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AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

FORESTS AND RESERVOIRS
IN THEIR RELATION TO STREAM FLOW,
WITH PARTICULAR REFERENCE TO
NAVIGABLE RIVERS.

BY

H. M. CHITTENDEN, M. Am. Soc. C. E.

WITH DISCUSSION BY

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TRANSACTIONS

Paper No. 1098

FORESTS AND RESERVOIRS IN THEIR RELATION TO STREAM FLOW, WITH PARTICULAR REFERENCE TO NAVIGABLE RIVERS.*

BY H. M. CHITTENDEN,† M. AM. SOC. C. E.

WITH DISCUSSION BY MESSRS. F. COLLINGWOOD, THOMAS P. ROBERTS, STEPHEN CHILD, L. J. LE CONTE, F. B. MALTBY, J. FRANCIS LE BARON, EDWARD P. NORTH, A. MILLER TODD, WILLIAM W. HARTS, GEORGE OTIS SMITH, GEORGE F. SWAIN, W. H. LEFFINGWELL AND A. M. STRONG, BAILEY WILLIS, M. O. LEIGHTON, W. D. PICKETT, ROBERT E. McMATH, H. F. LABELLE, EMIL KUICHLING, ROBERT FLETCHER, J. P. SNOW, CLARENCE T. JOHNSTON, GIFFORD PINCHOT, AND H. M. CHITTENDEN.

The following paper is presented at this time with the purpose of eliciting from the Society membership the results of observation and experience touching the important matters of which it treats. They are vital features of one of the chief living questions before the public to-day, and an expression of views by men accustomed to look at things from a practical standpoint cannot fail to be of great value to our legislators upon whom the ultimate responsibility for action must rest.

While the writer's views traverse, to some extent, currently accepted theories, they are based upon long observation and study, and are what seem to be unavoidable conclusions therefrom; but he is com-

*Presented at the meeting of November 4th, 1908.

†Lieut.-Col., Corps of Engineers, U. S. Army.

mitted to no theory, as such, and his mind is entirely open to conviction upon any point in which his opinions may be shown to be erroneous. His sympathies are wholly on the side of the present movement for the conservation of our natural resources, and, so far as this paper takes issue with certain tendencies of that movement, it is only for the purpose of inquiring whether such tendencies are not really inimical to the cause to which they pertain.

With this preliminary statement, the writer will take up the first part of his paper, viz., the influence of forests upon stream flow.

FORESTS AND STREAM FLOW.

The commonly accepted opinion is that forests have a beneficial influence on stream flow:

(1) By storing the waters from rain and melting snow in the bed of humus that develops under forest cover, preventing their rapid rush to the streams and paying them out gradually afterward, thus acting as true reservoirs in equalizing the run-off.

(2) By retarding the snow-melting in the spring and prolonging the run-off from that source.

(3) By increasing precipitation.

(4) By preventing erosion of the soil on steep slopes and thereby protecting watercourses, canals, reservoirs and similar works from accumulations of silt.

There are many subsidiary influences, but, broadly stated, the above propositions cover the ground. They were first given general currency nearly forty years ago through the writings of Sir Gustav Wex, Chief Engineer on the Improvement of the Danube, whose treatise was translated into English by the late General Weitzel, of the Corps of Engineers. Wex's theories were stoutly resisted at the time by many European engineers, and still find only a limited acceptance in the profession;* though in the popular mind they have gained ground and in the United States are now accepted practically without question.

To establish by definite proof the truth or falsity of these propositions is an extremely difficult task. One would not think so, indeed, to judge from the cheerful confidence with which the popular thought accepts them; but it is nevertheless so. The elements of the problem are so many and conflicting, the necessary evidence is so hard to get,

*Almost simultaneously with the publication of Wex's treatise, a similar work was published in France by M. F. Vallée taking exactly the opposite view of the question.

and comparative records are of such recent date, that precise demonstration is scarcely possible. The popular belief is based upon a fact and an assumption forming together a basis for a conclusion. The fact is that forests in the eastern portion of the United States have disappeared to a large extent within the past century. The assumption is that floods and low waters in the same region are more frequent and severe than before the forests were cleared away. The conclusion is that these assumed conditions must be due to the disappearance of the forests. *Post hoc, ergo propter hoc* is the argumentative process relied upon, and little effort is made to consider whether there may not be some other and more satisfactory explanation. The writer will attempt to analyze the problem from a theoretical standpoint and will then cite existing records so far as these are sufficiently long-continued to be worth anything. He will consider, first, the effect of the forests where stream flow results from rain alone, and, next, where it results in part from melting snow.

Effect of Forests upon the Run-Off from Rainfall.—The first of the above propositions—the retentive action of the forest bed—may be accepted at once as strictly true for average conditions. It is not true for extreme conditions—great floods and excessively low waters—the conditions that determine the character and cost of river control. Consider an inclined-plane surface, practically impervious to water, with a layer of sand covering some small portion of it, and let a uniform spray of water be applied to the entire surface. Assume that the temperature and rate of evaporation are relatively low. As soon as the spray begins, water commences to flow from the uncovered surface, but not for a time from that covered by the sand. After a while it begins to trickle from the sand, increasing in volume until the sand is thoroughly saturated, after which it flows off in as great quantity per unit area as from the uncovered portion. If the spray is stopped, the water immediately ceases to flow from the uncovered area, but continues in diminishing quantity from the covered area until it finally ceases altogether; but not all the water that fell on this area has run away. The sand has retained some portion of it and given it off in evaporation, so that the total run-off per unit area is somewhat less than on the uncovered portion. If the shower be long-continued and the rate of evaporation very low, the difference of total run-off per unit area from the two surfaces will be very slight.

Suppose now that the temperature and rate of evaporation are high

and that the spray works intermittently. If the showers are small in volume and the intervals between them long, the sand may retain nearly or quite all of the individual showers and give them off in evaporation, so that there will be no run-off whatever.

Between these two extreme conditions, the covered area will exert a greater or smaller regulative effect upon the run-off. The retentive power of the sand will be less as the slope of the surface upon which it rests increases, or it will be greatest when the surface is nearly horizontal and least when it is nearly vertical.*

Now in Nature this ideal illustration is never fully exemplified in the cleared land and the forest. There is nearly everywhere a marked retentive capacity in the bare soil. In newly plowed ground it is probably greater than in the forest. Moreover, certain crops, like heavy grass or grain, obstruct the flow of water almost as much as the forest cover. On the other hand, the furrows of cultivated fields, drainage ditches, roads and, particularly, the pavements and roofs of towns, greatly accelerate the run-off; so that, while the full contrast of the ideal example does not exist in Nature, the principle of the illustration applies perfectly. That is, there are times when the percentage of retention in the forest bed is 0, and there are other times when it is 100; or, there are times when so much water comes that the forest bed can hold none of it and there are times when so little comes that it holds it all. Between these extremes there are periods when it holds more or less and gives up less or more and exercises a

*Since the above was written the writer has noticed, in the report of the hearing on House Resolution 208 before the Committee on the Judiciary, that Gifford Pinchot, Assoc. Am. Soc. C. E., Chief of the Forest Service, used an illustration very similar to that given above, except that he failed to carry it to its logical conclusion. Addressing the Committee, February 27th, 1908, he said: "I have in my hand here a photograph of a denuded hillside. After the forest has been removed rain falls on that hillside and runs off rapidly, as the water I drop upon the photograph does now, and disappears instantly (illustrating). If, on the other hand, I place a forest cover on the hillside, that is exactly analogous in texture and effect with this piece of blotting paper, and drop the water slowly upon it, we would find that, instead of running off slowly at the bottom, the water is held (illustrating with blotting paper). Part of it runs off, but, as soon as the absorbent quality of the paper or the forest floor has time to take effect, the water is kept and drips gradually for a considerable length of time off the hill into the stream. This is an exact illustration of the way in which the forest controls the stream flow on that hillside."

Mr. Pinchot should have completed his illustration. He should have continued to sprinkle the paper long enough and heavily enough to have saturated it completely in order to show that the water would then flow from the paper as rapidly as from the uncovered area; and he should then have explained that this condition represents what always happens in the forest in times of great flood. Then he should have sprinkled the paper intermittently in small quantities, and at such long intervals that the warm air of the room would evaporate all of the absorbed water, and that none whatever would flow away. He should then have explained that this condition represents what always takes place in the forest in times of great drought.

corresponding influence upon the run-off. There is another important condition not exemplified in the illustration, and that is that the forest areas are scattered everywhere, the ground has an infinite variety of slope, the showers never fall uniformly over an entire water-shed, and the final result in the total run-off is the summation of thousands of tributary results.

It is true, therefore, as popularly understood, that, in periods of ordinary rainfall with sufficient intervals for the forest bed to dry out somewhat, forests do exert a regulative effect upon run-off. They modify freshets and torrents, and prolong the run-off after storms have passed, and thus realize in greater or less perfection the commonly accepted theory.

This result utterly fails, however, in those periods of long-continued, widespread and heavy precipitation, which alone cause great floods in the large rivers. At such times the forest bed becomes completely saturated, its storage capacity exhausted, and it has no more power to restrain floods than the open country itself. Moreover, the fact that the forest bed has retained a portion of earlier rainfall and is yielding it up later to the streams, produces a condition that may be worse than it would be in a country cleared of forests. Really great floods in large rivers are always, as is well known, the result of combinations from the various tributaries. It is when the floods from these tributaries arrive simultaneously at a common point that calamitous results follow. Any cause which facilitates such combinations is, therefore, a source of danger. Now, unquestionably, in a heavily wooded water-shed, forests do have a tendency in this direction. When a period of heavy storms occurs, spreading over a great area, continually increasing in intensity, the forests, by retaining some portion of the earlier showers and paying them out afterward, do produce a general high condition of the river which may greatly aggravate a sudden flood arising later from some portion of the water-shed. That the forest does promote tributary combinations, there would seem to be no question, and that it may therefore aggravate flood conditions necessarily follows. It is not contended that this increase is ever very great, but it is contended that forests never diminish great floods and that they probably do increase them somewhat. The forests are virtually automatic reservoirs, not subject to intelligent control, and act just as the system of reservoirs once proposed by the French Government

for the control of floods in the River Rhone would have acted, if built. These reservoirs were to have open outlets, not capable of being closed, which were intended to restrain only a portion of the flow. A careful study of their operation in certain recorded floods showed that they would actually have produced combinations more dangerous than would have occurred without them.

Consider now periods of extreme drought, and grant that, as a general rule, springs and little streams dry up more completely than when forests covered the country, although this difference is very greatly exaggerated in the popular mind.* At first thought one would conclude that, since the springs and streams make up the rivers, these also ought now to show a smaller low-water flow than formerly. This, however, is not the case. The difference between the former low-water flow of a spring or rivulet and what it is now is relatively an insignificant quantity. Most of such water sources yield but a small fraction of a cubic foot per second. Whether these small quantities are a trifle more or less cuts very little figure in the aggregate; and so it counts but little in the flow of a great river whether some of its extreme sources lose a portion of a volume that is already inappreciable. When the summer showers come, however, there is a marked difference. At such times the forests not only hold the water back—they often swallow it completely. Small showers that make a perceptible run-off in the open are often practically all absorbed in the leaves of the trees. Heavier showers, that make freshets in the open, are largely absorbed in the leaves and forest bed and pass off in evaporation; so that, contrary to the general view, the evaporation from the forest is greater at such times than in the open country, and the run-off from summer precipitation is less. A single shower may produce a sufficiently greater run-off in a deforested area to more than offset the diminished low-water flow for several weeks.† Now on most of the smaller streams quantity of flow is a more important matter than

*The term "as a general rule" is used, for it is by no means absolute. In particular the drainage of low swamp lands leads off into the streams, in dry weather, waters that formerly remained or passed off in evaporation, and in such cases even the low-water flow is greater than it used to be. In 1895 the writer saw an example of this on the Scioto River near the outlet of the great Scioto swamp which had recently been drained. A small mill was able to operate during the low-water season more regularly than formerly. Tile drainage, now so widely used, has the same tendency.

†So far as the writer is aware, Colonel T. P. Roberts, of Pittsburg, Pa., was the first to call attention to this characteristic of stream flow.

natural uniformity of flow, particularly in the summer time. The day of the small mill, which was so dependent upon such uniformity, is past. The modern water-power invariably seeks uniformity by artificial regulation, and the ups and downs of its sources of supply are abolished in its storage. Therefore it does not matter nearly as much that the run-off of the small streams be uniform as that it yield a good flow of water; and if forests diminish the total low-water supply, this fact more than offsets the gain in uniformity. Likewise, the great rivers swallow up and equalize the small irregularities of their head-waters and actually experience a somewhat larger low-water flow than if their water-sheds were still thickly forested. Thus, while forests may decrease somewhat the extreme range between maximum and minimum run-off on very small water-sheds, they do not do so on great ones, which are combinations of very small ones. At the same time it seems certain that forests decrease somewhat the total run-off from water-sheds small or great.*

Influence of Forests upon Snow-Melting.—The second proposition—that forests have a beneficial effect upon the run-off from snow-melting—is quite as firmly fixed in the popular belief as that just considered, but has even less foundation in fact. It is a relation that can be definitely traced, and it can be demonstrated that the effect of forests upon the run-off from snow is invariably to increase its intensity. This results from two causes, one affecting the falling of the snow and the other its melting.

In the first place, forests break the wind, prevent the formation of drifts, and distribute the snow in an even blanket over the ground. In the open country, the snow is largely heaped into drifts, their size depending upon the configuration of the ground, the presence of wind breaks, and the prevalence and force of the wind. These drifts form admirable reservoirs, and in the high mountains are the most perfect known. Forests prevent their formation entirely.

The period of snow-melting begins in the open country much earlier than in the forests. At first the melting is due mainly to the direct

*This subject was ably discussed by Mr. Raphael Zon, of the Forest Service, Department of Agriculture, in *Transactions, Am. Soc. C. E.*, Vol. LIX, pp. 494-495. He states among other things that "the quantity of water available for stream flow from forested water-sheds, all other conditions being equal, is less than from non-forested water-sheds"; that "the forest soil receives least precipitation, next comes meadow land, and lastly tilled land"; that "in the forest, only the upper layer of the soil is moister than in the open, the lower layers being always drier." This discussion is well worth perusal.

action of the sun's rays before there is sufficient warmth in the general atmosphere to produce any effect. The thinly covered areas melt off first and the streams experience a diurnal rise and fall following the warmth of day and the frost of night. Nothing like a flood ever arises from such melting.

Under forest cover this action is interfered with more or less, depending upon the density of the shade. Even after the ground in the open is entirely bare, except under the drifts, the forest areas may still be covered with an unbroken layer of snow. It is generally, though erroneously, considered that this delay is beneficial, by carrying farther into the summer the release of the winter precipitation and giving it more time to soak into the ground; but in fact this benefit does not result. The water from the first melting of the snow blanket does not sink into the ground but into itself. Snow is like a sponge. A painful light will shrink to one-fourth of its volume, or less, before any free water appears. The author has seen an 8-ft. covering of snow dwindle to 2 ft., with the ground beneath it still comparatively dry.

The forest shade thus holds the snow, which gradually becomes saturated from its own melting, until the heat and warm rains of late spring or early summer arrive, the soft air everywhere pervading the forest depths and finding a maximum exposure of surface to the melting influences. A cubic yard of snow which in a great drift might stand 27 ft. deep with a square foot of exposure, may here lie with a depth of 1 ft. and 27 sq. ft. of exposure. The result is that when the final melting begins the whole body of snow disappears very rapidly, rushing from every direction into the streams, swelling them to their limit and often causing disastrous freshets. The active melting lasts but a short time, and there is little opportunity for the water to soak into the ground. The delay in melting, caused by the forest shade, has simply operated to concentrate it into a shorter period and increase the intensity of the resulting freshet. It comes so fast that the greater portion of it cannot be utilized at the time and is lost altogether unless intercepted by reservoirs.

In the open country, on the other hand, the drifts last for weeks after the snow has entirely disappeared from the forest, and continue to yield a supply of water far into the summer. The period of active melting in the open may have lasted four months, that in the forest scarcely as many weeks. Fig. 1 illustrates, in a general way, the

FIG. 1. -SNOW IN FOREST, YELLOWSTONE PARK, JUNE 13TH, 1899. ALTITUDE, 8200 FT.

FIG. 2. -SNOW-DRIFT, YELLOWSTONE PARK, JUNE 13TH, 1899. ALTITUDE, 7800 FT.

processes just described. These curves apply more particularly to the forests of the Rocky Mountains, where the writer has had exceptional opportunities for studying their action. In the northwest corner of Wyoming and in contiguous portions of the adjoining States, lies an elevated region of probably 20 000 sq. miles, which is the source of nearly all the great river systems of the West. It is a very remarkable region in this respect. Its average altitude is about 7 500 ft., and it is in large part covered with a dense evergreen forest. At the very summit of this elevated region is that singular section now visited annually by thousands of tourists—the Yellowstone Park. The opening of the tourist season in spring occurs just about the time of active snow-melting, and the most onerous and difficult task of those in charge of the road system of the Park is to get the roads into condi-

GRAPHIC ILLUSTRATION OF SNOW MELTING IN FORESTS AND OPEN COUNTRY, ROCKY MOUNTAIN REGION.

FIG. 1.

tion for the first travel. This frequently has to be done while the snow still lies deep on the ground. It was the repeated execution of this task that first drew the writer's attention to the fact that, as a general rule, the floods of this region are forest floods, and that the same conditions of precipitation which force the forest streams out of their banks produce only moderate effects in the open. The traditional "June rise" comes mainly from the mountain forests.

The photographs presented herewith were taken about the middle of June in a year of heavy snowfall and only two days before the tourist season opened. Fig. 1, Plate XXXVII, shows an east and west road through a dense forest of lodge-pole pine at an altitude of 8 200 ft. It shows very effectively the deep, even blanket of snow everywhere covering the ground, except along a narrow strip at the roots of the

trees on the north side of the road, where the sun had access through the opening in the tree-tops caused by the 30-ft. clearing for the roadway. Fig. 2, Plate XXXVII, taken practically at the same time, shows one of the great drifts in the open country, which it was impossible to avoid in locating the road.

At this time a period of very warm weather had set in, with frequent rains. Severe floods followed which did great injury to the roads and bridges, not only in the mountains, but for a considerable distance below. Within two weeks the snow had practically disappeared in the forests, but in the open country the drifts, like that in the photograph, continued until the middle of July, giving forth a continuous supply of water.

A most illuminating article, and one which every one interested in the subject should read, was published in *Science* for April 10th, 1896. It gives the results of observations in the mountains of Nevada for more than 25 years, during which "extensive tracts of timber" were cut off "to the very ground," and new growths had been well started. It was found that springs, which were active after the land was cleared, dried up when the new forest growth developed; "that the water supply from the mountains is greater and more permanent now than it was before the timber was cut off"; that freshets were no more "frequent or violent than before the trees were cut off," and that "spring floods were less frequent." The greatly increased loss due to evaporation in the forest was pointed out. This results partly from the vast extent of surface on the ground exposed to the air and partly from exposure on the leaves and branches of the trees.

"The foliage on this class of trees being as heavy in winter as in summer, the branches catch an immense amount of the falling snow and hold it up in mid-air for both sun and air to work upon; and only those who have had experience of the absorbing power of the dry mountain air can form any idea of the loss from that source." Moreover, "the trees absorb from the soil quite as much water as would be evaporated by the action of the sun in the absence of the shade."

The writer of that article states that

"the strongest force at work to save our rivers is the drifting winds which heap up the snow in great banks; and in this the trees are a constant obstacle." He declares that "close observers, after long years of study, have been led to believe that if there is any difference in the

"IN THE BASKET."

flow of streams and the size of springs before and after the trees are cut from above them, the balance is in the favor of the open country.”*

In the current literature upon this subject one invariably encounters the same fallacious assumption, that because the forests delay melting their action is therefore beneficial. The fact is entirely overlooked that delay means concentration and greater intensity of run-off, while the open country prolongs the melting and gives a more even distribution. If the true action of forests in this respect, however, is rarely recognized by public writers, it is recognized, though perhaps unconsciously, by those who are benefited by it. The monthly reports of the Weather Bureau in the Rocky Mountain region are instructive reading in this connection. The following are a few extracts from those sent in to the Central Office of the Western Montana district at Helena:

“Where there is no timber to break the force of the winds solid drifts of considerable depth have collected.” * * * “The snowfall has been very light and the drifts are not large or solid enough to furnish an adequate flow of water in the streams.” * * * “In some sections the winter’s snowfall has been the lightest for many years, and as there is little likelihood that the later snows will form solid drifts, it is practically certain that the flow of water in most streams will be inadequate for irrigation and mining purposes.”

These extracts, which could be multiplied indefinitely, show how well the practical ranchman understands the value of snow-drifts. It has always been a mystery to the writer that writers will persist in statements like the following, which appears in one of the ablest addresses at the recent Conservation Conference in Washington:

“The possibility of irrigation depends largely on the preservation of the forest cover of the mountains, which catches and holds the melting snows, and thus forms the great storage reservoirs of nature.”

The forests destroy the reservoirs, and the flow would be more uniform, prolonged and plentiful, if they were not there.

It will doubtless be urged that while the foregoing conclusions may hold for an elevated and densely wooded region, they will not hold

*The writer recalls only a single other writer who has set forth this matter in accordance with the facts, and that was an anonymous correspondent in a recent issue of the *Pacific Sportsman*. His view of the case is summarized in rather terse language as follows: “Trees in the mountains make floods in the spring.” * * * “Snow in the timber melts too fast. The timber keeps it from drifting.” * * * “The agency which maintains the river is the snow in the huge drifts.” * * * “That (the dr:*) is your reservoir that feeds the living streams of summer time.” * * * “The timber has nothing to do with the water supply but is a result of the water supply.”

for a lower altitude, warmer climate and different kind of forest. In reply it may be said that, in proportion as the conditions described prevail, they apply everywhere. In deciduous forests where the foliage is absent during seasons of snowfall and melting, the winds have greater play in winter and the sunlight in spring, and there is, of course, less difference between the forests and the open country; but while the difference is less it is not obliterated altogether, and in hilly regions, like the Adirondacks and the White Mountains, it exists in full force. The writer is very familiar with the region of Western New York—having been reared on a farm nearly on the divide between the waters of the Ohio and Lake Erie—a beautifully wooded country, deciduous growths prevailing, and one of the snowiest regions in the United States. While there is less drifting in the open and more in the woods than in high mountains, still it is strictly true that the open-country drifts outlast the forest snows just as the latter outlast the thin snows in the open.

A striking example of the action of forests on snow-melting may be seen in the mountains of the Pacific Coast. Here are the densest forests in the world, the deepest beds of humus, and the most perfect reservoir effect so long as it is in action. Yet in this very region, particularly around Puget Sound, are to be found some of the most torrential streams in the country. This fact is largely due to the distribution of snowfall caused by the forests. Conditions like the following are constantly developing. Heavy snow storms sweep over the forest-covered mountains. The snow cannot drift, for the dense woods break the wind. A great deal of it does not reach the ground at all, but hangs on the branches and undergrowth all the way from the highest tree tops down. This covering is often so dense as to prevent cruising operations altogether, because the cruisers cannot see the timber through the impenetrable screen of snow. Of an 18-in. fall, perhaps 12 in. is on the trees and the rest spread evenly on the ground. To show what now happens, let an illustration be drawn from the opposite process of drying clothes. When the housewife has finished her washing and wishes to dry the clothes, she does not set them out in a basket, where it would take weeks for them to dry, but spreads them upon the ground or hangs them on a line, so that the sun and air can reach them on all sides. So these forests increase, by a thousand-fold, the exposed area of the snow over what it would be if heaped in Nature's clothes

PLATE XXXIX.
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"ON THE LINE."

baskets (the great drifts), and give it the maximum possible exposure to the melting influences whenever these shall arrive. As a general rule, these snow storms are followed by warm southerly winds and rains—the rains frequently heavy in themselves—and rain and snow join hands, two storms in one, and rush down to the ocean in tremendous freshets and floods. The Skagit River, the largest in Washington except the Columbia, and a very considerable stream, has been known to rise 1 ft. per hour for 16 hours, and this where the stream has a fall of 4 ft. to the mile and carries off its floods very rapidly. Fig. 1, Plate XL, taken on another stream with only 480 sq. miles of water-shed above it, shows the terrific power of these streams that come down from the most densely wooded and perfectly protected watershed in existence. The great flood of 1906 in this section, was a perfect demonstration, not only of the vast intensifying effect of forests upon floods due to snow-melting, but of the utter helplessness of the forest bed, when saturated with long rains, to restrain floods.

The same effect was very manifest in the great flood of 1907 in the valley of the Sacramento River, California. The tributaries on the east side come down from the densely wooded slopes of the Sierras; those on the west side from the bare or sparsely wooded slopes of the Coast Range. If the forest theory be true, these smooth western slopes should send down a greater flow for the same precipitation than the eastern slope. Exactly the reverse seems to have been the case. For the period, March 17th-26th, the precipitation on the Puta Creek watershed, on the west side (805 sq. miles), averaged 22.7 in. The maximum resulting run-off per second per square mile for one day was 39.1 cu. ft. Directly across the valley, on the Sierra slope, the precipitation on the American River watershed (2 000 sq. miles), averaged 14.6 in. for the same period, and the maximum daily discharge was 48.7 cu. ft. per sec. per sq. mile. Considering the fact that unit run-off for the same conditions is always less, the greater the water-shed, this result is quite remarkable. It is undoubtedly due to the action of the Sierra forests on snow-melting, and again illustrates the inability of forests to exercise any restraining influence upon great floods.*

*In the paper, "The Flood of March, 1907, in the Sacramento and San Joaquin River Basins, California," by Messrs. Clapp, Murphy and Martin, published in *Transactions, Am. Soc. C. E.*, Vol. LXI, p. 281, the authors say, "In the Sierras the greater part of the precipitation is normally in the form of snow, and the magnitude of floods depends largely on the rate of melting. A heavy warm rain on deep, freshly fallen snow produces a maximum run-off."

TABLE 1.—GAUGE RECORDS OF CERTAIN RIVERS OF THE UNITED STATES.
Highest and Lowest Stages for Each Year.

MISSISSIPPI.				
Year.	St. Paul.		St. Louis.	
	Highest.	Lowest.	Highest.	Lowest.
1785	....	....	40.6*	....
1826	....	....	? 33.7	....
1828	....	....	36.4	....
1838	....	....	27.0	....
1843	....	....	27.2	....
1844	....	....	41.3	....
1845	....	....	32.4	....
1846	....	....	25.0	....
1849	....	....	27.4	....
1851	....	....	36.5	....
1852	....	....	28.0	....
1853	....	....	30.0	....
1855	....	....	37.1	....
1856	....	....	27.4	....
1858	....	....	37.0	....
1860	....	....	....	0.6
1861	....	....	25.5	1.3
1862	....	....	31.5	3.5
1863	....	....	18.0	0.0
1864	....	....	20.3	1.2
1865	....	....	26.8	1.2
1866	....	2.2	26.8	5.6
1867	....	3.0	28.2	1.2
1868	....	2.0	24.1	1.0
1869	16.1	2.8	29.2	4.7
1870	....	....	26.2	5.2
1871	....	....	21.8	2.8
1872	? 7.7	1.9	23.0	2.4
1873	16.4	2.4	25.5	4.6
1874	11.6	3.0	18.4	2.8
1875	18.0	2.1	30.0	2.3
1876	11.0	1.9	31.8	5.0
1877	7.7	1.8	26.5	7.0
1878	6.7	0.6	25.7	5.6
1879	10.8	0.9	21.2	3.4
1880	15.3	1.7	25.5	2.7
1881	19.7	3.3	33.6	7.6
1882	13.3	2.9	32.0	2.8
1883	12.5	1.5	34.8	4.5
1884	10.3	1.8	28.1	3.0
1885	7.4	1.9	27.1	2.0
1886	8.2	1.2	27.0	1.4
1887	9.6	0.8	20.6	0.9
1888	14.4	2.4	29.4	3.2
1889	4.5	0.8	24.6	2.5
1890	7.0	0.6	20.5	2.8
1891	6.4	0.1	23.7	3.0
1892	12.6	1.0	36.0	1.0
1893	14.7	0.6	31.6	- 0.2
1894	11.8	0.2	23.3	0.2
1895	4.6	0.2	23.4	- 0.5
1896	10.7	0.9	27.7	3.7
1897	18.0	2.3	30.9	- 0.5
1898	10.7	2.8	27.2	0.3
1899	11.0	2.4	25.7	- 1.0
1900	6.6	0.7	23.5	- 2.5
1901	7.5	1.2	22.5	- 2.0
1902	7.5	1.1	26.8	- 1.0
1903	13.5	2.5	38.0	0.6
1904	9.9	2.6	39.6	- 0.1
1905	14.8	2.0	30.2	- 0.3
1906	13.3	4.9	26.2	3.0
1907	13.6	1.3	....	....

* "L'année des grandes eaux."

TABLE 1.—(Continued.)

OHIO.						
Year.	Pittsburg.		Cincinnati.		Louisville.	
	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.
1810	32.0	.....	.....	.....	Upper	Gauge
1813	29.0	.....	.....	.....	.....	.....
1816	33.0	.....	.....	.....	.....	.....
1832	34.0	.....	64.2	.....	40.8	.....
1840	26.9	.....	.....	.....	.....	.....
1846	25.0	.....	.....	.....	.....	.....
1847	26.0	.....	63.6	.....	.....	.....
1848	23.0	.....	.....	.....	.....	.....
1851	30.9	.....	.....	.....	20.3	1.5
1852	31.9	.....	.....	.....	.....	.....
1853	31.9	.....	.....	.....	.....	.....
1855	18.0	2.1	.....	.....	.....	.....
1856	19.6	0.3	.....	.....	.....	1.1
1857	21.4	0.0	.....	.....	.....	.....
1858	26.0	0.5	43.1	2.5	19.1	1.5
1859	22.0	1.1	55.5	3.3	33.8	2.6
1860	29.7	2.8	49.2	5.3	.....	.....
1861	30.9	1.1	49.4	5.1	.....	.....
1862	30.0	0.3	57.3	2.3	.....	.....
1863	16.0	0.1	42.7	2.5	.....	.....
1864	18.6	1.0	45.1	3.1	.....	.....
1865	31.4	1.4	56.2	5.7	.....	.....
1866	15.4	0.4	42.5	4.7	18.6	2.8
1867	22.6	0.0	55.7	3.0	37.6	1.8
1868	20.6	0.0	48.2	5.1	22.3	3.0
1869	19.6	0.7	48.7	5.3	24.3	2.8
1870	18.0	1.3	55.2	3.8	.....	.....
1871	19.0	1.2	40.5	2.7	21.0	.....
1872	20.6	1.6	41.7	3.0	21.0	2.0
1873	25.6	1.6	44.4	3.7	18.3	2.3
1874	22.4	1.1	47.9	2.3	22.4	1.8
1875	25.0	0.4	55.3	4.2	30.3	2.7
1876	26.0	0.2	51.7	6.2	32.5	3.7
1877	25.0	0.7	53.7	3.2	29.9	2.2
1878	24.6	0.0	41.3	4.3	15.7	2.9
1879	20.0	0.1	42.7	2.5	19.6	2.2
1880	22.0	0.3	53.1	3.7	30.0	2.8
1881	23.0	0.6	50.6	1.9	22.5	1.7
1882	21.9	0.6	58.6	6.1	37.4	4.7
1883	27.6	0.1	66.3	3.6	43.8	3.2
1884	34.4	0.3	71.0	2.7	46.7	2.0
1885	23.0	1.0	46.0	2.5	22.2	2.9
1886	22.8	0.3	55.7	3.3	32.7	2.4
1887	22.0	2.0	56.2	2.7	32.5	2.2
1888	26.0	0.0	39.9	5.2	16.1	3.6
1889	24.0	0.2	33.2	5.2	13.8	3.5
1890	24.3	1.2	59.2	5.7	35.3	3.6
1891	31.3	1.9	57.3	4.4	32.4	2.8
1892	23.0	1.3	43.7	3.4	21.9	2.1
1893	24.0	1.5	54.9	3.6	25.8	2.0
1894	23.2	2.0	35.6	3.1	12.8	2.2
1895	25.8	1.2	48.4	2.3	20.7	1.8
1896	23.0	2.0	47.8	5.5	22.4	3.9
1897	29.5	1.7	61.2	3.1	35.3	2.4
1898	28.9	2.2	61.4	4.5	36.3	3.1
1899	22.0	2.4	57.4	3.4	32.8	2.2
1900	27.7	1.6	40.0	3.2	15.4	2.0
1901	27.5	0.8	58.7	4.2	33.2	2.8
1902	32.4	1.1	50.9	3.9	24.8	2.8
1903	28.9	0.0	53.1	4.5	25.7	2.8
1904	30.0	1.7	45.9	3.8	22.9	2.0
1905	29.0	1.0	48.2	6.5	22.0	3.1
1906	18.5	0.0	50.2	7.1	26.4	3.1
1907	35.5	0.0	65.2	7.0	41.2	3.4

TABLE 1.—(Continued.)

TENNESSEE.				
Year.	Chattanooga.		Florence.	
	Highest.	Lowest.	Highest.	Lowest.
1867	58.6	....	31.1	....
1871	....	....	....	0.0
1872	....	....	16.4	—0.8
1873	....	....	22.9	—0.5
1874	....	0.7	26.0	0.0
1875	54.0	2.2	29.4	0.4
1876	31.1	1.0	19.8	—0.6
1877	28.7	1.2	19.4	0.0
1878	19.2	0.9	13.6	—0.8
1879	38.0	0.2	21.5	—0.5
1880	38.3	1.0	24.5	0.1
1881	22.4	0.0	17.4	0.0
1882	40.2	1.7	29.6	1.2
1883	38.2	0.0	23.3	0.4
1884	42.8	0.2	25.2	0.3
1885	30.4	0.7	17.8	0.6
1886	52.2	1.2	28.1	0.5
1887	27.3	1.2	17.5	0.5
1888	27.0	1.8	20.8	0.7
1889	29.6	2.1	19.7	1.2
1890	42.5	2.0	23.8	1.7
1891	38.9	1.2	23.2	1.0
1892	37.9	1.1	24.0	0.8
1893	33.4	1.6	21.4	1.1
1894	25.5	0.7	17.7	—0.1
1895	32.1	0.7	17.5	0.0
1896	40.5	1.1	20.0	0.1
1897	37.9	0.4	32.2	—0.5
1898	24.6	1.6	13.8	0.4
1899	40.0	0.8	25.2	—0.1
1900	24.3	1.0	19.5	0.1
1901	37.4	2.1	18.9	0.8
1902	40.8	1.2	21.7	—0.4
1903	31.8	0.6	18.8	—0.5
1904	22.1	0.1	17.2	—0.5
1905	22.4	1.2	16.7	0.0
1906	33.3	3.2	16.7	1.5

TABLE 1.—(Continued.)

