone quite new and strange, one coming from the Atlantic States meets in these canyons so many old friends of his native woodlands that he might easily fancy himself at home. In such places cypress has attained a diameter of 5 feet and over, and sometimes a corresponding height. The American elm, the sycamore, the pecan, the overcup oak, the basket oak, the cottonwood, sometimes the Texas red oak, and the hackberry become here large trees. Of smaller growth are black cherry, box elder, walnut, soapberry, and many others. Beneath these flourish dogwood, spicewood, buckthorn, smoke bush (*Rhus cotinoides*), hollies, and black haw. In the rich, leaf-covered humus the Canadian columbine grows under the ledges, and long fronds of fern overhang the streamlet's edge. This timber on wider bottomland, however, is not so luxuriant nor so like typical Atlantic forest as in narrow sheltered canyons.

THE HILL AND BLUFF TIMBER.

Mixed timber.—This constitutes by far the larger part of the timberland of the region. It abounds on the area of greatest erosion or dissection of the plateau. This is the type of forest occurring, for example, on the breaks of the Colorado, along the escarpment front from Austin westward, and on the Guadalupe, the Pedernales, and the Frio. It extends northward also upon the breaks of the Grand Prairie and the jagged hills of the granite country. The stand of timber

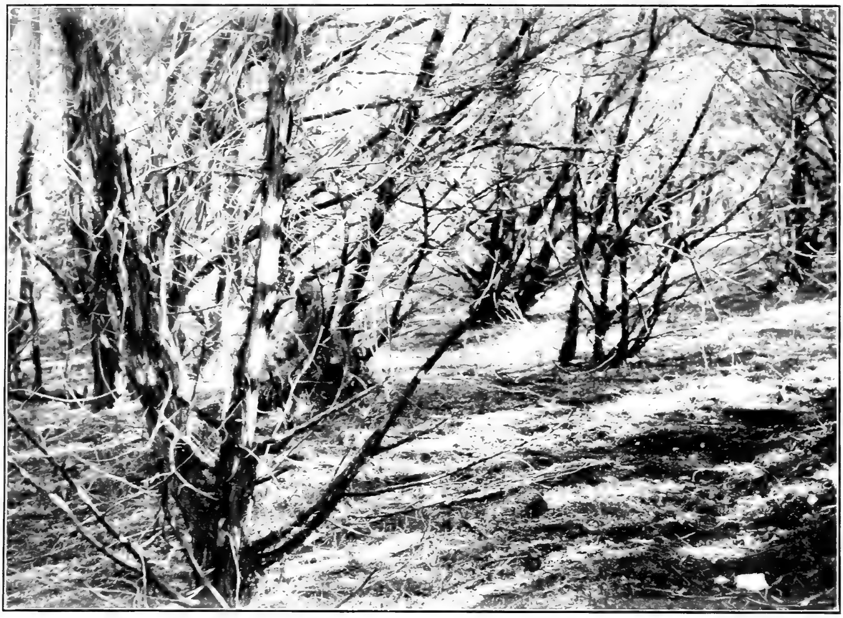

FIG. 1.—VIEW IN A CEDAR BRAKE.

The adobe soil and rocks are covered with a thin layer of brown soil and forest débris, showing capacity of cedar to accumulate soil even on the arid slopes of crumbly limestone.

FIG. 2.—CHARACTERISTIC OCCURRENCE OF CEDAR UPON A STEEP SLOPE COVERED BY LOOSE LIMESTONE TALUS, UPON WHICH MOST VEGETATION IS UNABLE TO ESTABLISH ITSELF.

Dry bed of Bull Creek.

varies in density with local conditions. On lower flats, where the soil is deep and black, there is a heavy mixed timber of cedar, live oak, cedar elm, hackberry, mountain oak, shin oak, and other species. This kind of timber also occupies the side gorges and draws leading out from the main streamways. (Pl. II, fig. 1; Pl. V, fig. 2.) Heavy also, though more stunted, is the timber on the level uplands known as "hardscrabble," where the limestone is hard and breaks in vertical fissures, as for example about McNeil, in Travis County. The same is true on the flat-topped buttes, where the rock is hard and fissured and the soil of good depth. Such timber-capped buttes may be observed on the Colorado 10 miles northwest of Austin, and again on Post Mountain at Burnet, and thence off toward the Colorado below Marble Falls. Where a crumbly limestone underlies the harder cap the timber ceases abruptly on the slope, the broken and unstable débris of this lower formation offering no foothold except for a few of the most hardy plants, like mountain cedar. Such timbered caps stand out in strong contrast with the white, scantily clad or quite bare slopes, and at a distance of many miles one can mark the lower edge of the timber line as clear-cut as if the mountain side had been artificially denuded up to the level of the harder stratum. Very often the harder cap has been wholly removed from the stratum of crumbly limestone, and this weathers into slopes of low gradient. Here an open, dwarfed timber growth establishes itself, generally of mountain cedar. This species, which elsewhere may be so close set as to form almost impenetrable brakes, becomes on this arid and unstable soil or rocky adobe a more open growth of individually rounded out trees. Rarely does the timber occupy these slopes so closely but that their white glare is visible through the foliage (Pl. I, fig. 1). That these slopes, covered with loose débris, may be captured and transformed by woody vegetation we hope to show in a subsequent paragraph. (Pl. III, fig. 2.)

Shinneries.—A special feature of the mixed timber covering on the "hardscrabble" limestone areas is that form of growth which has received the name of "shinnery." Although the shinneries are made up of the mixed timber above mentioned, they are generally thought of as oak shinneries, because of the predominance of dwarf shin oak. They are simply dense thickets which, both because the growth is relatively new and because the conditions are more severe, are scarcely more than tall shrubbery. Such, for example, is the dense thicket covering many square miles of the divide between the Colorado and the San Gabriel drainage valleys, in Burnet County. Much of this is too dense to ride through on horseback. It constitutes a favorite cover for deer, and as a soil retainer and gatherer is unsurpassed. Mixed with the shin oak is small live oak, mountain oak, hackberry, black haw, plum, sumach, and holly, and much thorny smilax, grapevine, and other climbers.

In addition to these types of mixed forest, which are distinguished from one another by differences in density and growth rather than in make-up, there are three very different types, two of which are characteristically pure, while in the third two species of oak dominate the mixture. These are mountain oak thickets, cedar brakes, and post oak timber.

Mountain oak thickets.—The mountain oak, also called Spanish oak (*Quercus schneckii*, a mountain form of *Quercus texana*), makes a tall, symmetrical, and rather rapid growth. Its timber is valuable for fuel and for some other purposes. On slopes of low gradient (formed especially by harder limestone which splits into large blocks), on the sides of gorges cut in this harder limestone, and on the flat tops of buttes this mountain oak establishes itself in dense thickets, and soon makes a most effective covering and protection (Pl. II, fig. 2). Beneath it débris collects rapidly. Its close stand, its uniform, symmetrical growth, and its fresh, green, finely cut foliage give it a beauty possessed by no other forest type of the region—a beauty which is enhanced when, with the coming of November frost, the foliage assumes the richer hues of red and orange, quite unlike the gradual somber browning of most deciduous foliage in this climate.

Mountain oak is most eagerly bought for fuel; the tree sprouts up quickly from the stump and is easily renewed. It ought to be more generally established in this region.

Cedar brakes.—The writer knows of no region in which any species of cedar is so uniformly abundant and dominant as is the mountain cedar in the limestone country of Texas. By any structural characteristic it is difficult to distinguish this tree from the red cedar of the Atlantic States, yet in its natural occurrence it does not suggest the red cedar at all. While the red cedar is associated largely with bottomlands, and even with swampy bottoms, the mountain cedar is one of the most pronounced and hardy xerophytic trees of all the arid Southwest. It is, in fact, one of the most valuable assets of the region, as well as the most characteristic feature of the hill timber. It is most conspicuous on the white, arid hills of crumbly limestone, because it is there the dominant and practically the only species (Pl. I, fig. 1; Pl. III, fig. 2). But it also grows in mixture with other species, and attains its largest growth in the mixed forest of lower flats already described, where there is more water and richer, deeper soil. In such situations the best yield of poles and ties is found. Reasonably clear poles 20 to 30 feet in length and with a base diameter of from 1½ to 2 feet were formerly common.

The typical cedar brake is an almost impenetrable growth, the interlocking branches of the close-set trees persisting to the very ground

(Pl. III, fig. 1). It is true that some natural pruning occurs, but the intense light of this climate is little checked by cedar foliage, and so the undermost branches are not starved as they would be with a shadier foliage or in a climate of greater humidity and less intense illumination. There is no such thing therefore as a mountain cedar pole free from knots.