MISSOURI.			CONNECTICUT.		
Year.	Kansas City.		Year.	Springfield.	
	Highest.	Lowest.		Highest.	Lowest.
1844	36.0*	....	1801	21.0	....
1873	19.3	2.0	1843	20.4	....
1874	16.2	1.5	1854	22.2	....
1875	17.8	1.8	1862	22.0	....
1876	18.0	2.0	1869	20.4	....
1877	22.2	3.8	1871	13.0	0.10
1878	19.6	3.5	1872	14.2	1.10
1879	19.2	3.2	1873	15.0	0.6
1880	16.7	2.0	1874	17.5	1.0
1881	26.3	3.0	1875	15.0	0.8
1882	19.2	1.2	1876	17.0	0.6
1883	23.8	25.0	1877	16.5	1.2
1884	17.2	23.0	1878	18.5	1.2
1885	19.1	3.8	1879	15.8	1.6
1886	15.8	0.2	1880	10.8	1.0
1887	20.2	1.8	1881	11.5	1.7
1888	20.4	4.7	1882	10.9	1.6
1889	13.9	3.2	1883	14.6	1.8
1890	17.2	0.2	1884	16.0	2.2
1891	23.1	2.5	1885	13.3	2.4
1892	24.9	1.5	1886	16.0	1.6
1893	18.1	3.1	1887	17.0	2.1
1894	20.1	4.3	1888	17.7	2.2
1895	16.9	3.3	1889	11.3	3.2
1896	19.2	2.8	1890	11.7	2.8
1897	22.8	2.0	1891	14.3	2.8
1898	21.5	4.0	1892	13.8	3.0
1899 *	23.3	5.2	1893	18.2	2.1
1900	17.8	4.2	1894	10.4	2.6
1901	19.4	3.7	1895	20.2	3.4
1902	23.2	3.5	1896	20.2	3.5
1903	35.0	3.5	1897	15.3	3.8
1904	25.2	2.1	1898	15.5	3.8
1905	23.0	2.0	1899	16.2	3.6
1906	19.7	2.3	1900	17.0	3.6
1907	24.0	4.1	1901	19.8	3.6
1903	30.5	3.7	1902	19.3	3.1
			1903	17.4	3.1
			1904	15.3	3.1
			1905	17.6	3.6
			1906	15.1	3.0
			1907	15.5	3.3

* Approximately.

During the spring of 1908 occurred a record-breaking flood in Western Montana, nearly all the streams on both sides of the Continental Divide going far over their banks. As might have been predicted, this occurrence was promptly cited as another example of the effect that a forest-barren country has upon floods. Nevertheless it is as certain as anything of this kind can be, that if the country affected by this extraordinary downpour (in some places breaking all previous records) had been thickly forested, and the ground still covered, as it would have been, with a solid layer of saturated snow, the flood would have far exceeded in magnitude and destructiveness that which actually took place. Wherever forests existed in the higher altitudes they did have this effect.*

Having now considered the influence of forests upon stream flow from a theoretical standpoint, let the records themselves be examined as far as they are available. These records in the United States, unfortunately, are not so useful as might be wished, because of their brevity. No continuous records on any of our streams run back for more than eighty years, and most of them less than half as far. This is far short of the 200 years considered by certain European engineers who investigated Wex's theories as the minimum period "necessary in order to draw a reliable conclusion" upon this subject.† It does indeed seem absurd to take present-day records, as is constantly done, and draw conclusions one way or the other as to comparisons with the past, of which records are entirely wanting; but such as they are, a few of these records are given in Table 1. They include in most cases both high and low water, although the low-water records cannot, in the nature of the case, be of very much value. Works of channel improvement on most of the streams have probably affected somewhat the low-water stages for the same discharge, while, as is well known, a given stage, even in a natural stream, does not mean the same discharge at different times.‡ It is really the discharge of the streams rather than the stage that forms the correct basis for comparison; but data for discharge are almost wholly wanting.

An examination of these records shows how utterly impossible it is to find anything in them to support the current theory of forest

*In the Weather Bureau report, Montana section for June, 1908, it is stated that "the rainfall was phenomenally heavy over most of this district, and, combined with the water from the rapidly melting snow in the high mountains, caused unprecedented floods in nearly all streams."

†During the past 20 years the low-water stage of the Mississippi at St. Paul has been materially modified by reservoir action.

FIG. 1.—DESTRUCTION FROM FRESHET IN WHITE RIVER, WASHINGTON.

FIG. 2. —NEW GROWTH OF TIMBER, ABOUT SIX YEARS AFTER FIRE.

influence. They prove conclusively that there has been no marked change since the settlement of the country began, and that such change as there has been is on the side of higher high waters and lower low waters before the forests were cut off. What the record would be if we could go back 200 years cannot be said, but it may safely be conjectured that it would show both floods and low waters that would equal or surpass any modern record. It is the experience of every engineer who has the opportunity to observe the action and study the history of great rivers to find everywhere evidence of the occurrence of higher waters than any of which he has positive record. The up-building of bottom lands, the survival of old water marks, and many other indications, show that, great as are modern floods, those of the past were greater still. In the very nature of the case, it is not possible to find similar evidence of former low waters, because such evidence is wiped out by every succeeding high water; but whoever will take the trouble to study records of early expeditions on our rivers, when barges, keel boats and similar craft were used, will conclude that extreme low water is not a modern development by any means. Measurements of the Monongahela River, at Brownsville, in 1838 and 1856, low-water years, gave discharges of 75 and 23 cu. ft. per sec., respectively. It is quite certain that the river has not fallen so low in late years. At Pittsburg in 1895 (the driest season in recent years), it fell to 160 ft.

The point should be fully recognized that these records are valueless for establishing either side of the forestry argument unless they clearly indicate a new tendency in river flow. It is not enough to cite a few isolated cases. In a period of, say, 200 years, there must be a record year for high and one for low water. Is there any reason why it might not occur this year as well as earlier? There must be clear evidence of permanent change before any conclusion can be legitimately drawn. In two instances such a tendency may possibly be claimed, the Ohio at Pittsburg and the Connecticut at Holyoke, which show, in the past few years, a greater frequency of high waters than for some years previously.* To whatever extent this may be true, it

*In the period of 34 years from 1874, the Ohio River at Pittsburg rose above 15 ft. on the gauge 148 times. In the first half of this period, 68 of these freshets occurred and 80 in the second half. The mean for the first half was 19.3 ft. and 20.2 ft. for the second half. The mean of the lowest waters of the first half was 0.3 ft. and 1.6 ft. for the second half. In *Transactions*, Am. Soc. C. E., Vol. LVIII, p. 31, is a 20-year volumetric record of the Connecticut, which indicates somewhat higher high waters during the last half of the period. But in this case, as at Pittsburg, higher low waters are also indicated. In fact, in both cases, the greater runoff in the later period was clearly due to greater precipitation.

is certainly not due to deforestation. The change in the forested areas on the water-sheds of either of these streams has been relatively very slight in the past 20 years. The great inroad into the timber of the Upper Ohio took place many years ago. Since that time many cleared areas have grown up to timber while new areas have been cut. The change one way or the other, in recent years, compared with the total area, is altogether insignificant. The Connecticut watershed above Holyoke has a greater forested area than it had 40 years ago. This is due to the abandonment of former farms which, in many instances, have grown up to timber. It is doubtful if the recent cutting in the White Mountains offsets this, and, so far as snow-melting is concerned, what cutting there has been is certainly in favor of uniformity of flow.*

The records of some American rivers have been given. It is, of course, in Europe that one would expect to find more definite data because of the longer periods through which records have been kept. The histories of several of these streams have been examined without finding any confirmation whatever of the forestry theory. The floods on the River Seine, for example, show greater heights in the 16th century than in the 19th. The most exhaustive investigation of the records of European rivers, however, is that of the Danube, the great river of Central Europe, recently made by Ernst Lauda, Chief of the Hydrographic Bureau of the Austrian Government. The years 1897 and 1899 brought destructive floods to the Valley of the Danube, that of 1899 being particularly severe. M. Lauda prepared an exhaustive report upon this flood, published in 1900, accompanied by elaborate maps and tables and a searching analysis of the climatic and other conditions. In his "Concluding Remarks," M. Lauda traces the history of the Danube floods for 800 years, including in all 125 floods. His conclusions are that floods were formerly just as frequent and as high as they are in recent times, and that the progressive deforesta-

*"I have seen in the last few years abandoned farms (abandoned because of their unprofitableness) on the Western slopes of the Allegheny Mountains, which are almost impenetrable forests of thrifty trees suitable for making mine posts and telegraph poles. There are, of course, large areas subject to fires at intervals of a few years, but that they are subject to such recurrent fires is proof of their rapid production of fuel which means twigs and leaves in great abundance." (Col. Thomas P. Roberts, Pittsburg, Pa.)

"The forest area in Vermont is probably 10 per cent. greater than forty years ago. Of course the quality of the forest is inferior, but that has no effect on the water-shed." (Arthur M. Vaughan State Forester.)

"Farms in the Connecticut Valley are among the richest in the state [New Hampshire] and have been less abandoned than elsewhere. There has been, however, a goodly acreage, very probably amounting to 25 per cent., which was cleared land in 1850, and which at the present time has reverted to forest; much of it excellent white pine forest." (Philip W. Ayres, Forester.)

tion of the country has had no effect in increasing them. In fact the records of the flood of 1899, which was a summer flood, produced almost entirely by rain, showed that it was severest on those very parts of the water-shed that were most heavily forested.

At the 10th International Congress of Navigation, held at Milan in 1905, one of the four questions appointed for discussion was the very one here under consideration. Papers were presented by representatives from France, Germany, Italy, Austria and Russia. While all the writers heartily favored forest culture, the opinion was practically unanimous that forests exert no appreciable influence upon the extremes of flow in rivers. It appears, therefore, that European experience does not support the currently accepted theory.

So much for the evidence supplied by the records in this country and abroad. The constantly reiterated statement that floods are increasing in frequency and intensity, as compared with former times, has nothing to support it. There are, it is true, periods when floods are more frequent than at others, and hasty conclusions are always drawn at such times; but, taking the records year after year for considerable periods, no change worth considering is discoverable. The explanation of these periods of high water, like the one now prevailing, must, of course, be sought in precipitation. That is where floods come from, and it is very strange that those who are looking so eagerly for a cause of these floods jump at an indirect cause and leave the direct one entirely untouched. In the records of precipitation, wherever they exist, will be found a full and complete explanation of every one of the floods that have seemed unusually frequent and severe in recent years. A few examples will be cited:

The great Kaw River flood of 1903, which wrought such havoc in Kansas City, was caused by a wholly exceptional rainfall over nearly all the water-shed of that stream. In the first three weeks of May, 1903, more than the normal amount (4.5 in.) for the entire month fell. This was followed in the next five days by 3.4 in., and upon this was piled 4.7 in. in the succeeding five days, by which time the flood had crested.

In the flood of 1906 in Western Washington, which did enormous damage and stopped railway traffic for upward of two weeks, the crest of the flood occurred about the 15th of the month. The month of October had been very wet, and the ground and forest storage was

exhausted. In the first half of November, 25% more rain fell than in the normal for the entire month, and of this about one-half came on the 13th, 14th, and 15th.

In the flood season of 1905 on the water-shed of the Upper Mississippi, there fell in the month of April above Pokegama Falls 2.55 in., in May, 4.95 in., in June, 8.03 in., and in July, 6.88 in., a total of 22.41 in. The normal for the entire year is 26.5 in.

In the record-breaking flood of 1907, in the Sacramento Valley, 88% of the normal for the month of March (based on 21 years' observation) fell in three days (17th-19th), and, on one day, the precipitation ranged from 5 to 8 in. at the different stations.

In the extraordinary flood of May and June, 1908, in Western Montana, the precipitation for May, at four selected stations, was 6.5 in., and for June, 4.2 in. The greater portion of this fell late in May and early in June. The normal for May is 2.6 in. and for June, 2.3 in.

Similar conditions prevail in every great flood, and the true explanation is found in them and not at all in the presence or absence of forests on the water-sheds. Whether the forests are in any way responsible for the precipitation itself, and so, indirectly, for the floods, brings up the third of the foregoing general propositions, viz., that forests do increase precipitation. However strong may be the popular belief in this theory, there is nothing in the records of rainfall to give it substantial support. The writer has had occasion, in connection with his official work, to compare the rainfall records in the northern half of the United States from the Atlantic to the Pacific, often with this particular point in mind, and he has never found anything to indicate a change. So far as he has examined European records the same result holds, and he believes it to be true the world over except where climatic changes have resulted from causes entirely disconnected with the operations of Man in changing the face of Nature. In fact, the claim that forests increase precipitation (about 10%, according to Mr. Pinchot) leads to some contradictory results in the forestry argument. Coincident with our recent high waters, which are attributed so largely to deforestation, there has been an increase in precipitation, where there should, apparently, have been a decrease.* It is evident that, where one rule applies, the other fails.

*As a step in the crescendo of gloomy forebodings upon this subject, that have filled the periodicals during the past twelve months, the following from the September *Scrap Book* is the very latest: "When our forests are gone the streams will

So, likewise, it is held that forests are necessary to protect mountain slopes because of the greater precipitation prevailing there; yet the forests are said to increase this precipitation materially.

There is really very little, theoretically, to support the claim that forests increase precipitation. It is said that the cooler status of forest areas condenses moisture and induces precipitation; but if this were so in midsummer, when the least precipitation falls, how about the rest of the year when no such difference exists, but the reverse, if anything? Take, for example, the great forests around the source of the Yellowstone. During the period when the bulk of the precipitation falls, the temperature of the forests cannot differ materially from the outside, and it is impossible to believe that the forest exercises much influence upon the snowfall.

The fact that these high areas are generally wooded is frequently cited to prove that forests produce the higher rates of precipitation which also prevail there. But would it not be more reasonable to say that the forests flourish there because of the higher precipitation, and that the latter is due to the elevated situation and consequent lower temperature? Is not this, in fact, the reason why precipitation is nearly always greater upon the hills than upon the neighboring lowland? The mountains are Nature's wine-press by which she extracts from an unwilling atmosphere the elixir of life for the hillsides and the valleys below, and she does this whether the forests have been cut away or not.

In one respect, and a very important one, forests diminish precipitation, and that is in the deposition of dew. Dew is essentially an open-country phenomenon, where the radiation of heat from the earth's surface is unobstructed. Clouds or high cover of any kind, and also wind, interfere with this process and prevent the dew from gathering. It collects in full strength on low shrubbery, to a less degree on small trees, as in orchards, and penetrates for short distances under forest cover. In the heart of the native forest of full-grown timber, however, dew is practically unknown. The quantity deposited in the open country in a single night is quite large under

dry up, the rivers will cease to run, the rain will fall no more, and America will be a desert!" Considering how large a percentage of our forests has already disappeared, the extraordinary rains in all parts of the United States during the past year are not exactly in line with this dismal prophecy. If one were to judge from the records of the past few years only, he must conclude that deforestation is increasing rainfall.

favorable conditions, leaving the effect on shrubbery and on the ground of a considerable shower. As it gathers in greater or smaller quantities on every clear, still night in the eastern sections of the country, except in the colder season of the year, the total quantity must be quite large.*

One authority holds that dew does not come entirely from the air, but in part from the ground. It is said that water, which in the daytime passes from the ground and plants into the air, is prevented from doing this at night, because the air cannot receive it, and, therefore, it gathers in visible form on the ground and vegetation; but if this were true, it really makes no difference in the benefit which comes from the dew. Whether the low temperature due to radiation causes a deposit of moisture from the air or prevents the air from absorbing moisture which it otherwise would, the result, so far as the ground and vegetation are concerned, is practically the same.

This may be as good a place as any to note one important characteristic of precipitation, and that is its tendency to move in cycles. It is well known that dry years often follow each other for long periods with great regularity, and that these are succeeded by wet periods. Take the region of the Upper Mississippi reservoirs where the normal precipitation, based upon 21 years' observation, is 27.1 in.; in the ten years (1886-1895), this normal was exceeded only once; in the succeeding ten years the record fell appreciably below it only once. Omitting these two years, the mean for the two periods of 9 years was 24.7 and 30.0 in., respectively, an average yearly difference of nearly one-fifth of the normal. Following the well-known law that the percentage of run-off increases and diminishes with the precipitation, the disparity between the run-offs for the two periods was greater still.

This phenomenon is also admirably illustrated in the rise and fall of the levels of the Great Lakes, for these immense storage reservoirs, not only absorb and distribute annual variations of run-off, but equalize to a large degree the variations from year to year. During the period of the Eighties, there was a general rise in the lake levels except Superior,

*The writer has never seen any data as to the actual quantities of dew deposited in different localities and conditions, and hopes that the discussion of this paper may bring some to light. He has, however, vivid recollections on the subject when, as a lad on a dairy farm, it was his unlucky lot to go barefooted after the cows every morning without waiting to see whether the sun was going to shine or not. He knows from experience how near zero the dew point can get, and how wet dew is; and also that the warmest place in the world, at such times, is where a cow has lain all night, and next to that the dry precincts of the tall woods.

and many people ascribed this fact to deforestation, which allowed the water to find its way more quickly into the lakes. During the Nineties, there was a period of general subsidence, occasioning considerable anxiety, and it was frequently asserted at that time that this was due to deforestation, which was drying up the streams. For some years now the Lakes have been rising, Ontario being the highest in 40 years; and with another wet year the levels will almost reach record heights.

The long record of the Danube floods, already referred to, is another example. Almost invariably high floods would follow each other for several years in close succession, and then would come long intervals of ordinary high waters.

These periodic changes are not, of course, due at all to the presence or absence of forests, for they occur just the same whether forest conditions remain unchanged or not. It is an order of Nature not at all understood, but nevertheless fully established as a fact. Just now we are in an era of high precipitation and consequently of high waters. There is a disposition to "view with alarm" these exaggerated conditions. Rarely does one stop to think how far better it is to the country to have these wet periods, even with all their floods, than the dry periods that will surely follow. A single dry year may cause more loss to the country through the shrinkage of crops than the floods of an entire cycle of wet years.

Related to the subject of precipitation is that of evaporation as affecting the quantity of water that remains upon the ground. Generally speaking, the surface evaporation in summer should be greater in the open than in the forest because of the more direct action of the sun and wind; but in the height of summer the forests arrest precipitation to such an extent in the leaves and humus, that more of it escapes through evaporation than in the open. The effect of forests upon evaporation through the medium of their leaves finds its counterpart in the similar action of the growing crops that overspread deforested areas. As already pointed out, the forests of the mountains increase the evaporation from snow very materially.

Where the balance lies among all these conflicting influences affecting precipitation and evaporation it is impossible to say, and when the records are examined it must be admitted that they afford no answer. So far as the researches of Science have yet determined, the presence or absence of forests cuts no figure in climatic conditions.

These depend upon causes of far greater magnitude, and are influenced, if at all, only to an insignificant degree by the operations of those who occupy the planet.

The fourth proposition of the forestry argument is that forests are necessary to prevent erosion on steep slopes and the consequent silting of reservoirs and watercourses below. Here again there is the same deficiency of evidence to support the theory that has characterized the three propositions already considered. The writer has been unable to find anything to confirm it. In his observations, embracing pretty nearly all varieties of timber land in the northern two-thirds of the United States, he has still to see a single example where the mere cutting off of forest trees has led to an extensive erosion of the soil. Almost invariably, and it may be said always except in very unusual conditions, a soil that will sustain a heavy forest growth will immediately put forth, when the forest is cut down (or even burned down), a new growth, generally in part different from the first, but forming an equally effective cover to the soil. The only approach to an exception to this rule that he has observed is in some of the high mountain forests where the soil is extremely thin and weak and the action of Nature in producing vegetable growth is slow. Fig. 2, Plate XL, shows one of the best examples of this class of timber land; but even here the slow growth is very evident and no large amount of soil erosion has resulted. In the forest areas of the East, the growth that follows tree-cutting, consisting not only of new trees but of briars and small brush of every description, accumulates very rapidly and forms a more effective mat against erosion than the original forest itself and is equally effective in storing water. Such low growths have also a better effect upon snow-melting because they give both wind and sun freer play. Certainly the ground in a forest under culture, with the *débris* raked up, is more easily eroded than that of a slashing or second-growth area, or even good meadow or pasture. A forest soil unprotected by forest *débris* is almost as erodible as a field under culture.

The increased erosion of the soil, of which so much is heard, does not result from forest cutting, but from cultivation, using that term in its broad sense to include all of Man's operations for the occupancy and utilization of the ground from which the forests have been removed. It is the "breaking of the soil" that leads to its

erosion by the elements. Roads and trails are one of the great sources of erosion in hilly countries, but plowing and tilling are the principal causes. The question is not one of forests in the first instance, but of how far the cultivation and occupancy of the soil can be dispensed with. Even on steep mountain slopes, where erosion and ruin have resulted, the effect is often due to the clumsy and injudicious work of the husbandman who uses no judgment of cause and effect in the way he exposes the soil to the force of the storms. The successful cultivation of hillsides in every quarter of the globe is an everlasting refutation of the argument that forests are necessary to protect the face of the earth wherever cultivation is practicable. Some classes of cultivated vegetation, like the well-knit turf of meadow or pasture, are a better protection against erosion than any ordinary forest cover. That there are sections of the country where erosion of the soil is much more rapid than in others under similar conditions, is perfectly true. This is especially the case with certain districts in the Southern States, and very likely forest protection is there better than any other; but it is still true that the problem of control of soil erosion on cleared lands is essentially a problem in cultivation. It is not so much the absence of the forest as it is the cutting of roads and ditches, the upturning of the soil, and the various kindred operations of Man that quicken the run-off and increase the surface soil wash.

The oft-repeated assertion that, owing to the cutting off of forests, our rivers are shoaling up more than formerly may be challenged absolutely. There is nothing in our river history to support it except in a few instances, like the Yuba River in California, where extensive hydraulic or similar operations have produced vast changes. It is exceedingly doubtful if it can be established by any evidence worthy of the name that the streams of the Mississippi Basin are more obstructed by sand bars than formerly. The writer's observations of upward of 20 years and inquiries from many sources fail to disclose any such evidence. It would not, indeed, be surprising if some such result were noticeable, for it would naturally seem that the cultivation of the soil has facilitated to some degree the wash into the streams. If this is the case, however, the rivers do not show it. They have a way of distributing their burdens so as to meet their

necessities and, except in rare cases, they do not shoal appreciably more than formerly.*

The distinction between erosion actually resulting from cultivation and that assumed to result from timber cutting, is important to keep in mind, for it fixes the burden of responsibility where it belongs. It shows that this erosion or soil wash can be reduced only by the elimination or control of cultivation, and the question at once becomes that of the extent to which such control or elimination is practicable. For example, it is insisted that the suggested reservoir system of the Ohio, to be referred to later, will be absolutely dependent for its integrity and permanence upon keeping the water-sheds above them covered with forests. But it is understood not to be the policy to include in the proposed forest reserves any lands that are fitted for agriculture.† As elsewhere pointed out, that portion of these areas, which is not reduced to cultivation, will not be subject to erosion more than at present by the mere fact of cutting off the timber; for the natural growth on logged-off lands is just as good a protection as the forests themselves. If the agricultural tracts are still to be left open for occupancy, the source of sediment remains uncurbed and the whole argument for forest reserves, on the ground of protecting the reservoirs from sedimentation, falls to the ground.

Some reference should be made to the real significance of the alarming reports which have been put forth concerning the washing of our soils into the sea. Over and over during the past year has the statement appeared that 1 000 million tons of our soil is annually carried by our rivers into the ocean. This figure itself is quite conservative, but the conclusions drawn from it are not at all so. Taking the results of silt observations on the Mississippi River and its tributaries for 1879, and applying the Missouri rate to all Western streams outside the Mississippi Basin, and the Ohio rate to all Eastern streams outside the same basin, a total of about 1 100 million tons is indicated.

*The absurd length to which this erosion argument has been carried is well illustrated by the remark made in a recent address by one of the officials of the Forestry Service: "This energy [of running water] is expended in rolling along stones and gravel to finally build up the mouths or beds of the great rivers. Next year there will be a bill introduced in Congress providing a forest reserve in the Appalachian Mountains, so that the rocks from these mountains will be kept from the Mississippi River!"

†Among references to the intention not to absorb agricultural lands in the areas conserved by the reservoirs is the following from A. F. Horton, Assoc. M. Am. Soc. C. E., in *Engineering News*, June 11th, 1908: "The reader should not lose sight of the fact that the conserved area is not rendered unfit for cultivation or other use, but that only a small portion of the conserved area [that covered by the reservoir] is so utilized that its value for cultivation is destroyed."

But 1879 was a low-water year in the Mississippi Basin and the quantity for average years may probably be 1 500 million tons and for extreme years, 2 000 million tons.

Let us look these prodigious quantities squarely in the face and see what they mean. Where does this enormous volume of soil come from? Is it, as one might infer from published references to the subject, from our cultivated fields—an annual toll laid upon the precious fertility of our agricultural lands? Not at all. Only a very small proportion comes from this source. Possibly half of the total quantity of sediment goes down by the Mississippi. All authorities agree that the greater portion of this comes from the Missouri. From computations which the writer has made, he believes that fully two-thirds of it comes from that source. The observations of 1879 indicate that five times as much sediment comes from that stream as from the Ohio. But where does the Missouri get it? Almost entirely from the most useless areas of land with which any country was ever afflicted. The barren Bad Lands are the principal source. Much comes from the mountains; much from the sand hills; very little, relatively, from cultivated areas. Of the remainder of the soil wash of the United States, by far the greater portion comes from other similar sections of the West where the streams carry enormous loads of sediment. The entire Colorado system is even more distinguished in this respect than is the Missouri. The same is true of the Rio Grande, the Pecos, and the upper courses of the Arkansas and Red. Even the streams of the Great Interior Basin are heavy silt bearers, and the same is true of many of the streams of the Pacific Coast. The streams flowing into Puget Sound are heavily laden with silt at certain portions of the year, and the great Columbia Bar is impressive evidence of the vast burden of sediment which that mighty river has carried to the sea. Nearly all the annual load carried by these streams is entirely unaffected by anything which Man has done. It is the regular natural carving down of the hills and building up of the valleys and estuaries below.

The Eastern streams are clear and sediment-free compared with those of the West; but even in these, a large portion of their sediment is eroded from the gorges and cañons of the hills and mountains, which will continue to wash away as long as the rivers flow. This particular class of erosion, on both Eastern and Western rivers, is far less objec-

tionable than one is led in these later days to believe. Has it not from the beginning been one of the most beneficent operations of Nature? Are not the richest lands in the world—the river bottoms and deltas—built up in this way? To a very great extent the irrigated lands of the West are composed entirely of the *débris* from the mountains and the bad lands. Even to-day this tribute from the highlands is of great value. The periodic enrichment of the Ohio bottom lands and similar tracts in hundreds of other places, is of the highest economic importance. The soil-laden waters of irrigation in the spring, though sometimes injurious to the growing crop for the time being, are, on the whole, extremely beneficial. The damage from sediment is not in its injury to the lands ordinarily, but to ditches, canals, reservoirs and similar works. On the whole, it is, and always has been, a benefit to the lowlands. Even that portion carried out to sea builds up deltas and surely, though slowly, extends the habitable area of the globe. Not alone in the resources of water and timber, but in the perpetual renewal of soil as well, has the valley said to the mountains throughout the world's history: "I will lift up mine eyes unto the hills from whence cometh my help."

Sediment of this character, except when accompanied by alkaline salts or other similar ingredients, is not injurious to domestic supply. The water of the Missouri River is one of the healthiest drinking waters in the world in spite of the fact that it is one of the muddiest.*

The proportion of soil wash that comes from cultivated fields is really very small compared with the enormous total that the rivers carry away. Heavy rains undoubtedly wash farm soils a great deal, but this erosion is in large part a transfer from one spot to another and not an absolute loss. The history of the old Ohio Canal reservoirs indicates very little filling in the 66 years that they have been in existence. According to the Chief Engineer of the Ohio State Board of Public Works, it is scarcely appreciable in some of the reservoirs and in none does it amount to as much as 6 in., or $\frac{1}{200}$ in. per year from the tributary water-shed. Yet these reservoirs are surrounded by rich agricultural lands. The silt observations on the Ohio in 1879 indicate only a little more than $\frac{1}{800}$ in. over the entire water-shed; but this, it is true, was a year of light rains.

*The late J. B. Johnson, M. Am. Soc. C. E., used to say, in extolling the virtues of Missouri River water, that it was the most perfectly filtered water in the world; with this difference, however, that in the ordinary case water is run through the filter, but here the filter is run through the water.

It is readily seen that the formidable danger of which so much has been written of late becomes quite harmless as to quantity when it comes down to the individual farm. The harm is probably not so much in the quantity of soil actually lost as in the fact that the soil may be leached of some of its more important ingredients. The evil is one which can be controlled only by better methods of farming, whereby the surface waters will be restrained from eroding the soil; but even these measures have their adverse side, for when heavy rains prevail for a long time it is more important to the farmer to get the water off his land than it is to save a little soil. Most of the soil will stop on lower ground and not be wholly lost, but if the water is not gotten rid of the crop may be ruined.

The caving of the banks of our great rivers is constantly cited as an example of soil loss on an enormous scale, and it is asserted that this condition is worse now than formerly. The Mississippi and Missouri Rivers, practically alike in this respect, are the two most prominent examples. The writer will consider briefly the case of the Missouri because he has had a long and intimate acquaintance with that stream from its mouth to its source.

It may be stated by way of refutation that the actual condition of this stream to-day is better than before settlement began in its valley, except that possibly the low-water flow is slightly diminished to meet the demands for irrigation. The stream is not "constantly becoming more and more savage," as a recent writer asserts. On the other hand, its natural savagery is much restrained. Probably 100 miles of its banks are protected; snags and drift heaps are largely removed; considerable bottom land has been reclaimed and turned to industrial use; floods are no greater than they used to be, and navigation is safer and easier. Navigation has ceased, not because the river has deteriorated, as is commonly asserted, but because the natural difficulties peculiar to this stream are so great and so hard to overcome that boats cannot live and do business at the same rates at which railroads transport freight.

That the river is a most destructive one to the bottom lands along its course is only too true; but the character of its destructive work is generally misunderstood. The writer just quoted states that the river carries away annually 8 000 acres of bottom land within the limits of the State of Missouri alone. The total acreage of these lands

is about 640 000. If this statement were true, more than the entire area would have been carried away since the voyage of Lewis and Clark, and if the process had been continuous since Columbus discovered America, the river to-day would be flowing in its original channel in the solid rock, 75 to 90 ft. below the present surface. As a matter of fact, there is more soil in the valley to-day than there was at the date of either of these events. Taking an average for a considerable period, none of the bottom land is lost. It has always been slowly rising through accretion. The bank caving is only a transfer from one point of the shore to another. For every dissolving bank there is a nascent bar. Where steamboats ran last year, willows may be growing this, and next year the farmer may be planting his corn. The havoc wrought concerns the individual owner, but not the valley bottom itself. The cruel losses attract attention; the unobtrusive gains do not; but the account always balances itself. The harm done is first to the individual whose possessions are swept away, and second to the community through paralysis of development, depreciation of values, and the holding back of this natural garden spot from becoming what it ought to be. The evil is a very real one, and the writer has long endeavored, though without success, to secure provision in the River and Harbor Bill for its amelioration.* Great as the evil is, however, it is not at all in the nature of an actual loss of land to the valley.

It must be clear from the foregoing that the bottom lands of the Missouri add nothing whatever to the total quantity of sediment that passes out of the mouth of the stream, for these bottoms have been increasing rather than diminishing in quantity. Likewise the Mississippi bottoms contribute nothing to the volume of sediment that is carried into the Gulf of Mexico. It all comes from the uplands, far and near, but principally from the more remote and hilly regions. This load is in the nature of through traffic. The local freight picked up from a caving bank is mostly discharged at the next station. It follows, therefore, that if the banks of these streams were revetted from the Gulf to Pittsburg, the Falls of St. Anthony and the mouth of the Yellowstone, the quantity of sediment passing into the Gulf would not be diminished a particle. Such revetment would never-

* *Transactions, Am. Soc. C. E.*, Vol. LIV, p. 336.

theless be of the very highest value, if it could be made to hold, for it would give permanence to the banks, security to riparian property, and would largely prevent bar-building by training the river in a regular channel and relieving it of everything except its through load of sediment.

The bank-caving problem of these valleys is unaffected in any appreciable degree by the influence of forests or cultivation on the water-sheds, and cannot be solved or materially assisted by any practicable changes in these conditions. The problem is strictly a local one, and the remedy must be a local one. Even if it were possible to bring the waters down from the uplands perfectly clear, it is not at all certain that the effect upon the bottom lands would not be injurious rather than beneficial; for then the caving soil, instead of being quickly deposited again, would in part be carried out to sea, and the bottom lands, unless protected, would be gradually eaten away.

In addition to the four main propositions discussed above, a few subordinate features of the question will now be considered.

A feature of the Forestry Service which is generally overlooked is the possible effect of culture upon the bed of humus so much relied upon in these discussions to prove the restraining action of forests upon run-off. Mr. Pinchot, in his statement to the Judiciary Committee, said:

"The effect of a forest on a steep slope is to cover that slope with leaves, rotten and half rotten sticks, and other mechanical obstructions which prevent the water from running below as rapidly as it would otherwise."

It is understood that the forest policy is to keep this litter cleared up as a measure of fire protection, and one frequently sees in articles on forestry, photographs of the typical forest culture in which the ground is thoroughly cleaned up. The result must be to diminish proportionately the retentive action of the forest bed and to increase its liability to erosion. In the light of the foregoing discussion, fire protection is of much greater importance than the retentive effect of the forest bed on the run-off. The remarkable degree to which the forest bed will dry out in prolonged drought, making it one vast tinder-box, supports this conclusion, and is another proof of the extreme desiccating effect of forest growth upon the soil.

It often escapes attention, except with those who are in the woods a great deal, that the water establishes little channels through the *débris* where the latter is of long accumulation and somewhat permanent in character. Such *débris* does not in reality offer so great an obstruction to flow as one would suppose, and as would be the case if its condition underwent frequent change.

The statement is constantly met that forests are very efficacious in the protection of river banks from undermining and steep slopes from sliding. The exact reverse is the case. As every river engineer knows, nothing is more disastrous to a river bank on an alluvial stream than heavy trees. This is due partly to their great weight, but in large part to the swaying effect of the wind and the enormous leverage of the long trunks which pry up the ground and facilitate the tendency to undermining. One of the regular policies of river control is to cut down these trees for a distance back from the edge of the bank wherever complications with private ownership do not prevent. Snags and driftwood in the channels have always been among the most serious obstacles to navigation on streams flowing between forest-covered banks. Likewise where railroad or highway grading cuts the skin of unstable mountain slopes, the presence of large trees immediately above tends powerfully to loosen the ground and cause it to slide; and in such cases it is necessary to cut down the timber. Far better than forest trees on river banks are thick growths of willow, alder, or any of the smaller close-growing shrubs; and on side hill slopes either such shrubbery or a good turf.*

In the current discussion a great deal is made of the fact that mountain slopes are "quick spilling," the deduction being that they therefore are more productive of floods. This is quite contrary to the fact. It is perfectly true that more rain falls on the hills than on the lowlands, that a greater percentage of rainfall runs off from steep than from flat slopes, and that it runs off more rapidly; but it does not follow at all that these conditions produce greater floods. A mountain stream carries off the water within its banks a great deal faster

*The following testimony before the Board of Consulting Engineers, Panama Canal, is to the point (Report, p. 329):

Question by Mr. Welcker: "Mr. Chairman, I would like to ask if Mr. Dauchy thinks that vegetation prevents the sliding?"

Mr. Dauchy: "My experience has been the reverse; I have stopped sliding hills by cutting off the vegetation. The weight of the timber on a sliding slope aids materially to assist the sliding."

Mr. Welcker: "Does not the vegetation diminish it?"

Mr. Dauchy: "If you could get a grass-covered slope it would help to diminish it."

FIG. 1.—CUT-OFF ON MISSOURI RIVER ABOUT TO TAKE PLACE.

FIG. 2.—CREW FELLING TREE FROM RIVER BANK.

and more safely than a similar stream in the lowlands. The banks are almost always stable and the bottoms rocky or composed of heavy gravel or boulders; in fact, floods do less harm on such streams than on any others. In the low land, where the streams have smaller slopes and unstable banks, much smaller run-off produces greater floods and more destruction. Moreover, Nature to a large degree adapts streams to the work required of them. The channels of the tributaries of the Ohio have been carved out through long ages to carry in safety the average flood flow. Area for area of water-shed, their cross-sections are much larger than those of streams in climates of less rainfall. The normal section of the Ohio at Wheeling is over 2 sq. ft. for every square mile of water-shed, while that of the Kaw River at Kansas City is less than $\frac{1}{2}$ sq. ft. per square mile. It is therefore wholly erroneous to conclude that the streams of these mountains are more subject to over-bank freshets than those of the low lands or that the freshets themselves are more destructive. Considering the conditions growing out of settlement, the reverse is unquestionably the case.

There is one other consideration of prime importance in this forestry argument, and that is the fact that no possible development of forestry can increase the present percentage of forest-covered areas. At least as much ground as is now devoted to agricultural purposes must continue to be so used. The utmost admissible expansion of National forests will never require a greater area than is now occupied by forests and second growth or logged-off lands, which, so far as run-off and erosion are concerned, are just as effective as the virgin forest itself, and more effective than will be the groomed forest of the new régime. There may be a shifting of areas devoted to forests, but possible expansion, compared with the present area, is so small that its influence upon the great rivers, even admitting the full force of the forestry argument, would be wholly inappreciable.

The fact just dwelt upon should make us thankful that the forestry theory as to the stream flow is not correct. Whatever the value of forests, we cannot have them everywhere, and by far the greater portions already cleared away must always remain deforested. If this fact of deforestation has brought with it in greater degree than of old the calamities of high and low waters, then, indeed, we are in an unfortunate case. But it has not done so. Nature has decreed no such penalty for the subjugation of the wilderness, and on the whole these

natural visitations are less frequent and less extensive than they were before the white man cut away the forests.

In summarizing below the foregoing argument, the writer would be particularly careful to guard against sweeping assertions in any of his conclusions. He well understands how little the subject is capable of precise demonstration. Snow, for example, does not always fall, even in the open country, under the influence of the wind, or it may fall in a wet condition that keeps it from drifting. Altitude comes in with its lower temperature and modifies the general result. There is a vast difference between a northern and a southern exposure even with the same slope and topographical conditions. Precipitation scarcely ever occurs twice alike on the same water-shed. The combination of flow from tributaries is never the same in any two floods, and there is an endless variety of conditions that must qualify our rules and make us cautious in making claims in a matter of this kind. The writer objects solely to the contrary course pursued by many forestry advocates—to the extreme claims that forests exert a regulating influence upon stream flow in times of great floods or extreme low water in our larger rivers. These claims stand to-day absolutely unproven. The difference between past and present conditions is not great. One influence offsets another with such nicety that the change, if there is any, is hard to find. The "delicate balance" maintained by Nature where Man has not cut away the forests is replaced by other balances equally delicate and efficacious in the drainage of lands, the growing of crops, and the deposition of dew.

In the following seven propositions the writer sums up the arguments presented in the foregoing pages:

(1) The bed of humus and débris that develops under forest cover retains precipitation during the summer season, or moderately dry periods at any time of the year, more effectively than do the soil and crops of deforested areas similarly situated. It acts as a reservoir moderating the run-off from showers and mitigating the severity of freshets, and promotes uniformity of flow at such periods.

(2) The above action fails altogether in periods of prolonged and heavy precipitation, which alone produce great general floods. At such times the forest bed becomes thoroughly saturated, and water falling upon it flows off as readily as from the bare soil. Moreover, the forest storage, not being under control, flows out in swollen

streams, and may, and often does, bring the accumulated waters of a series of storms in one part of the water-shed upon those of another which may occur several days later; so that, not only does the forest at such times exert no restraining effect upon floods, but, by virtue of its uncontrolled reservoir action, may actually intensify them.

(3) In periods of extreme summer heat forests operate to diminish the run-off, because they absorb almost completely and give off in evaporation ordinary showers which, in the open country, produce a considerable temporary increase in the streams; and therefore, while small springs and rivulets may dry up more than formerly, this is not true of the larger rivers.

(4) The effect of forests upon the run-off resulting from snow-melting is to concentrate it into brief periods and thereby increase the severity of freshets. This results (*a*) from the prevention of the formation of drifts, and (*b*) from the prevention of snow-melting by sun action in the spring, and the retention of the snow blanket until the arrival of hot weather.

(5) Soil erosion does not result from forest cutting in itself, but from cultivation, using that term in a broad sense. The question of preventing such erosion or soil wash is altogether one of dispensing with cultivation or properly controlling it. The natural growth which always follows the destruction of a forest is fully as effective in preventing erosion, and even in retaining run-off, as the natural forest.

(6) As a general proposition, climate, and particularly precipitation, have not been appreciably modified by the progress of settlement and the consequent clearing of land, and there is no sufficient reason, theoretically, why such a result should ensue.

(7) The percentage of annual run-off to rainfall has been slightly increased by deforestation and cultivation.

If the foregoing propositions are correct they enforce two very important conclusions—one relating to the regulation of our rivers and the other to forestry.

It follows that no aid is to be expected in the control or utilization of our rivers, either for flood prevention, navigation or water power, by any practicable application of forestry. Remember always that it is the extreme of flow, not the medium condition, that controls the cost of river regulation. It is the floods and low waters that measure the cost. Any scheme of control that is not based upon these

is worthless. This proposition need scarcely be urged upon the experienced engineer. For himself he would never place any real reliance upon forestry. Called in consultation, for example, in the problem of protecting the City of Pittsburg from floods, he would be bound to take as his measure of the problem the highest recorded flood on the river with a good factor of safety on that, and then figure out by what methods—artificial reservoirs, levees, raising of grades, or clearing the river channel of artificial obstructions—he would obtain the desired relief. He would not dare, as the physician in the case, to advise his patient that he could dispense with or lessen in any degree the application of the remedies proposed, nor save one dollar of the cost, by anything that might be done in reforesting the water-shed of the rivers themselves.*

In like manner no engineer could honestly advise lowering in height by a single inch the levees of the Mississippi because of any possible application of forestry to the water-shed of that stream. And again he could not advise that forestry development would lessen in any degree the cost of improving the rivers for low-water navigation. Engineers fully understand their responsibility in these matters. But great engineering projects cannot be carried out without money, and the people will not give the money unless convinced of the necessity and wisdom of the plan proposed. So long as there is apparently some easier and simpler plan, some panacea, no matter how nebulous or unproven, that offers a way out without the expenditure of so much cold cash, they will be backward in voting money, and the counsel of the engineer will be of no avail. Hence the complete divorcement of forestry from any connection with river regulation—so far, at least, as its effect upon the cost of such regulation is concerned—will be a distinct and positive gain to the latter.

In the second place, forestry will be left to work out its own salvation without any reference to the rivers. Will not its cause be promoted by this divorcement? At first thought it may seem that thereby one great argument for forestry is lost; but no argument can be of

*Possibly the writer is too positive in this opinion. He finds that, in one case at least, the City of Williamsport, Pa., reputable engineers have advised reforestation of mountain slopes as a protection against floods. The statement of "an eminent authority" was cited with approval to the effect that "four-fifths of the precipitation is detained by the surface of the ground" under forest cover. But here, as in all these assumptions, the rule applies only to the average condition. The point is overlooked that in periods of heavy precipitation the retentive capacity of the forest bed becomes exhausted. If the City of Williamsport is relying upon this advice it is certainly laying up for itself a season of repentance.

value in the long run that is not based upon truth, and the disappointment that is certain to result in the fulfillment of these hopes will do more harm than good. Forestry does not need any such support. It stands on a basis of its own, too broad and too sure to require any extraneous aid. What is this basis? The reply may be given in the beautifully appropriate phrase that occurs in the Act of Congress creating the first of our National Parks, "the benefit and enjoyment of the people." In the matter of benefits, forests are necessary, because they produce the most important material of construction known to Man; even iron cannot be excepted. From the lead pencil to the mast of a ship, from the infant's top to spacious temples and palaces, it enters into nearly every requirement of human existence. A large portion of the structures for human habitation are built of it. The land transportation of the world is closely dependent upon it, for if it were not for the railroad tie scarcely a car could run. It is only when one stops to think a little upon the unlimited adaptability of wood to human needs that its transcendent importance is borne in upon him.

In the matter of enjoyment, no other work of Nature has done more for the uplifting and ennobling of the mind than these "first temples" of God. It requires no argument to enforce this assertion, particularly with him who has been reared in close companionship with the woods. Sad indeed will be the day, if it ever comes, when the people are deprived of this source of healthful pleasure for which no adequate substitute can ever be found.

And yet this supremely important resource in human happiness is strictly limited, and the visible supply is fast disappearing. Statistics fix the date, almost as confidently as an astronomer predicts an eclipse, when the doomsday of its final disappearance will come unless something is done to prevent. Most fortunately, this material, unlike copper or iron or stone, is a vegetable product capable of self-renewal, and the supply can be kept up forever. This is what gives its immense importance to forestry. It requires no dubious support from any other source. It fully justifies the splendid work that the Forestry Service is doing, and demonstrates the wisdom of the far-sighted men who are laying the foundation of our future National forests.

Let us now inquire if it will not be to the advantage of this great work to be absolutely independent of any connection with water

way development. Will it not be better in every way for forestry if it is promoted solely on the basis of producing trees for human use and enjoyment, and not at all for any supposed influence upon flow of streams? Is it really a wise move, so far as forestry is concerned, to single out the rugged and inaccessible mountains as localities where our future supply of timber must come from? The availability of forests to human needs depends very largely upon the situation in which they grow. Few people understand the exceeding importance of this matter. The converting of a forest tree into form for use involves two distinct processes, the conversion of the tree into lumber or other product and its transportation to the place of consumption. The cost of logging operations is immensely increased by the roughness of the ground. In our Western forests, for example, it requires a higher grade of skill, commanding higher wages, to "lay" a tree on a steep hillside than on even ground. The losses from breakage in falling are much higher, and the difficulty and expense of getting the logs out much greater. In fact, the increase of cost runs all the way from \$1 to \$10 per 1 000, depending upon the situation. *Engineering News* stated the case very forcibly in regard to the Appalachian forests (though it did not have this particular thought in mind), when it said in a recent issue that "the cutting off of forests on the remote mountain slopes has only become possible with the high price of lumber that has prevailed for ten years past." This increase of cost represents the perpetual tax that the public must pay for timber from these regions as compared with that from the lowlands. And a great deal of it can never be gotten out at all. The poet's "gem of purest ray serene" was not more lost to human needs than are tens of thousands of noble trees in the rugged fastnesses of our mountains, east and west. Benefit? To convert them into lumber will cost more than they are worth. Enjoyment? Only the solitary hunter or mountaineer ever sees them. These are not the places to rear up forests for the good of the people.

Consider the question of transportation and take Chicago as being practically on the meridian through the center of population of the country. The rate on fir from the Cascades to Chicago is 55 cents per 100, or \$16.50 per 1 000 ft. B.M. The average rate from the Appalachian forests is about 18 cents, or about \$9 per 1 000 for green oak. By a proper distribution of our forests, these rates on the average

ought to be brought within 10 cents per 100. In logging and transportation together, the country will tax itself on the average not less than \$10 per 1 000 for whatever supply it derives from these mountain forests as compared with what it might receive from forests more favorably located.

If it were not for the erroneous assumption that forests have a regulative effect upon the flow of our navigable rivers, would not the policy in regard to the acquisition of lands for forest reserves be quite different from that now proposed? If Congress were to vote, say, \$10 000 000, at the next session to commence the establishment of National forests by purchase, would it not be far better spent in lands where the pine, oak, cherry, and ash used to grow, in locations convenient for access by the people and in every way better adapted to their needs? States, counties or other agencies should be required to meet half the original cost. Even if the total cost to the Government were several times what equal areas in the mountains cost, it would be far more economical in the long run. There is an abundance of land in nearly all the States, suitable for the purpose, that can be had at not excessive cost. In New England, for example, would not the development of forests in the lowlands, where in many places former cultivation has been abandoned, be far better than to buy up the difficult slopes of the White Mountains? Let there be a National forest in every county of the United States where it is practicable to create one. Let its location be carefully chosen so that its product may be manufactured and shipped with the smallest cost to the people, and serving also, not only as a pleasure ground, but as a stimulus to similar work by private agencies.

It will be urged that these mountain lands are worth more for forestry than for agriculture. Very true, but that would not justify their purchase if the same money would produce a better result elsewhere. "Never buy what you do not want because it is cheap." Again, it may be said that here is our only remaining timber supply in the East, and it must be saved. Except in some possible economy by the more judicious cutting under Government control, it is not apparent how a forest tree that has attained its growth is going to render any greater good to humanity by being saved for the next generation than by being cut for this. There is a general sentiment current in these later years that if timber is cut off by private agencies it is wasted;

but does it not find its way into common use just the same? Not as completely, perhaps, but still substantially the same. Take the combination of the Weyerhaeuser Timber Company, considered entirely apart from its economic and ethical aspects as a great trust or corporation, and solely as a preserver of our forests. With its system of fire control, its policy of holding its timber for high prices, is it not really conserving the timber for future use? To speak of such timber as being "lost" to the people, "wasted," and its acquisition as a "looting of our heritage," is as disingenuous as it is untrue. Will its lumber cost the consumer a cent more per thousand than if it were from a Government reserve? It is a wholly gratuitous assumption that our timber is going to be "wasted" unless it is placed under Government control. The thing of prime importance is to get new forests started. In the 30 to 50 years that our present supply will last, new forests should be brought into existence all over the country. This is far more important than to buy the virgin timber of the Appalachians.

Moreover, it seems now to be considered that the virgin lands have already risen too high in price to be purchased by the Government, and that it is only the second-growth lands that can be economically acquired.* Be that as it may, it is certain that the acquisition of such of these lands as are desirable for the strict purposes of timber production will be greatly facilitated by disabusing the minds of the owners of the impression so diligently fostered of late that the very salvation of the country depends upon their selling out to the Government. Can anyone doubt that the present course will add vastly to the purchase price?

Still another argument that may be urged is that only by linking the forests with the rivers in a way to establish their utility in maintaining navigation can the constitutional objection to the acquisition of these lands be overcome. But does this apply to mountain forests more than to any others? It is incontestably true that whatever restraining effect forests have upon run-off is greater upon the lowlands than upon steep mountain sides. This legal feature of the question will be referred to farther on.

*Report of Secretary of Agriculture on Southern Appalachian and White Mountain water-shed, December, 1907, pp. 8, 30, 35.

RESERVOIRS IN THEIR RELATION TO STREAM FLOW.

Under this heading artificial reservoirs alone are included. Natural reservoirs of various kinds exist nearly everywhere, and exert a profound influence upon stream flow. The ground is the most important of these, absorbing on the average probably one-third of the total rainfall. Natural lakes are great regulators, the St. Lawrence system being the most perfect example. Forests are effective reservoirs at certain seasons. Swamps and low-lying grounds along river courses, like the great flood basins of the Sacramento and the Mississippi, are, in their natural state, enormous reservoirs which greatly reduce the flood flow of the river channels. Snow-drifts, particularly the great drifts of the mountains, are splendid reservoirs. The streams themselves have immense storage capacity; for example, the Mississippi within levees stores at least 2 000 billion cu. ft. of water from Cairo to the Gulf, between extreme high- and low-water stages. All these reservoirs and many of less importance are ever active in regulating the flow of streams. Without them, precipitation would flow off as fast as it arrives, and our greatest floods would be magnified many times.

Here we are considering only those reservoirs constructed by Man to supplement and extend the regulating effect of Nature's reservoirs. If the conclusions reached in the first section of this paper are correct, forests cannot be relied upon in any degree to help solve the problems of high and low water. Present conditions must be met by purely artificial means, since Man has so far discovered no way of controlling the climatic conditions which govern precipitation. He cannot "stay the bottles of heaven" in times of flood, nor open them in seasons of drought. He must take the water after it reaches the earth, and deal with it the best he can.

The artificial reservoir is intended to attack this problem at its source. It catches and holds back the water in the near vicinity of its deposition, instead of waiting until it gathers into the rivers, and then building huge bulwarks to contain it there in times of flood. It saves the stored-up supply and gives it out in the low-water season, thereby helping navigation, instead of dredging and otherwise treating the watercourses to increase the low-water depth. It corrects one of the greatest deficiencies of Nature by abolishing inequalities of stream flow and converting waste into utility. Theoretically, it is

the perfect plan. It has always appealed to the imagination of layman and professional alike. It has often been resorted to, and the number of reservoirs in the world is very great and constantly increasing. Hitherto they have been mainly used for power, municipal supply, irrigation, and for navigation in canals. In very few instances have they been applied to improve the navigation of large natural watercourses, and in none, so far as the author is aware, for the exclusive purpose of preventing floods.

The question arises, why are they not regularly applied to these last-mentioned purposes? The answer may at once be given that in the general case the cost is greater than the benefits to be received. This element of cost arises mainly from the absence of good sites (including dam sites as well as holding basins) and also, to considerable extent, from an interference with the purely artificial conditions growing out of the settlement of the country.

The best reservoir site is a natural lake. Such a site is already covered with water, and original conditions are not materially changed. Evaporation is not much increased by the necessary enlargement. Smaller and safer dams accomplish a given storage than for the average dry site. The question of public health involved in uncovering large areas for reservoir beds in the heated portion of the year is less serious. Everything makes these sites the most advantageous that can be found, and it may be laid down as a rule that the public good requires the utilization of every such site to the fullest possible extent.*

Except in a few cases, dry sites are deficient in these advantages. Greater areas of land have to be condemned, and larger and costlier dams are required, with vastly greater danger in case of accident. Really good sites are not as abundant as one might wish, and the

*An interesting feature of these natural reservoirs may be noted. A natural lake, wholly uncontrolled at its outlet, may have a more effective control of the outflow than an artificial reservoir of equal superficial area when full, though of far greater capacity between high and low water. The outflow from a lake can be increased only by storing simultaneously a quantity of water measured by a rise in the surface equal to that in the outlet necessary to give the increased flow. But if the artificial reservoir has reached the limit of its allowable filling, the outflow must be made equal to the inflow. If this limit is reached before or at the time of maximum run-off, then a quantity equal to this run-off must be let out of the reservoir. This contingency can never happen in a natural lake. The turning point where outflow and inflow balance each other is always after the crest of the flood has passed—in fact at the time when the diminishing inflow and increasing outflow balance each other and the lake ceases to rise. In the case of the Yellowstone Lake (140 sq. miles), for example, this rise, in average seasons of snow-melting, continues from 10 days to 3 weeks after the inflow has reached its maximum, and surrounding streams have subsided materially before the Yellowstone River (at the lake outlet) ceases to rise.

problem of developing storage on such sites is beset with difficulties of many kinds that greatly increase the cost.

In 1897 the writer made a careful study of this question of flood control by means of reservoirs in connection with an official investigation of the advisability of building reservoirs in the arid regions. His view of the difficulties in the way of any general application of such a system is quite fully stated in his report,* and the following extracts are directly in point:

"It is the cost, not the physical difficulties, which stands in the way. It may be stated that as a general rule a sufficient amount of storage can be artificially created in the valley of any stream to rob its floods of their destructive character; but it is equally true that the benefits to be gained will not ordinarily justify the cost. The reason for this is plain. Floods are only occasional calamities at worst. Probably on the majority of streams destructive floods do not occur, on the average, oftener than once in five years. Every reservoir built for the purpose of flood protection alone would mean the dedication of so much land to a condition of permanent overflow in order that three or four times as much might be redeemed from occasional overflow. One acre permanently inundated to rescue three or four acres from inundation of a few weeks once in three or four years, and this at a great cost, could not be considered a wise proceeding, no matter how practicable it might be from engineering considerations alone. The cost, coupled with the loss of so much land to industrial uses, would be far greater than that of levees or other methods of flood protection. * * * The construction of reservoirs for flood protection is not, therefore, to be expected, except where the reservoirs are to serve some other purpose as well."

The above conclusions are still as applicable as they were when written. The subject has been given renewed prominence quite recently in connection with the Ohio River floods, but, before considering this particular application, attention will be given to certain reservoir systems that have been proposed elsewhere, and particularly to one already built and put in operation by the Government and which will be referred to frequently in the following pages. This is the system at the head-waters of the Mississippi—the largest artificial reservoir system in the world.

The project of converting the more important of the numerous lakes around the sources of the Mississippi and its tributaries into

*House Doc., No. 141, 55th Cong., 2d Sess., p. 46.

storage reservoirs as an aid to navigation was originally proposed by General G. K. Warren, and was first put into definite shape by the late Colonel F. U. Farquhar, M. Am. Soc. C. E., of the Corps of Engineers. The plan then embraced a large number of lakes in Minnesota and Wisconsin, but only five sites have actually been improved. The dams were first built of timber cribs, but have recently been rebuilt in concrete, as shown on Plate XLII. The combined storage is about 93 billion cu. ft. It is about twice the mean annual run-off from the water-shed, and the system is probably the only one, except the Great Lakes, which equalizes periodic as well as annual fluctuations of flow. That is, it carries over the surplus from wet years to help out in dry years, and its utility is, therefore, of the most comprehensive character. The cost of the five reservoirs is remarkably low, although it is not now possible to tell the exact cost of the present structures on account of the mixture of old and new work; but it probably does not exceed \$750 000, including a lock in the Sandy Lake Dam. This is only \$8 per 1 000 000 cu. ft., or 35 cents per acre-foot on the basis of total capacity. It would be about twice this on the basis of the mean annual run-off from the water-sheds.

A large portion of the original project has been abandoned because public sentiment did not support its continuance. The writer has always regretted this backward step, as he believes in developing to the fullest extent the exceptional opportunities here offered for the storage of water. The available reservoir sites which could be cheaply improved in Minnesota and Wisconsin are sufficient to control absolutely the floods of the Mississippi within the danger line, for a long distance below St. Paul, and to improve the navigation of the upper river very materially, while their value for industrial purposes is almost beyond estimate.

In spite of the great and obvious advantages of this system, it has not yet received the popular approval that might be expected of it. In fact, about three years ago, there arose a widespread sentiment in the community around the reservoirs that the system was, on the whole, injurious, that its disadvantages far offset its advantages, and a strong movement was organized to have it abolished altogether. For the purpose of investigating this matter, a Board of Engineers was appointed, of which the writer was a member. The Board found that there was a general belief among the people below the dams that

Fig. 2.

they actually increased the floods, while the people above complained bitterly of the back waters caused, throughout that low country, by filling the reservoirs so full. The water-powers immediately below the dams complained that they were not getting even the normal flow of the stream, which was the case. Navigation interests below St. Paul have always been lukewarm in regard to the beneficial effects of the reservoirs, and the Board was able to find only one steamboat captain who would make a positive statement that the boating interests derived any particular benefit from them.

Some curious results developed in this investigation. It was found that, great as the reservoirs are, conditions may arise in times of excessive precipitation that will compel them to discharge a greater quantity of water than would flow from the lakes in their natural condition. That is, they might actually operate to increase the floods if they should fill to their limit during a period of excessive precipitation. This very contingency nearly happened in the season of 1905, as may be seen on the curve (Fig. 2) illustrating the effect of the reservoirs on the flood situation at Aitkin, Minn., about 130 miles below. On Fig. 3 is shown a comparison of the natural and regulated flow of the Mississippi below the three upper reservoirs, the latter being operated in the interest of navigation alone. These curves show very clearly that the natural flow of the river was more uniform than is the regulated flow.

In like manner, during the period of lowest water, viz., in mid-winter, the reservoir gates are closed down to about 400 cu. ft. per sec., and the great water-powers, like those at the Falls of St. Anthony, are even worse off than in a state of Nature; but this drawback is not as great as might be thought because the powers are able to utilize most of the storage when it comes during the period of navigation.

Such are some of the complications and drawbacks which are encountered in this reservoir system and which would surely be met in a system built up under less favorable natural conditions.

Nevertheless the Board found that the system was in itself a very great benefit and that the lack of appreciation of its advantages was for the most part due to ignorance of what they actually were. At the public hearing the opposition fell to pieces by the mere force of a better understanding, and it is safe to say that the system will

DIAGRAM SHOWING COMPARISON BETWEEN NATURAL AND CONTROLLED FLOW OF
MISSISSIPPI RIVER BELOW THREE UPPER RESERVOIRS.

Fig. 3.

never be abandoned, but will be extended along the lines of the original project.*

The U. S. Geological Survey has recently proposed quite an extensive reservoir system for the Sacramento Basin, similar in principle, though smaller in extent, to that of the proposed Ohio system. The flood problem of the Sacramento River is the most difficult in the United States in proportion to its magnitude. In fact it seems as if it will prove impossible to convey the extreme floods of that river to the sea without extensive overflow of the bottom lands along its course. The proposition to control the floods to some extent by means of reservoirs was elaborately set forth in the paper by Messrs. Clapp, Murphy, and Martin, previously referred to. The subject had already been considered by the Commission of Engineers appointed by the State of California in 1904 to devise a plan of flood relief. The Commission reported that, while any help from such a source must, of course, be welcome in solving the problem, it was very doubtful if such aid would be of sufficient importance to justify giving it much weight.† In discussing the paper above referred to, the writer stated that, while he had never visited the sites in question, it was his opinion that, as to most of them, it would not be possible to realize more than one-fourth to one-third of the benefits claimed, and he based his opinion on the published records of the flood of 1907, which was the greatest in the history of the river. George L. Dillman, M. Am. Soc. C. E., in discussing the paper, flatly pronounced the whole scheme impracticable, and gave his reasons in detail for this conclusion.‡ Among them he cited in one case the great value of the lands to be flooded by the reservoirs, which he claimed were altogether more important for agriculture than for any diminution of flooding which the storage might cause in the valley below. In another case he cited the difficulty, which always suggests itself to an engineer in considering the subject, of timing the operations of the reservoirs so as to combine their effects to the best advantage, and particularly in keeping them empty in periods of prolonged precipitation, so that their capacity may be available at the critical moment. Other obstacles were pointed out, and the whole discussion presents another instance

*The report of this Board contains exhaustive data upon the system and its operation. It may be seen in the annual report of the Chief of Engineers for 1906, p. 1443 (Appendix AA, published separately in pamphlet form).

†Report, Commissioner of Public Works, State of California, for 1905.

‡Transactions, Am. Soc. C. E., Vol. LXI, p. 357.

of the practical difficulties that stand in the way of any comprehensive reservoir scheme for controlling floods.

In 1903 the great flood of the Kaw River brought up the reservoir question again. Ex-Senator Burton, of Kansas, advocated the plan very urgently, stating in a speech at Kansas City that he "would have tens of thousands of reservoirs beginning at the head-waters of the stream and coming right down." A Board of Engineer Officers was appointed to investigate the practicability of providing against future disasters such as this flood had caused. The reservoir idea had made so deep an impression upon the public mind that a specific consideration of that feature of the problem was requested. In its report* the Board found adversely to the scheme on the ground that its great cost, conservatively estimated at \$11 000 000, and the annual loss from the withdrawal of the necessary lands from occupancy, conservatively estimated at nearly \$600 000, would not be justified on the ground of flood protection alone. Owing to the character of the country, this last consideration was particularly strong. The only real justification of so extensive a system in a country so largely devoted to agriculture would be its use in irrigation and power, and, if it became necessary for these purposes, doubtless a portion of it would be built.

The most elaborate study of this subject ever undertaken until very recently was made by the French Government, to determine whether reservoirs could be utilized to prevent the recurrence of such great disasters as the floods of 1856 in the valleys of the Rhone and other streams. A full résumé of these studies is given in the writer's report already referred to on Reservoir Sites in the Arid Regions. The conclusion was the same that has been reached in every similar investigation. An interesting feature of the system then considered was that the reservoirs were to have sluices permanently open so that it would not be possible to close them entirely. They would operate, it was expected, to hold back a definite percentage of flood discharge—enough to keep the floods below the dams within safe limits. They would thus act automatically, just as forests are supposed to do. This was all right so far as the individual tributaries were concerned, but it was found, when the possible effect upon tributary combination in the main stream was considered, that, by holding back earlier portions of freshets and prolonging their run-

*Senate Doc. 160, 58th Cong., 2d Session, pp. 14-17.

off, they might actually swell the combination in the lower courses of the main stream.

Similar studies have frequently been made in all the principal countries of Europe, and in none of them, so far as the writer is aware, has such a project on a large scale ever been undertaken or even favorably considered.

Coming now to the Ohio River, the immense importance of that stream as a factor in the floods of the Mississippi makes the regulation of its flow a matter of greater moment than that of any other stream. The project of controlling the run-off of its water-shed by means of reservoirs was urged very forcibly more than 60 years ago by Colonel Charles Ellet. The subject has often been considered since, both in private and official investigations. The conclusion has invariably been that, great as the benefits of such a system would be, if in existence, the cost of bringing it into existence would be out of all proportion to such benefits.

The scheme has recently been revived in a more attractive form, with data not hitherto available, and at a time when a period of heavy floods and much loss therefrom has turned public attention strongly to the subject. Moreover, it comes supported by a comparatively new element in its favor—the vast expansion of water-power development made possible by the electric transmission of energy. The new presentation of the project is by M. O. Leighton, Assoc. M. Am. Soc. C. E., Chief Hydrographer, U. S. Geological Survey, and is understood to bear the approval of both the Interior and Agricultural Departments.* Mr. Leighton does not claim that his presentation is at all final or complete, but is rather a “statement of possibilities” which he believes are sufficiently promising to justify the Government in giving the scheme thorough investigation before further extensive steps are taken on present lines in the matter of flood control and channel improvement in the main rivers of the basin. Although an estimate of cost is submitted and certain conclusions are based thereon, it is stated that the data are too meager to give much confidence therein. Subject to these qualifications, the system, as set forth in Mr. Leighton’s paper, embraces reservoirs on nearly all the tributaries

*The writer has seen the description of the proposed system only as published in *Engineering News*, May 7th, 1908. He has had some correspondence with Mr. Leighton, and is under great obligation to him for a complete set of topographic sheets showing the various reservoir sites.

of the Ohio; the total cost is estimated at \$125 000 000; the income from resulting water-power at \$20 per horse-power, and a certain computed lowering of flood heights on the Ohio and Mississippi Rivers, and a corresponding increase in low stages, are given. The full details of the scheme are set forth in quite elaborate form. So far as the present criticism is concerned, the practicability of finding the necessary sites will be accepted, and only the estimate of costs and revenues, and the deductions as to benefits will be called into question.

In their effect upon floods, admitting that all the reservoirs proposed can be built, the result must fall short of the claims put forth. If built at all, they must be built, as will be shown later, primarily for power development. Now it will never be possible, until Science can forecast the weather more perfectly than it is yet able to do, to regulate reservoirs for the maximum benefit of both purposes. This consideration is sometimes made light of, but nevertheless it is one of real importance. For industrial purposes the reservoirs should be full before the rainy season ends; for flood protection they should be so far empty that they may be able to hold back any flood-producing storm that is likely to come. While, doubtless, in a majority of years, a middle course could be pursued that would not involve much risk on the flood side of the question nor much loss on the power side, yet there would surely come exceptional seasons—the seasons of flood-producing rains or the seasons of great drought—when the reservoirs would be caught too full on the one hand or too empty on the other. Their full calculated capacity would not then be available for either purpose, and it is difficult to conclude that this would not happen frequently. In particular, if the reservoirs are really operated to prevent floods, it must often happen that dry weather will find them only partially filled, and that their full capacity will not be available either for power or navigation. This would not apply, of course, to a reservoir great enough to store all the run-off from its water-shed in the greatest known flood, unless considerable storage were left over from previous years—as is often done in the Upper Mississippi reservoirs. Mr. Leighton's estimates are based upon the mean discharge of the streams, which is, of course, greatly exceeded, possibly doubled, in very wet years. In any case it would seem to be necessary to hold ample capacity in the reservoirs as late as the end of March each year to provide for possible emergencies; but if

this is done there will be many years when the reservoirs will not fill.