Although we have no very definite information as to the total area originally covered by commercial cedar or the amount still available, it is tolerably certain that the ground actually covered by the species, including what is being reforested or newly occupied, has not been greatly diminished. Cedar land is not of much value for farming purposes, and tends after clearing to be rapidly regained by young growth (Pl. IV, fig. 1). It would appear, however, that there are some noteworthy exceptions to this. For example, instances are cited from Bell County where cedar clearings were captured by mountain oak, and a very capable observer in Kerr County writes:

> When the brakes are once burnt out they never recover, but very soon grow up with different kinds of brush. * * * Some of my own cedar was burned about five years ago, and the ground is now covered with shin oak and Spanish oak sprouts.

The writer's observations as to the behavior of cedar on cleared lands on the Colorado would seem to justify the statement that it tends to regain ground formerly occupied by it, as well as that cleared of oak and mixed timber, and that in many cases it is rapidly spreading over slopes hitherto wholly free from timber. (See Pl. IV, fig. 1.)

In general, cedar timber occurs upon all of the hilly or rough parts of the limestone region of Texas from the Palo Pinto country to the Colorado, and thence westward over all of the drainage breaks and the escarpment nearly to the eastern forks of Devils River. The most extensive bodies of cedar known to the writer are those of the Colorado River breaks from Austin to the San Saba country. Mr. Howard Lacey (whose opinion has just been quoted in connection with cedar reforestation) says:

> There is a vast quantity of cedar on the upper waters of the Frio, Nueces, Llano, Guadalupe, and Medina rivers. The scattered brakes begin a little way this side [west] of San Antonio, are at their best on the heads of the rivers named, and apparently play out about the heads of Devils River.

The post oak timber.—In a previous paper (Bulletin 47, U. S. Bureau of Forestry) the writer attempted to describe this type of forest and to give its geographical distribution in Texas. It is not a timber of limestone formation at all, but of sand and gravel-covered areas, such as the east Texas Lignitic Belt, the Cross Timbers, the Carboniferous area in central and north Texas, and the granite gravels and sandstone débris of the granite area. Smaller patches of this timber occur also on old gravel terraces, as in the vicinity of Austin.

Black jack and post oak constitute the chief elements in this type of timber, the post oak forming the more abundant and larger growth. The largest bodies of this timber of significance for our present discussion are those of the granite country. From Marble Falls to Llano the post oak timber is more or less continuous, generally forming an open, park-like growth, but sometimes a thick forest covering, as in the vicinity of Granite Mountain. On the rich and moister sandy loam near Fredericksburg is heavy post oak timber of large size, with a dense undergrowth and a larger percentage of other hardwood trees than is usual on the more arid gravel beds.

COMMERCIAL VALUE OF THE HILL TIMBER.

This phase of the subject is of importance for our consideration, since it affects the treatment of timbered tracts, and consequently their relation to water supply.

With the exception of cedar, the hill timber finds a market chiefly as fuel, of which enormous quantities are consumed, both in stoves and grates and in the furnaces of lime and brick kilns, gin engines, etc. Cedar likewise is extensively consumed as fuel and in charcoal burning; but its great value lies in its yield of railway ties, poles, posts, sills, and innumerable other articles which utilize its great durability.

A large part of the support of the hill country population comes from the sale of wood for fuel. Especially during those parts of the year when the cultivation and harvest of meager crops does not claim their time, woodcutting is a prominent industry and an essential resource wherever markets or shipping points are within teaming distance.

Cedar is handled at all points within hauling distance of brakes; but cedar timber large enough to furnish ties and poles is becoming scarce, except in remote districts. Much is still handled at Marble Falls, Kerrville, Boerne, and other points not specifically known to the writer. Locally, cedar furnishes construction material for every possible demand, as for rail fences, slat or picket fences, fence posts, house sills, supports, and joists; so that, altogether, available supplies are constantly drawn upon, often to their temporary exhaustion and to the great detriment of the denuded hillsides.

AGENCIES WHICH TEND TO REDUCE THE TIMBERED AREA.

CLEARING FOR FARM LANDS.

It was to be expected that most of the timber on the rich bottomlands would be cleared off in order to bring the land into cultivation. This sacrifice of the timber seems, on the whole, to have been advisable and profitable. A considerable amount of level uplands has also been cleared. Where the soil was deep enough and rich enough to make cultivation continuously profitable, this was the best use to make of the land. The cases in which injury has been done are those in which timber has been cleared from thin-soiled, stony slopes in order to cultivate in a slovenly fashion for a few seasons, after which the land is worn out and abandoned. These clearings constitute the little cotton patches or cane and truck patches of mountaineers.

THE DEMAND FOR FUEL, POSTS, TIES, AND OTHER CLASSES OF TIMBER.

We have seen that the commercial value of the timber, particularly of the cedar, results in a heavy drain on the supplies. So long as small owners depend in large measure for their income upon the sale of wood, the temptation will be strong to denude rough, thin-soiled hillsides which would far better be kept with a protective timber covering (Pl. II, fig. 2). While it is not to be expected that the private owner will ever wish to maintain a protective forest cover in behalf of the community at the sacrifice of personal profit, there is nevertheless room to hope that private owners will eventually find they can make more in the long run if they cut conservatively. Under the pressure of public sentiment and with the guidance of a practical object lesson, these timber owners may find it possible both to sell the merchantable timber and at the same time to maintain a protective covering for the hills. In this, fortunately, they will be assisted by the natural tendency of this forest to reoccupy lost ground.

CEDAR BRAKE FIRES.

There are few types of forest which more invite destruction by fire than the cedar brakes of dry central Texas. It is probable that during the past twenty-five years far more cedar timber has been burned than has been marketed, and vastly greater areas denuded by fire than by the axe. A cedar brake during the dry season is almost as likely a mark for fire as a prairie covered by tall dry grass. The evidence of fires recent or ancient is always near at hand. Some hillside has been swept bare, or a whole succession of formerly cedar-covered hills has been denuded of timber. The writer has not attempted to collect information about cedar brake fires methodically, but conversation with old residents reveals the fact that each community has had its fires.

The most destructive fire reported in several years was that which raged for over two days near Marble Falls, in July, 1901. The following extract from a correspondent's statement in the Austin Statesman of July 7 will indicate the local interest:

> Intelligence has just reached here to the effect that a great deal of valuable cedar land in the immediate vicinity of Marble Falls has been destroyed by fire. * * * The conflagration has been burning since Friday. * * * The residents have made heroic efforts to block the course of the fire, but so far they have not succeeded. * * * Of course a great many people living there are interested in those

timberlands. * * * For a time the place fairly went wild, and everyone seemed to be in a frenzy of excitement. Up to the time when I left nothing definite had been learned, although it was known that many thousands of dollars' worth of cedar had been consumed.

ENCROACHMENT OF TIMBER GROWTH UPON THE EDWARDS PLATEAU.

In previous paragraphs there has been occasion to mention the energy with which the timber tends not only to renew itself on ground previously occupied, but also to gain upon the untimbered slopes and even upon the grass prairie. It was pointed out as a striking phenomenon that the region is in reality in a gradual process of transition from open prairie to forest land. This phenomenon is by no means peculiar to the Edwards Plateau. The Rio Grande Plain strikingly illustrates it. In that region the mesquite and chaparral have captured hundreds, perhaps thousands, of square miles of open prairie.

ENERGY AND RAPIDITY WITH WHICH LANDS ARE REFORESTED.

Specific data concerning the growth rate of the various species of trees in the climate of central and western Texas are not at hand. Naturally, however, under the semiarid conditions prevailing on the hills, this rate is slow, and the timber is characteristically hard and stunted.

Renewal is partly from young timber left on the ground, partly from seedlings, and in a considerable degree from coppice growth or sprouting from the stump. This latter method is especially characteristic of oaks. Mr. Lacey's statement that five years after a cedar-brake fire on his land in Kerr County the ground was covered with shin oak and Spanish oak sprouts has already been quoted. Some hillsides near Austin from which the timber was cut five years ago are now fairly covered with young growth. On numerous clearings in the same neighborhood seedling cedar occurs in thickets. Indeed, this hardy tree appears to be the most strenuous ground-gainer of all. The most striking instance known to the writer of its capacity in this respect is afforded by a tract on Dry Creek, near Austin, from which the timber was cleared twenty-five years ago. During the past two or three years this tract has again been cut, with a large yield of fuel timber. Fig. 1 of Pl. IV shows the condition of the cedar brake after twenty-five years' growth. Of course there was very little, if any, tie or post timber in this, and no clear heart cedar. Mention was made earlier in this paper of the prompt and rapid reforestation of denuded cedar brakes by mountain oak in Bell County. These instances suffice to show that the forest type of the limestone country is very strenuous in maintaining its ground.

HOW SCRUB OAK TIMBER GAINS ON THE UPLAND PRAIRIES AND DIVIDES.