An important consideration in the use of the reservoirs for flood control is that of a proper combination of their outflow. To any one who will try to figure out how this can be accomplished over a water-shed of such vast extent, with storms arriving at different times in the various portions, with no way of telling when, where, or with what intensity they will arrive, with the varying distances of the different reservoirs from those points where flood control is particularly important, the problem seems almost impossible—that is, impossible to realize the full effect based upon the aggregate capacity of the system. It is understood that Mr. Leighton has endeavored to do this, but it would be interesting to see the application to some of the great floods that might be designated. For example, in the flood of 1907, which reached its maximum at Cincinnati and Pittsburg about the same time, no amount of holding back of the storm water on the Upper Ohio at that time would have helped the situation at Cincinnati at all.

Another important consideration in the effect of these reservoirs, as they would have to be operated to prevent floods, is the great change that takes place in a flood wave as it propagates itself down stream. The writer is unable to tell from Mr. Leighton's paper to what extent he has considered it. The paper itself seems to indicate that the discharge held back by a particular reservoir produces a corresponding volumetric effect (not gauge effect, of course) at all points below, after making a due allowance of time for the transmission of the wave. This would be an erroneous conclusion. For example, a wave that might rise at Pittsburg from 100 000 cu. ft. per sec. to 150 000 a day later and to 200 000 the next day, and then fall at a corresponding rate, would not at any point below produce a maximum increase of 100 000 sec.-ft.; and the farther away the point considered, the less would be the increase. At Cairo, nearly 1 000 miles below, the same wave would take a much longer time in passing, probably not less than a week, and the maximum increase would probably not be more than 25 000 sec.-ft. This is merely a general illustration, for exact data on the subject are not available. The problem is of such complexity that nothing but the results of long experience could establish a rule as to what might be expected in any given case; but

FIG. 1.—LAKE WINNIBIGOSHISH DAM.

FIG. 2.—PINE RIVER DAM.

it can be stated with certainty that the diminution of discharge at any considerable distance below the reservoirs for a given time would never be as great as the amount held back by the reservoirs in the same length of time, and that, the quicker and the higher the flood, the smaller the relative effect at all points below. It is only when such wave elimination merges into a constant quantity, continuing for a considerable time, that the full effect of a reservoir would be experienced at any point below. This, in fact, is what would actually happen in the contrary case of the low-water season when the reservoir discharge is kept up for a long time.

Still another feature in the high-water effect of such reservoirs is the demand for water for power at all times. If there should ever result any really general use for all this water, as is predicted, then the consumption for power would make a considerable river in itself. Now this much cannot be shut off in any case. Street cars and shops must run and houses must be lighted whether the flood is ruining the lowlands or not. An example of this occurred in 1905 on the Upper Mississippi where the outflow from the upper dams was cut down to a minimum to reduce the flood in the valley at Aitkin, which was then being overflowed by the river. The mill at Grand Rapids, just below the reservoirs, made a strenuous protest, and even threatened legal proceedings to compel the release of the full normal flow of the river.

Considering all the foregoing features of the operation of the proposed system, even if every reservoir were built with the full, estimated capacity, it would be extremely fortunate if 75% of the predicted results, either in flood protection or in aid of navigation, could be realized.

It is in the matter of cost, however, that the weak point of Mr. Leighton's system appears. Judged by any reasonable standard, his estimates are hopelessly wide of the mark. The method itself of getting at a basis of cost is inadmissible. For example, in determining a unit of cost for that class of reservoirs which embrace the greater portion of the total storage, the figures for nine reservoirs are taken, counting as one the whole Upper Mississippi system. Only the Mississippi system has been built; two others are under construction and six are merely projected. In accordance with almost universal experience, and especially in view of the great advance in prices of

all kinds since these estimates were prepared, it must be expected that these works, if ever built, will cost from 25 to 50% more than the estimates. Three of the projected dams are of the relatively cheap rock-fill construction, which would be inapplicable to most of the Ohio dams from considerations of safety.

The controlling element, however, in the unit estimate, is the Mississippi system, whose capacity is nearly one-third of the whole group considered and whose unit cost is only about one-seventh of the average cost of the others. The use of the Mississippi reservoirs in any way as a basis of estimate for the Ohio system is wholly inadmissible because of the dissimilarity of sites. The Ohio sites, with one exception, are dry sites—totally different from the lakes of Minnesota. Even the latter reservoirs could not now be built for three times what they have actually cost the Government. The flowage lands embraced about 80 000 acres, which were nearly all reserved while yet belonging to the Government. A few recent purchases of additional lands found necessary, and the experience now being met in acquiring the flowage rights for a reservoir at Gull Lake, show that, if these lands were to be bought to-day, they would cost from \$10 to \$25 per acre. The right of way alone would now cost twice as much as the dams.

Compare any one of these structures—Leech Lake, for example—with a representative masonry dam like the Cheesman Dam on the South Fork of the South Platte River above Denver, Colo. The writer is familiar with both sites, and once submitted a plan and estimate for a structure on the Cheesman site almost exactly like the one built. Lake Cheesman is a more favorable site than most of those on the Ohio system, for, although its capacity is not as great as some, the dam site is exceptionally advantageous, one of the most perfect in Nature—a very narrow gorge in solid granite, with a natural spillway already provided. In several of the Ohio sites, entire towns will have to be removed, important railroads will have to be re-located, a few mineral properties will be destroyed, and, in nearly all, road systems will be seriously disarranged. None of these conditions were encountered to anything like the same extent in the Cheesman site. Undoubtedly its unit cost, which is estimated at about \$250 per 1 000 000 cu. ft., was as low as can be possibly realized on the Ohio system as a whole. Compare this with less than \$5 for Leech Lake or \$8 for the whole Mississippi system!

FIG. 1.—LEECH LAKE DAM.

FIG. 2.—LAKE CHEESMAN DAM.

A recent example of projected storage is that presented by the late George Rafter, M. Am. Soc. C. E., for the Genesee River near Portage, N. Y. Owing to the moderate height of dam (apparently less than 150 ft.) and the large capacity of reservoir (15 billion cu. ft.), this is believed to compare favorably as to unit cost with the Ohio system. The estimate was \$216 per 1 000 000 cu. ft. If it were to be built under the present conditions of the market, it would doubtless cost \$250. It is understood that later investigations have shown that Mr. Rafter's estimate is only one-half large enough.

In 1895 the writer made an extensive examination of storage possibilities in Ohio, near the divide between Lake Erie and the Ohio River, for the purpose of providing a water supply for certain projected canals. He prepared estimates for two sites on the head-waters of the Cuyahoga, for one site at the head of the Scioto, and for one at the head of the Great Miami. The estimates were based upon actual surveys, and are given in detail in the report upon the subject.* The type of construction was not expensive. The total capacity was 11 000 million cu. ft. and the unit cost \$300. To-day it would be at least \$350.

Most of the proposed sites for the Ohio reservoirs are not advantageous sites. The topography of the country is unfavorable. The sites are not compact basins, like those occupied by lakes or ponds or mountain meadows, but are, for the most part, trunk valleys with numerous tributaries, nearly all of them quite narrow. They may be roughly compared to the form of the hand with the fingers outspread, the dam occupying the position of the wrist. The ends of the fingers are frequently many miles from each other and from the dam. Numerous villages occupy the valleys. The road systems of the local communities traverse them. The disadvantage that will result to public travel, by forcing it out of these natural routes over the hills and around the ends of the fingers, will be very great. The lands lying between the fingers, in some instances, will be so far cut off from convenient access that their value will be much impaired, and damages will have to be paid on that account. In several instances the necessary changes in railroad alignment in the hilly country will be extremely costly, if not impracticable. A great many cemeteries will have to be removed, which means, not only the cost of removal, but

*House Doc. 278, 54th Cong., 1st Sess., pp. 78. 83. 86.

extensive purchase of lands outside. Such drawbacks are, of course, encountered in all similar work, but they are excessive in these sites. They are mentioned solely from their relation to the question of cost. No one can examine the maps of these sites and not be convinced that the cost of right of way and damages alone will considerably exceed Mr. Leighton's estimate of the entire cost of the system.

An element affecting cost is that of safety. Owing to the situation of many of these proposed reservoirs, the results of failure of the dams would be so appalling that no chances can be taken. The structures can be made safe, of course (except against earthquakes), but it will cost money. Nothing short of the highest type of construction—masonry for all the larger dams—can be considered. Mr. Leighton has cited certain dams upon the integrity of which great interests depend as evidence of the confidence of engineers in these structures, but if he will apply their costs, particularly those of important structures in Europe, to his proposed system, the money value of safety will mount up to a prodigious figure.*

A feature of this question of safety often overlooked is the depreciation of the market value of property, due to its location below a dam where failure of the dam would mean a disaster of great magnitude. However safe the structure may be, many people would not purchase property below it, and its market would be correspondingly diminished. While such loss can hardly be made a subject for damages, it is a real loss to the owners.

These reservoirs being built for flood protection, the sluices must be very large, so that at times they can be discharged practically as fast as the water runs in. This will be necessary during periods of prolonged precipitation in order to keep the reservoirs from filling too full before the danger is past. This detail of construction will add largely to the cost.

*The recent failure of the Hauser Lake Dam on the Missouri River, near Helena, Mont., is a good illustration of how the unexpected may happen. Here was a dam built of steel and concrete, two materials whose properties are thoroughly understood. The case was one which "ordinary engineering" might be expected to handle successfully. The public had reason to feel confidence in the structure. Yet "it fell and great was the fall thereof," not only in the total wreckage of the dam, but in the losses caused along the valley below.

The accident affords also another illustration of the omnivorous claims put forward in these days in the supposed interests of forestry. The disaster was promptly cited as an example of the havoc wrought by floods in a country without forests. The normal flood discharge of the Missouri at this point is 20 000 cu. ft. per sec.; for 1907, it was 26 000 cu. ft.; the maximum on record is about 50 000 cu. ft. At the time of the accident the discharge was about 7 000 cu. ft. per sec.

Taking everything into consideration on the most liberal basis, it is evident that this system cannot be built for less than \$250 per 1 000 000 cu. ft. The probable increase in the value of property to be condemned before the system could be built, and the present scale of prices of labor and material, make this figure a minimum. This would swell the cost of the whole system to more than four times Mr. Leighton's estimate, or over half a billion dollars.*

This is not all, however. It appears that the complete development of the reservoir system as proposed will take from industrial use probably 1 500 000 acres of land, including the lands actually overflowed, the margins subject to damages, and sites for the dams and various structures appurtenant thereto. These lands will be in large part, by the very fact that they lie in valleys suitable for storage grounds, the best lands in the localities. Sooner or later they are bound to come into agricultural use, and with proper cultivation their annual net revenue value will be at least \$5 per acre. If utilized for forest culture, they ought to yield 500 ft. B.M. of lumber and 1 cord of wood annually per acre. The value of the land for this purpose ought to be as great as the figures just given. It thus appears that the occupancy of these lands for reservoir purposes will take from the community an annual product of at least \$7 500 000 worth, and probably more.

The reservoirs will store about 2 150 billion cu. ft. of water. Assume that this can all be utilized for water-power, with the average head of 200 ft., giving theoretically about 1 600 000 h.p. per year, or 1 280 000 h.p. at 80% efficiency. At \$5 per horse-power (the basis for this figure will presently be considered), the revenue from water-power will be \$6 400 000, which falls short of the loss resulting from withholding the sites from productive use.†

Viewed in the light of the foregoing exposition, the weakness of the reservoir scheme, as a measure of flood control or for improving navigation, is at once apparent. The question is: Will the ends justify

*Recent examinations of certain sites, embracing nearly 70% of the proposed Monongahela storage, indicate that the whole Ohio system will cost at least a billion dollars, and possibly a billion and a half.

†The sanitary feature has not been considered, although it is one of some importance. The laying bare of large areas of reservoir bottoms in the heated portion of the year, is objectionable, but it is not a matter affecting the element of cost. Neither is much stress here laid upon the danger to the reservoirs from silting up. This is not a region of heavy silt movement. In most of the reservoirs, the process will be very slow, and we may safely leave to distant generations the task of dealing with this problem whenever it reaches an acute stage.

the means? If the ends sought could be attained in no other way, possibly they might; but they can be, and for a small fraction of the reservoir cost. Consider the estimate, already given, of \$500 000 000. Take \$40 000 000 and reinforce the entire levee system of the Mississippi. That will make it impregnable—as safe as any of the proposed reservoir dams. Take \$60 000 000 and revet the banks of the Mississippi wherever necessary from Cairo to the Gulf.* The reservoir project does not touch this important matter at all. Devote whatever sum is necessary to the protection of the bottom lands of the Ohio basin. Give Cincinnati and Pittsburg each \$10 000 000 to assist in local changes necessary for complete flood protection. Devote a sum to navigation such as our engineers have never dared dream of, and the Government will still save more than Mr. Leighton's estimate of the whole cost of the reservoir system. The more closely this reservoir proposition is scrutinized, as a scheme for flood prevention, the more impracticable it appears. It is only a trade-off at best. It is giving up to perpetual overflow valuable lands to save others from occasional and even rare overflow for short periods. Now if, at less cost, these lowlands can be better protected by other means, thus leaving both the valley lands and reservoir sites open to productive use, how much better it will be!

If the writer were to venture a criticism on Mr. Leighton's attitude in this matter, it would be that he has not fully appreciated his responsibility in bringing forward again this old proposition without fuller consideration of its organic defects. This is well illustrated in the opening paragraph of his paper, in which he says:

"This report will be confined to a statement of possibilities. There will be no attempt to prescribe methods for treatment of each local modifying condition that will be encountered in the prosecution of the plan here proposed. Such features are merely collateral, and their proper disposition is a matter of ordinary engineering."

This is a complete reversal of his obligation in the matter. The "possibilities" of reservoir control have long been recognized. The logic of the plan is well understood. It has always appealed to the popular mind. In particular, reservoir control of the Ohio floods has been advocated for more than 60 years, and its possibilities have often been investigated. The plan has been uniformly rejected on

*Report, Mississippi River Commission, 1896, p. 3457.

one ground, viz., that as a scheme for flood control and navigation improvement its benefits would not justify its cost. It is, therefore, incumbent upon whoever revives the scheme to come well fortified upon this particular feature. He must give some study to the treatment of "local modifying conditions." It makes a difference whether he can go to a great natural lake like Winnibigoshish and store 40 billion cu. ft. of water for a mere trifle, or whether he must evict whole villages, disturb railroads and highways, absorb valuable lands and possibly subject communities to serious risk. These are the questions upon which the success or failure of the scheme depends. Yet Mr. Leighton brushes them aside, as it were, with a wave of the hand, as "merely collateral" features, matters of "ordinary engineering" only. Here is the weak point of his project. Weighed in the balance of practical accomplishment, either for flood control or navigation, it will be found utterly wanting, and the development of the system, as has always been held, will have to be based primarily and mainly on its value for industrial use. For the same reasons that the development of a great reservoir system in the Far West is justified by its industrial value—its use for irrigation—so a reservoir system for the Ohio, or any other rivers, except in a few unusual cases, must depend primarily upon its industrial value—the development of power.

In pursuing his criticism further, the writer would not be understood to be "knocking," as current slang goes, the feature of the reservoir system just mentioned, because, in his judgment, there is no one thing in the present movement for the conservation of our natural resources that is more important than storing the flood waters of our streams for power development. It stands in the same category with the preservation and extension of our forests. It stands on even a surer basis, for Man, either wilfully or through neglect, can destroy the forests, but he can never diminish in the smallest degree the power of running water. It is a great solar engine, perennial and perpetual in its action. It requires no aid from Man in its production. All he has to do is to utilize it. Providentially, electricity has unfolded its power to transmit this energy over great distances, and has thus made practicable a development which would otherwise have been impracticable. In time water-power will replace coal and oil, and will become the one great source of power, unless discoveries are made which are not now foreseen. The writer thoroughly believes in devel-

oping this power through public agencies and preserving it from private ownership and control. His present criticism is directed not at all at the principle involved, but at the extravagant expectations now being fostered as to the possible revenue which the Government may derive from such development.

The quantity of power estimated in the publications of the Geological Survey and the Agricultural Department are based upon an assumption that most engineers will question, viz., that 90% of the fall of our rivers can be utilized in effective head upon water-wheels. This is too great a figure. The most thoroughly developed river in the United States, namely, the Merrimac, in New Hampshire and Massachusetts, develops only 70% of the total head. Taking all the streams into consideration, it seems hardly possible that more than 50% of the fall can be utilized. When the fall of a river is uniform, even if quite steep, the cost of long canals or high dams necessary to concentrate it at one point often prohibits development altogether. From altitudes of 3 000 ft., the Missouri and Yellowstone, for example, descend to the sea with a total energy of possibly 5 000 000 h.p.; yet comparatively little of this can be developed advantageously. It is only in those places where Nature has helped out by concentrating the fall at cataracts or rapids that water-power development is commercially profitable. At low dams, such as are ordinarily built at lock sites, the head is often nearly all obliterated during high water. How far storage may affect these drawbacks cannot be said, but it should, of course, help a great deal. The official estimates of flow for non-regulated streams are based on two weeks' average lowest flow. This may probably be extended materially with reservoir aid or supplementary steam power. Possibly the total estimated horse-power may ultimately be realized.*

When it comes to the royalty which the Government may receive for these water-powers, if developed by private interests, the price of \$20 per horse-power, adopted by the Geological Survey and the Agricultural Department, is wholly out of the question under present conditions. Possibly the writer does not understand what the figure is intended to embrace. From Mr. Leighton's articles, the inference has been drawn that wherever the work of the Government renders power

*There has recently been invented a device called a fall increaser, an adaptation of the Venturi meter, by Clemens Herschel, M. Am. Soc. C. E., which promises to utilize the extra flow of streams in time of flood water and low heads to increase and maintain the head upon the wheels. If this invention proves a success, as seems probable, it will be an immense gain to all water-powers of low head subject to large fluctuation, as would doubtless be the case in very many of those under consideration.

available which was not available before, either by building dams, as at lock sites, and thus creating a head, or by storing water which might supply powers below with more than they would have without, the value of the power thus rendered available should return to the Government \$20 per horse-power per annum—an “exceedingly low price,” as Mr. Leighton puts it.*

It is not understood that the Government is to build the power plants, but that this is to be done by the interests availing themselves of the privilege. Estimates of undeveloped water-powers on many streams of the Atlantic slope, by the Geological Survey, leave one to infer that these powers are considered worth at least \$20 per horse-power to the Government even without dams or reservoir aid. While the statements are not clear as to what is actually meant, the various references to resources to be derived by the Government from these powers lead to the above conclusion. It would be of advantage in considering questions involving these published estimates, if the basis for this \$20 price or royalty could be made more specific.

Under present conditions, or such as can be reasonably foreseen, no such royalty is possible except in extraordinarily favorable circumstances. Efforts which have been made to derive a satisfactory revenue from existing powers do not justify any such prospect. The many and various practical difficulties in exploiting these powers are rarely appreciated by those who have not encountered them in actual experience. The cost of water-power development is restricted to narrow limits, if it is to compete with coal. An engineer of high standing whose life-work has been connected with water-power development says:

“I am advised that, with good coal at \$2.00 per ton in this territory, the cost of fuel per horse-power per annum (300 days of 24 hours each) is less than \$8.00 for producer gas engines and for steam power about \$12.50 in large size equipments. In many localities coal will cost even less than \$2.00 per ton, allowing thus a still wider margin. If we now consider the usual and unavoidable handicaps and incumbrances to all water-power installations, such as floods, low water, ice-flow, back water, etc., etc., we have conditions which will make it a serious study for any power consumer to determine if the balance is not considerably against water-power in that particular territory, at this time, from a purely commercial standpoint. At any rate it must be obvious that no such rate as \$20 per annum per horse-power can be paid to the

*“On the Youghiogheny alone, where it is proposed to install a slackwater system comprising three locks and dams, at an expense of \$600 000, proper development of storage will insure the production of a minimum of 4 100 h. p., the value of which, reckoned on the exceedingly low price of \$20 per horse-power-year, would produce a total income of \$82 000.”

Government by any power user for the right to draw the water only, and besides this, stand the expense of installing and operating the water plant."

Another hydraulic engineer of national reputation says:

"I think that, as a general proposition, the suggestion that all water-powers to which the Government consents should pay royalties, and especially where the parties own their riparian rights, would tend to defeat the development of most water-powers and would certainly very much curtail the number of water-power developments. I am impressed with these conclusions because of the present difficulties in financing good water-power propositions."

In *Power*, May 19th, 1908, is an article by Mr. Henry Docker Jackson, in which a critical comparison is made between steam and water-power. In this article occur the following tabulated estimates of cost of installation and of annual operation, based upon a (theoretical) installation of 1 000 h.p. The costs are averages of a number of different plants:

"PLANT COST.

Plant.	Steam.	Water.
Building and works.....	\$10 000	\$77 000
Engines, boiler, etc.....	48 000	.....
Turbines and generators.....	15 000	17 000
Trans. lines, etc., 20 miles.....	.....	40 000
	<u>\$73 000</u>	<u>\$134 000</u>

"FIXED CHARGES.

Interest	\$3 650	\$6 700
Fuel, \$2.50 per ton.....	6 160	.....
Water	600	.....
Operation	3 400	3 800
Oil, waste, etc.....	770	500
Maintenance	1 500	2 680
Depreciation	3 650	3 500
Taxes	1 460	2 680
Insurance	650	
	<u>\$21 840</u>	<u>\$19 860</u>

Cost per indicated horse-power per year.....	\$21.84	\$19.86
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"COST PER HORSE-POWER-YEAR.

	Steam, 88%.	Water, 95%.
100% Load factor.....	\$24.82	\$20.90
75% Load factor.....	39.92	32.00
50% Load factor.....	54.60	45.00"

From the last part of these tables, it is very evident that a royalty of \$20 per horse-power would turn the scale wholly in favor of steam under all conditions of load. In fact, it is reasonably certain that \$5 per horse-power per annum would be an outside figure, and even this would often be prohibitory. The situation will not necessarily be improved by the growing demand for power, but rather by the diminishing supply and increased cost of fuel. So long as coal can be had for anything like present rates, no very great charge can be realized from water-power wherever fuel is readily available. Under present conditions \$120 per horse-power may be considered as an average limit for first cost of a water-power plant, if it is to compete with steam. A charge of \$20 per horse-power per annum would be equivalent to doubling this first cost.*

A variable element in the cost of water-power development is the distance from plant to market, or the length of the transmission line. When this is very great, as in numerous plants in the mountain districts of the West, it makes a large addition to the cost of installation and must correspondingly reduce the royalty that could be paid for the power itself.

An interesting example of what the Forestry Service has been able to do in this line with unimproved water-powers is that of a recent permit for the development of a large power in the Cascade Mountains within the forest reserve. The beneficiary of the privilege is required to pay annually for "conservation," 10 cents per 1 000 kw-hr.—equivalent to 65 cents per horse-power per year continuous running. The right is retained by the Government to increase this charge 25% every 5 years for a period of 40 years, after which the whole arrangement may be readjusted. The maximum charge at the end of the 40 years will, therefore, not exceed \$4 per horse-power.

The only way in which a rental of \$20 per horse-power can be obtained with any degree of certainty, and that in only a small proportion of the localities for many years to come, is for the Government to build the plants. It is admitted that this suggestion will grate harshly on many ears because of its newness and its departure from

*Mr. Leighton cites the Falls of the Ohio as an example of an opportunity to develop 110 000 h. p. by aid of his proposed reservoir regulation. This, he states, at \$20 per horse-power is 3% interest on \$73 000 000. To any one familiar with the physical conditions involved in the development of this power, it will appear extremely doubtful if any company could guarantee to deliver continuously this amount of power, even with the full aid of reservoir regulation, and pay any royalty whatever.

the established ideas. But a little consideration will show it to be not only the best way for both private and public interests, but really the only practicable way. This may be illustrated by a concrete example:

The Government has just completed a survey and adopted a project for the construction of what is known as the Lake Washington Canal in the City of Seattle. It is a canal to connect Lakes Union and Washington with Puget Sound. The discharge from the tributary water-shed which will flow through the canal averages about 1 500 cu. ft. per sec. The mean fall at the lock site is about 15 ft. The theoretical energy is about 2 500 h.p., but owing to the tidal fluctuation and variations of flow with the seasons (which cannot be wholly eliminated on account of the necessity of limiting the fluctuations of level in the lakes to about 3 ft.), and also to the requirements for canal power, lockage and leakage, it was thought that about only 1 000 h.p. could be depended upon with certainty for outside use. As this power is located in the heart of a great city, it seemed as if it ought to be turned to good account in helping bear the cost of maintaining the canal. Efforts to obtain tentative propositions for developing this power were, however, wholly fruitless. The plan was then considered of having the Government build the plant and lease it to consumers of power. On this basis a tentative offer was obtained from a responsible consumer to take the plant, operate it, keep up all repairs, and pay the Government \$18 per horse-power-year. Probably by the time the canal is completed, a figure of \$25 can be obtained, and as more than 1 000 h.p. will probably be developed, it is likely that the Government will receive upward of \$30 000 per year for this power—enough to pay the entire cost of operating the canal. The extra cost to the project of adopting the power-plant feature is \$220 000, so that the revenue will be nearly 14% upon the expenditure.

In recommending this plan to the Department, it was pointed out that the true advantage of the Government, even apart from the revenue expected, favored its adoption. It simplified the whole relation between the Government and the consumer. If private interests were to build the plant, they would acquire vested rights which would always stand in the way of future control, and lead to complications if it should become necessary to terminate the arrangement. With the plant in the possession of the Government, and the

users standing simply in the relation of lessees for a limited period, without great initial expense on their part, and with freedom on the part of the Government to control the arrangement without the complication of private ownership, the whole plan would stand on a simple, practical, business basis. This view prevailed with the Department and is now before Congress for adoption, being possibly a departure in this line.

The principle involved in this case should be given general application. In addition to avoiding complications with private ownership, there are other important considerations. When a power is developed or a reservoir built, it should be so planned from the start as to bring out its full possibilities. A private company can rarely do this. Generally its scheme does not require it, nor its resources permit; but a site once occupied by an inferior work may be perpetually barred from complete development. Moreover, in any such work, the Government can derive a greater benefit than any private individual or association. A private company must build for the immediate future; it cannot wait long for dividends, and it can generally realize only on such application of the power as is possible in the immediate vicinity. The Government, on the other hand, derives all the benefits which come from the stored water anywhere on its course from the reservoir to the sea. These benefits arise from all the powers through which the water flows; from the improvement of navigation and the prevention of floods, and from every other use to which the water can be put. Furthermore, the Government is building for all time, while the individual builds only for the present and near future. The case is similar to that of landlord and tenant. A tenant cannot afford to make improvements on the farm because it is not his and he may remain on it only a short time. The most he can do is to get out of the farm what he can in its actual condition. The owner, on the other hand, can put in improvements which yield him no immediate return, because he holds the property long enough to realize upon them. So it is with the Government; it can wait for realization upon its improvements much longer than a private company. In forestry, for example, no individual can afford to wait from three to ten generations for a crop. Only the Government or a great railroad corporation can do this. Likewise, in building great reservoirs, no private company can build for the distant future. It

is only the landlord who can make such far-reaching improvements upon his estate.

Wherever, therefore, there arises any real demand for power development at the site of any Government work, as a lock and dam, the judicious course would seem to be for the Government to prepare a comprehensive plan for development capable of being carried out progressively as the market for power may justify. Let it then build the plant as fast as needed and lease it to private agencies under suitable restrictions. Likewise, when the building of a reservoir promises to be of obvious utility, and the conditions are such as to make it properly a subject of Government adoption, let the Government build it, utilizing the water in its own plants below and collecting a revenue from private plants that may use it. Whenever at the time of construction there is a direct return in sight of 2 or 3%, it should be considered justifiable from a Government point of view. The certain enhancement in the future value of such utilities and the incidental advantages in flood protection and navigation make this a conservative proposition.

That difficulties will be encountered in deriving the full return from its work to which the Government would be entitled cannot be denied. This would be the case particularly wherever it is a question of compelling existing power plants to pay for the extra water they might receive through Government storage. This question came up before the Mississippi Reservoir Board in regard to the powers at St. Anthony's Falls which derive such benefit from the reservoirs. The Board remarked as follows on the subject:

"It may be urged that if the incidental benefits of the reservoirs to the water-power interests are so great, these interests should be required to contribute something to the maintenance of the system. There would doubtless be a willingness to do this if a satisfactory method could be found. But there is no practicable method of enforcing any charge upon the use of this water. Where water is taken in a separate channel from above a dam or lock and conducted to a mill, it is a simple thing to measure it and to cut it off if it is not paid for. But when it must be let into a natural stream, where it mingles with the run-off from below, it is impossible to determine what proportion of stored water the mill may be using, or to enforce its non-use if not paid for. But, if such an arrangement is not practicable, that fact does not constitute an argument against the reservoir system. So long as the reservoirs are performing the service for which they were

created, every additional benefit derived from them is only an additional argument in their favor."

These disadvantages will adjust themselves in time.

Such, in the opinion of the writer, must be the basis of any great reservoir system in our country—industrial use. Even in the uniquely favorable conditions at the head-waters of the Mississippi, no one can doubt that the real purpose being served is that of mill power, whatever the theory upon which the reservoirs were built. The great system of the Far West is being built for irrigation, power and domestic supply. So on the Ohio and other eastern streams, the system must rest upon an industrial basis and expand only as industrial demands justify. The innovation involved in building reservoirs with public funds for these uses is admitted; but it is no greater than it was ten years ago to build them for irrigation. When the writer was investigating that subject in 1896-97, he found a widespread opposition throughout the arid regions against Government control of irrigation works in any way, and in his report he went no further than to advise the building of reservoirs for giving the people more water, leaving its distribution exactly as it was before. Yet in the short space of ten years public sentiment has completely changed and, to-day, no one questions the wisdom of the broader plan upon which these works are being carried out. So it will surely be in regard to reservoirs in all other parts of the country. The principle is the same. It may be accepted that only the General Government can do this work in the comprehensive way in which it ought to be done, because only the Government can reap all the benefits; only the Government can wait the long periods necessary for full returns, and only the Government has the necessary resources to make expenditures on the required scale. These points will not be enlarged upon, and the many and cogent reasons why this is so will not be given. The trend of public thought is all in that direction. The old idea that the Government cannot execute great works or small as cheaply, efficiently and expeditiously as private agencies is fast being dispelled, and the vast benefits which the people derive from public control of important enterprises are coming into fuller recognition all the time.

The foregoing remarks should not be construed as in any way rejecting the idea of local help by states, counties, cities, or even private

agencies. It often happens that public works have a special local importance in addition to their public value. It is just and proper in such cases that local aid be given. This principle is now fully incorporated in river and harbor legislation. For example, the Lake Washington Canal, which will be of very great local importance to the City of Seattle, is a joint enterprise between the Government and the City, the latter paying fully one-third of the cost. The co-operation between the U. S. Geological Survey and the several States in preparing a contour map of the country is an example on a large scale. The principle ought to find an extensive application in the establishment of national forests throughout the country.

CONCLUSION.

This paper will be closed with some reference to the relation of navigation to other uses of our streams, and to certain legal obstacles that stand in the way of comprehensive measures. That the improvement of our inland waterways should be organized upon a more rational system than it has ever been, that the reciprocal relation between navigation, water-power, etc., should be given practical recognition, above all, that the prosecution of these works should be placed upon the same sure basis as is the construction of the Panama Canal, with positive assurance that, when once commenced, funds will be forthcoming for their prompt completion, would seem to admit of no doubt. How far navigation should be correlated, in improvement work, with other uses of the streams, is an open question. Water-power and navigation are in many cases so closely related that they will have to be considered together. In regard to soil wash, no such intimate relation exists. To whatever extent soil erosion now exceeds that of former times, it relates almost exclusively to cultivation and has no appreciable influence upon the channels. Its control is of far greater importance to agriculture than it is to navigation. This is also true of irrigation, which, so far as it affects navigation at all, affects it injuriously. If the development of irrigation is ever carried to the length that we hope it may be, it will cause a heavy drain upon the low-water flow of the Missouri, Sacramento, San Joaquin and the Columbia Rivers (not important as to this stream), the only navigable waterways of consequence that are affected by it. Except for this fact of drawing water from the streams, irrigation has no relation to navigation.

Forestry, irrigation and prevention of soil wash are all related to the conservation of the vegetable resources of the country. They are kindred purposes and should naturally fall under the same administrative control. Navigation is a function of transportation, which is a very different subject. Water-power is becoming more and more closely related to it, and these two subjects naturally go together. It must not be expected that the character of works for river regulation can be materially changed by means of reservoirs, forests or soil-wash prevention. Levees and bank protection, locks and dams, dikes and dredging will continue to be standard methods of river improvement in the future as in the past. The accumulated experience of centuries in all civilized countries cannot be set aside in a moment. In particular, flood protection is not likely ever to find any complete substitute for levees. They have been used extensively the world over throughout recorded history. People who think only of the Mississippi and the Po, when levees are mentioned, little understand to what an extent "diking" is resorted to wherever rich bottom lands have to be guarded against floods or tides. Some of the finest agricultural lands in the world are behind levees where almost perfect security is felt. No class of river control is in more extensive use, none is better understood, and from none has the world, throughout its history, derived greater security and benefit.

Municipalities, like Pittsburg, Cincinnati, and Kansas City, must look in the main to their own efforts for protection against floods. In particular, they must reject absolutely the delusive promises of forestry. These cities are trespassers upon grounds dedicated by Nature to a condition of overflow. They have occupied these grounds and placed themselves in the way of the floods deliberately and with their eyes open. They have gone farther than this, and in many instances have encroached upon the channels, and have thus made the floods worse than they used to be. It is not for them now to look for outside deliverance, but they themselves should grapple courageously with the problem. In most cases these problems admit, if not of complete solution, at least of a very large measure of relief. The maxim that Providence helps them who help themselves may also apply to the Government. Co-operation in connection with its regular work, either in channel improvement or in the building of reservoirs, would doubtless be given. The disposition which must be met and

overcome is to let things go as they are, trusting blindly to chance to deal more kindly in the future. This supineness of spirit and the enervating reliance upon indefinite future relief through the agency of the Government must be replaced by self-reliance, and these great industrial centers must rise in their own might and free themselves from their bondage to these ever-recurring catastrophes. In Boston, Chicago, Galveston, San Francisco, and even that lusty young giant of the Northwest, Seattle, are examples enough of what an aroused civic spirit can do in the direction of self-aid.*

The part that reservoirs will play in the larger problems of channel improvement and flood control on the great rivers will be in the nature of an insurance. Every cubic foot of water taken from the crest of a flood and released when the rivers are lowest is *pro tanto* a benefit. If the great floods of the Mississippi can be cut down by so much as a foot through reservoir storage, it will be an immense gain; and the same will be true if the low-water stages can be increased by 2 or 3 ft. Whether the much greater results expected by Mr. Leighton can ever be realized is a question which the future alone can determine.

A word, finally, concerning the legal obstacles in the way of a broad Government policy looking to the development of National forests and the storage of water on an extensive scale. The expansion of Government work into fields of obvious utility is often blocked by the structure of our Government through the bar of constitutional prohibition or at least lack of power. It is said that the purchase of lands for the rearing of forests for timber alone is unconstitutional, and that the same is true of the storage of water for any other purpose than navigation; and yet, forests for timber and reservoirs for power must always remain the real justification for public expenditure along these lines. To the average understanding the distinction between things constitutional and things unconstitutional is often hard

*The writer is not closely familiar with the situation at Pittsburg and Cincinnati, but he is familiar with that at the two Kansas Cities where, in 1903, the greatest loss occurred that any American city ever sustained at the hands of a river flood. He speaks from the results of careful study on the ground when he states with the utmost positiveness that, for approximately \$10 000 000, with such aid as might reasonably be expected from the Government on the Missouri River front, the flood problem of the Kaw and Missouri in that hive of industrial enterprise known as the West Bottoms can be solved absolutely; the too small area of these bottoms can be increased by upward of 200 acres; two-thirds of the bridges in the same area can be eliminated; that prodigious barrier to free movement—the Kaw River—can be practically removed or placed where it will not be in the way, and the general situation can be so improved that the resulting benefits, wholly apart from that of flood protection, would be well worth the cost.

to discern. The Government is now expending millions in storing water and conducting it upon land whereby the products of the soil may be obtained. It is applying this water to both public and private land, or to lands that were in private ownership when the projects began. Is there any real difference between providing the power to raise sugar beets, for instance, and that for manufacturing them into form for human consumption and transporting them to the consumer? Are not the last-mentioned purposes quite as necessary as the first?^{*} And again, is there any distinction in principle between improving a river so that boats can navigate it and improving it so that it may provide power that will transport produce by land as well as by water?

Again, the Government has accepted gifts of land like the Yosemite Valley and the Muir Redwood Grove, to be given over to the enjoyment of the people and involving perpetual expenditures for maintenance in the future. It has traded lands of its own for lands with which it has parted ownership. It reserves vast areas to-day which might be private lands to-morrow. What is the distinction of principle between doing all these things and buying outright lands that are needed for the same or similar purposes? They are distinctions without real differences. They concern the letter and not the spirit, and they cannot stand whenever the interests of the public really demand their abrogation.

Still, it is probably a fact that Federal authority to buy lands for forest culture alone and to create reservoirs for industrial use exclusively, would be considered by the Courts as transcending the power of Congress under the Constitution, and it is this fact that forces those who believe in having the Government do these things to strain the truth by attempting to prove that they are necessary for navigation and for the prevention of floods. It enforces a policy of indirection instead of permitting these things to be done squarely for their real purpose and as a matter of right. In his address before the Judiciary Committee, in its hearing on the Appalachian Bill, Mr. Pinchot stated that that proposition must stand or fall upon the theory that the forests regulate stream flow, and are therefore useful to navigation. Did he not refer to the particular point here under

^{*}It has even been hinted by high judicial authority that the Reclamation Act itself would not stand the test of constitutionality, if brought into Court.

consideration—that on any other theory the measure would be unconstitutional? Surely he did not mean that the cause of forestry itself must stand or fall upon any such issue.

Does not this situation suggest the necessity for an important initial step which shall sweep away these artificial barriers and let these great questions stand or fall on their intrinsic merit? If the upbuilding of new forests, if the storing of our flood waters, are necessary measures for the welfare of the Nation, the way should be cleared for their accomplishment. There may be differences of opinion about amending the Constitution in the interest of uniform divorce laws, popular election of Senators and the like, but, if we may judge from the universal agreement upon the particular subjects here considered, every State in the Union would ratify an amendment giving to Congress the power to legislate for the conservation and development of the natural resources of the country.

The writer should possibly state, in justice to the official body of engineers to which he belongs, that the arguments presented in the foregoing paper are his individual opinions only. He is not acquainted with the views of any other officer upon the subjects treated, except as he has seen them expressed in official reports or in the public press.

DISCUSSION

F. COLLINGWOOD, M. AM. SOC. C. E. (by letter).—In these days of unrest, it would seem that no conclusions in any realm of thought or observation are so firmly established but that some acute thinker will bring forth arguments to prove their unsoundness. Mr. Collingwood.

This is the case in this interesting paper, but, while acknowledging the force of the arguments advanced, the writer is unable to accept the author's deductions as a whole.

Four propositions are given, as covering the ordinarily received opinion as to the effect of forests on stream flow.

The first of these relates to the effect of the humus acting as a sponge which absorbs the rain and melting snow and pays out the water in a more equable flow. The word, "humus," does not fully cover the point involved, as consideration must be taken also of the sponge of dead leaves, and, in many cases, the great depth of moss growing upon the surface. Then, as helping in a marked degree to resist soil erosion, the matted roots of a forest must not be overlooked. These are particularly important in the case of a thin soil cover resting on sloping rock. Observation would seem to show that the young growth does not fully take the place of large trees, particularly in such locations.

It must be admitted that in time of extensive and heavy down-pours of rain, when the ground is practically saturated with moisture, the effect of forests as regulators of stream flow is at a minimum; but it is not believed that it is ever entirely without effect. A rivulet which can run straight to its destination is one thing; but a rivulet which is constantly twisting and turning about obstacles of all sorts can never attain the eroding effect of the first.

The author grants that, in periods of drought, springs and streams dry up more completely when a country is deforested, which is another way of saying that forests do, in a measure, regulate the run-off. As bearing upon this point, it was the writer's good fortune, about fifty years ago, to listen to a series of lectures by the noted geologist, Professor James Hall. He stated that, in his memory, the removal of the forests from large sections of the State of New York had resulted in drying up a large portion of the springs formerly so abundant. This was especially noticeable in the removal of the watering troughs which had been so numerous along the public roads. This coincides with the writer's memory as to Chemung County, in that State.

The next point controverted by the author is that forests regulate the flow by retaining snow, which slowly melts at a later period, and thus replenishes the streams. In reply to this: the writer well remembers that, in the woods on the hills near Elmira, N. Y., the drifts

Mr. Colling-wood. remained unmelted long after every bit of snow had disappeared from the cultivated portions of the valley. It was a common remark that there was enough left to add perceptibly to the flood usually expected in June. Exposure and the kind of forest may have had something to do with this, but the fact remains.

Passing to the third proposition—that forests increase the precipitation of moisture—it is not believed that this idea is now held to any extent by meteorologists. While admitting this, it does not follow that they have no effect upon storms. Probably no person would question the statement that a chain of mountains causes most of the moisture in the clouds to be deposited on their windward side, so that the rainfall is always greater there, and less on the opposite or leeward side. If this be true, are we not forced to believe that a belt of forest must have a similar effect, but in less degree?

When there is nothing to deflect them, the several moisture-laden currents of air tend to travel parallel to each other. Let them meet a forest, and the lower current is deflected upward, and, by mingling with the upper, causes the formation of clouds and rain.

The contention, then, is that forests tend to cause a more uniform distribution of the rainfall, lessening the mighty downpour and giving more frequent gentle showers; with this would follow fewer severe winds and an amelioration of the climate. It is probable, also, that forests act electrically to induce precipitation, by restoring equilibrium between earth and clouds.

The author's fifth conclusion in summing up is that "Soil erosion does not result from forest cutting in itself," and that "The natural growth which always follows the destruction of a forest is fully as effective in preventing erosion."

The writer's contention is: That forest destruction is always followed by a more rapid flood discharge, a consecutive increase in the flood volume, a diminution in the low-water volume, and a greatly increased erosion of the banks and damage of the flood plane in the lower reaches of every stream. His opinion is based largely on his life-long knowledge of a single river, he having been born in 1839 at Elmira, N. Y., on the banks of the Chemung. The conditions in his boyhood days were these: The stream had a fairly uniform width; the banks were largely grassed; the channel was comparatively uniform; there were very few bars, and all through the summer there was a good flow of water.*

On May 31st, 1889, and the following day, there was a freshet, exceeding in height any previously known, this being the result of a very heavy and extensive rain. The writer was employed to make an

* This whole region, including the head-waters of the streams forming the Chemung, had been heavily wooded, and the cutting and rafting of pine lumber, for a market on the Lower Susquehanna, formed one of the chief industries for many years. Rafting ceased somewhere in the early Fifties, but lumbering and the cutting of hardwood for ties, fuel, etc., have continued the forest destruction.

examination and report upon the best method of protecting the City of Elmira against such floods. Mr. Collingwood.

A careful survey was made of about three miles of the river, with cross-sections every 100 ft., these being carried entirely across the flooded portion of the valley.

Having lived elsewhere for about 20 years previous to this, the writer was amazed at the extent of the changes in the stream. At one point it had widened from about 600 to about 1300 ft. All through this portion there were bars covered with black alder, and on the south bank there was a matted mass of alders, in some places 100 ft. wide. In early days there were no alders, and the land that had been cut away was rich and arable.

At other points, over considerable areas, every particle of mould had been washed away, down to the hard clay, and the whole region was covered with coarse weeds.

In a previous survey of another portion of the river, in a dry time, the stream practically disappeared in its gravelly bed. A gentleman living on the Susquehanna, at Wyalusing, told the writer that his lands along the river, which he used to consider the best parts of his farm, were now so cut and gashed by the freshets that they had largely lost their value. Any person riding along one of the railroad lines through the valley can see the damage done by the river, often at points considerably distant from its main channel. These devastations seem to be increasing, and records of the flood heights, kept for many years at Elmira, indicate a tendency of the floods to be higher as the years roll on.

To the writer's mind, the cause is very plain. One of the streams heading into the Chemung is very steep, and, when the heavy woods were cut from its bank, the flood-waters were more rapidly concentrated, and poured into the main stream, so that the time required for the flood from a heavy rain to reach Elmira was very much shortened. The writer's recollection is that this time was reduced to one-half. The other two streams did their quota of damage, but not to the same extent. If this be true, the conclusion is irresistible: that the forests do act as powerful conservators and regulators of stream flow.

The conclusions seem sound, from another point of view: Here is a stream flowing for centuries, having a uniform regimen, with fairly uniform section and smooth banks up to, say, 50 years ago, showing, up to that time, but few signs of destruction from floods. Within 20 years there is a complete change, and a beautiful stream is transformed into an irregular, wilful, destructive thing.

If the cutting of the timber did not do it, what was it?

THOMAS P. ROBERTS, Esq.* (by letter).—This paper covers the subject in a very broad and comprehensive manner. Mr. Roberts.

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Mr. Roberts. It is a curious thing that, in relation to forests and stream flow, the river engineers seem to be arrayed as a small but compact body against "popular opinion." It must be remembered, however, that the engineers concern themselves only with large areas and navigable rivers, while the views of their opponents, in the great majority of cases, are based upon observations of restricted areas and small streams. It might be contended that a collation of the reports from a multitude of such local observers should be the most trustworthy basis for national legislation bearing upon the improvement of rivers, yet it may be questioned whether this conception is not an erroneous one.

In 1885 the writer was invited to address the American Forestry Congress at its Boston meeting upon a text similar to that adopted by the author. He was warned by the Secretary of the Congress that he was in a woful minority; in fact, almost a lone man, but nevertheless the Congress would be pleased to be entertained with his theories. His paper enunciated no theories, but simply presented certain records of navigable rivers, American and European, which appeared to show nothing in support of the idea that floods were increasing in height and frequency, or that the low stages had less discharge and were more protracted, on account of any works of man. The Congress was informed that perhaps the common belief that the whole was equal to the sum of all its parts was a proposition after all not without exception, as, for instance—to refer to extreme cases—the discharges of the Colorado and Rio Grande Rivers at times make up but fractions of the united volumes of their respective upper tributaries.

At a recent meeting, a speaker, after referring to the destruction of timber by the girdling process, leaving the trunks to decay uselessly then, rose to the climax of his argument, and said:

"Again, every man knows how in the late spring the roads in the open country may be firm and dry, but upon entering the forest one is sure to find pools of water and deep mud holes. This, gentlemen, illustrates the utility of forests, and it is the whole story in a nutshell: the open country dried up and the forests abounding with countless 'miniature reservoirs.'"

It was not the whole story, however, for, later in the season, in the same region, pedestrians might have been seen hastening toward the adjoining forests to escape drenching from the summer rain squalls. Still later, during the recent drought in Western Pennsylvania, beneath the shade of trees might have been seen corn actually dead for lack of moisture, while the corn 50 ft. distant, in the same rows in the open field, while somewhat wilted, still lived and filled its ears with a medium crop. There might also have been seen in the forests saplings here and there beneath larger trees with their leaves dried up and falling off. So great, apparently, was the draft of the tap roots of the big trees for water that no moisture whatever was left for a depth

of several feet; otherwise the saplings would not have withered as Mr. Roberts. they did.

It might be asked, is the forest, in its usual late winter and spring condition, with its "miniature reservoirs" full to overflowing, capable of holding back more water from later rains than the dry open country, as described by the speaker referred to? Or, when it comes to protracted droughts, are the forest areas contributing more water to the streams than equal areas of deforested country under similar conditions of soil composition, depth, and slopes? Writing in 1838, in his first report to the Monongahela Navigation Company, the late W. Milnor Roberts, Past-President, Am. Soc. C. E., the company's engineer, states, in reference to the drought of that season, that all the tributaries of the river between Brownsville and the mouth of the Youghiogheny River, a distance of about 42 miles, were dry at their mouths, and again the same thing occurred in 1895 and is practically true at this writing.*

It appears that Colonel Chittenden must be correct in his assumption that, for the extremes of high floods and low water, as observed in our navigable rivers, forests exert no appreciable control. For the intermediate, or what might be termed summer, freshets, there is apparently some reason to think that forests have a measurable influence in reducing their height and prolonging their discharge, and this statement may hold, notwithstanding that less rainfall reaches the earth in forests than in open country. The fact is perhaps indicated for the Ohio in Table 2—for freshets not exceeding 10 ft.—and in Table 3—for the months of June and July—when the mean of freshets was 2 ft. higher in the second than in the first period. For the coal-boat stage—10 ft. or more—during the first period, the annual duration was 57.8 days; for the second period, it was 58.9 days. Doubtless the excessive rains in recent years will account for the difference in the higher stages. Speculations, however, regarding the Pittsburg river records in connection with forests, must be received with caution, in view of the fact that in eight of the counties on the Allegheny River water-shed, during the decade 1890-1900, there was a decline of more than 20 000 in the rural population, that is, exclusive of boroughs and villages, many one-time mountain farms being now covered with young trees or brush.

Table 5 shows the number of rises in the Ohio at Pittsburg, by months, reaching to or exceeding 15 and 20-ft. depths, from 1855 to 1907, inclusive. The table shows that the winter storms of January, February, and March were much more frequent in the second than in the first half period. No forest influence appears to be indicated for the leafy months, a fact contrary to the common impression.

*While it is true that the Upper Ohio, about October 1st, 1908, was lower than officially known since 1838, it is reported from East Liverpool, Ohio, that the "Indian picture writing" on a rock ledge at that place was not yet completely bared.

Mr. Roberts. TABLE 2.—YEARLY MEAN NUMBER OF DAYS THE OHIO RIVER AT PITTSBURG REACHED THE INDICATED STAGES IN THE PERIOD SHOWN.

Years.	At or below 1 ft. stage.	Bet. 1 ft.-2 ft. stage.	Bet. 2 ft.-3 ft. stage.	Bet. 3 ft.-4 ft. stage.	Bet. 4 ft.-5 ft. stage.	Bet. 5 ft.-6 ft. stage.	Bet. 6 ft.-7 ft. stage.	Bet. 7 ft.-8 ft. stage.	Bet. 8 ft.-9 ft. stage.	Bet. 9 ft.-10 ft. stage.	Bet. 10 ft.-12 ft. stage.	Bet. 12 ft.-15 ft. stage.	Bet. 15 ft.-20 ft. stage.	Bet. 20 ft.-25 ft. stage.	Over 25 ft.
1855-1880.....	0.4	2.9	12.1	39.9	42.9	45.1	46.8	44.0	42.0	31.4	32.9	17.1	6.8	0.7	0.3
1881-1907.....	1.4	20.0	40.4	43.4	43.6	41.2	36.0	31.6	26.1	22.7	29.5	18.9	8.2	1.5	0.8

Note for Table 2.—Some confusion in stages below 3 ft. since 1885—upon completion of the first dam in the Ohio—has resulted from attempts to conform the readings below the dam to the old Pittsburg datum; hence too much importance should not be attached to differences shown in the table for periods when the river was below 3 ft.

TABLE 3.—MEAN MONTHLY HIGHEST STAGES, IN FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1855-1880.....	14.71	13.99	16.02	15.85	12.00	8.65	7.26	7.13	7.44	6.91	10.85	14.97
1881-1907.....	17.07	16.76	18.26	15.45	11.44	10.52	9.18	7.80	5.71	6.75	10.34	13.66

Note for Table 3.—But for a remarkable flood, reaching 31 ft. in September, 1861, the means of the two periods for that month would have been much the same.

TABLE 4.—MEAN MONTHLY LOWEST STAGES, IN FEET.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1855-1880.....	3.52	3.72	5.14	5.08	3.75	2.52	2.03	1.74	1.20	1.47	2.69	3.62
1881-1907.....	4.42	5.06	5.93	5.64	4.31	3.50	2.61	2.04	1.75	2.08	3.07	4.15

TABLE 5.

Period.	JAN.		FEB.		MAR.		APR.		NOV.		DEC.		MAY.		JUN.		JULY.		AUG.		SEPT.		OCT.	
	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.	15 ft.	20 ft.
First (1855-1881).	18	4	15	4	22	5	21	3	5	1	18	5	6	3	6	1	0	0	1	1	4	2	1	0
Second (1882-1907).	29	11	27	15	30	12	17	6	2	1	11	2	7	1	2	1	4	1	2	1	1	0	2	0

SUMMARY.

Mr. Roberts.

Period.	WINTER MONTHS.		LEAFY MONTHS.	
	15 ft.	20 ft.	15 ft.	20 ft.
First (1855-1881).	99	22	18	7
Second (1882-1907).	116	47	18	4

Since 1875 there has been no marked change in forest or brush-covered areas about the heads of the Ohio; while, during the winter and early spring months, covered in the second period, storms from the Gulf of Mexico, traversing the well-worn storm trail *via* Vicksburg, Chattanooga, and Charleston, W. Va., have, for some occult reason, reached Pittsburg with unprecedented frequency.

In the case of "cloudbursts," or storms of the tornado type, which, as a rule, traverse very narrow paths, few will dispute that a dense forest, by prolonging the discharge, even for brief periods, of the small streams they cross or follow, may reduce their flood heights. It is, however, from such limited areas, apt to be struck by violent storms once in from 3 to 5 years only, that reports come that are made the basis of arguments applicable to large rivers. The worst known storm of this nature, which deluged some of the suburbs of Pittsburg in 1874, raising two small runs to 15 or 20 ft. depth and destroying more than 200 human lives, affected the depth of the Ohio only about 5 ft. Hence it becomes important to differentiate the storms producing floods on small streams and on navigable rivers, as Colonel Chittenden intimates is so necessary for a complete elucidation of the subject.

In his treatment of co-ordinate topics, such as effects of forests on rainfall, dew, evaporation, erosion of slopes, silting up of rivers, and soil wash, Colonel Chittenden may be assailed by some who will differ with him in opinion. It is a mistake, however, to assume that those who endorse the author's views are antagonizing forest culture. No abler exposition, perhaps, of the importance and value of the forests has been presented than can be found in his résumé. He asks, however, that the new forests be planted convenient to the markets near the homes of the people. It is not wanton destruction on the part of the mountaineer to girdle the trees to make room for his corn and buckwheat crops, for gladly would he part with the biggest of the tree trunks for a pittance, but no offers are made him because the cost of transportation stands in the way.

So, while all of us have the same love for the trees, business considerations are very rude at times with our sentiments. We may hold

Mr. Roberts. on to all the trees, as the Indians did, without business; but, without continued business with the trees, we cannot make homes for many more modern Americans. Yet, without more of those trees to cut, what is to be done for homes in the future? The problem is indeed a vast one, well worthy the attention of the governments, National, State, and Municipal. Confronting us, however, there are other problems, not connected with the timber question, especially that of transportation on our inland waterways, but, so long as it is contended that transportation and the forest problem are in the same category, so long will the public mind be confused by conflicting statements and arguments, and so long will decisive action be delayed.

As for the silting up of our rivers, complaints regarding it do not emanate from navigators, at least on the Ohio. The writer, as a young man, lived for four years on an engineer steamer on that river in charge of the construction of dikes or wing-dams, surveys, etc., and upon inquiry has been assured that, if any changes in conditions of navigation have occurred during the past forty years, they have been for the better. A great rise from the Cumberland and Tennessee Rivers by backwater effect may cause the deposition of much silt in the main stream, noticeable at times for 200 miles or more, but eventually comes a current amply competent to restore the channel to its former condition. From end to end the great river has this reserve of energy. The theory to the effect that with afforesting of the regions about the head-waters there will result such clarification of the waters that the river will cease to be silt-bearing, receives scant courtesy from the author. One writer argues that the sand now carried in suspension, acting like sand-paper, destroys the banks by "abrasive action." We have thus, in one breath, to consider the river banks being sand-papered down and the stream itself filling up. The Ohio between Pittsburg and Cincinnati has preserved its width between banks and its volumetric capacity very much the same for many decades, while, during the same period, that capacity has doubtless been largely exceeded by the volume of silt which the river has borne along. The author, therefore, is correct in saying that walling up the river banks would have no effect in reducing the volume of silt it transports; nothing would do that possibly for the Ohio but a tarpaulin spread over the steep hillsides of West Virginia and Kentucky, whence the greater proportion of the silt comes. Tributaries from soft-rock regions in those States can be named by the writer, from personal observation, which abounded with shifting sand-bars while yet the country about them was practically an unbroken forest. Those primeval forests did not prevent the carving of the nearly horizontal strata into the deep ravines found in the States named. If, however, the carving process is proceeding faster than formerly on some of the tributaries, troubles from it have not been reported on the main streams.

Regarding reservoirs to restrain floods on our Western rivers, the Mr. Roberts. writer's opinions may have been perverted in youth by a parent who was in open opposition to Colonel Charles Ellet, the distinguished and able advocate of reservoirs. M. O. Leighton, Assoc. M. Am. Soc. C. E., has again raised the standard, but upon more specific and detailed lines than those of his great predecessor. It is a subject which should be considered apart from forest problems. Engineers must necessarily discuss its merits by weighing the cost with the advantages to be secured. If, for instance, it can be shown that levees along the Ohio can be built protecting all the property exposed to serious flood damages for one-fifth, or even less than one-fifth, of the cost of reservoirs necessary to secure that result, the engineers will be very apt to recommend the levee method. It requires no further surveys to hold tenable opinions on the questions herein involved. The matter of power development is, of course, a part of Mr. Leighton's project which should not be overlooked. At the same time we may have to content ourselves with fewer horses in our "power stables" than he hoped to provide. As to cost of flood-storage reservoirs in the Ohio Valley, readers are referred to an article* by Major H. C. Newcomer, Corps of Engineers, U. S. Army.

If Mr. Leighton's studies for the improvement of navigation do not meet with the results he expected, he can, in any event, congratulate himself upon showing the country where some very valuable water-powers can be found. The engineers fully appreciate the value of the elaborate topographic maps of the United States Geological Survey.

Colonel Chittenden argues that the water-powers should be under the control of the authorities managing navigation interests. They are certainly related in the cases where the powers are located immediately at dams with locks, and it seems to be apparent that the shutting down or stoppage of flow in other cases, resulting in possible detriment to transportation interests, should be under the control of the navigation engineers.

The author's final argument that all the interests of forestry, power, and water transportation are within the purview or jurisdiction of the National Government will appear reasonable to most thinkers. The revenues of the individual States, and schemes of taxation, cannot well be adapted to projects of this nature, where State lines would so frequently stop an adequate exploitation. At the late Governors' Convention in Washington no strong voice was raised against this conception. What everybody wants in this country, one would think, should be constitutional, and in the few brief words of the preamble of the Federal Constitution our wise forefathers did not forget to say something about the promotion of the general welfare. Away then with the foreign criticism that our Constitution has caged a giant incapable of development in response to modern demands.

* *Engineering News*, October 8th, 1908.

Mr. Child. STEPHEN CHILD, M. AM. SOC. C. E. (by letter).—Colonel Chittenden's arguments are so evidently based on careful study and years of practical experience that they carry great weight, and certainly one who has been able to give these matters comparatively little investigation should hesitate to combat them. The writer's interest in them, however, is intense, and, if they remain uncontroverted, they will be a strong argument for politicians in Washington who are opposed to the Appalachian and White Mountain Forest Reserve bills. As a member of the Council of the American Civic Association, it was the writer's privilege, while in Washington, to use what little influence he had in the interests of these bills, the passage of which is believed to be of the utmost importance to New England and the South Atlantic States.

The author takes up the influences of forests upon stream flow, and states "the commonly accepted opinion," "that forests have a beneficial influence on stream flow." He then proceeds to controvert these opinions pretty thoroughly. Certainly his arguments are strong and most interesting, and the writer frankly admits that he is entirely unable to meet them. As stated, the above-noted opinions are very commonly accepted at the present time, and no one is more responsible for their common acceptance in the United States than Gifford Pinchot, Assoc. Am. Soc. C. E., of the Forestry Bureau, whom the author frequently quotes and whose writings and lectures upon this subject have been accepted by many, up to the present time, as the final word on this subject. The writer, therefore, is very glad to know that Mr. Pinchot is to be given an opportunity to reply.

One of the author's statements, with reference to waste in lumbering operations, certainly appears to be extravagantly put. Commenting on the improved lumbering methods of the Weyerhaeuser Timber Company, he says:

"To speak of such timber as being 'lost' to the people, 'wasted,' and its acquisition as a 'looting of our heritage,' is as disingenuous as it is untrue. Will its lumber cost the consumer a cent more per thousand than if it were from a Government reserve? It is a wholly gratuitous assumption that our timber is going to be 'wasted' unless it is placed under Government control."

While the writer is in no position to controvert the statements as to the progressive methods now being used by the Weyerhaeuser Timber Company, he thinks he is well within the facts in stating that the improvements which this and other progressive lumbering concerns have adopted within recent years have been due largely to the campaign of education waged by Mr. Pinchot, and to the aroused public opinion which his work has brought about. It is hard to believe, as Colonel Chittenden would intimate, that there have not been in the past and are not now, in many sections of the United States, wasteful methods of lumbering; yet the statement quoted would imply

that, and also that the Forestry Bureau, by its acquisition of Government reserves and its progressive handling thereof, has done, or can do, little good. Mr. Child.

Colonel Chittenden leads up to the decision that if the people expect to have the Government purchase land for the rearing of forests for timber, or for the storage of water for any purpose other than navigation, or upon the theory that forests regulate stream flow and, therefore, are useful to navigation, the Constitution of the United States must be amended—a small matter, which he thinks can be easily accomplished in view of the widespread interest in these questions. The writer may be pardoned for disagreeing with him and for believing that, if his arguments are correct, he has furnished Speaker Cannon and the opposition to the Appalachian and White Mountain Forest Reserve bills a two-edged sword which they will not fail to use, and he speaks from the experience of personal contact with several members of the Committee on the Judiciary of the recent Congress. In the interests of these bills, therefore, and their great importance to an immense section of the country, the writer looks forward to Mr. Pinchot's reply with great pleasure.

L. J. LE CONTE, M. AM. SOC. C. E. (by letter).—The writer is Mr. Le Conte. greatly impressed by the intrinsic value of this remarkably well written paper. The author's remarks about Sir Gustav Wex's pamphlet on the flow of the Danube are well taken. In 1879 a second treatise was issued by the same authority, accompanied by elaborate tables and maps, and cross-sections of the river—all going to show the alleged fact that there is a decrease in the flow of water in springs, creeks, and rivers contemporaneously with an increase in the height of floods in cultivated countries. After most elaborate calculations he finally concludes that the decrease in rainfall due to this cause is found to be 0.0027 in. per annum, and the accumulated losses extending over 18 years, 0.0486 in. This refinement in the measurement of rainfall is unique. It is not at all surprising, therefore, that nearly all the meteorological stations in England, France, and Denmark, with records extending back from 100 to 120 years, failed to find any changes to speak of.

As far as the writer's observations extend, forests do not exercise any appreciable restraining influence on great river floods. The influence of the forest bed of vegetable humus is altogether too insignificant in amount to affect the problem.

The phenomenon of dew mentioned by the author is certainly most pronounced in the open, and at certain times of the year constitutes a very material addition to the precipitation. The writer recalls a striking experience on the San Joaquin Plains, California, while running a trial line, practically east and west, through the Town of Grayson. This was in August, when the rainfall was nothing. The line

Mr. Le Conte. passed through 40 miles of continuous and unbroken wheat field. In places the wheat stood 42 in. high, was well headed, and, when harvested, frequently averaged 60 bushels to the acre. The surveying party began work early every morning without exception, and every member, the chainmen especially, was drenched with the heavy dew on the wheat, and never got dried out until noon each day. This continued for five days while passing through this mammoth wheat field. Of course, the popular phrase "dewfall" is a misnomer. The phenomenon is purely one of condensation; nevertheless, it is a very important and material element in the daily precipitation in the open, and should not be overlooked. In the forests, of course, this is *nil*.

Another most interesting feature about these plains is the effect of cultivation on the surface run-off. Experience everywhere shows that plowing the surface soil reduces the surface run-off enormously. The reason for this is easily understood when the physical facts are known. In the natural state the surface soil is generally sun-baked and hard. When the rains come, this surface crust sheds water like the roof of a house. On the contrary, when this land is plowed up into deep furrows, after the first rains have softened the ground, all the rainfall thereafter sinks in, and the run-off is practically nothing. More than that, the top soil, being broken up and porous, stops subsequent surface evaporation enormously, and holds the ground-waters for the subsequent useful purposes of agriculture.

Of course, later in the season, when very heavy and prolonged rains come, the surface wash from the plowed lands is more heavily charged with sediment than it would have been before the lands were plowed. It should be remembered, however, that this run-off lasts for a much shorter time, and, therefore, it is an open question whether, considering the entire year, cultivation materially increases the total solids transported to the streams. The effect of cultivation, therefore, is to store the rain-waters in the soil, reduce surface evaporation, and enlarge and equalize the flow of ground-waters to the streams. These functions are certainly in keeping with the requirements of conservation, and tend to increase the percentage of annual run-off to rainfall. At all events, observations on lakes and artificial reservoirs certainly fail to show any noticeable increase in silting up due to cultivation of the soil.

The author's remarks about the relative efficiency of storage reservoirs in controlling the flood-water flow of rivers are exceedingly timely and strictly to the point. If these reservoirs are to be used for power or irrigation purposes, all efforts at flood control must be abandoned. The all-powerful interests of water-power and irrigation are diametrically opposed to storage capacity for the accommodation of great storm-waters, as these generally come at the end of the wet season. These two interests can never be reconciled, but will always

be in endless conflict. In view of the large financial interests in water-power and irrigation, it is not difficult to see the final outcome of this conflict. Mr. Le Conte.

The big artificial reservoirs at the head-waters of the Mississippi are a great object lesson. They occupy ideal sites for storage reservoirs, and such sites are extremely hard to find.

The author mentions the fact that in times of heavy rainfall it sometimes happens that reservoirs will be compelled to discharge a greater quantity of water than would flow from the lakes in their natural state, that is, they would operate to increase the floods. Here again is evidence showing the conflict with power development, where the storage room is divided between several years instead of being confined to two years, as called for by the natural development. This conflict always arises, and it cannot be prevented. Necessity calls for it, and necessity knows no law.

The grand scheme of storage reservoirs proposed for the Ohio River system is altogether too Utopian, and is utterly impracticable as applied to the control of great river floods. Let water-power development and irrigation each stand on its own bottom, which both are amply able to do. The irreconcilable conflict between irrigation and low-water navigation in great rivers is rapidly approaching and will not down.

The writer's sympathies are largely on the side of irrigation, simply because the public benefits derived therefrom are so much greater than the damages sustained by a few months' interruption of low-water navigation, which, in many rivers, does not amount to very much.

In the arid regions, where irrigation is the very life-blood of the entire community, it would be equivalent to public suicide to insist upon the rights of low-water navigation; the exigencies of the case forbid it. Here, it is well to call attention to a fact, not generally known, in reference to low-water navigation on the Ganges River in India. The head-works are located at Hurdwar, where the river leaves the foot-hills. The fall of the river at this site is from 10 to 12 ft. per mile. Below the dams the river bed is dry, the entire low-water flow being taken for irrigation. Going down stream, however, the irrigation seepage waters, together with underground flowage, increase enormously, and on reaching a point 40 or 50 miles below the dam the river is as wide and deep as it was before the head-works dam at Hurdwar was built. Later, in 1878, the engineers built a regular weir dam, with locks for slack-water navigation, lower down the river at Narora—4 miles below the railroad bridge at Rajghat. This dam also takes all the low-water flow of the Ganges at this site, and necessarily leaves the river bed dry for a few miles; and then it is as wide and deep as ever. When one considers the enormous public benefits derived, viz., 1 600 000 acres irrigated on the Main Ganges Canal, and 1 900 000

Mr. Le Conte. acres on the Lower Ganges Canal, the small damage to navigation, caused by these great public works for a few months in the year only, sinks into insignificance and, in many cases, can be entirely ignored.