Though the encroachment of timber on the prairie is gradual and insidious, to those whose observation covers a space of twenty-five years the change is truly startling. Where at the beginning of that period the prairie held undisputed sway, the observer now finds himself shut in by miles of oak scrub on every side. Men who drove cattle in the earlier days say that they rode across an open country from above Georgetown to the Colorado breaks, in Williamson County. This same region is now all heavily timbered. A great deal of the shinnery country undoubtedly represents a recent gain of timber growth on prairie divides.

This struggle of the timberlands to capture the grass lands is an old warfare. For years the grass, unweakened by overgrazing of stock, and with the fire for an ally, held victorious possession. Now the timber has the advantage. It spreads like infection. From the edge of the brush each year new sprouts or seedlings are pushed out a few feet farther, or, under the protection of some isolated live oak or accidental briar or shrub, a seedling gets its start, and presently offers shelter for others. This has been going on all along, but in former days these members of the vanguard and the scattered skirmishers were killed by the prairie fires, and the timber front was held in check or driven back into the hills.

HOW CEDAR CAPTURES ADOBE SLOPES.

It will be recalled that some of the limestones of this region break up on exposure into a crumbly débris, ranging from cobblestone size to adobe clay. Slopes occupied by this débris are long and gradual, except where harder strata alternate. On account of the unstable and arid nature of the formation, vegetation is commonly too scanty to hide the white glare of the limestone.

The mountain cedar has shown its capacity to establish itself upon such slopes in advance of every other species of timber, and almost of every other plant. Pl. III, fig. 2, shows the cedar on a steep slope where harder limestones intervene. This furnishes a particularly picturesque and parklike view, to which the photograph has by no means done justice. There is a beautiful gradation in size of these symmetrical young trees, from the youngest bushes toward the flats to the old trees which cap the summit of the buttes, from whence the invasion began.

THE SPREAD OF MESQUITE AND CHAPARRAL.

By no means the least striking phenomenon in this campaign of encroachment of timber upon prairie land has been the spread of the mesquite over the cattle country. Mesquite is essentially an occupant of flat prairie lands; hence its extension in the hill country proper is limited. But throughout the area of the Edwards Plateau it has established itself upon pastures, often covering these with a thicket as close as that of the scrub oak. More commonly, however, the mesquite forms an open, orchard-like growth, into which finally enter various shrubs, or chaparral species, with very commonly the prickly pear and the slender round-stemmed Opuntia. The final result of mesquite encroachment is a heavy covering of vegetation, which, however well it might serve as a protector of water supply and soils, is to be regarded as an incubus upon lands which would be vastly more profitable under cultivation or under a good grass cover.[a]

The capturing of pasture lands by mesquite is shown in Pl. IV, fig. 2.

HOW THE TIMBER GETS STARTED ON STEEP, ROCKY HILLSIDES.

The characteristic way in which some types of limestone formation have been eroded leaves them so steep and bare of soil that timber trees can find no anchorage. Even the cedar is for the most part absent; but more likely because there is so little opportunity for seeding than because of lack of adaptability to the location. The writer has observed that certain shrubs, especially a southwestern sumach (*Rhus virens*), find lodgment at the base of the low ledges of the harder limestone strata, and, spreading thence, form a protection for other species which slowly come to occupy the difficult location.

INFLUENCE OF THE EDWARDS PLATEAU TIMBER UPON CLIMATE, SOIL, AND WATER SUPPLY.

The foregoing pages have described the importance and character of the water supply derived from the Edwards Plateau, and the timber growth found upon it. It remains to consider the relation of this timber growth to the water-yielding capacity of the region, with a view to discovering what practical conclusions can be drawn as to how to secure the best usefulness of the forests.

INFLUENCE OF THE TIMBER GROWTH UPON CLIMATE.

Although the general subject of the influence of forests upon climate has been for many years under careful investigation, final conclusions have not yet been reached. The widespread belief that forest destruction on a large scale brings after it marked climatic changes rests on no scientific proof, and is undoubtedly in part at least the result of a misinterpretation of certain broad facts. That flourishing forests and a moist climate go together, while the nearer the approach to arid conditions the sparser and poorer does the tree growth become,

[a] On many square miles of the Rio Grande Plain the mesquite has already become a thicket, harboring the prickly pear and shrubby growth to the great detriment of the cattle ranges. In spite of this the mesquite must be looked upon as a prolific source of fuel, and to a less extent of construction material.

FIG. 1.—CEDAR BRAKE NEAR AUSTIN TWENTY-FIVE YEARS AFTER FIRST CUTTING.

A heavy crop of fuel and charcoal. Shows capacity for reforestation.

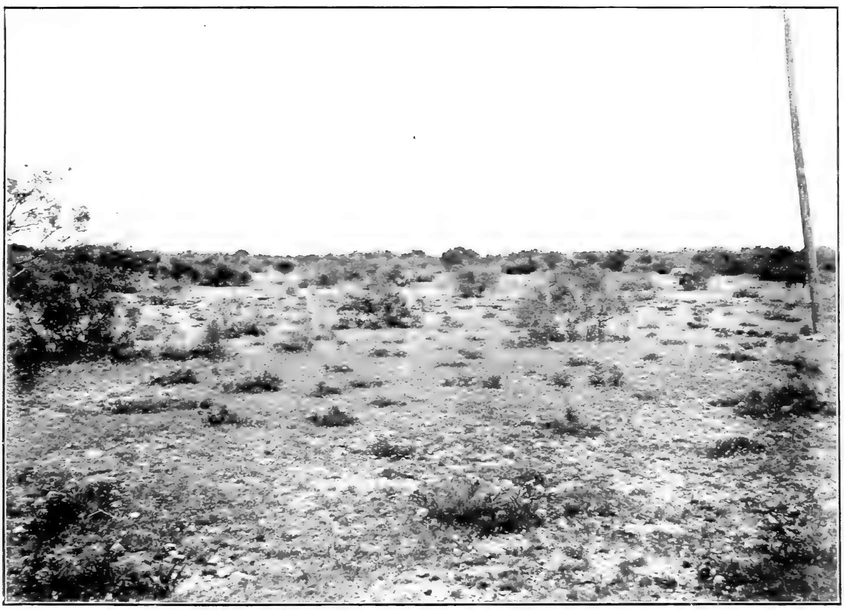

FIG. 2.—CHARACTERISTIC ENCROACHMENT OF MESQUITE ON PASTURE LAND IN CENTRAL TEXAS.

With the exception of a few scattered live oaks this was a clean prairie a few years ago.

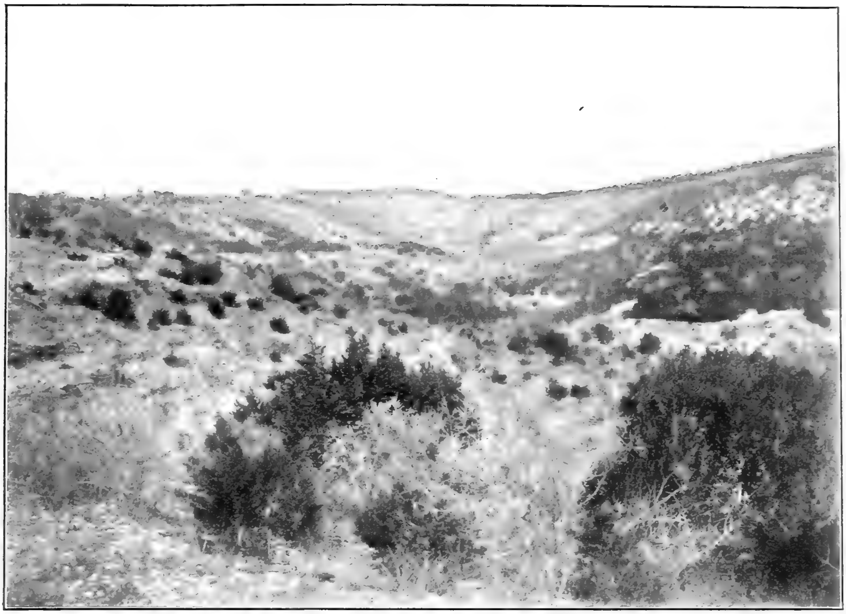

FIG. 1.—"SOUTH GORGE" AT ITS HEAD UNDER LONE TREE HILL, NEAR AUSTIN.

The slopes have been denuded of timber. The run-off water after heavy rainfall is very violent.

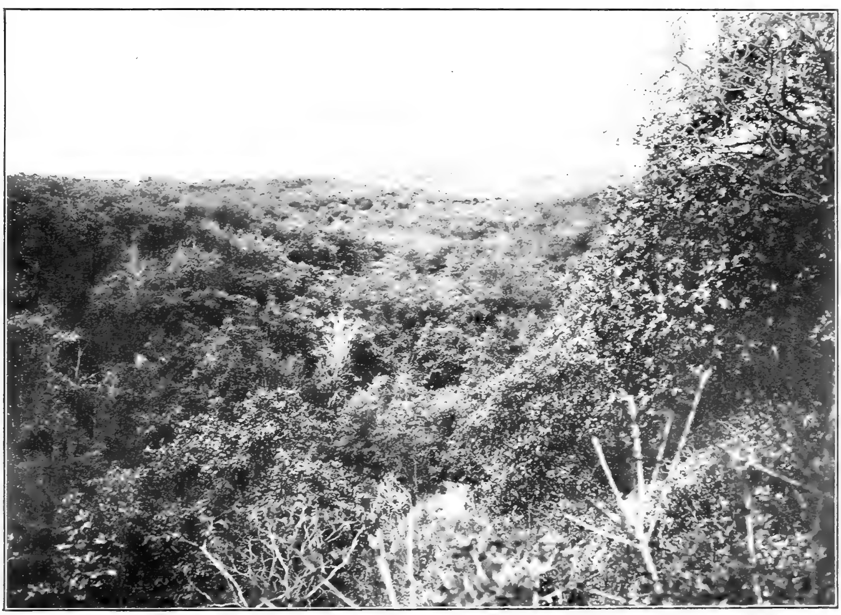

FIG. 2.—"NORTH GORGE" FROM LONE TREE HILL.

Heavily timbered slopes. Violence of rainfall broken and rapid run-off prevented.

is known to everyone. It is also a matter of common observation that forest denudation is followed by marked changes in the character of stream flow and in the permanency of springs. Forests also protect from drying winds and sunshine, and tend to maintain a higher water-level in the soil. A natural but mistaken inference from these facts is that an absence of forests makes a dry climate. It may be that forest removal over large areas does appreciably lessen precipitation, though conclusive evidence of this has never been secured, but a sufficient explanation of all that has just been said is found in the undoubted truths that a moist climate favors forest growth, and that forests economize the rainfall by retarding evaporation and equalizing distribution.

Bearing these facts in mind as a preliminary caution against drawing too wide conclusions from what may be said, it is possible to set forth certain ways in which the forests of this region may exercise more or less influence on the climate. How important this influence may be is another matter. The climatic features likely to be chiefly affected are temperature and humidity. To discover by observation within the region itself to what degree forest growth does actually influence these would be exceedingly difficult, if not impossible; especially in view of the marked instability of weather conditions as well as wide variations within short distances which, as already remarked, characterize this transitional zone. Such facts can be established anywhere only after the most careful and long-continued meteorological observations and measurements. Some general principles, however, are now commonly accepted by students of forest problems, and by fitting these to the conditions which we know to exist in the Edwards Plateau region certain deductions may fairly be made. But the method thus employed is, so far as the particular locality is concerned, theoretical, not experimental, and at best can lead only to very indefinite conclusions as to the actual extent of the influence on climate which it is possible to ascribe to the forests of the plateau.

INFLUENCE UPON TEMPERATURE.

In the first place, the forest cover furnishes a canopy against the sun's rays, which, with the accumulated soil and débris incident to forest growth, prevents intense heating of the rocks. The burning sensation of the reflected midday heat is vividly present to those who have toiled on horseback or in a stage over the stony wastes of the Devils River and Pecos countries during midsummer. Here an endless stretch of bare limestone is exposed to the most intense sunlight, until the air feels like the blast from a furnace. The transpiration of water vapor which is constantly going on from the leaf surface of a forest also operates to reduce the temperature to some degree, just as drinking water is commonly cooled in this dry air by suspending it in the breeze in an open pail or in a porous earthen vessel. Over against this, however, must be set the fact that the transpiration from heavy grass is still greater than that from a forest. But in those regions which are too arid to support more than a scanty vegetation of other than forest growth, the presence of timber would doubtless conduce to some mitigation of the intense heat, and would also tend to increase the moisture in the air through evaporation from the leaves.

INFLUENCE UPON SOIL AND WATER SUPPLY.

One of the most important services of a forest cover is the mechanical effect which it exercises upon falling rain and upon the run-off. In this way it both checks erosion and promotes the entrance of water into the earth. In the first place, the crowns of the trees, especially when the foliage is on, break the force of the rain and cause it to run harmlessly down the trunk, or to drip slowly through the canopy. Further, the organic débris of the forest floor holds back the fallen water until it has time to soak into the soil. The spreading and interlacing network of roots serves the same purpose, and binds the soil fast against erosion. Thus the rain is kept from swift discharge into the streams, gullying is prevented, and the run-off does not gain sudden volume and velocity after a downpour. The removal of timber from broken or mountainous areas is pretty sure to be followed by more frequent and destructive floods.

A forest also increases the water supply from a region by increasing the moisture-holding capacity of the soil. The undecomposed litter which forms the upper layer of the forest floor will itself take up much water, as well as delay its run-off. A thick mat of leaves will be wet at a little distance down long after those on top have become thoroughly dry. Still lower, the half-decayed rubbish is like a sponge in its water-holding power. And finally, the humus, or forest soil proper, with its loose texture and large proportion of organic matter, is peculiarly fitted to delay percolation. Thus the forest builds up a storage reservoir, the loss of which often makes necessary the construction on a large scale of artificial lakes to conserve the water supply. This work the forest does not only without expense, but while itself growing wood.

Not only does the forest store water in the soil, but it also prevents its loss by evaporation. The trees themselves shield the ground from the sun, and check the movement of drying winds. They also keep the soil cool, and in consequence lessen the giving off of moisture. This defense against evaporation is further reenforced by the undergrowth and the leaf litter, while the forest soil itself acts as a mulch to prevent drying out. We have seen that the dry air of the Edwards Plateau region is capable of removing by evaporation over 50 inches of free water in the course of a year. When rain falls on the bare earth, therefore, the thirsty air soon takes most of it up again, rapidly drying out the earth to a depth fatal to any but very deep-rooted plants. More extreme is this drying out when the surface is covered by loose stones, as is the case with most of the limestone country, especially west of the timber belt. It is true that a forest evaporates much water from the foliage, but it draws this largely from the lower soil levels; so that, even if the total loss of water from a forest area were equal to that on an exposed area, the earth would not be baked so dry, nor would shallow-rooted herbaceous vegetation be so effectually excluded.

Pl. II, fig. 1, illustrates the value of heavy timber covering in this direction. The canopy of foliage itself is heavy. Beneath, there has been an accumulation of organic débris to the depth of from 8 to 15 inches, the lower layers of which are decomposed into pure humus soil. In such places flourish moisture-loving plants which are altogether wanting on similarly situated naked slopes. (See Pl. V.)

For all these reasons forests tend to conserve the water supply and to maintain full springs and an even flow of streams.

ILLUSTRATIONS OF THE EFFECTS OF THE EDWARDS PLATEAU FOREST.

Conditions in the vicinity of Austin furnish an unexcelled opportunity to observe both the effect of heavy timber upon the behavior of precipitated water and the results of rainfall on bare slopes. Beginning at the site of the old Austin dam, there is a series of deep gorges which extend for 10 miles up the river, and head in the high hills of the divide between the Colorado and Barton Creek. Two such gorges lead down from Lone Tree Hill (Pl. V, figs. 1 and 2). The head of each gorge spreads out in slopes which lead upward to the summits of the hills like an amphitheater, and, by their convergence below, act as a funnel to direct the water into the channel of the stream. The slopes of the southernmost of these gorges, though well timbered below, have been almost denuded farther back, especially over the part likened to an amphitheater (Pl. V, fig. 1). The northernmost gorge is heavily timbered throughout (Pl. V, fig. 2). The slopes of the southern gorge are denuded of soil down to the rock and adobe, and are never covered with more than a scanty growth of drought-enduring plants, which do not suffice to hide the white, arid slopes. The channel of this gorge is swept clear of organic débris and even of the finer rock débris, leaving a rough, stony channel.

On the slopes of the northern gorge, under an almost impenetrable growth of cedar and mixed timber, there has accumulated a deep layer of rich soil covered by an unreduced débris of fallen leaves and twigs. Loose stones, which even a moderate flood would sweep downward, lie on the slopes, as well as the loose leaf litter—striking evidence of the difference in conditions between this and the southern gorge.

At the bottom of the gorge the timber growth still continues, almost blocking the channel, which, instead of being swept clear by flood water, is filled with forest litter and fine mineral sediment.

What happens in these two cases after a heavy rainfall? In the south gorge the water at once begins to pour down as from a steep roof, converging into swift streamlets which erode every vestige of organic soil, and in addition the adobe and smaller stones, which it often piles in heaps below. Uniting at the main channel, these flood waters pour down with the characteristics of a mountain torrent. In the north gorge, on the contrary, the downpour, particularly during the season when foliage is on (which is also the season of heaviest rains), broken by the timber covering, is shorn of its force, and, instead of packing the soil and débris and then running off, is largely taken up by the porous ground. Thus the water is prevented from getting head enough to form a flood or to erode the soil, and at the same time is detained so that vastly greater quantities are absorbed by the limestone formation beneath.