Mr. Maltby. F. B. MALTBY, M. AM. SOC. C. E. (by letter).—The presentation of this paper now, while the agitation and interest in the "Conservation of Natural Resources" is at its height, is particularly fortunate, and the placing on record, in an available form, of facts of observation rather than theories or popular opinions, is of the greatest value. The writer is in thorough sympathy with the movement for the preservation, and the intelligent and careful use, of forests and other resources of the United States, but agrees most emphatically with the author that the popular belief that deforestation is responsible for floods and low waters is an erroneous one.

There are ample reasons why forests should be carefully preserved and cared for and reforestation encouraged for the sake of future timber supply, without the necessity of charging to the destruction of the forests all the ills due to flood conditions on the one hand or the deficiency of water for industrial or domestic supplies and low stages for navigation during dry seasons on the other.

The author has shown in detail the fallacy of such beliefs, and these details show the painstaking care and thought that has been given to the preparation of the paper. The writer, unfortunately, has no other facts of observation to present as an addition to the discussion, and only wishes to approve most heartily the conclusions concerning the relations between run-off and deforestation.

During the Eighties or early Nineties, in the first days of extensive improvement work on the Mississippi by the General Government, it was impossible to secure appropriations for the construction of levees, except where built as an aid to the improvement of navigation, and one or more appropriation bills expressly prohibited such expenditures except as stated. There doubtless were engineers and others who honestly believed that the construction of levees did tend to improve conditions for navigation, and there is no desire to open up a discussion on this subject at present. Any one knowing the conditions and the vast benefits which have followed the construction of levees in the Mississippi Valley, however, will agree that there was ample and sufficient reason for their construction without any reference to navigation.

It is also true that the conservation of forests, the protection against flood conditions, or the improvement of low-water navigation are each of National importance; each can stand alone on its own merits, though it is undoubtedly true that all should be carefully considered by a commission charged with a careful study, in a broad way, of the whole subject.

The data presented by the author, as to the relation of stream flow and reservoir effect, are also particularly valuable in refuting some of the extravagant statements made by reservoir enthusiasts. It is to be regretted that the presentation of facts, with the calm arguments and conclusions based on them, cannot be given the same publicity as some of the wild assertions and schemes of the magazine writers. This cannot be expected, as there is nothing sensational in a consideration of the facts and conditions.

That much, very much, can and should be done in the direction of forestation, water supply for power purposes and navigation, and the control of floods, is undoubtedly true; and the engineering profession is to be congratulated on having the underlying facts concerning the relations between the various subjects so clearly brought before it.

J. FRANCIS LE BARON, M. AM. SOC. C. E. (by letter).—This paper is very timely, and the author has handled the subject in a very thorough manner. His observations in regard to snow run-off from forest and open areas, are borne out by the writer's experience. In his early days, while running railroad lines in New England, in the early spring, he was often surprised to find the woods nearly devoid of snow, while deep drifts still remained under the road fences and stone walls, and in deep road cuts.

The writer, however, must take exception to what he considers too sweeping a generalization of the statement that "there is really very little, theoretically, to support the claim that forests insure precipitation." It is undoubtedly true that when warm, moisture-laden air strikes a cold air current, the moisture will be precipitated in the form of rain. Forests are sometimes warm and sometimes cold. In northern latitudes forests are warm in winter and cool in summer; in the tropics, they are always cooler than the open, where the sun's rays are unimpeded. Take, for instance, the thick forests that clothe the eastern slopes of Nicaragua. For many months in the year, the warm trade-winds that have passed over the Caribbean Sea blow day after day from the coast over these forests, and the precipitation is phenomenal. It is common, when traveling on the larger rivers, to see spiral columns of vapor resembling the smoke of camp fires arising from the low hillsides when this warm wind from the sea is blowing over them. So perfect is the resemblance that at first the writer unhesitatingly supposed the vapor columns to be the smoke from the fire of some lonely hunter or settler.

There may be, as the author says, "very little to support the claim, theoretically"; but, practically, it is abundantly proven throughout the whole of that relatively narrow isthmus known as Central America, from Guatemala to Panama, as the writer has frequently observed. This phenomenon is particularly noticeable in Nicaragua, and the in-

Mr. Le Baron. fluence of the forest is there particularly observable, because that country is, in general, low, so that the excessive rainfall on the eastern side, amounting to 365 in. per year at Greytown, cannot be attributed to mountains. On the western side of that Republic, the precipitation is only about 45 in., and the forests are very different, being more open, and there are many large areas of cultivated lands and unwooded plains. All the moisture held by the eastern trade-winds is dropped when they pass over the dense and cool forest jungles that cover the entire eastern water-shed.

The author falls into another error of generalization, due, probably, to the fact that his observations have been confined to the limited area of the central and western United States. He states that "precipitation is nearly always greater upon the hills than upon the neighboring lowlands." This statement is quite true in British Columbia, where the observed rainfall in the Fraser River Valley is about 60 in., while less than 10 miles away, at Lake Coquitlam, among the mountains, but in the same water-shed, the precipitation is 130 in. On the Central American Isthmus, however, the reverse is true. While the precipitation at Greytown is 365 in., and at Bluefields, about 290 in., at Tegucigalpa, Honduras, at an elevation of 3 000 ft. above the sea, it is about 90 in., and at Suina, Nicaragua, about 260 miles from the sea, it is about 100 in. Observations were taken for two years under the writer's immediate supervision, at Greytown and vicinity and near Suina, when he was in charge of the work of the Nicaragua Canal and other and later enterprises in that country.

Touching the fourth subdivision of this paper, the author says that "the increased erosion of the soil * * * does not result from forest cutting, but from cultivation." Cultivation, however, is a concomitant of deforestation; not the intensive cultivation of the market gardener on the outskirts of a great city, but the rough cultivation of the first settler. In the broad sense of the word, deforestation is not the cutting down of the trees alone, for, as the author remarks, the stumps and roots remain and a new growth succeeds, perhaps closer and more impermeable to water erosion than before. In the sense in which we speak of the deforestation of the United States, there is meant the complete eradication of the forest, not the cutting down of the timber alone, and this includes clearing and grubbing to eradicate the trees, root and branch. That is what has actually been done in the United States and in any country that is deforested. When this is done, the soil is broken and its subsequent cultivation is of secondary importance. The trees are gone, the roots and many of the stumps are removed, the soil has been broken, and, although the land may lie fallow and be uncultivated for several years, it is exposed to the wash of the rain. The effect of this wash is very noticeable on the hill slopes in Tennessee and Georgia, and even in New England, Ohio, and on all denuded hill slopes known to the writer.

In these localities the small brooks are filled with muddy water Mr. Le Baron. during every sharp rain. This was not so before the land was cleared, and is not so now in the adjoining woodlands.

The author states that "no possible development of forestry can increase the present percentage of forest-covered areas." This appears to be a very sweeping and unconsidered statement. To any one who has ridden over the vast prairies of the West, it is quite conceivable that Man, by irrigation or, in many places, solely by care and perseverance in judicious selection in tree planting, can and undoubtedly will in the next hundred years increase immensely the percentage of woodland, and there will still remain abundant open land for cultivation. At the same time, as the author states, many abandoned farms in the East will be grown up in wood. The writer knows of many such places in New England, and there are also many in Florida, and other Southern States, where large plantations have grown up in native forest trees since the Civil War, owing to inability to cultivate them profitably without slave labor.

The author states that the action of the forest to moderate the run-off and mitigate the severity of freshets fails entirely in heavy and long precipitation. He admits that the humus and débris in forests retain precipitation and act as a reservoir for a time, but eventually may become saturated and thenceforth will be of no value for that purpose. In an extensive forest this impounding capacity is very great, and by just so much it reduces the peak of the run-off or at least the first part of the ascending curve, and there is no proof that, by the time the forest reservoir is full, the peak of the flood may not be past.

In his third proposition, the author says that "while small springs and rivulets may dry up more than formerly, this is not true of the larger rivers." If there were no springs, rivulets, or brooks, there would be no rivers, and, if these all run dry, the large streams must run dry also.

The sixth proposition, that climate has not been appreciably modified by land clearing, may be true for large areas, in a general sense, but it has been modified, in small areas, in northern latitudes, by the added exposure to wind, so that the cold and inclemency are more pernicious for the farmer and stock grower.

In the author's discussion of the cost of hydro-electric power, using the storage reservoirs built by the Government for water conservation, he quotes an article by Mr. Henry D. Jackson, giving costs based upon averages of a number of different plants, compared with steam power. Mr. Jackson's estimate includes the cost of the dam, "Building and works, steam, \$10 000; water \$77 000." The author does not take into account the cost of the dam and spillway, which are supposed to be already built by the Government for another purpose, so that this estimate, as it stands, is not applicable, but should be reduced by \$67 000, or

Mr. Le Baron. the cost of the dam, in favor of the hydro-electric plant. This makes a difference of 50% in first cost and the same in interest charge, and throws the balance in favor of the water-power. Therefore, his subsequent deductions are valueless.

The writer quite agrees with the author in his remarks about diking for flood protection, and about transportation by river or rail. This question of the propriety of Congress aiding navigation, and having no authority, under the Constitution, to build power works to aid transportation by rail, only exemplifies the fact that the world is growing so fast that a Constitution, which was a perfect instrument in its day, can be outgrown by the totally changed conditions of the present time.

Mr. North. EDWARD P. NORTH, M. AM. SOC. C. E.—This very able paper brings up a collateral and important question: Even if they accomplish all that is claimed for them, will National forests be a National beneficence?

The general and patent objections to the proposal now before the public are: The general installation of National forests would necessitate a still larger body of Government employees, and either tend to the perpetuation of a hierarchy, or to more or less violent changes of governmental policy.

Their control by the Central Government would impair our habits of individual initiative and also those of free association for production. These two habits, possibly more than any others, have been the governing factors in the progress of English-speaking peoples.

Their proposed locations, remote from centers of consumption for their products, by entailing the maximum cost for transportation, would diminish the resources of both producers and consumers. The fact that the General Government is a party does not obviate the necessity of making all expenditures return either insurance or profit.

As an alternative to the dedication of large areas to National forests under the control of the Central Government, and as free from the objections above recited, the following plan* seems preferable, namely, that lands covered by specified stands of trees should be free from taxation while the timber is growing and ripening. The numerous small groves which would be developed by the adoption of this measure would not be subject to the widespread destruction by fires invited by large forests, and, in addition to such modification of climate and runoff as may be due to timbered areas, would, by furnishing breeding places for insect- and vermin-eating birds, hinder, if not arrest, their extinction, besides adding to the beauty of the country; both additions not without pecuniary value. There should also be a provision of like kind for trees grown by the roadside. A prejudice against roadside trees, due to the combined effect of the trees and fences in forming

* Proposed in *The Engineering Record*, June 18th, 1908.

drifts and keeping the roadbed wet, dominates the public mind long after the watering-cart has proved inadequate to keep down the dust or prevent the raveling of the roadbed. Mr. North.

Thinking that the illustration cited (with blotting paper) would have been more valuable if the paper had been surcharged—*e. g.*, with shavings—it is not contended that erosive and disastrous floods have not originated on uncleared areas, and they are likely to recur notwithstanding any development of forest culture. Reservoirs, if of sufficient capacity, seem to be valuable adjuncts, at least, to forests, in reducing the damage from all but exceptional floods. They would also be of great importance to more valuable National interests than either the growth of timber or the prevention of soil denudation. The most important of these interests is cheap transportation, with the production it develops. Following transportation closely, and governed by it, is manufacturing.

About forty years ago our Lake commerce was limited to vessels of 7- or 8-ft. draft. Excepting for a short time in the late Seventies, Lake channels have been persistently deepened and improved, so that the tonnage of vessels has increased faster than that of freight trains on our railroads. In 1856, the year after the canal at the "Soo" was opened, the tonnage through it was 101 458. In 1907, 58 217 214 tons of freight passed through it.

Comparing the ton-mileage of our railroads with that through the "Soo," neglecting, of course, the through and local traffic not passing the locks, we have:

Ton-Mileage, etc., Reported for 1907.

Railroads as per "Poor."	233 137 507 807	0.782 cent.	\$1 812 115 341
"Soo," as per "U. S. Statistical Abstract."	48 221 465 547	0.080 cent.	38 457 345
	<hr/> 281 358 973 354		<hr/> \$1 850 572 686

The saving on this 17.1% of the total ton-mileage reported, compared with a like service by rail carriage, was more than \$336 000 000. The total appropriations by the General Government for river and harbor improvements, with surveys, etc., pertaining thereto, were, up to March 2d, 1907, \$552 943 025. If the ton-mileage of the Lakes not passing through the "Soo" was equal to two-thirds of that above recorded, the saving to the country by the low Lake freights was greater in 1907 than the total sums appropriated. Some will immediately object to this comparison: that the freight carried on the Lakes is of a lower classification than the average carried by railroads; but the lowering of freight rates during the season of Lake navigation has been recognized and fully understood for about thirty years, as also the increase in the high-class traffic on railroads.

Mr. North. In 1887, the first year of the admirable records kept by the U. S. Engineers at the "Soo," the ton-mileage through those locks was 4 458 544 804, which was carried at 0.230 cent, and the average railroad rate was 1.034 cents. The saving for that year was \$36 026 200. If we average the 21 years we will have a rough aggregate of more than \$4 000 000 000.

It would seem that a competent improvement of either the Lakes-to-Gulf waterway or of the proposed coastwise canal would result in a like increase of tonnage and an equal saving in the cost of transportation, for both routes are now offering much more traffic than was in sight or believed possible when the canal at the "Soo" was either projected or completed.

For nearly 20 years attention has been directed to the difference in growth of cities on the Lakes and in the valley of the Mississippi, where but immaterial improvements in depths have been made. And note is also taken that the progress of our centers of gravity of manufacturing values is following our centers of population, but about midway between the centers of population and the Lake front; which shows, without doubt, that the cost of transportation is a very important factor in the location of manufacturing plants.

This influence is shown in particular by the nearly total withdrawal of heavy manufacturing from the New England States, where, from 1880 to the present, the freight rates have been about 50% higher than the average rate for the whole country. It is also shown by the ruin of the iron industries of Troy and Albany, with the depopulation of the counties about the head of navigation of the Hudson, consequent on the successful effort of the Chamber of Commerce of New York City to prevent the deepening of the river channel above Coxsackie.

The foregoing considerations have led to a growing insistence in the Mississippi Valley that the wealth of that section should be augmented by increasing the navigable depth of the river. The demand was growing too strong to be ignored when it was determined to combine any plan for improved navigation with one for "the conservation of our natural resources." This is of loss and damage to the prosperity of the country through the delay necessary for the consideration of so large and complicated a project. This delay will be prolonged by the selection of our most able opponent of internal improvements as Chairman of the Inland Waterways Commission, who, after the endorsement of this extended plan at Washington in May, 1908, is understood to have announced that there would be neither Congressional consideration of the Atlantic coastwise route nor appropriations for surveys in the Mississippi Valley. At the same time, the declaration for improvements of watercourses to a "standard depth" forecasts an intention, on the part of the protagonists of this movement for con-

servation, that the issue of their labors should be a standardization of Mr. North. what ought to be main arteries for the exchange of products to 'the economic depths of the smaller subsidiary streams. So that there will be no substantial reduction in the average of our total freight rates: that production may not be encouraged and the wealth of our lower Atlantic Coast and of the Mississippi Valley may not be unduly increased as the wealth along the Great Lakes has been.

The extension of our manufacturing interests, which in 1905 paid out in salaries and wages \$3 186 310 754 and produced values of \$14 802 147 087, as well as the enlargement of the area of cheap freightage, is threatened by this conservation plan. It is understood that the Central Government proposes to seize all sources of water-power and put them under bureaucratic control. This control may be relied upon to hold the value of these natural resources so near a prohibitive price and to hamper their use by vexatious restrictions in such a way as to retard unnaturally their development. All the employees of this branch also are likely to be auxiliary to Government by executive decree.

The development of water-powers, and particularly of our timber supply, without control by the Central Government, would free the country from the danger to be apprehended, under our elective system, of large bodies of Government employees who could be made to act with nearly as much unanimity as a regiment of soldiers. The individual growers of timber, with their employees, could not be induced to act together. The lands selected would be chosen on economic grounds, without taint of political corruption or even political influence. They would be widely disseminated, mostly on the broken ground heading all our streams that do not originate in swamps, and the undisputed cooling-effect of groves would break up the ascending currents from highly heated areas which dissipate possible rain clouds. The lumber they furnish would be in proximity to the demand, while the waste products of scattered groves would have a local use and value probably more than offsetting the economies of manufacture in large establishments. In both cases, the areas devoted to tree growing would not contribute directly to local taxation; but, in the case of woodlands cultivated by individual initiative, a careful selection would be made of the less productive and less easily tilled areas. Our proposed National forests, on the contrary, would include in their large areas all those fertile spots that support farmers, and cover the land with men increasingly trained to look to the Government for their means of support.

This entire scheme of Conservation of National Resources seems to be on a parity with the present demagogic demand that no more railroads should be built lest there should be ruinous competition, coupled with the claim that the return on the capital invested in railroads should be carefully limited through the supervision of our Central

Mr. North. Government instead of by the action of free competition. It seems to be planned that even our waterways—if improved—shall not compete freely.

Our best National resources are the production and consumption of our people.* It is doubtful if our entire natural wealth would have sold for £5 000 when Elizabeth and Raleigh commenced exploiting this country. Until natural resources enter into destructive consumption, few of them have anything but a speculative value. Some of these resources are destroyed by their use. The power of falling water, though destroyed by that act, renews itself indefinitely, and any non-use of that power is an irremediable loss to the world's wealth. There is no impairment of value to any watercourse by its use, and, when there is money enough available for its improvement, neglect of its possible aid to production seems to be an economic crime.

Mr. Todd. A. MILLER TODD, M. AM. SOC. C. E. (by letter).—The writer has read this paper with great interest. He has also read many of the treatises referred to by the author, and other literature on the subject. Having been intimately connected with the work of improvement and flood control of the Lower Mississippi River for the past fifteen years, the subject is of vital interest to him. Every suggestion as to cause and effect, as bearing particularly on great floods, has been closely studied, and also every proposed remedial measure.

Coincident with the whole country's great awakening to the value of the inland waterways, and the growing sentiment that they must be regulated and improved to the fullest extent, there has been a tendency to lay too great stress on certain conditions which are very remote from the locality in need of improvement, a change or modification of which conditions is held to be necessary in order to obtain immediate results leading to river improvement, often to the detriment of local methods and treatment sorely needed with the least possible loss of time. Particularly, there seems to be a great popular belief, even among some residents of the Lower Mississippi Valley, that deforestation is largely responsible for most of the recent great floods. Colonel Chittenden has demonstrated clearly, from indisputable data and records, that there has not been, throughout the Mississippi Valley, any perceptible increase in the number and volume of floods that could be attributable to any cause, much less to deforestation. It is true that floods produce greater disaster and suffering than in years past, but this is due solely to the fact that the population in the overflow areas has increased, and many great industrial improvements have been built up directly in the face of the fact that the ground occupied was subject to serious overflow. The writer has seen this exemplified in numerous cases, even along the Lower Mississippi. In nearly every town or city, from Cairo to New Orleans, can be found extensive and important railroad yards, depots, shops, factories, warehouses, com-

presses, dwellings, and many other improvements deliberately located Mr. Todd. and built on ground which is sure to be overflowed again; and, what is more surprising, only in a very few instances have steps been taken to protect these improvements when high water comes.

The writer does not mean to condemn reforestation as applied to forestry, having observed too many examples of wanton waste of valuable timber throughout the entire Mississippi Valley. It is doubtful if there has been anywhere a greater waste of timber than along the shores of that river. A recent magazine writer deprecates the fact that he saw "squashes and pumpkins" caving into the river with the banks and going to waste! The loss of growing crops by caving banks has been very small, compared with the great amount of merchantable timber which has been lost in the river in that way during past years; and even now there is a great annual loss. These trees, as pointed out by Colonel Chittenden, after they fall into the stream, vie with the sand-bars as to which can cause the greatest obstruction to navigation. Again, the writer has seen areas of hundreds of acres of the finest timber land cleared by deadening the trees, which are thus utterly ruined. Timber firms have acquired the timber right on lands, and have cut everything large enough to make a railroad tie with two sides flat; however, there is usually such a variety of timber growing that the land is seldom entirely cleared from this cause. Timber conservation, local or otherwise, however, would not have the slightest effect upon the regimen and flow of the lower river; and, as Colonel Chittenden well states, "no engineer could honestly advise lowering in height by a single inch the levees of the Mississippi" even if the fondest expectations of the forestry advocates could be realized.

The whole matter, of the benefit that the forestry experts expect to contribute to the ultimate improvement of navigable rivers by the application of forestry, rests on theory built up on certain rainfall data and stream gaugings collected in various sections of the country. Many of the data, though most carefully observed and compiled, are often very discrepant and misleading, owing principally to the lack of a sufficient number of gauging stations properly located and efficiently observed.

The paper by John C. Hoyt, Assoc. M. Am. Soc. C. E., on rainfall and stream flow,* and the discussions thereon bear out the foregoing statement.

It is a peculiar fact that nearly all writers and investigators of rainfall and stream flow neglect to take into consideration the influence of slope on run-off percentages. The author states:

"It is perfectly true that more rain falls on the hills than on the lowlands, that a greater percentage of rainfall runs off from steep than from flat slopes, etc."

**Transactions, Am. Soc. C. E., Vol. LIX, p. 431.*

Mr. Todd. In connection with a drainage project in the Mississippi Delta, in attempting to ascertain the proper percentage of run-off to rainfall, the writer was surprised to discover, from a very carefully compiled table of run-off compared with rainfall, covering the entire Mississippi Valley, that seemingly the flatter the slope the greater the percentage of run-off. The table referred to is contained in a publication by the Weather Bureau,* from which the following extract is taken:

"Normal Annual Discharge from River Basins."

"Basin.	"Ratio of discharge to downfall.
"Ohio	0.300
Upper Mississippi	0.275
Missouri	0.150
Arkansas	0.156
Red	0.220
Central Valley.....	0.515."

Commenting on this table, in the same publication is found the following:

"The Central Valley includes about 30 000 square miles of swamp land and 39 000 square miles of upland; the ratio over the former is doubtless much greater and over the latter much less than this average."

It is a noteworthy fact that even at this date probably less than 40% of the swamp area of the Central Valley is deforested, and where the timber has been cut, vegetable growth is very rank and luxuriant, and conditions would seem to be in every way ideal for the conservation of the rainfall.

In regard to the caving banks on the Lower Mississippi, Colonel Chittenden is correct in his statement: "The problem is strictly a local one, and the remedy must be a local one."

It is a fact that neither extreme high nor low waters are very greatly to be feared as causing excessive caving; in fact it has been the writer's observation, checked by actual surveys and measurements, that the greatest amount of caving is usually coincident with periods when moderately high stages occur in succession, alternating with a drop to about a three-quarter bank-full stage. Of course, no general rule can be stated as applicable to caving banks, but in the main the foregoing conditions produce acute caving in the bends, where nearly always important levee locations and valuable plantation improvements are destroyed. Hence reforestation, no matter how generally accomplished, could not hope to cure this very distressing and acute problem of river improvement. The same conclusion is equally applicable to any effect proposed reservoir systems might have on the stages of the river. As to local forests checking caving banks, it has

*"Floods of the Mississippi River," Bulletin E, 1897, p. 27.

been the experience on the Lower Mississippi, that only one species Mr. Todd. of timber will have the slightest effect. Cypress trees, where they occur in considerable numbers, and where their roots extend far below the natural surface, have been the means of checking the caving in a few localities. However, the cypress has less value as a conservator of rainfall than any other tree found in the delta.

With reference to "reservoirs and their relation to stream flow," undoubtedly, they are more intimately connected with river regulation than forestry, yet, as a means of affording material relief from floods, especially along the Lower Mississippi, the writer is forced to the conclusion that in the main their influence can be but little felt. This conclusion is reached after a very careful study of all available data, together with an intimate experience with floods, and from a careful observation of their inception and propagation through the valley. Yet the hope is held out, by some of the advocates of the reservoir system, that it will be the means of solving the flood-control problem along the lower valley. The following is quoted from a paper* by A. H. Horton, Assoc. M. Am. Soc. C. E., Assistant Engineer, U. S. Geological Survey, entitled "The Effect of the Conservation of Flow in the Ohio Basin on Floods in the Lower Mississippi":

"This paper is the result of an attempt to determine from a review of actual records the contribution made by the Ohio basin to Mississippi floods, and the effect produced on the latter by flood conservation in the former. The following facts are shown:

"(1) That the Missouri basin, by reason of its great area of flat country, is slow-spilling and floods therein do not rise with rapidity sufficient to gorge the channel of the Lower Mississippi.

"(2) That the Upper Mississippi basin, although subject to more rapid fluctuations in flow than the Missouri, is very much smaller than the latter and could not originate floods of capacity sufficient to gorge the Lower Mississippi.

"(3) That the Ohio basin discharges at maximum flow 50% more water than the Missouri and Upper Mississippi combined, and as the basin is a quick spilling one, it practically alone is the cause of floods in the Lower Mississippi.

"(4) That inasmuch as it has been shown possible to reduce floods in the Ohio, the same means will also reduce to a point well within the capacity of the Lower Mississippi channel all the floods that are likely to visit that channel."

Checked by actual occurrences, only the second of Mr. Horton's statements can be accepted as a fact. There have been times when the Missouri, practically alone, has "gorged the channel of the Lower Mississippi," or, as the writer understands the above term to mean, the exceeding of the overflow stages. The second flood of 1903, cited by Colonel Chittenden, is an example: Originating almost entirely in the Missouri Basin, the flood stage was equalled or exceeded at almost every point from Cairo to New Orleans, notwithstanding the fact

**Engineering News*, June 11th, 1908.

Mr. Todd. that the Ohio and its tributaries were comparatively low. Great damage was caused to unleveed areas on account of the lateness of the season. Numerous very disastrous floods have been caused by the streams entering from the western slopes, culminating with stages in the Ohio and tributaries well below the flood level. Table 6 shows a few floods of the above character:

TABLE 6.

Stations.	Flood stage, in feet.	HIGHEST GAUGE READINGS, IN FEET.				
		1888.	1892.	1903.	1904.	1908.
Cincinnati.....	50.	39.8	43.2	16.0	44.4	44.1
Nashville.....	40.	39.5	38.8	26.8	37.6	19.3
Chattanooga.....	33.	27.0	13.7	11.6	16.9	12.2
St. Louis.....	30.	25.6	35.8	38.0	25.3	24.3
Cairo.....	45.	45.3	48.3	43.4	49.1	45.1
Memphis.....	33.	34.2	34.6	33.0	39.2	35.3
Little Rock (Arkansas River).....	22.	19.2	31.2	26.2	29.4	25.9
Arkansas City.....	42.	45.4	50.0	45.6	49.0	49.9
Vicksburg.....	45.	44.2	48.4	43.2	46.9	47.9

The flood of 1892 was the greatest on record along a large portion of the lower valley up to that date, the serious balance to this flood was added by heavy rains over the Arkansas and Central Valleys.

The floods from the western slopes, when unrestrained, are always the cause of greater damage than the earlier floods out of the Ohio, usually materializing during the latter part of May or June, catching the growing crops at just the time when if destroyed they cannot be started successfully again after the overflow recedes. Hence it is evident that the Ohio is not the sole cause of damaging floods in the lower valley; and, even if they are held well down to below the danger or overflow stage, disastrous overflows may still occur below Cairo.

It cannot be denied that the reservoir system as proposed by Mr. Leighton, if executed as designed, would have some effect on the flood flow for a certain combination of excessive rainfall conditions; but, unfortunately, just the combination taken into Mr. Leighton's calculations may happen only once in a decade. The advocates of the reservoir system neglect to take into account the great natural reservoir effect of the stream beds, and they overlook the fact, fully recognized by all close observers of flood phenomena, that a very general rainfall over a tributary water-shed, may not cause any higher gauge readings, at lower stations, than the same amount of rainfall occurring over only a portion of the water-shed. In the case of the general rainfall the lower streams are backed up and act as reservoirs until the upper streams run out, and thus the flood is passed often with little, if any, higher gauge readings, but of somewhat longer duration. The reservoirs could only be of service as eliminating those floods originat-

ing entirely at the stream sources; and it is well known that floods of this character, coming by themselves, are less to be dreaded on the lower river than those from any other source. In fact, there are so many combinations of flood inception and flow that it is practically useless to undertake to deduce theoretical results from data which are insufficient and likely to be in error. The result of Mr. Horton's deductions when compared with gauge heights actually reached by moderate floods, illustrates the futility of attempting to reduce discharge to gauge height and *vice versa*. His results are given in two tables: One shows the computed reduction in gauge height at Cairo for certain flood years, assuming the reservoirs operative; the other gives the computed heights for certain gauge stations below Cairo. Mr. Horton's figures are reproduced here as Tables 7 and 8, with the reductions, stated in terms of equivalent gauge heights, added.

TABLE 7.—AMOUNT THE MAXIMUM READING OF THE CAIRO GAUGE WOULD BE REDUCED BY RESERVOIRS IN THE OHIO RIVER DRAINAGE AREA.

Year.	Reduction in gauge height at Cairo, in feet.	Equivalent gauge height,* in feet.
1880	7.0	38.6
1881	5.0	41.8
1882	7.0	44.9
1883	7.5	44.7
1884	8.5	43.3
1885	7.0	39.0
1892	6.0	42.3
1893	6.0	43.3
1897	7.0	44.7

* Figures supplied by the writer.

TABLE 8.—THE AMOUNT, IN FEET, THAT THE CREST OF VARIOUS FLOODS WOULD HAVE BEEN REDUCED AT DIFFERENT SECTIONS ON THE LOWER MISSISSIPPI HAD ONE-THIRD OF THE DRAINAGE AREA OF THE OHIO RIVER BEEN CONSERVED.

Station.	1882.	1883.	1884.	1892.	1893.	1897.	
Cairo.....	7.0	7.5	8.5	6.0	6.0	7.0	
Memphis.....	7.0	7.0	8.5	5.5	5.5	7.0	
Helena.....	6.0	6.5	7.0	5.0	5.0	6.5	
Mouth of White River.....	8.0	8.0	9.5	6.0	6.0	8.0	
Lake Providence.....	8.0	8.0	10.0	6.0	6.0	8.5	
Vicksburg.....	8.0	9.0	11.0	6.5	7.0	9.0	
Reducing above to equivalent gauge height.*							Flood* stage.
Cairo.....	44.9	44.7	43.3	42.3	43.3	44.7	45
Memphis.....	28.2	27.8	25.7	29.1	29.7	30.6	33
Helena.....	41.2	40.4	40.0	40.7	42.9	45.3	42
Mouth of White River.....	39.8	40.0	38.4	43.3	43.5	44.4	42
Lake Providence.....	30.2	28.5	28.4	35.8	35.8	36.0	36
Vicksburg.....	40.8	34.8	38.0	41.9	41.3	43.3	45

* Figures supplied by the writer.

Mr. Todd. A careful examination of Tables 7 and 8, and a comparison with the actual heights from gauge to gauge during only moderate freshets about equalling the computed restrained flow at Cairo, will show that the results obtained are radically wrong; especially the figures deduced in Table 8. Mr. Horton has all the great floods, of whatsoever source, reduced to just below the flood level at Cairo. The writer is doubtful whether this condition could ever be realized. It is not his purpose to go into the correctness of this table at present; but, considering Table 8, it is evidently seriously in error. There has never been a time when the flood stage of 45 ft. at Cairo has been about equalled or exceeded, but that the flood stages at all points below have been exceeded, and especially if a flood from the Arkansas River happened to culminate with the Cairo wave.

A good example of a high water where the flood stage at Cairo was just reached is found in the record for 1908. Table 9 compares the computed heights for 1882 with the heights actually obtained during the May-June flood in 1908.

TABLE 9.

Station.	Flood stage, in feet.	Restrained flow, as estimated* for 1882, in feet.	Heights reached by May-June flood of 1908, in feet.
Cairo	45	44.9	45.1
Memphis	33	28.2	34.3
Helena	42	41.2	44.4
Mouth of White River	42	39.8	49.5
Lake Providence	36	30.2	44.2
Vicksburg	45	40.8	47.9

* By Mr. Horton.

About the same discrepancies are evident for all the years considered by Mr. Horton. Certainly, it cannot be said that the reservoirs on the Ohio could influence in any way the heights of a freshet after it had passed Cairo. Hence Mr. Horton's conclusions as to the effects of the reservoir system on high water along the Lower Mississippi cannot be accepted as even approximately correct.

The writer is of the opinion that all the investigations and discussions as to conservation, forestry, reservoirs, etc., are valuable, and the matters treated are worthy of the fullest investigation; but it is wrong to recommend great innovations, claiming great benefits to localities, if there is any possibility that further investigations may prove the proposed plans useless for the objects considered. In reference to the work of flood control and leveeing the Lower Mississippi, there are already many persons who seize the slightest pretext to condemn the levee system as wrong in principle and execution, and, indeed, many of the current writers, while passing the levees as a "necessary evil," so to speak, seem to harbor the opinion that they

are only a makeshift at best, and that they can be eliminated ultimately Mr. Todd. by some other treatment. Some very eminent civil engineers have expressed this opinion openly, and, in the minds of some laymen, it places in a bad light the engineers of the valley who are earnestly laboring, with extremely limited means, to bring the levees to a completed state.

The writer states emphatically that the levees are a complete success, and, if the caving banks can be minimized, they can be completed with a very moderate expenditure, as compared with even the smallest of the reservoir estimates.

The needs of the Lower Mississippi, to render it navigable to the very highest degree of usefulness, are well known and thoroughly demonstrated, and these consist in three steps, as follows:

1. Complete confinement by levees, making the high- and low-water channels practically coincident;

2. Revetment of all the most serious caving reaches, without which it will never be possible entirely to complete the levee system;

3. Dredging at low water, where found necessary; and it may not be necessary after the first two steps are completed and the low-water channel is thoroughly established. Contraction works may have to be resorted to in a few instances to close up chutes and secondary channels.