In the case of some of the gorges farther up the river, e. g., Devils Gorge, the upper slopes are bare; but farther down there begins a heavy growth of mountain oak or mixed timber, which extends to the bottom of the gorge. Beneath this is a rich soil, covered by a foot or more of looser organic débris, which disorganizes slowly because so persistently dried out, but which retains moisture beneath and is all the more active in absorbing the rainfall. In spite of the velocity gained by the water on the upper slopes, its progress is so checked by the vegetation and débris below that only after an unusual downpour does the channel flood attain violence.

It is unusual for any of these short gorges to maintain running streams throughout the season. Ordinarily they are entirely dry before midsummer. In those gorges whose slopes are denuded, the flow ceases almost directly after each fall of rain. But there is one gorge which furnishes a very instructive object lesson of a different character. It is some 12 miles up the river from Austin, and is heavily timbered. During the spring of 1903 this gorge became a favorite resort because of its natural wooded beauty, and especially because of its series of cascades and deep, clear pools. It had all the appearance of a mountain stream of the humid Eastern States. The streams which feed the streamlet appear to be gravity springs, from which flows water which has fallen upon the local catchment area.

Naturally, their flow reflects the season's rainfall. The upper spring, at least, dries up with the advance of the dry season, and the flow from the main lower one becomes very meager. Nevertheless, these springs were still flowing freely long after the streams in all the other gorges had been completely dry. This difference seems to be due to the two facts that, in the first place, the local catchment area (the slopes feeding the gorge) is larger than the others, and, secondly, that the slopes and bottom of the gorge are densely timbered and possess a heavy covering of loamy débris beneath.

Let us suppose that what is true for the small area just described were true in the case of the whole plateau region. The effects as to checking floods, collecting soil, preventing erosion, promoting the entrance of water into the earth, and maintaining a longer and more constant flow of springs and streams would be multiplied many thousandfold. That would be a fact of vast significance for this region in its relation to the activities of human life within it, and still more to those of the rich plain on its coastward side.

This enforces the fact that from the point of view of water supply the Edwards Plateau is to be regarded as sustaining the same sort of relation, if not in the same degree, to the Rio Grande Plain that the Sierras do to the San Joaquin Valley, the Wasatch Mountains to the irrigable lands about the Great Salt Lake basin, and the Rocky Mountains to the high plains in Colorado.

THE PROBLEM OF MAINTAINING A FOREST COVER ON THE HILLY COUNTRY OF THE EDWARDS PLATEAU.

The problem of dealing with such a region as the Edwards Plateau scarcely falls within the scope of individual enterprise, although if cooperation between private owners and the State could be brought about, it would result in mutual gain. The rice planter on the coast wants the most constant flow possible in the Colorado, Guadalupe, San Antonio, and other rivers. Ranchmen on the inner border of the coast plain want the largest possible flow of artesian water. The hill ranchmen want their soils preserved and built up and the level of soil moisture kept near enough to the surface to be available for crops. All desire to see destructive floods prevented; all want this water held back to be given out so as to be utilized. All these classes of citizens would be gainers if the rough country were kept fully timbered and the dry plains covered with heavy grass. At the last it will rest with cattlemen of the plains and with ranchmen of the hills whether their pastures are worn out by overgrazing and their hills denuded by unwise cutting. In the long run, these men will find that they can both pasture the plains and market the timber without destroying the protective value of a grass cover on the one hand or of a timber cover on the other. Meanwhile the rough breaks of the margin of the plains, which are not especially valuable for pastures, and certainly of no value for farming, offer a task the performance of which, in the writer's opinion, may be undertaken only by the State itself. Considering all the interests dependent upon the water supply of this region, there would seem to be little ground for opposing the policy of maintaining (and where necessary establishing) a forest cover upon these arid hills. Cooperation with individual owners fails to meet the needs here. Nothing short of absolute ownership and management by the State will suffice.

In Bulletin 47 of the Bureau of Forestry the writer has discussed more fully the question of the relation of the State of Texas to its forests. Without repeating what was said there, it may be remarked that the present is a rather auspicious time and the water supply of the Edwards Plateau a practical opportunity for the State to enter upon a policy of forest management in the interests of its people. We may, in conclusion, refer to the possibilities of water storage in canyon reservoirs on the margin of the plateau overlooking the Coast Plain as a field for further activity by the State, analogous to the recently adopted comprehensive irrigation policy of the National Government.

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United States Department of Agriculture,

BUREAU OF FORESTRY.—Circular No. 27.

GIFFORD PINCHOT, Forester.

RECLAMATION OF FLOOD-DAMAGED LANDS IN THE KANSAS RIVER VALLEY BY FOREST PLANTING.

The flood of 1903 did great damage to much valuable land in the Kansas River Valley. The injured lands may be classed under the following four general heads:

(a) Sanded lands.

(b) Eroded lands.

(c) Eroded lands subsequently silted.

(d) Caving river banks.

Lands that were silted but not eroded are not classified as "injured," since it is believed that such lands were benefited rather than injured by the flood.

The following recommendations for the treatment of these lands are made with full knowledge of their former great value for agriculture, and with a keen realization of the extent of the damages wrought by the greatest calamity that ever visited this fertile valley.

SANDED LANDS.

At least 5,000 acres of fertile plowland were buried in coarse sand to such a depth as to be rendered worthless for agriculture for many years to come. This should receive the first attention, for the sands are likely to be shifted by the winds and deposited on land that is now fertile. In order to fix this sand, cottonwood trees should be planted over its entire surface this spring (1904). The flood of 1903 caused millions of cottonwoods to germinate on fields that were too wet for cultivation. From these natural nurseries may be obtained all the seedlings needed. If the planting is delayed until another year, the seedlings will be too large to plant, and the sand will have been blown into ridges, so that the ground will not be in as good condition for planting as it is now.

The cottonwood seedlings on farm lands should be gathered when the ground is plowed for a spring crop. It may be that a boy riding the front of the carriage of a sulky plow can catch and pull out from the loosened soil the best specimens before they are turned under. Otherwise they must be taken from beside or behind the plow. When an armful has been collected, the roots of the trees should be buried in the fresh soil for protection until they can be planted. The planting is a very simple operation. It may be advantageously performed by a man and a boy working together. The man, driving a spade into the sand, makes a slit, into which, behind the spade, the boy slips a tree; the man then withdraws the spade, tramping the soil about the tree as he advances to plant the next one. The trees should be planted about 6 feet apart each way. This distance will require 1,210 trees per acre. The sanded land is already partially stocked in many places with trees from natural seeding, so that a considerable amount of the work of planting will be saved if this growth can be utilized. But to do this, planting must begin at once, because the irregular and scattered nature of the stand will cause such naturally-planted trees to be branchy if left in their present density, rendering the future growth almost worthless. Close planting will cause the young trees to form clean, straight boles.

After the plantation has grown six or eight years, it should be thinned by removing about half the stand. A second thinning at the end of twelve to fifteen years should remove about half of the remainder of the trees. At the end of twenty years the majority of the trees remaining may be cut out for sawlogs.

ERODED LANDS.

The eroded lands from which the fertile soil has been partially removed may be profitably planted to black walnut or hardy catalpa. If the plantation is to be made of catalpa alone, the work of planting should begin immediately. For this purpose one-year-old seedlings should be purchased from a nursery.

The trees should be planted from 4 by 8 to 4 by 6 feet apart. This rate of planting will require from 1,360 to 1,815 trees per acre. The catalpa after planting will need as good cultivation as is usually given to a corn crop. For the first two or three years the young trees must be kept free from weeds.

The catalpa may also be planted on sanded land, provided the sand is not over 2 feet in depth. This tree requires a rich soil, but its roots, which at maturity reach down to a depth of 4 or 5 feet, will quickly penetrate a foot or two of sand.

If the walnut is desirable it will probably be more profitable to plant it in mixture rather than in pure plantations. The walnut grows so slowly than the planter would have to wait too long for returns. If planted in mixture with such a rapid-growing species as the catalpa, the walnut seeds should be planted in the permanent sites two or three years prior to the introduction of the catalpa. This will give the walnut seedlings time to gain sufficient height to avoid being overtopped by the more rapidly growing catalpa. The catalpa makes its most rapid growth during the first ten years of its life, and matures early, while the walnut persists in its growth for a century or more. The Kansas River bottoms are exceedingly well adapted to the growth of walnut, and for a permanent forest growth there is no better species. Like the catalpa, it requires a fertile soil, and will probably give poor returns on lands covered with more than 2 feet of sand.

LANDS ERODED AND SUBSEQUENTLY SILTED.

Much land in the Kansas River Valley had the surface soil removed for several feet in depth, and was then covered with silt from a few inches to a foot deep. Where this land lies so low that it is likely to be submerged at every future freshet, the best way to manage it is to let it grow up to willows and cottonwoods. The trees will collect the silt at each rise in the river, and will assist in building the soil up to its former level. Where the land is not so low as to be liable to inundation oftener than once in four or five years, such rich silted flats may be profitably planted with hardy catalpa.

CAVING RIVER BANKS.

At many places along the stream the flood has left perpendicular banks of soft soil that are being constantly undermined by the current, causing the land to cave into the river from time to time. It is very important that such places be protected, for every such caving bank is a menace to all the land lying back of it in the valley.

In such a valley, where the bed of the stream does not come within scores of feet of bed rock, the use of stone structures for protecting the river banks is very expensive, and at the same time ineffective. The most successful method of protecting a soft alluvial river bank is to make it sloping instead of perpendicular, and to keep it covered with vegetation.

The willow is admirably adapted to holding alluvial soil in place. It is far more serviceable for this purpose than walls of masonry, and the facility with which it reproduces itself by seed, suckers, sprouts, and cuttings, both natural and artificial, makes its use very simple and inexpensive.

The great difficulty with planting any sort of tree on perpendicular banks is that the caving of the soil is so rapid that the planted tree has no opportunity to get a start before it is undermined and precipitated into the river. An excellent scheme has been proposed by Mr. E. Bayles, of Linwood, Kan. The plan is as follows: Green willow poles 18 to 20 feet long are secured in the spring, just after the ice goes out of the stream. These poles are laid on the ground near the bank 2 feet apart, with their butts all pointing toward the river. Woven fence wire is then stretched along over the poles and stapled fast to each one. Sections of wire about 100 feet long can be handled to best advantage. After the wire has been securely fastened to the poles, they are all pushed over the bank together, so that the butts of the poles will fall and sink into the soft mud at the water's edge. As the bank caves off some of the falling soil will lodge on the wire, partially burying and weighting down the poles, which will consequently strike root and grow. The wire will serve to hold the mass of willows together until they have become firmly rooted. The ends of the woven wire should be made fast to wire cables running back over the bank some distance, and fastened to posts set firmly in the ground. The caving and erosion of the bank will soon round off its top corners, and the growing willows at the water's edge will catch the soil as it rolls down the declivity, causing a bank to form of just the right slope to resist erosion most effectually. The following diagram illustrates the method of fastening the poles to the wire.

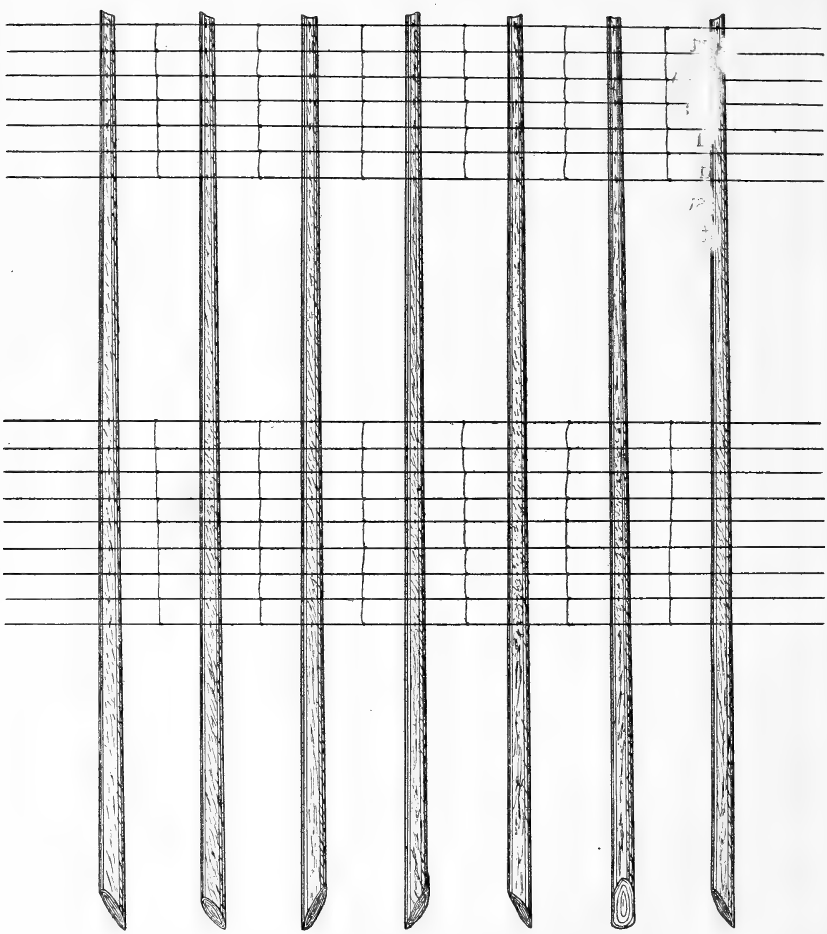

Fig. 1.—Revetment for protecting river bank.

IMPORTANCE OF BEGINNING NOW.

It is urgently recommended that landholders begin operations at once for the reclamation of their injured lands. If these lands are planted to forest trees, in twenty years' time the soil will have been restored to its former state of fertility. During this time the growing trees will be accumulating a valuable product, for which there is every prospect of a good market. Prof. Chas. E. Bessey, of the University of Nebraska, maintains that even for fuel the growth of cottonwood timber is a very remunerative business, since the cottonwood is capable of producing more heat units per acre per annum than any other tree adapted to the Middle West. The cottonwood makes good lumber for dimension stuff, and will attain a size large enough for sawlogs in twenty years.

The hardy catalpa on rich soil will produce more fence posts per acre in a shorter time than any other species. Some catalpa plantations in Kansas have paid 6 per cent compound interest on the land and labor invested and $10 an acre per annum net profit, for a period of twenty years. This is a much greater income than the average returns from agriculture.

With such prospects in view the owner of Kansas River Valley lands need not feel discouraged, even though his valuable farm lands have been rendered temporarily worthless for agriculture.

George L. Clothier,
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Approved:
James Wilson,
Secretary.

Washington, D. C., March 10, 1904.

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THE RELATION OF FORESTS TO STREAM FLOW.

BY

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Collaborator, Bureau of Forestry.

[REPRINT FROM YEARBOOK OF DEPARTMENT OF AGRICULTURE FOR 1903.]

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THE RELATION OF FORESTS TO STREAM FLOW.

By James W. Toumey,
Collaborator, Bureau of Forestry.

INTRODUCTION.

For the purposes of the present discussion "forest" must be understood to mean a growth of trees sufficiently dense to form a fairly unbroken canopy of tops, not a scattered growth of low, round-headed trees with bushes and herbage constituting the dominant types of vegetation.

Forests of this kind do not occur in the United States where the mean annual precipitation falls below 18 to 20 inches, except on restricted areas where unusual conditions prevail. The line of separation between the great eastern forest area and the plains approximately coincides with a north and south line marking a mean annual rainfall of 20 inches. The streams which rise in the Rocky Mountains and flow eastward are bordered by forests for long distances into the plains, where the annual rainfall is much less than 20 inches. These forests, however, are not so much a result of the rainfall in the regions where they occur as of surface and seepage flow from adjacent regions. The mesquite forests of the desert regions of southern Arizona, where the mean annual rainfall is but 8 to 12 inches, are made possible by the seepage and surface waters from the adjacent mountains.

The question of the exact relation which exists between forests and stream flow has long been under discussion. The broad fact that a relation exists is indeed indisputable. Forest destruction always produces a change in the character of the run-off. But the scientific determination of all the causes which produce this effect, and of their relative importance is a difficult and complicated matter. In spite of the fact that for many years European forest experiment stations have been carrying on observations, measurements, and experiments designed to clear up this subject, final conclusions covering the whole field have not yet been established. In this country almost nothing has ever been done to secure accurate data for the investigation of this problem as a whole. Some light, however, has been thrown on the subject by means of a series of observations which have been going on for several years in the San Bernardino Mountains in southern California. It is the purpose of the present article to make clear what are the various factors entering into the problem, and to state some of the more important facts that these observations in southern California reveal.

In the San Bernardino Mountains records of precipitation for several years, at a large number of stations, show that differences in forest cover are closely correlated with differences in rainfall. This correlation is so close that it is possible to judge the mean annual precipitation with a fair degree of accuracy from the appearance of the forest alone. In these mountains forests cover the slopes wherever the mean annual rainfall exceeds 20 to 24 inches; however, on southern and western slopes forests of equal density represent a larger rainfall than on northern and eastern slopes.