Forestry and reservoirs can never be of any direct benefit. Reservoirs may serve finally, if built for other purposes, to render certain conditions of maximum and minimum flow somewhat less acute, but the amount of benefit is absolutely indeterminate beforehand, and for this reason they cannot be considered seriously by engineers on river regulation and control, at least in so far as concerns the Mississippi River below Cairo.

WILLIAM W. HARTS, M. AM. SOC. C. E.* (by letter).—The adoption Mr. Harts. of extensive projects for the reforestation of our mountain regions, and for the construction of a system of impounding reservoirs, to provide for increasing the navigable capacity of our inland rivers, to prevent floods, to create water-power, and to secure many incidental advantages, has recently been proposed and is being persistently urged as an advisable governmental policy. In two bulletins of the Department of Agriculture,† some of these ideas have been publicly advocated, and in many periodicals the officials of the U. S. Forestry Bureau have heralded their hopes and plans. These theories have been elaborated in more than sanguine terms, occasionally in engineering publications, sometimes in public addresses, and often in the popular magazines. It seems well, therefore, to scrutinize the claims of these earnest advocates, and test their theories in the light of facts not pre-

*Major, Corps of Engineers, U. S. Army.

†Nos. 143 and 144.

Mr. Harts, sented heretofore and by the application of reason and common sense. Colonel Chittenden has performed a valuable service to the country at large and to the engineering profession in calling attention to the other side of these popular arguments, and has admirably expressed his well-considered doubts of the feasibility of these projects and his conviction as to their many inherent fallacies.

A careful perusal of this paper should convince even the skeptical that many of the claims of these advocates of forestry are unsound, and that this entire subject, as now being urged, should be reconsidered, so that a more rational programme may be proposed if this important matter is to receive the support of the people of the country. It has all along been suspected that much of the literature on these subjects was not well supported by facts, and now the arguments and records brought forward by the author give little comfort to those who have put such apparent faith in forestation as a panacea for so many ills.

The writer has had exceptional opportunities for observing the action of rainfall and snow on mountain sides, in several years' travel over the Sierra Mountains, in connection with the work of the California Débris Commission. In general, the worst scour from rainfall may be said to have been found in cultivated fields, where the land had been cleared and plowed. Deforestation, apparently, had not much effect on the land wash, as a second growth promptly sprang up, practically as useful for protecting the ground surface as the original forest, if not even better when its effect during the snowy seasons is considered. Even when burned over, no immediate scour of the ground occurred, to any noticeable extent, and a new growth at once appeared, which in a few years seemed to become practically as effective as the first.

In observing the action of melting snow, the effect mentioned by the author was particularly noticeable. On bare hillsides there were usually snowdrifts in gullies and valleys, where they formed excellent reservoirs for equalizing the flow. A warm rain in the spring, on the other hand, usually brought down a large part of the snow covering the ground in the forests, where the sun's rays were not allowed full effect. The most severe and destructive floods in the Columbia River are those following a warm rain in early spring, when the snow cover is melted and its volume is added to that of the rainfall.

In like manner the theory of reservoirs is also singularly defective. Its weak points are easily exposed, and its fallacies may be made plain with a little study.

As a fertile field for academic discussion, however, the doctrine of impounding the flood waters of rivers in their upper portions, to be liberated later as needed during low stages, for the conservancy of the water-power, for the benefit of navigation, and for many other pur-

poses, offers fine opportunities to the enthusiastic theorist. The average man of intelligence is accustomed at the present time to regard preventable waste as an almost criminal loss. The theory that the flood waters of our rivers, now causing so much damage, may be retained behind enormous dams for later profitable use at low stages is so plausible and attractive that it is little to be wondered at that the propaganda of this theory at present being persistently urged by its advocates should find many earnest listeners. This is especially so as only the merits of such a system are thus far being dilated upon. The public, however, is obviously entitled to the benefit of comments on the project as seen from the practical viewpoint.

There are so many glittering possibilities apparently connected with the theory, such as the diminution of floods, the development of enormous and presumably profitable water-powers, material assistance in the effort to reclaim flooded areas, and increased depths for navigable rivers (to say nothing of incidental benefits to fisheries, irrigation, forestry, and other interests), that it is not strange that these possibilities should be eagerly accepted at first glance as being easily within reach of the people. On the other hand, any attempt to analyze and view in their proper proportions the enormous difficulties that must be overcome before even moderate success in this direction can be expected, may be subjected to harsh criticism; but, obviously, the defects of the proposed system should not be concealed.

The method of conserving the flood waters of rivers by controllable reservoirs is by no means new. It was tried on the Loire, in France, about two centuries ago.* In Germany and Russia, and also in America, this method of storing the flood waters of rivers has been attempted. The results, up to the present, have been such that its extension for flood control, in most if not all of the countries in which it has been tried, has been abandoned and its application condemned by the highest exponents of engineering skill. Messrs. L. F. Vernon-Harcourt and R. Rawlinson in England, M. Malézieux in France, and Mr. W. Milnor Roberts, Colonel William E. Merrill, General H. L. Abbot, and many other distinguished engineers in America, have reported strongly against its adoption. The high reputation of these men as experienced and practical river engineers is well known.

It may be claimed by the supporters of the theory that in the few actual applications of their principles (in each of which the natural conditions were especially favorable) the system has given some satisfaction. According to reports, it has been applied on the Volga and Msta Rivers, in Russia, which are provided in their upper portions with vast natural reservoirs in the shape of inland lakes, where the plan was easy to establish, requiring but few flowage rights and in-

*"Rivers and Canals," Vernon-Harcourt, p. 221.

Mr. Harts. expensive dams; a natural reservoir system was, in effect, already in existence.*

It is also reported that this system was tried in France early in the last century. In 1856 investigations were made with a view to determining whether it should be applied to the Seine, Loire, Rhône, and Garonne, for flood control. These resulted in the decision not to construct the reservoirs proposed for these streams, owing to the "uncertainty and doubtful efficacy of their action." In 1875 this matter was again examined in France, with a similar result; so that in 1881 we find the reservoir system for controlling floods on these streams definitely abandoned by the official engineering organization of the French Republic.†

In America the experiment has been tried on the Upper Mississippi in what are known as the Lake Winnibigoshish, Lake Pokegama, Leech Lake, and other reservoirs. These also were in a naturally favorable location, where almost all the land to be overflowed was unoccupied, practically valueless, and already largely covered by lakes. The cost of the early surveys for these reservoirs was paid by those corporations which were exploiting the water-powers near St. Anthony's Falls, as they were to be incidentally large beneficiaries under the system.‡ Much of the present-day enthusiasm for reservoirs, when traced to its logical head, would in all probability likewise be found to emanate from those who were expecting to benefit, at Government expense, out of the power feature. It seems now to be admitted by many that the Mississippi reservoir system as an accessory to the navigability of the river was originally urged by the water-power companies as a subterfuge to cover their designs of securing more power at public expense.

These Mississippi reservoirs have now been in existence many years, and notwithstanding that they are the largest in the world used for this purpose, having an actual storage of more than 93 000 000 000 cu. ft., and have developed valuable water-powers at Minneapolis and elsewhere, the effect on the navigability of the Mississippi River at St. Paul has been so slight and the difficulty of maintenance so great that the extension of the system to the St. Croix, Chippewa, and Wisconsin Rivers for the benefit of navigation has been definitely reported against by several boards of engineers constituted to examine the subject.§ The reservoir method for the improvement of navigation on the Ohio River, advocated by Charles Ellet, Jr., in 1849 and subsequently, was examined in 1873 by a board of engineers, and an unfavorable report was submitted after careful study.|| These adverse reports were not made through any lack of appreciation of the enormous benefits to be

*Annual Report, Chief of Engineers, U. S. Army, 1898, p. 2850.

†*Annales des Ponts et Chaussées*, 6th Series, Vol. II., 1881.

‡Annual Report, Chief of Engineers, 1870-71, p. 283.

§Annual Reports, Chief of Engineers, 1881, p. 2753, and 1887, p. 1692.

||Annual Report, Chief of Engineers, 1873, p. 541.

derived if the system could be successfully and practically applied, but Mr. Harts were based on its inherent defects, which were considered so serious as entirely to overwhelm its advantages.

In their publications, the advocates of the reservoir system lay much stress on the increased depths that are practicable by releasing certain quantities of water at low river stages. No mention, however, is made of the the fact—and sight of it seems completely lost—that depths due to additional flow are invariably less the farther downstream the observations go, and that the theoretical discharge necessary for navigable depths is not the same at all points along the same stream. The Ohio and Tennessee are not canals having uniform widths, depths, and slopes.

Navigation depends, not on maximum depths, but on minimum depths; so that, when use by boats is referred to, it is of no value to say that we may have 5 ft. of water in our river, when at shoal places there may not be more than 2 or 3 ft. These minimum depths determine the limit of use to be made of the stream. Ordinarily, the depths of channels vary with natural conditions. Where rivers widen, the depths grow relatively less. To say that we may have a 5-ft. depth in the Tennessee River at Knoxville, Chattanooga, or Riverton, by no means proves that at Colbert Shoals, Muscle Shoals, and various other places, the depths would be as great. As a matter of fact, the depths on the gauges at these towns bear only a remote relationship to the navigable depths on the shoals. As the discharge of the Tennessee increases, the slope at Colbert Shoals decreases; while at the "Suck" the slope increases, owing to the gorging effect of the banks. Local conditions thus affect the flow to an important degree.

Then, too, it is believed that the reservoirs would soon fill with silt. All reservoirs must necessarily be located near the head-waters of the streams, since nowhere else will land be cheap enough or otherwise available for this purpose. In such localities the erosion in the water-shed is at a maximum, the slopes of all streams being steeper in their upper than in their lower portions. In the case of the Tennessee River it is found that the area claimed to be available for furnishing water for the reservoirs specified covers a water-shed of 19 520 sq. miles. The scour from this area is enormous, and is now carried down mainly at high water. It cannot be claimed by the most enthusiastic supporters of this theory that these reservoirs would not rapidly fill with silt due to this erosion. It is folly to claim that the hillsides draining into the reservoirs can ever be adequately protected against this scour by forests. As mentioned above, the production of silt in river valleys is due far more to the cultivation of fields and farms than to the cutting away of the large trees of the forests, as these are promptly followed by a second growth almost as useful as the first for protective purposes. The cleared farms are

Mr. Harts. usually valuable, and will be vacated in favor of forests only after a bitter struggle. Forestation is independent of the reservoir system in any event, and can protect the hillsides as well without reservoirs as with them.

Experience shows that most dams for the production of water-power are sooner or later filled with silt unless special precautions are taken to sluice out these accumulations into the rivers below, where they will inevitably form shoals and bars in the reduced currents. This sluicing is at best a precarious operation. Thus the dilemma of ruined reservoirs or injured rivers must be faced.

The dam at Austin, Tex., which failed some years ago, was found to have had its storage capacity materially diminished by a large quantity of sediment, so much so that it is admitted that in a few years it would have ceased to be an effective reservoir.* Within three years after its completion its capacity had been reduced 38%, and it was estimated by Professor T. V. Taylor that in 40 years its capacity would have been diminished 98 per cent. No methods of sluicing out this sediment are yet satisfactory, and the operation, if attempted at all, would be attended, it is generally admitted, with great danger to the structure and with much uncertainty. Do the advocates of this plan rely on sluicing into the lower rivers these deposits of silt and sediment? Unless they do, it seems certain that their reservoirs would sooner or later be ruined.

The wash in all parts of the country is not alike, and the rates of filling behind reservoir dams would vary. The scour in the arid regions of the West, as along the Colorado River, would probably far exceed the rate in the Mississippi Valley, and this would likewise far exceed that of New England. We are told by the advocates of forestry that the Mississippi River carries billions of tons of sediment annually into the Gulf, and it is undeniable that a large part of this sediment comes from the region in which it is proposed to erect dams for reservoirs.

That the power that can be generated from flowing water is often valuable in localities favorable to its consumption cannot be gainsaid; nor can it be denied that this feature is relied upon by the advocates of the reservoir theory for its main support. Wherever great reservoirs have been constructed, in the past, the primary purpose has been an industrial one, with other considerations distinctly secondary. To what extent navigation will benefit from such a secondary consideration it is not difficult to predict. As Colonel Chittenden has stated:†

"The function of reservoirs will always be primarily the promotion of industrial ends; secondarily only, a possible amelioration of flood conditions in the rivers.

**Engineering News*, Feb. 22d, 1900.

†In the Annual Report of the Chief of Engineers for 1898, p. 2878.

"While it is perhaps physically practicable to build reservoirs of sufficient aggregate capacity on the water-shed of any stream, even so large a stream as the Mississippi, as to exercise some influence in diminishing the height of floods, the great cost of such works, as compared with the results to be expected from them, will always prohibit their construction, unless it is called for by other and more direct causes."

The effort to combine in one plan the improvement of depths in navigable rivers, the diminution of flood waves to a safe point, and the utilization of the stored water for electrical power can never be satisfactory to any single interest. To prevent floods, the reservoirs should be empty until the danger of floods is past; and, for furnishing water for navigation or power, they should be full when the dry season approaches. The difficulties attending the operation of a single reservoir to meet these divergent demands may be guessed at; but what shall be said of those involved in the combined operation of many?

Captain E. H. Schulz, Corps of Engineers, states in his report on the reservoirs of the Upper Mississippi:*

"It is endeavored to operate the reservoirs to the best advantage for the general welfare. Daily reports are received from each of them and from gauge stations along the river, and the orders to the dam tenders are changed from day to day to best meet the requirements of the situation. The reservoirs affect seven different interests which often conflict—steamboat navigation below St. Paul, steamboat navigation above St. Paul, logging, mills at Minneapolis, mills above Minneapolis, riparian owners on the river, and riparian owners on the reservoirs. It is impossible to so manage the reservoirs as to suit all concerned, because each party minimizes or ignores entirely the interests of all the others. The reservoirs are being so managed as to benefit in the course of the year, every one of the seven interests concerned except the riparian owners on the reservoirs, who have been, or are being, compensated in cash. Each of these interests is materially better off than it would be if the reservoirs did not exist, but none are entirely satisfied, and some very much dissatisfied, because each would like the reservoirs managed exclusively for its own benefit, so that it might receive, if possible, all of the great public good which the reservoir system is intended to accomplish and does accomplish."

It is well known that powerful corporations are at present eagerly securing the best water-powers available for future development, for their own benefit, on the best terms obtainable. The earliest surveys of the reservoir sites of the Upper Mississippi were undertaken at the instance of the private companies owning water-power dams at Minneapolis, and although this work was ordered by Congress and done under the direction of General G. K. Warren, the expenses of the first examination and survey were paid for by these corporations.

This project, being urged as it was from its very inception by the water-power companies at Minneapolis, has never inspired the usual

*Annual Report, Chief of Engineers, 1907, p. 1584.

Mr. Harts. hearty enthusiasm of the engineer officers in charge of the work, as seems plain in reading their many reports. Whether the interests of navigation were the predominant ones, or whether the incidental benefits were the most important, it is clear that Congress, in appropriating money for these reservoirs, intended to accept no responsibility for the expenditure of public funds in such a way as to make private benefits the main object of the appropriation. In the law of July 5th, 1884, we find the following:

"For continuing operations at the headwaters of the Mississippi River, sixty thousand dollars: *Provided*, That the money hereby appropriated shall be used solely for the improvement of the navigation of the Mississippi River and its tributaries, and no part thereof shall be expended with the view to the improvement of private property."

It would solve many questions if the United States could be involved in this question so that its right of eminent domain could be used to obtain possession of such areas as are necessary for the production of water-power for industrial purposes. There seems, however, to be no warrant in law for such a course. The following is quoted from General Mackenzie's report on the questionable legality of any such efforts:*

"Regarding the proposition to empower the Secretary of War to authorize the use and development of the water-power at localities not improved by the United States, it should be borne in mind that natural water-power—that is, power made available by the existence of natural falls and rapids in a river—is appurtenant to riparian ownership, and the right to use it is governed by State laws on the subject of private property. As above set forth, the Federal Government can regulate and control it only to such extent as may be necessary in the interest of navigation."

It may be pertinently asked whether these dams and their controlling works could be operated successfully if built. Even assuming the reservoirs in place, all legal questions of riparian and other ownership solved, the safety of the dams assured, and the system ready and waiting to spread far and wide its benefits, would there be found any one competent to regulate the flow of water through these dams, taken as a system, so that when a flood threatened the reservoirs would be empty to receive it, and when a drouth came they would be full and ready to supply water for navigation, water-power, irrigation, and other necessities? Is it within the scope of ordinary human ability to do such work without constant and vital errors, and with any degree of satisfaction to those affected? We know how difficult it is to predict, even a few hours ahead, what will happen in the way of precipitation. Does it seem reasonable to expect the regulation of the flow

*Cir. 13, Office, Chief of Engineers, 1905.

of the stored water to be any more exact or satisfactory than our Mr. Harts. weather predictions? Colonel Chittenden, in discussing the use of reservoirs for preventing floods in the Sacramento River, says:*

"It must be remembered that a fatal obstacle to the perfect handling of any system of reservoirs, from the point of view of flood protection, is that Science has as yet furnished no means of predicting climatic conditions with any degree of certainty. It can never be foretold when or in what magnitude storms will come, and, therefore, the only safe plan to follow, if reservoirs are to be kept in use for purposes of preventing floods, is always to keep them as nearly empty as possible; but this, as previously stated, is contrary to the policy required if they are to be used for industrial purposes."

The question of cost is a vital and conclusive one. In the Ohio Valley the officials of the Geological Survey have estimated the cost of the work at \$125 219 000 for the entire system.† This estimate was carefully examined by Major H. C. Newcomer, Corps of Engineers,‡ who found, after a detailed reconnoissance of many dam and reservoir sites in the Upper Ohio tributaries, that this question had by no means been carefully studied. Major Newcomer found that the estimate would vastly exceed the figures given, and, according to his calculations, amounted to \$72 757 731 for the Monongahela River Basin, \$44 531 056 for the Allegheny River Basin, and \$901 915 905 for the Ohio River Basin. In other words, the estimates of the Geological Survey seem to be much too small. It seems absurd to think that the American people will regard favorably the expenditure of any such sum in testing what is nothing more than a doubtful experiment. Whatever else may be said about this system, no one can claim that it offers a satisfactory argument in the direction of economy.

After the installation of a reservoir, the unwholesome conditions arising from decaying matter in the reservoir, exposed to the sun after the water has been drawn off, and the invasion of the riparian rights of individuals would still cause bitter litigation. The results of these actions, as to the time and money involved, could not be foreseen.

Although the reservoir system at the head-waters of the Mississippi has been in existence for more than 24 years, all claims in litigation have not yet been settled. The reservoirs in question are located as favorably for minimum land damages as any could be in this country. The land when the system was first adopted was wild, unoccupied, strewn with lakes and ponds, and almost valueless. In spite of this we find a record in the reports of operations showing that condemnation proceedings were still necessary in 1899 to extinguish claims for damages, and private injuries are still being paid for in cash.

**Transactions*, Am. Soc. C. E., Vol. LXI, p. 347.

†*Engineering News*, May 7th, 1908.

‡*Engineering News*, October 8th, 1908.

Mr. Harts. In general, it may be stated that the rights of riparian owners have never been definitely ascertained. "They are as ancient as the riparian settlements, and are inevitably a thorn in the impounder's side." As stated by Fanning:*

"The Courts and Legislatures of the manufacturing States have wrestled with this question, their judges have grown hoary while they pondered it, and their attorneys have prospered, and yet who shall say what riparian rights shall be, until the Court has considered all anew."

Nor must we by any chance overlook the danger of such a system. Our memories are still fresh with regard to the disastrous flood at Johnstown, caused by a breached dam on the South Fork of the Little Conemaugh River, Pa. This dam failed on May 31st, 1889, causing a loss of 2 280 lives and from \$3 000 000 to \$4 000 000. The Bouzey Dam, near Epinal, France, failed on April 27th, 1895, resulting in the loss of nearly 150 lives. Only a few months ago the Hauser Lake Dam, built at a cost of about \$1 500 000, failed, causing the complete destruction of the Village of Craig, Mont. The dam at Austin, Tex., failed in 1900, on account of neglect to protect properly an insufficient foundation, although the cross-section was of good design.

The number of successful dams undoubtedly far exceeds the failures; but the best practice of the most skilful engineers can never remove entirely the danger of failure. The storage of enormous quantities of water far above the levels of the populous valleys would be a constant and terrible menace to all enterprises. No one can fail to realize that the destruction would be tremendous in case of failure of one of these dams, so that the values of all manufacturing, real estate, and other property in the threatened areas would be affected. For it must be remembered that these dams would necessarily be placed, in many cases, where foundations are inadequate, where rock is not readily obtainable, and where exact knowledge as to conditions of construction is not to be secured. Local conditions in the Southern Appalachians are not as favorable for reservoir construction as in the regions farther north where the rock has been bared by glacial action.

In the case of the Tennessee River Basin, we see a dam proposed for the French Broad, one of its tributaries, having a height of 200 ft., and impounding 199 600 000 000 cu. ft. of water. The height of the South Fork Dam above Johnstown, Pa., was about 70 ft., and its capacity was 466 000 000 cu. ft. The dam now proposed for the French Broad River is nearly three times as high and has a storage capacity of more than 400 times as much water. In case of failure of such a dam there would be no warning, and the effect might perhaps be measured by the Johnstown flood. Nothing could save the lower parts of Knoxville and Chattanooga from widespread ruin,

*"Treatise on Hydraulic and Water Supply Engineering," 1887, p. 85.

and all villages, bridges, canals, and other structures along the banks Mr. Harts. would be swept away in the general flood. One such disaster might easily be considered to outweigh all the benefits received or expected from the entire system.

Let us now examine into the effectiveness of the system. In addition to the statement of a board of engineers that the reservoir system on the head-waters of the Mississippi was producing benefits probably commensurate with its cost, and hence should not be abandoned,* we also have the statements of two former boards which, after mature consideration, recommended against the extension of the system to other rivers. Although the Mississippi reservoirs are the largest in the world used for such purposes, the increase in navigable depth at St. Paul, 350 miles down stream, is only a little more than 1 ft. at low water. In the Annual Report of the Chief of Engineers for 1881, p. 2753, is found the following:

"In recapitulation, the conclusions of the Commission may be stated as follows:

"First. The system of works in progress on the Mississippi River between St. Paul and the mouth of the Illinois River, with the modifications which experience will suggest, is adequate for the improvement of navigation, and should be pushed rapidly to completion.

"Second. A sufficient improvement of the river is not to be expected from the action of a system of reservoirs alone.

"Third. It is possible that on the completion of the observations now in progress, some of the proposed reservoirs which furnish water at the least cost, may be found to be economical aids to the principal system of channel contraction. But they should only be built when the works for channel contraction approved have been carried to the fullest economical development."

In the Annual Report of the Chief of Engineers for 1887, p. 1692, is found the following (referring to the Mississippi River):

"The region already occupied by reservoirs is exceptionally well suited for the system, and the dams have accomplished all that was reasonably to be expected from them. They now 'adequately improve navigation' in the sense that they render a fair return for their cost; and in the opinion of the Board they should be completed by raising the Pokegama Dam 2 feet and by building a dam in the Sandy Lake district, as recommended by Major Allen, if more elaborate surveys there confirm present indications.

"The Board does not favor the extension of the system to the St. Croix, the Chippewa, and the Wisconsin at present. It is believed that funds applied to the bed of the river in contraction works, dredging crests of troublesome bars, etc., will yield a better return. That method has proved effective so far as applied to the Upper Mississippi, and it will be soon enough to consider the advisability of reinforcing it by new reservoir systems when the necessity therefor has been demonstrated."

*Annual Report, Chief of Engineers, 1906, p. 1470

Mr. Harts. In reporting on the improvement of the Ohio, in 1873, an engineer board commented as follows:*

"The Board are decidedly of the opinion that there are but two possible ways of securing such a permanent depth of water in the Ohio River as its importance demands, the first of which is that advocated by the late Charles Ellet, a highly distinguished civil engineer, which proposed storing up the surplus water of floods in reservoirs near the head-waters of the tributary streams; and the second is the ordinary plan of slack-water, which has long been in use on the Monongahela and other rivers, and which was ably presented by Mr. W. Milnor Roberts, formerly United States civil engineer in charge of the improvement of the Ohio River.

"The first of these plans the board deem impracticable on account of the difficulty, if not impossibility, of finding locations for the necessary reservoirs, the immense cost of the system, its interference with the navigation of the tributaries on which the dams are located, its injury to agricultural, mining, and railroad interests in the valleys of these rivers, the difficulty of regulating the supply from the reservoirs, and the terrible effects that would be caused by accidents.

"Mr. Ellet proposed dams 100 feet high, ponding back twenty-five miles of water. Should one such dam burst—and several such casualties are on record—all others below it would be sure to break, and a terrific flood would sweep down the river, destroying bridges, river-craft, houses, and thousands of human lives. For these reasons, which we do not think it necessary to elaborate, the board are decidedly of the opinion that the reservoir plan should be unqualifiedly rejected and that the slack-water system alone deserves investigation."

In France, as mentioned above, this subject was examined with a view to learning whether reservoirs actually diminished to any useful degree the danger of floods. The following is an abstract† of a paper by M. Gros, published in the *Annales des Ponts et Chaussées*, on "The Insufficiency of Reservoirs for Diminishing the Danger of Floods:"

"The utility of reservoirs in diminishing damage from floods was taken into consideration, in France, after the inundations of 1856. Investigations were made in the valleys of the Seine, the Rhone, the Loire, the Garonne, and other important rivers, and resulted in the decision not to carry out the numerous reservoirs which had been proposed, owing to the uncertainty and doubtful efficacy of their action on floods.

"Similar investigations were made on these rivers after the inundations of 1875. These latter observations showed, in the case of the Garonne, that a reservoir capacity of 720 000 000 cubic yards would be required to protect Toulouse from a similar flood, and two or three times larger to protect Agen and the rest of the basin. The Saint-Ferréol reservoir, supplying the Canal du Midi, which has been cited as a specimen of the reservoirs that should be constructed, has only a capacity of under 8 000 000 cubic yards, so that a very great number

*Annual Report, Chief of Engineers, 1873, p. 541.

†*Minutes of Proceedings*, Inst. C. E., Vol. LXVI, p. 408.

of similar reservoirs would be required for protecting effectually the basin of the Garonne. The capacity, however, of the reservoirs which would be of value in reducing the height of floods, and could be constructed in the upper valley of the Garonne, would amount to only one-sixth of that required for protecting Toulouse. The investigations led to similar conclusions in the case of the lower Garonne, and of the other principal river basins of France. Mr. Harts.

"The distribution of rain and advantages of situation would oblige the reservoirs to be placed as much as possible in the hilly portion of the basins, where, however, owing to the declivity, the reservoirs would be smaller, and would be liable to be rapidly filled up with detritus. It might also sometimes happen that a flood would be produced by a heavy rainfall in the lower part of a river valley, as was the case in the great flood of the Garonne in 1875, and then the reservoirs in the hills would be useless.

"The action, moreover, of reservoirs on the river further down, with an increasing discharge, becomes rapidly less. Thus a lowering of the Rhone at Lyons of $3\frac{1}{2}$ feet, by means of reservoirs above, would amount to only $1\frac{1}{2}$ foot below the confluence of the Saône, and to only 8 inches below the confluence of the Isère at Valence. In like manner a retention of 130 000 000 cubic yards on the Garonne at Toulouse would only act like a retention of 65 000 000 at the mouth of the Tarn, of only 52 000 000 at Agen, and of only 23 000 000 at Tonneins, and its effect would become insignificant at Langon. This shows how large the reservoirs in the upper valleys would have to be made to produce an adequate effect in the lower portions of the rivers. Reservoirs on tributaries, by retarding a flood, would modify the flow in the main river in a variety of ways, which could hardly be determined beforehand, and might be injurious by causing a coincidence of floods.

"Often continuous floods are produced by the coming down of several high floods at short intervals apart. Thus the inundation of the valley of the Garonne in 1856 was caused by five successive floods, keeping the river in flood for more than two months. Under such circumstances the reservoirs would be filled by the first flood, and would not be available for lowering the subsequent floods. The reservoir embankments might be endangered by the flow of water over them, and a failure of an embankment might entail more disasters than a very high flood.

"It has been proposed that flood reservoirs should be also utilized for supplying canals, for irrigation, and for water power, thus serving a double purpose. Flood reservoirs, however, to be useful against floods, must be kept empty throughout the whole season when floods may occur. Storage reservoirs have small outlets, and a flood discharge would have to flow over the embankment, or over a wide overfall weir. Such an arrangement might be adopted in a rocky valley, and where the discharge of a river is small; whilst the erection of high embankments across the lower valleys, where the discharge is large and the ground liable to be eroded by the fall of the water, would be dangerous.

"The system of reservoirs for providing against floods must accordingly be entirely abandoned, not only on account of the excessive expense and difficulty of obtaining adequate capacity, but also because a carefully designed system of reservoirs along a river valley, which

Mr. Harts, might provide against a flood occurring under definite conditions, would be totally inadequate to cope with all the various combinations of distribution of rainfall and floods of tributaries, by which floods are produced in the main river."

In a "Discussion on the Conservancy of Rivers,"* Mr. L. F. Vernon-Harcourt is reported as saying that flood storage reservoirs had been proposed for torrential rivers, and might possibly be adopted with advantage where deep valleys, with narrow gorges, would admit of a large volume of water being retained by a short high dam.

"This system had, indeed, been partially adopted on the Loire; but the extension of this system on that river, and its adoption on the Yonne, had been rejected on economical grounds. The valleys of gently-flowing rivers were not suited for storage reservoirs. The lands bordering on these rivers were too valuable to be devoted to such a purpose; and the long duration of winter floods would render such reservoirs of little avail. It must suffice, in most cases, to provide against summer inundations; and high winter floods must be allowed to flow over the land, except where towns were liable to be flooded."

Further on (p. 291) Mr. R. Rawlinson remarked that rivers in a civilized country had two purposes to serve, which were in some degree antagonistic.

"Those who used them for navigation wished to put them in an effective state to accomplish that purpose; those who wished to prevent land flooding would act in a different way; they would not care much about the navigation if floods could be kept from their lands.* But there, again, the question was complicated. There were riparian owners who would be glad to have floods kept off their land if they had not much to pay for it, while others would say that if the floods were kept off their lands they would be seriously injured. The proposition had been to prevent floods by making reservoirs, and it had been stated that in some continental countries that system had been tried. He could only say that any engineer who made himself acquainted with meteorology, and with the volume of water that came down in excessive floods, would soon abandon the idea of forming impounding reservoirs to prevent flooding."

Referring to the same subject, M. de Lagréné stated (p. 309) that the authors [of the two papers under discussion] were right to reject large impounding reservoirs, as, in order to be of use, they would have to be placed low down in the valleys, where the land was generally most valuable, and their construction would be costly.

"Also, their functions would be exercised at times irregular and far apart, and they would induce serious opposition from the neighboring inhabitants.

"Longitudinal banks, notwithstanding their occasional failure, offered the best preservation against floods, but certain considerations

**Minutes of Proceedings*, Inst. C. E., Vol. LXVII, p. 287.

attached to their establishment. For instance, as no absolute knowl- Mr. Harts.
edge could be obtained of the height of future floods, no ordinary embankment should be considered as offering absolute security, and the riverside owners should understand that bursting of the bank was a contingency to be allowed for, which it would be prudent to meet by some sort of accident assurance. Further, it was advisable not to make the banks unnecessarily long, because the more scope allowed to a flood the less dangerous it became, and consequently the less scour would occur in the river-bed and banks."

And M. Malézieux, in his communication on the subject (p. 312), stated that about twenty years before, much attention had been directed to this means of preventing, or at least diminishing, the effects of floods:

"Vast reservoirs were to be made, kept empty during the dry season, in which might be retained the water from heavy rainfalls, so that it might be released progressively and at preconcerted times, in such a way as to prevent the coincidence and the accumulation of the flood water from several rivers of the same basin. It had been found, however, that this plan, very simple in theory, would be difficult and uncertain in practice, and that it might under some circumstances do more harm than good. This was referred to in a paper in the 'Annales des Ponts et Chaussées,' vol. ii. of 1881, p. 6."

In spite of its theoretical advantages, we see this reservoir system condemned for practical reasons, in several countries, by distinguished engineers, after mature study. It is now resurrected and advocated in the United States, mainly by men who have had no experience in the improvement of rivers for the benefit of navigation or in the practical control of floods. They are endeavoring to establish a system theoretically designed to combine various utilities, but which, like the combination tool, "is the joy of the inventor, but the despair of the user."

It seems clear that, to justify the high cost, their main efforts will necessarily be directed toward producing profitable water-power first; then to the secondary benefits, such as the interests of forestry, attempting flood control, assisting in the reclamation of flooded areas, and perhaps finally including the improvement of navigation. That our rivers would obtain any decided benefit from such a project, or that it could be practically applied, needs a more convincing argument and more accurate and pertinent facts than any that have been thus far advanced.

DR. GEORGE OTIS SMITH* (by letter).—Colonel Chittenden's paper Mr. Smith.
on the relation of forests to stream flow is especially suggestive to all who have had opportunity to observe forests and streams. It is indeed a subject for practical men, and inasmuch as geology, like engineering, is a practical science, it may be appropriate for a Fellow of the

* Director, United States Geological Survey.

Mr. Smith. Geological Society of America to join the Members of the American Society of Civil Engineers in a discussion of the paper.

While the author has everywhere exhibited the engineer's desire to cover the ground thoroughly, his presentation of the subject omits any mention of important factors that lie beneath the surface, and the writer desires to call attention to certain of these well-known geologic conditions, although time has not permitted him to elucidate them with the thoroughness that characterizes the paper, and also to record a few observations made in the course of his geologic field work in the West, which apparently run counter to those cited by the author.