Other things being equal, regions having the greatest rainfall bear forests of the greatest density and luxuriancy of growth; but where the mean annual rainfall falls below 18 to 20 inches, types of vegetation in which trees predominate are replaced by those in which shrubs and herbage predominate.

WHAT CAUSES RAINFALL.

Because rainfall is most abundant where forests grow, many believe that forests exert an important influence on the amount of precipitation. A more reasonable inference, however, is that *rainfall is the great factor in controlling the distribution and density of forests.*

Precipitation occurs whenever the air is suddenly cooled below the dew-point. The most effective cause of this is the expansion of air on ascending. This upward movement is caused very largely by cyclonic storms.

Whether forests have any appreciable effect in cooling the air to below the dew-point is uncertain. From the known effect of forests on the temperature and relative humidity of the air, it is reasonable to infer that they may have some such effect, at least to a small degree, and consequently that they have some influence in increasing precipitation. The present evidence, however, derived from many series of observations conducted in Europe and elsewhere, is so conflicting that a definite answer to this question, having the stamp of scientific accuracy, is not possible.

WHAT BECOMES OF THE RAINFALL.

That the excessive destruction of forests is followed by the drying up of streams and springs and by a diminution in the minimum flow of rivers is a well-established fact. The forest is the most effective agent known in regulating the disposition of the precipitation after it reaches the ground.

Rainfall escapes from the ground upon which it falls in five ways—through evaporation, transpiration, surface run-off, seepage run-off, and deep seepage. By evaporation is meant the moisture which passes into the atmosphere in the form of vapor from water and soil surfaces and from objects resting upon such surfaces, including vegetation. Transpiration is that portion of the rainfall which sinks into the soil, and which is later taken up by the vegetation through the roots and given off to the atmosphere through the stems and foliage. To this latter should be added, although not actually a part of it, the comparatively small amount of moisture taken up by the vegetation, but which through chemical change becomes a part of the organic vegetable structure. By surface or superficial run-off is meant that portion of the precipitation which, from the time of falling until its exit from the drainage basin, passes over the surface without gaining access to the soil. On the other hand, by seepage run-off is meant that portion of the rainfall which sinks into the earth, but which later reappears on the surface at lower elevations, and with the surface run-off escapes from the drainage basin in the streams. By deep seepage is meant that portion of the precipitation which sinks into the soil, but to such depths that it does not reappear later on the surface of the drainage basin.

Evaporation and transpiration are frequently classed together as evaporation. In the irrigated parts of the West they are together known as "fly-off." So, also, the rainfall which does not escape through evaporation and transpiration or through deep seepage is often classed as run-off or stream flow.

DO FORESTS INFLUENCE EVAPORATION?

In order that the moisture which falls to the earth in the form of rain and snow should be most efficient in sustaining vegetation and in feeding streams, as little as possible should escape in the form of evaporation. Under the best of conditions a very large part of the annual rainfall is returned to the atmosphere through evaporation. For humid regions, bearing the same types of vegetation, the amount does not vary much from year to year, no matter what the fluctuations in rainfall are—a fact first made known by Messrs. Lawes, Gilbert, and Barrington in the classical Rothamsted investigations. These gentlemen explain this persistency in the rate of evaporation by the fact that heat and abundant rain seldom occur at the same time. Consequently, in a wet season, the lower temperature and more or less saturated atmosphere prevent excessive evaporation; while in a dry season, although the temperature is higher and the air drier, there is less water to evaporate, and the two extreme conditions balance each other so far as the amount of evaporation is considered. This is not true, however, in arid and subarid regions, because during years of minimum rainfall the upper layers of the soil are often so dry for months at a time that there is very little moisture to evaporate, while on the other hand during years of maximum precipitation the atmosphere is not sufficiently saturated to check rapid evaporation.

There is little or no difference between evaporation from a water surface and from any other surface that is thoroughly wet, when both are exposed to the same atmospheric conditions. The evaporation from a water surface is, however, always the same under the same conditions, but it is not the same from other surfaces, because they vary from completely wet to completely dry.

In the forest the crowns of the trees remain wet but a short time after precipitation. During this period, however, the evaporation is undoubtedly very rapid, on account of the large surface and from the fact that the crowns are exposed to the wind and sun. But in a long series of investigations made at the Forest Experiment Station at Nancy, France, and recently published, it was found that a deciduous forest near that station held back from the ground less than 8 per cent of the total precipitation. Although this is almost immediately returned to the atmosphere in the form of evaporation, it is a comparatively small amount of the annual rainfall. On the other hand, evaporation from the soil in the open and in the forest continues often for long periods after the precipitation ceases. After the crowns become dry, evaporation is much retarded in the forest, because the forest floor is protected from the wind and sun. To such an extent is this true that the loss of moisture through evaporation is much less than that lost from an equally saturated soil or from a water surface in the open. Repeated European observations, extending over long periods of time, and shorter observations made in this country, conclusively show that evaporation from water or other wet surfaces on the floor of the forest is but one-third or one-fourth that from similar surfaces in the open. From the investigation of the moisture content of soils in the San Bernardino Mountains, the results of which are as yet unpublished, it appears that the first foot in depth of the mineral soil in the forest may contain two or three times as much moisture as soil of the same general character from similar situations in the open.

During the summer it is impossible to determine by actual measurement the loss of water from the soil either in the forest or in the open, because conditions as to moisture content constantly vary. During the winter, however, the evaporation from a snow surface can be measured with a fair degree of accuracy. Measurements made in the San Bernardino Mountains show that evaporation from snow surfaces may be four or five times as great as from water surfaces under similar exposure, and also that the rate of snow evaporation is profoundly influenced by the wind. In our Western mountains, where the snows are exposed to dry winds, the loss through evaporation is a large percentage of the total snowfall. In the San Bernardino Mountains, snowfalls a foot in depth are sometimes evaporated in two or three days without even moistening the soil. In so far as forests check the winter winds and provide shade, they lessen winter evaporation. This lessening of the evaporation from snow surfaces, through the action of forests, is seen in the fact that snows linger much later in spring in well-wooded regions than in open areas.

It appears, then, that forests materially retard evaporation, both of soil moisture and of snowfall.

DO FORESTS INFLUENCE TRANSPIRATION?

When land is covered with vegetation a certain amount of the rainfall is taken up by the growing plants. A small part, through chemical change, becomes incorporated into the plant, but the larger part is returned to the atmosphere through transpiration. Although those who have investigated this subject are by no means in accord, there is reason to believe that considerable difference exists in the amount of water taken up by the different types of vegetation in the process of growth. On the whole, the forest probably takes up less water from the soil than the average agricultural crop. Risler, from a lengthy series of investigations, reached the conclusion that forests actually take up less than one-half as much water from the soil as the average agricultural crop.

The above would lead one to infer that where the soil, if not covered with forest growth, is clothed with grass or some other low form of vegetation, the return of moisture to the atmosphere, through evaporation and transpiration, or, in other words, the "fly-off," is less from the forest than from the open. But in regions having a short wet season followed by a long dry one the return of moisture to the atmosphere is probably greater from a forested area, because in the open for a large part of the year there is very little to evaporate, and the scanty growth of grass and other low forms of vegetation gives little opportunity for loss through transpiration.

THE INFLUENCE OF FORESTS IN REGULATING THE RUN-OFF.

Stream flow consists of both surface run-off and seepage run-off. Although these two can not be separately determined, total run-off admits of accurate measurement. Surface run-off may be considered as flood water, while seepage run-off is that portion of the drainage which gives the streams a sustained flow. It is evident that any factor which decreases the surface or superficial run-off and increases the seepage run-off is of the utmost importance in regulating the flow of streams.

The proportion of flood water to seepage is influenced by the rapidity of the rainfall. It is well known from direct observation that a slowly falling, prolonged rain, even on the naked soil of steep slopes, is all taken up by the soil. On the other hand, a heavy shower of short duration, falling on the same slope, may largely escape as run-off. In the first instance each drop has time to be absorbed by the soil, while in the latter the accumulation of drops is more rapid than the absorption, and the excess moves over the surface to lower elevations. The forest canopy very perceptibly extends the period of time during which the rain reaches the soil, and in this way lessens surface run-off.

Again, forests, by checking the velocity of the wind and covering the mineral soil with a thick layer of dead leaves and other forest litter, effectively prevent soil transportation by both wind and water. On high elevations, where streams generally have their birth, the influence of the forest in this respect is of the utmost importance. So great is this influence that it exerts a marked effect upon topography. In mountainous regions particularly, the repeated destruction of forests permits the soil formed by the decomposition of the rocks at the sources of streams to be transported to lower elevations, with a consequent slow change in the details of the landscape. Such regions, if unforested, are apt to have precipitous slopes and scanty soil on the higher elevations. In that case there is no adequate medium to absorb the rain, and it flows over the surface. On the other hand, if such regions are well wooded, the slopes are less precipitous, and a considerable depth of soil usually covers the broad summits. As a result, the rain water is absorbed and the surface flow is reduced to a minimum.

Not only is it essential to have an adequate medium present to absorb the rain, but it must be of such character as to absorb quickly. The rapidity with which rain is absorbed is very largely governed by the physical properties of the soil, the organic litter upon it, and the vegetation. Decayed organic matter, by itself or in combination with mineral soil, absorbs moisture much more rapidly than soil containing little or no organic matter; hence, the greater the amount of leaf mold and other litter, the more rapidly will the rain be absorbed. Rapidity of absorption is also influenced by the degree of looseness of the mineral soil. In the forest the mulch of leaves and litter keeps the mineral soil loose and in the best condition for rapid absorption.

Not all the rain that is not absorbed by the soil where it falls reaches the streams by flowing over the surface. Much of it is taken up in passing from the place of falling to the stream. The amount taken up depends upon the obstructions in its pathway. Where there are no obstacles, as on barren ground, the moving water, by eroding channels, forms small rivulets, and these larger and larger ones, which flow with constantly increasing velocity. As a result, the water passes rapidly over the surface, and but little gets into the soil. When the soil is covered with obstructions, such as are offered by a forest with its accumulation of litter and vegetable growth, the rain which is not immediately absorbed is checked in its flow over the surface. The water, being held back, is finally taken up by the soil and thus prevented from forming small rivulets through erosive action.

The forest, in extending the time during which the rain reaches the soil, in its effect upon local topography, and in supplying a larger and better absorbing medium, must necessarily have a profound influence in increasing the seepage run-off, and in proportionately decreasing the surface flow.

COMPARISON OF RUN-OFF FROM FORESTED AND NONFORESTED AREAS.

There are so many complex conditions influencing the flow of streams that it is extremely difficult to determine the effect of forests on run-off by the comparison of the discharge of streams on forested and nonforested catchment areas. It is believed by many that stream flow is so largely influenced by the amount, intensity, and character of the precipitation, the configuration and area of the catchment basin, the character of the absorbing medium and the underlying rocks, and the general climate, as well as the forest itself, that we shall probably never be able to measure quantitatively the influence of forests on the flow of streams by the comparison of forested and nonforested regions. Catchment areas differ so greatly in the features mentioned above that our most conservative and able investigators have been forced to the conclusion that "in respect to run-off, each stream is a law unto itself." Although the above is probably in the main true, yet, by the careful selection of small catchment basins for comparison, it appears that the influence of the forest in diminishing the surface run-off can be determined with a fair degree of accuracy. When the catchment areas compared are in the same region, are influenced by the same or nearly the same climate and precipitation and by the same storms, have approximately the same configuration and area, and have a similar mineral soil and underlying rocks, the effect of these various factors on the run-off can be ignored, and the differences in the behavior of the stream flow on the forested and nonforested areas can be assigned to the influence of the forest.

In a careful study of the behavior of the stream flow on several small catchment areas in the San Bernardino Mountains, it has been found that the effect of the forest in decreasing surface flow on small catchment basins is enormous, as shown in the following tables, where three well-timbered areas are compared with a nontimbered one:

Precipitation and run-off during December, 1899.

Area of catchment basin.	Condition as to cover.	Precipitation.	Run-off per square mile.	Run-off in percentage of precipitation.
Sq. miles.		*Inches.*	*Acre-feet.*	*Per cent.*
0.70	Forested	19+	36−	3
1.05	....do	19+	73+	6
1.47	....do	19+	70−	6
.53	Nonforested	13−	312+	40

At the beginning of the rainy season, in early December, the soil on all four of these basins was very dry as a result of the long dry season. The accumulation of litter, duff, humus, and soil on the forest-covered catchment areas absorbed 95 per cent of the unusually large precipitation. On the nonforested area only 60 per cent of the precipitation was absorbed, although the rainfall was much less.

Rainfall and run-off during January, February, and March, 1900.

Area of catchment basin.	Condition as to cover.	Precipitation.	Run-off per square mile.	Run-off in percentage of precipitation.
Sq. miles.		*Inches.*	*Acre-feet.*	*Per cent.*
0.70	Forested	24	452+	35
1.05	.....do	24	428+	33
1.47	.....do	24	557+	43
.53	Nonforested	16	828+	95

The most striking feature of this table as compared with the previous one is the uniformly large run-off as compared with the rainfall. This clearly shows the enormous amount of water taken up by a dry soil, either forested or nonforested, as compared with one already nearly filled to saturation. During the three months here noted, on the forested basins about three-eighths of the rainfall appeared in the run-off, while on the nonforested area nineteen-twentieths appeared in the run-off.

Rapidity of decrease in run-off after the close of the rainy season.

Area of catchment basin.	Condition as to cover.	Precipitation.	April run-off per square mile.	May run-off per square mile.	June run-off per square mile.
Sq. miles.		*Inches.*	*Acre-feet.*	*Acre-feet.*	*Acre-feet.*
0.70	Forested	1.6	153−	66−	25−
1.05	.....do	1.6	146−	70+	30−
1.47	.....do	1.6	166+	74+	30+
.53	Nonforested	1	56+	2−	0

The above table clearly shows the importance of forests in sustaining the flow of mountain streams. The three forested catchment areas, which, during December, experienced a run-off of but 5 per cent of the heavy precipitation for that month, and which during January, February, and March of the following year had a run-off of approximately 37 per cent of the total precipitation, experienced a well-sustained stream flow three months after the close of the rainy season. The nonforested catchment area, which, during December, experienced a run-off of 40 per cent of the rainfall, and which during the three following months had a run-off of 95 per cent of the precipitation, experienced a run-off in April (per square mile) of less than one-third of that from the forested catchment areas, and in June the flow from the nonforested area had ceased altogether.

DO FORESTS INCREASE THE RUN-OFF?

Owing to the very complex nature of the investigation involved in determining the effect of forests on the amount of run-off, the available evidence does not admit a definite answer that will be of general application. It is reasonably certain from present evidence that in some regions the effect of the forest is materially to increase the run-off. It appears equally certain, however, that in other regions, and on certain classes of catchment areas, the effect of the forest is to materially decrease the stream flow.

Mr. Rafter, in his recent publication, "Relation of rainfall to run-off," makes this statement: "With similar rainfalls, two streams, one in a region having dense primeval forests, the other in a region wholly or partially deforested, will show different run-off. The one with the dense forest will show a larger run-off than the stream in the deforested area." This author concludes, from the careful study of a large number of catchment areas in the State of New York, that the effect of the forest on at least a portion of the area studied is to increase the run-off to an amount equal to from 5 to 6 inches in depth over the entire catchment area.

In humid regions, where the precipitation is fairly evenly distributed over the year, and where the catchment area is sufficiently large to permit the greater part of the seepage to enter the stream above the point where it is gauged, the evidence accumulated to date indicates that stream flow is materially increased by the presence of forests.

In regions characterized by a short wet season and a long dry one, as in southern California and many other portions of the West, present evidence indicates, at least on small mountainous catchment areas, that the forest very materially decreases the total amount of run-off.

Annual rainfall and run-off on forested and nonforested catchment areas in the San Bernardino Mountains, California.

Area of catchment basin.	Condition as to cover.	Precipitation.	Run-off per square mile.	Run-off in percentage of precipitation.
Sq. miles.		*Inches.*	*Acre-feet.*	*Per cent.*
0.70	Forested	46	731	28
1.05	.....do	46	756	30
1.47	.....do	46	904	36
.53	Nonforested	33	1,192	69

On small nonforested catchment areas in the West, and possibly on large ones as well, a very large part of the heavy precipitation of the rainy season flows over the surface, quickly reaches the stream, and is discharged from the catchment area as flood water, much as water escapes from the roof of a building. On such areas the actual loss through evaporation during the dry season is probably far less than from a well-wooded area, because the surface soil and streams are dry and there is very little moisture left to evaporate. On such denuded areas it appears that the run-off for the few months that the streams flow is considerably larger than that for the entire year from similar forested areas. Although a nonforested area may, in certain instances, produce a larger run-off than a forested one, this probably never occurs except when the run-off from the nonforested area is largely flood water, and of destructive rather than constructive significance.

CONCLUSION.

In conclusion, it may be said that although the forest may have, on the whole, but little appreciable effect in increasing the rainfall and the annual run-off, its economic importance in regulating the flow of streams is beyond computation. The great indirect value of the forest is the effect which it has in preventing wind and water erosion, thus allowing the soil on hills and mountains to remain where it is formed, and in other ways providing an adequate absorbing medium at the sources of the water courses of the country. It is the amount of water that passes into the soil, not the amount of rainfall, that makes a region garden or desert.