In the discussion of the effect of forests on rainfall, the illustration used at the very beginning of the paper impresses the geologist as defective, and does not seem to "apply perfectly" in assuming a "practically impervious" subsoil or rock floor. Every geologist who has investigated underground waters would pronounce such an assumption as quite contrary to the facts and, indeed, did the assumed conditions actually exist, large areas of the United States would be without potable water. Throughout the paper the author's failure to see any disposition for precipitation other than by immediate run-off and evaporation apparently leads him into a fundamental error that vitiates all his conclusions as to the effect of forests. In many parts of the country the underground supply—the water that saturates the soils and rocks—not only surpasses the surface flow in quality, but also exceeds it in quantity. The underground circulation of water is, therefore, not a negligible but a most important factor. This is indeed the important factor in maintaining stream flow during dry periods, and the beneficial effects that geologists generally believe forests to exert are exerted through their influence upon sub-surface storage and circulation.

In his casual mention of springs, Colonel Chittenden apparently regards these as of superficial and local origin rather than as marking the points of issue of water which may have traveled slowly for long distances and possibly at considerable depths. Again, many who have shared with the author the advantage of studying rivers at their sources will not agree with him that springs and small streams exercise but little regulative effect on large rivers. On the contrary, in the case of streams without lakes or artificial reservoirs along their courses, all the dry-season flow may be regarded as being maintained by the slow escape into the stream channels, by seepage or more definite springs, of water stored in the underground reservoirs earlier in the year, when rain was falling or snow melting.

Keeping in mind the existence of underground water, it is at least interesting to review the forest argument. The forest mulch not only acts as a temporary reservoir of limited capacity, but it contributes its

stored water downward, as well as outward, into the subjacent soil Mr. Smith. and rock as well as into the surface rivulets and streams. Similar diversion of a part of the precipitation into the ground-water supply takes place in cleared land, but not, it is believed, to the same degree, except where, under exceptional circumstances, the soil and subsoil is as open as it is under the forest mulch. The ability of the forest bed to delay run-off is admitted by Colonel Chittenden, who considers it likely to aggravate floods, in the logic of which deduction, however, the writer cannot follow him—at least this aggravation of flood conditions certainly cannot be regarded as an “unquestionable tendency of forests.” Rather this retarding action of the forest mulch will tend to increase the proportion of the rainfall contributed to the underground reservoir, thus reducing the amount immediately converted into run-off. Decreasing the rate of surface flow increases the time and opportunity for absorption by the pervious soil and rock beneath the forest mulch. This absorptive action must to a large extent make complete saturation of the forest bed of rare occurrence, and the only general areas where “the percentage of retention in the forest bed is 0” would be the tree-covered swamps, swamps ordinarily indicating the area where the ground-water table reaches the surface. This increased contribution to the ground-water reservoir, from which the progress of water to its point of issue, where it joins the surface drainage, is indirect and slow, cannot fail to counteract in some degree, sometimes in a very marked degree, the fluctuations in that part of stream flow originating in direct run-off. The persistence of springs during the period of minimum run-off is a matter of common observation, and is explained by the long and tortuous character of the underground route followed by the water, as contrasted with the surface route of direct run-off.

The question may be raised whether this function of the forests in increasing the contribution to the underground flow is quantitatively important. The drying up of springs, with the extensive cutting off of the forests, is a well-known and widespread phenomenon, and one that bears directly on this point, though Colonel Chittenden doubtless places slight value on its importance. The most definite data that have come under the writer's observation, as to the rate at which pervious rock will absorb surface water, indicate that in a short distance the amount so absorbed from a small stream is sufficient to be readily detected and even measured, being several second-feet in the case under observation.* Moreover, the conditions in a stream bed are not altogether favorable for such absorption—by reason of the silting up of the pores of the rock—probably less favorable than under the forest mulch. Indeed it appears reasonable that as a general rule the

* U. S. Geological Survey, Water-Supply Paper No. 55, p. 56.

Mr. Smith, contribution through the underground circulation will continue, just as long as the forest bed retains any portion of the rainfall.

The author's view, that delayed melting of snow is not beneficial, must also be challenged. While the writer too has found dry ground beneath a dwindling snow bank, on digging into the sand he has discovered the water beneath. Again, it seems probable that the bottom, as well as the top, of the snow cover is also a melting surface both in the open and in the forest. This is shown by the manner in which certain spring flowering plants penetrate the snow wherever the cover becomes thin. Thus it appears reasonable to believe that the time of snow-melting is a period of contribution to the underground flow, and the total contribution from snow is necessarily largest where conditions favor the longest period of melting.

On the subject of the influence of forests on snow-melting, observations will differ somewhat. As contrasted with Colonel Chittenden's excellent and detailed observations in the Yellowstone Park, the writer might mention the fact that even later in the same season, July 1st, 1899, on Table Mountain, in Central Washington, there was snow in the forest at an elevation of 6 000 ft., while, at the same elevation in the open, the snow had long disappeared, and the flood conditions on the Yakima River had passed. At one place in the forest on Table Mountain, the drifted snow was so deep on this date that the writer's horse was stalled and had to be dug out, so that, as in Colonel Chittenden's case, the difficulties attending travel forcibly drew attention to the depth of snow. Furthermore, the abundant springs of ice-cold water below the escarpment of Table Mountain, which persist through the summer, suggest that the snow banks in the forest above were contributing to the underground supply rather than to direct run-off.

The illustration, Fig. 1, Plate XL, is of a stream (White River, Washington), the water-shed of which is not aptly described as "the most densely wooded and perfectly protected water-shed in existence." White River is a glacial stream, as its name indicates, and has a well-deserved reputation for devastating floods. It has its principal source in the largest glacier on Mount Rainier, and, as the writer knows from observation, 23 sq. miles of the Mount Rainier portion of its water-shed are not forested, but are covered with ice and snow twelve months of the year, not to mention other snow-covered areas near the crest of the Cascades and at least 50 sq. miles of burnt and cut-over land in the lower portions of its basin. This fact explains why a warm "chinook" will cause the White to rise much more quickly than its sister stream, the Green, which, as its name suggests, has no glacial tributaries. The ranchers in the Lower White River Valley recognize the advantage of the high-water stage of the Green and Cedar Rivers reaching the valley after the maximum flow of Upper White River has passed. The Skagit,

of which mention is also made by Colonel Chittenden, is another river receiving important contributions from glaciers and snow fields. Mr. Smith.

Unfortunately, the stream-gauging records of the Geological Survey do not afford data for a direct comparison of the White River with neighboring streams, the water-sheds of which are wholly forested. At the time of the 1906 flood, to which Colonel Chittenden refers, only two of the Cascade streams for which complete records are available failed to record the highest stage of water on November 15th. Of the two streams which reached their maximum flow on the day preceding, one, Johnson Creek, has an unforested drainage basin and the other, Tieton River, has its origin in glaciers on the main range, not many miles from the head-waters of White River. Were stream-gauging records available for White River, the writer is confident that they would show that this stream, like the Tieton, reached its maximum stage at least 24 hours earlier than the streams in the same general region having drainage basins altogether forested.

GEORGE F. SWAIN, M. AM. SOC. C. E. (by letter).—The Society Mr. Swain. should be grateful to Colonel Chittenden for the interesting paper which he has presented, and for the able and forceful way in which he has discussed the question of the effect of forests and reservoirs on stream flow. His remarks are so well presented that upon a first reading those who believe in forest preservation might feel that their side of the case had received a severe blow, but a careful examination discloses many apparently contradictory statements, while the argument seems quite as conjectural and the specific statements quite as much without proof as those given by the writers with whom the author disagrees. As a matter of fact, he seems to admit most of what is claimed for forests. So far as his paper may be considered a protest against extreme views, the writer agrees with him, though many of his statements are extreme in the other direction, and are certainly unsound.

It is a characteristic of humanity to go to extremes, and at the present time, apparently, some people almost believe that if the country could be reforested there would be no freshets, and that our streams would be absolutely uniform in flow. On the other hand, occasionally but rarely a writer is found who denies their beneficial effect, and now the author seems to be attempting to convince us that, not only forests, but reservoirs, increase the violence of freshets.

The author has stated very clearly the difficulties attending quantitative demonstration in regard to this matter. In fact, absolute proof is almost impossible, for the reason that the factor to be studied cannot be isolated in the way that is possible in many scientific investigations. In order to demonstrate quantitatively beyond peradventure the effect of forests, it would be necessary to have the same area under identical conditions in every respect, except that at one time it should be wooded

Mr. Swain. and at another time deforested. It must also be borne in mind that other factors in the problem are more important than the forests, for instance, the amount and, particularly, the distribution of the rainfall. When, in two successive years, with practically the same rainfall in each year, the same water-shed shows a run-off of about 12 in. in one year and about 17 in. in the next, the difficulty of the problem will be apparent.

However, means of forming reliable opinions upon the more important aspects of this matter are not wanting, although some minor points will probably long remain matters of opinion.

The author first considers the relation of forests to stream flow, and states that:

"The commonly accepted opinion is that forests have a beneficial influence on stream flow:

"(1) By storing the waters from rains and melting snow * * * preventing their rapid rush to the streams and paying them out gradually afterward, thus acting as true reservoirs in equalizing the run-off."

"(2) By retarding the snow-melting in the spring and prolonging the run-off from that source.

"(3) By increasing the precipitation.

"(4) By preventing erosion of the soil on steep slopes and thereby protecting watercourses, canals, reservoirs and similar works from accumulations of silt."

This will probably be admitted to be a fair statement of what the believers in the benefits of forests consider to be true, except that some do not think that there is yet sufficient demonstration that they increase the rainfall, although the writer believes that they do.

With reference to the first of these points, the author states that it is "strictly true for average conditions." He says: "It is true, therefore, as popularly understood, that, in periods of ordinary rainfall, with sufficient intervals for the forest bed to dry out somewhat, forests do exert a regulative effect upon run-off. They modify freshets and torrents and prolong the run-off after storms have passed, and thus realize in greater or less perfection the commonly accepted theory." He believes, however, that this beneficial effect is not exerted under extreme conditions, *i. e.*, great floods and excessive low waters.

After the above admission, it would seem scarcely necessary to discuss this portion of the subject further, unless, as the author seems to believe, regulation under all but extreme conditions is of little benefit. Aside from the fact that it is a benefit to have the flow regulated, even to a small extent, during the greater part of the time, the writer cannot agree with the author that extreme conditions alone determine the character and cost of river control. The erosion of the land, the washing away of banks, the silting up and changing of channels, and the destruction of property, occur in the case of moderate floods as well as in the case of excessive floods; although, of

course, extreme conditions determine certain elements, such as the height of levees. A few great, but not extreme, floods may do more damage than one extreme flood, and may necessitate more expenditure for dredging and other purposes.

From every point of view—power, navigation, erosion, irrigation—it is of even more importance to diminish the frequency of great floods than the height of extreme floods which occur only at long intervals, and to keep up the usual low-water flow rather than the extreme low-water flow which seldom occurs.

If the writer fully understands the argument with reference to extreme floods, it appears to be this: Great floods are always the result of combinations from various tributaries, occurring after periods of long-continued and widespread precipitation; the forest bed becomes completely saturated, its storage capacity exhausted, and when this point is reached the water flows from the forest surface without restraint.

FIG. 4.

With reference to this it is, of course, evident that, when the forest bed has become fully saturated, it cannot hold any more water; but, even then, it will hinder its discharge, because the soil will not be washed away and the torrents will not flow down in gullies. In this sense the forest floor never discharges such torrents as come from un-forested areas. Moreover, it is certainly a gain if forest floors can absorb even a part of the rainfall and pay it out gradually to the soil beneath, and it seems quite erroneous to urge that because their storage capacity is not unlimited it is therefore not valuable. The author states that the fact that the forest bed has retained a portion of the rainfall and will yield it up later may produce a worse condition than if the country were clear, and asserts positively, but without proof, "that the forest does promote tributary combinations there would seem to be no question, and that it may therefore aggravate flood conditions necessarily follows." Perhaps the writer does not fully understand what is intended, but he is perfectly ready to admit that a case may be imagined in which the statement of the author would be true. Suppose, for instance, a storm is moving in the direction shown by the arrow on Fig. 4. It

Mr. Swain. passes first over the forested area and later over the deforested area, both of which are about equally distant from the junction of the two streams. On account of the fact that the rainfall has been somewhat held back in the forested area, the flood coming down stream, *A*, is retarded and arrives at the junction at the same time as the flood coming down stream *B*, from the deforested area, which received the storm later, whereas, if the forest were cut down, the flood from *A* might have reached and passed the junction before the flood from *B* arrived. If this is argued as a demonstration that the cutting down of forests would benefit the streams, it is only necessary to reply that, on the contrary, it is equally an argument that the deforested area of *B* should be reforested. Besides, how would it be if the storm were moving in the other direction?

FIG. 5.

Or, to take another instance, suppose two streams have their headwaters in a region, *a*, from which the run-off reaches the junction, *b*, in about the same time from both streams, as in Fig. 5. In this case a heavy rain at the headwaters, *a*, may result in a violent combination of floods at *b*. If, however, the forests along stream *A* were cut down, the water might reach *b* via stream *A* before it reached it via stream *B*, and so the flood might be distributed at *b*. It is thus no doubt possible to conceive of cases in which the destruction of a particular forest might reduce a certain flood at a certain point, but to conclude that the resultant effect of forests is not beneficial is clearly illogical, for (in Fig. 5), the clearing of the water-shed of *A* will increase the violence of floods on that stream, while there may be little or no damage due to a heavy rise at *b* or below; and, furthermore, if the storm, instead of being stationary as just imagined, is moving, as it always is, then a movement as indicated by the arrow would have the effect that the

clearing of *A* would cause a combination at *b* which otherwise would not occur. To argue from instances like the above against the beneficial regulating influence of forests (which perhaps the author does not mean to do) would seem like arguing that because it is possible to conceive that a man's food may choke him, therefore food is not beneficial, or that the heat of the sun is not beneficial because people are sometimes sunstruck.

The author's summary of this part of the discussion is perhaps contained in the following sentences: "That the forest does promote tributary combinations, there would seem to be no question, and that it may therefore aggravate flood conditions necessarily follows. It is not contended that this increase is ever very great, but it is contended that forests never diminish great floods and that they probably do increase them somewhat."

It would seem to the writer to be nearer the truth to say that forests greatly diminish floods, although it is conceivable that some forest may slightly increase some flood at some point.

The author further states that: "The forests are virtually automatic reservoirs, not subject to intelligent control, and act just as the system of reservoirs once proposed by the French Government for the control of floods in the River Rhône would have acted, if built. These reservoirs were to have open outlets, not capable of being closed, which were intended to restrain only a portion of the flow. A careful study of their operation in certain recorded floods showed that they would actually have produced combinations more dangerous than would have occurred without them." The last sentence of this quotation is rather conjectural, and its meaning is not clear, but it will be surprising to most engineers to be told that a reservoir not subject to intelligent control does not regulate, and they will hardly accept the statement. Of course, a lake is a more efficient regulator than a forest, for reasons suggested clearly by the author.*

The general aspect of this part of the subject seems, after all, very simple. The forest floor absorbs a large amount of water, prevents it from flowing off rapidly, and pays it out gradually into the soil, through which it finds its way to springs and to the underground water. If the land were clear of vegetation, or if it were cultivated, and especially if the slopes were steep, the erosion under heavy rains would be great, and might leave no soil upon the rocks to serve as a reservoir in future storms. The author's argument, therefore, leaves unassailed the beneficial effects of forests in regulating flow; and the illustration used by Mr. Pinchot seems a reasonable example of a usual phenomenon.

The author makes a fundamental error in the very beginning of his discussion, which vitiates all his reasoning on this matter, when he illustrates the action of the forest by comparing it to the action of a

* See page 288.

Mr. Swain. layer of sand on an inclined surface practically impervious to water. The ground under the forest bed is not impervious to water, but is in fact kept by that bed in a highly absorbent condition.

The fact must be emphasized that those who believe in the beneficial effect of forests upon flow do not urge the preservation of forests on lands needed for agriculture and topographically suited for it. The beneficial effects of forests on flat lands, in modifying the violence of freshets and increasing the low-water flow, is much less clear than in the case of forests in steep mountain regions. It is the preservation of these last—forests upon steep slopes not suitable for agriculture, where the erosion on cleared land is very great—that is believed to be especially important for the streams.

FIG. 6.

In fact, this part of the discussion seems rather academic. Probably few if any engineers will deny that lakes, even if unregulated, are or may be of great benefit in regulating the discharge of streams which flow out of them, and yet even here we may conceive of a case where the reverse would be true. Suppose, for instance, that the two streams, *A* and *B*, rise in the same mountain region, *a*, and unite at *d*, Fig. 6. If a heavy rainfall occurs at the head-waters, the part which flows *via A* will reach *d* much sooner than that which flows *via B*. Now, if a reservoir is placed on *A*, it is conceivable that it may check the flow on that stream sufficiently to make the rise of the water at *d* somewhat greater than before. But of course the flood has been reduced all the way from *a* to *d*. This simply illustrates the fact that if artificial reservoirs are to be located, their location should be carefully studied.

When it is claimed, as the writer does, that the preservation of the mountain forests will be of great benefit in regulating the flow, this does not mean that if a region is deforested the maximum flood will be greater than ever before, for the conditions are, as has been abundantly shown, extremely variable. On the Connecticut and Merrimac Rivers, for instance, the highest water ever known occurred before the present rapid cutting of timber in the upper parts of the basins. Nevertheless, it may be equally true that even those freshets would have been still worse if the forests had not been there; and it is quite certain that, if the height of extreme floods has not been increased by deforestation, the frequency and duration of great floods have. The statement* that

* See page 262.

the flood of 1908 in the Western States would have been much greater Mr. Swain. if the region had been forested is a mere statement of the author's opinion, entirely without proof, and undoubtedly incapable of a proof; and, further, if the records in Table 1 show that it is impossible to find evidence in them to support the current theory of forest influence, it may also be stated that there is nothing in them to support the author's theory.

Fortunately, however, we are not without valuable evidence in this matter, particularly in the experience in France. The work of M. Vallée, to which the author refers, was published in 1857 and was followed by two articles* by the same writer, his claim being that forests diminish rainfall and increase the violence of floods. These opinions, however, seem to have been without influence, for, in 1860, the French Government entered upon a policy of forest protection and reforestation, particularly in the mountain regions, which has been continued to the present time. To January 1st, 1900, the State had acquired, for the purpose of controlling torrents, 162 974 hectares (about 407 000 acres), and had expended upon the work of protection more than 66 million francs, with a further contemplated expenditure of more than 114 million francs, and one of the most recent writers† on the subject states: "The rôle of the forest as a regulator of the flow of streams may be considered as evident, and it is to-day universally admitted." Under the able direction of Prosper Demontzey, Chief of the Service of Reforestation in France, from 1882 until retired in 1893, and of his predecessors, much has been accomplished, and some formerly very destructive torrents have been reduced to inoffensive streams by reforestation and regulation, much more being expended for reforestation than for regulation. Perhaps it will be argued that the good results that have followed have been due entirely to regulation, and not at all to reforestation, but that is not the view of French engineers.

At first there was great opposition on the part of the inhabitants of the mountain valleys and slopes to the Government work of reforestation, and, in 1864, there were even riots in resistance, but this opposition has not only entirely ceased, but has been replaced by active co-operation. The people now frequently petition to have the Government pursue its work, and even voluntarily give up portions of their lands for the purpose, without asking any reimbursement.

With reference to extreme droughts, the author admits "that, as a general rule, springs and little streams dry up more completely than when forests covered the country," but he argues that, since each spring is small, their drying up will have little effect on the main stream, the flow of which will be kept up, if the region is deforested, by the rapid

* *Annales des Ponts et Chaussées*.

† G. Huffel, "Economie Forestière." 1904.

Mr. Swain. discharge of water from summer showers which will occur, first on one tributary and then on another, in such a way as to furnish to the main stream always a low-water flow greater than if the springs could all be kept up. The author objects to the illustration which Mr. Pinchot gave before the Congressional Committee, on the ground that he did not carry it far enough. If the author's argument be carried to the very common case where no rain falls upon a given drainage basin for weeks, or for a much longer time than it takes for a drop of water to flow from the most distant source to the mouth, it would seem to lead to the conclusion that there would be no flow at all in the stream. In other words, the author would have the mills at Lawrence and Lowell depend for their summer flow, not upon keeping up the "springs and little streams" so far as possible by increasing, through the effect of forests, the percolation into the ground, but would have these mills trust to luck that the summer showers would be so distributed—coming first on the Nashua River basin, then on the Contoocook River basin, the Winnepesaukee basin, etc.—that there would be a good flow at Lawrence and Lowell. This would, of course, require most intelligent planning, for it would not do to have these summer showers, which are supposed to flow rapidly from the surface, come down the different tributary basins in such a way that the water would arrive at Lawrence and Lowell at the same time. They must be accurately timed and distributed with reference to the position and size of the tributary basin.

Even a large drainage area, say 10 000 sq. miles, may well have its main stream possess a length from most distant source to mouth, measured on the stream, of considerably less than 300 miles. If the average velocity of the stream is 1 mile per hour, which is low, it would take less than two weeks for a drop of water to pass from the most distant source to the mouth. Now, even in districts which have a summer rainfall, it frequently happens that an area as large as that mentioned is without rain in any part for months at a time, under which conditions, if the writer understands the author's theory and his admission, even such a large stream would practically dry up. It would seem to be much more reasonable to depend upon some means of keeping up the springs and small streams, rather than upon the equal distribution of surface waters of summer showers from deforested areas. Of course, the larger the stream the greater the low-water flow per square mile, other things being equal, because the lowest flow from all tributaries will not arrive at a given point at the same time, partly owing, no doubt, to local rains; but it is illogical to argue from this in favor of deforestation, which admittedly reduces the lowest flow from these tributaries. The author here seems to be inconsistent. In discussing floods, he considers an extreme condition, in which the floods from various tributaries arrive simultaneously at a given point, and from this he argues generally that forests increase the violence of ex-

trema floods. In the case of extreme droughts, however, he considers Mr. Swain. the case, not where the low-water flow from various tributaries arrive simultaneously at a given point, which may equally well occur, but on the contrary where relatively high water from one arrives at the same time as low water from another.

The author, however, does not really take his own arguments seriously, for later he states: "In the records of precipitation * * * will be found a full and complete explanation of every one of the floods," and, "the true explanation is found in them and not at all in the presence or absence of forests on the water-sheds." This is quite true, except that the writer and many others believe—and the author admits—that there is abundant proof that as a rule forests reduce the violence, frequency, and duration of freshets.

The author says, "it seems certain that forests decrease somewhat the total run-off from water-sheds small or great." This would seem to depend upon the relative amount of evaporation from the forested land, and also upon whether there is an increased rainfall produced by the forests. If the rainfall is the same as without forests, while the evaporation is greater—including under the term evaporation, physical evaporation from the soil and physiological evaporation from the trees themselves—of course the total run-off will be less. Perhaps this is true. The writer does not deny that it is possible, although he has seen no proof of it to the present time; even if this is true, he believes that uniformity of flow is of much more importance than total amount of flow, even on the small tributaries which go to make a large stream. But if the forest increases the evaporation, it would seem to follow that it increases the rainfall. The rainfall is due to the condensation of the moisture in the air. This moisture comes from various sources: from the sea, from lakes and streams, or from the land. The rainfall depends upon the total amount of this moisture, independent of its source. Any cause, therefore, which increases the evaporation from a country increases the rainfall. This does not mean, of course, that if the writer increases the evaporation from his back yard, he increases the rainfall there. Large areas must be considered, and the statement is a general one. Regarding this question of rainfall, too, it must be borne in mind that the total amount of water reaching the soil is due not only to that which falls in drops from the sky, but also to that which condenses either on the ground or on the trees. The author refers to dew, which he says is not present in forests, but he does not mention the condensation upon the tree trunks and leaves, and on the ground (dew aside), which must be greater than in the open, because of the lower summer temperature not only of the air but of the trees themselves.

As to whether forests increase rainfall, the difficulties in the way of demonstration are obvious, but there is considerable proof that they do. The writer has not seen any reference to the results obtained in

Mr. Swain. Hanover, and therefore will state them. It was decided in 1887 to reforest a large area; at first from 1 000 to 1 250 acres were planted annually and, in 1891, some 18 000 acres had been reforested in pine and oak. There is a meteorological station in this region, at Lintzel. Considering a circular area of 15 000 acres with this point as its center, there were:

	Before reforestation.	After reforestation.
Cultivated ground and meadow land.	.12% of the area;	10% of the area.
Pasture	85% " " "	10% " " "
Forest	3% " " "	80% " " "

Rainfall observations were begun in 1882, and the results at Lintzel were compared with those at the neighboring stations of Brème and Gardelegen. The quantity of rain falling at Lintzel was as follows:

1882..	64.5%	of that at Brème;	96.3%	of that at Gardelegen.
1883..	68.7	" " " " "	101.1	" " " " "
1884..	77.8	" " " " "	106.7	" " " " "
1886..	83.9	" " " " "	114.2	" " " " "
1888..	106.8	" " " " "	120.1	" " " " "
1890..	101.6	" " " " "	120.1	" " " " "

Similar results are stated to have been obtained at Nancy, all of which are sufficient to satisfy Huffel that it rains more, other things being equal, at the center of the forest than at the edges, and more at the edges than several kilometers beyond on cultivated ground.

Whether forests decrease or increase the total run-off would seem to be still a somewhat open question. Probably it depends upon other circumstances, such as the slope of the ground, etc.

With reference to the effect of forests upon snow-melting, the author states that "it can be demonstrated that the effect of forests upon the run-off from snow is invariably to increase its intensity." It is undoubtedly true that forests reduce the formation of drifts, but the writer's observations and inquiries convince him that the snow in forests does drift to some extent, though much less than in the open, and that it lasts longer into the spring than even the drifts outside. Perhaps this is not true in the highest mountains and near the timber line, where the trees are small and the drifts very heavy, but the writer believes that it is generally true. If it is true, the author's argument on this point seems to fall. He also seems to ignore the fact that in forests the ground is warmer than it is in the open, and indeed that it frequently may not freeze at all under the snow. As the snow melts, it melts at the bottom, and the ground is more ready to absorb it than is the frozen ground in the open.

The writer has not had the opportunity to study to any extent the conditions in the Rocky Mountains, but he observes that Professor L. G. Carpenter, of the Colorado State Agricultural College—than

whom there is no more competent authority—in his paper on “Forests Mr. Swain and Snow,”* comes to the following conclusions, among others:

(a). “The greater the amount of forest cover the less violent the daily fluctuation, the more uniform the flow throughout the day and throughout the season, and the later the stream maintains its flow.”

(b). “The loss of the forest cover means more violent fluctuation during the day, greater difficulty in regulating the headgates and keeping a uniform flow in ditches, and hence an additional difficulty in the economic distribution of water. Also the water runs off sooner, hence the streams drop earlier in the summer, and on account of the lessening of the springs, the smaller is the winter flow.”

(c). “The preservation of the forest is an absolute necessity for the interest of irrigated agriculture.”

The writer is not in a position to question the statement of the author with reference to Yellowstone Park. He has observed, however, that the greater part of the Park is covered with forests. What the condition of things would be if this area were deforested can only be conjectured, and the writer would like to inquire whether Fig. 1 is simply a fictitious diagram showing the author's opinion, or whether it is based upon measurements of flow from approximately equal areas under similar conditions in every respect except that one is forested and the other not. The diagram does not coincide with the experience of the writer, which has convinced him that the snow run-off in forested areas extends later into the spring than the snow run-off on open ground.

Of course, in this, as in the other matters discussed, it is possible to conceive of circumstances under which a particular forest might increase a particular flood. If the forests retain a thick blanket of snow late into the spring, and there comes a sudden warm rain which carries away all this snow, there may result a freshet of greater violence than if the sun had previously melted the blanket of snow; but it is equally clear that if the forest had not been present, and the snow had gone off with the snow from open ground, the earlier freshets would have been increased. If a given amount of snow has got to run off into the streams, it is certainly an advantage to have the period in which it runs off lengthened.

With reference to the experience in the region of Puget Sound, the author states that the snow storms are followed by warm southerly winds and rains, which melt the snows and result in tremendous freshets and floods. A warm southerly wind and rain will easily melt 18 in. of snow even on the ground, and the author has not shown that the condition now existing would be bettered if the forests were cut down and the snowfall of 18 in. rested entirely on the ground instead of partly on the trees. His remarks on this point are an excellent illustration of illogical reasoning. He says that the great flood of 1906 “was a perfect demonstration of the vastly intensifying effect of forests

* Bulletin 55, Agricultural Experiment Station of the Agricultural College of Colorado.

Mr. Swain. upon floods due to snow melting." Would it not be more correct to say that it was simply a perfect demonstration of the fact that even in densely forested areas there may be tremendous floods?

Similarly, inconclusive, to the writer's mind, is the statement about the flood of the American River compared with Puta Creek, in California. Water-sheds differ, not only as regards forests, but in other respects. The facts stated simply seem to show that in this case the forests did not regulate the flow to an extent sufficient to counter-balance other factors. For instance, if the writer is correctly informed, the slopes of the Sierras are steeper than those of the Coast Range. Again, the shape of the drainage area is a matter of considerable importance with reference to the maximum rise of water at a given point, as has been illustrated previously in this discussion. The author, of course, may be correct in his opinions, but his statements are entirely inconclusive.

The logical position with reference to the forestry question is indeed quite similar to that of the author regarding the reservoirs on the Upper Mississippi. After showing that, as actually controlled, the flow of the river was less uniform than the natural flow (though it need not have been so), he concludes that the reservoir system "is nevertheless a very great benefit." Admitting, as the writer is ready to do, that a forest may conceivably increase the high-water stage in a given stream at a given point, it is yet safe to say that nevertheless the forests are a very great benefit as regulators of stream flow; and this conclusion is not shaken by the arguments of the author.

It must be borne in mind that of all the influences which affect the uniformity of flow of streams, but two are subject to human control, namely, forests and storage. By preserving the forests and by building storage reservoirs it is possible for Man to regulate the flow and render it comparatively uniform. The preservation of the forests is the more important of the two, and should come first, because of the erosion and consequent filling up of reservoirs which results from deforestation.

The preservation of the forests on the mountain slopes is especially important in the interests of navigation. Where they are destroyed, not only is the frequency and duration, and as a rule, the violence, of the freshets much increased, but fire often succeeds, adding to the evils by destroying the forest bed, and thus increasing the erosion. If the soil is thin, as in the White Mountains, or if it is fine and clayey, as in the Southern Appalachians, the results are almost equally bad. If, with the increasing demand for timber, these mountain slopes should be completely or largely deforested, the erosion and consequent silting up of our rivers and the impairment of navigation on account of floods and low waters, would be so great that there would be no doubt in anybody's mind of the action of the forests. But it would then be too late, and many years would be required to repair the damage, if it could be repaired at all.

W. H. LEFFINGWELL, M. AM. SOC. C. E., and A. M. STRONG, ASSOC. M. AM. SOC. C. E. (by letter).—Colonel Chittenden's deductions in regard to the action of forests on floods are borne out very markedly in the streams of the Southern Sierras. Messrs.
Leffingwell
and Strong.

The control of the flood flow of these streams is of nearly as great commercial importance as that of the navigable rivers of the Middle and Eastern States. Various national, municipal, and private projects are affected by large and sudden fluctuations in the flow of the streams on which they are located. It is claimed that the floods are largely affected by the conditions of forest cover, and can be made less serious in many places by building up the forests. The Sierra Nevada Mountains, in California, upon the streams of which the State depends largely for its prosperity, have been the scene of floods which have caused great damage in recent years. This entire range has been placed in the National Forests, in order that the forest cover may be preserved and nurtured under Government control, and beneficial effects are hoped for.

Four of the principal streams in the Southern Sierras have been gauged by the Government, thus obtaining definite data on their flow. These are the Merced, Kings, and Kern Rivers on the western, and the Owens River on the eastern slope. The characteristics of their drainage areas are described as follows:*

Merced River.—Merced River drains the middle portion of the western slope of the Sierra Nevada Mountains with a drainage area of 1 090 sq. miles. The topography of the country is rough and rugged, and, in this basin, is the famous Yosemite Valley. The formation is of granite, which, on the upper reaches, rises in precipitous domes and peaks, smoothly marked by glacial action. The middle reaches of the basin are well timbered and contain the Mariposa Grove of big trees. The timber growth extends well down on the lower elevations of the foot-hills, where the covering is of brush and grass. Numerous lakes are scattered over the upper portions of the basin. The mean annual precipitation is from 25 in. in the foot-hills to 60 in. in the higher elevations, where it falls in the form of snow. The gauging station is at the lower edge of the foot-hills.

Kings River.—Kings River drains a portion of the western slope of the Sierra Nevadas, quite a little south of Merced River, and has a drainage area of 1 742 sq. miles. The crest of the Sierra Nevadas at the head of this basin reaches an elevation of more than 14 000 ft., and forms the most rugged portion of the range. A large number of small lakes on the higher elevations are fed by small streams from the perpetual snow banks and glaciers. The formation is granite, which, above an elevation of 10 000 ft., is bare. Below this elevation there is a heavy covering of timber and underbrush. Extensive groves of

* "Progress in Stream Measurements," U. S. Geological Survey.

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big trees are scattered through the basin. On the lower elevations of the foot-hills the covering is light. The gauging station is at the lower edge of the foot-hills.

Kern River.—Kern River drains 2 345 sq. miles of the western slope of the Sierra Nevadas at its extreme southern limits. It has its source in the highest elevations of the range. The topography is extremely rough and broken in the upper reaches of the basin, becoming less rugged in the middle portion, where there is quite an extensive valley. The formation is of granite, which above the 10 000-ft. contour is bare. Between 3 000 and 10 000 ft., there is a good depth of soil, with timber and brush covering; the lower reaches have a light covering of brush and grass. There are several lakes and marshes scattered through the basin, but they are less numerous than in the case of the other rivers. The precipitation is very light throughout the basin, with the possible exception of the high elevations, where the snowfall is heavy. The gauging station is at the lower edge of the foot-hills.

Owens River.—Owens River has its source in the Sierra Nevadas in Eastern California and, flowing southeast parallel with the range, finally discharges its waters into Owens Lake. This basin has a length from north to south of approximately 150 miles, with a width of from 20 to 25 miles. Practically the entire flow of this river is derived from the Sierra Nevadas, as it drains the eastern slope from opposite the head-waters of Merced River on the north to those of Kern River on the south. The gauging station is above all irrigating canals at the head of Owens River Valley and near the middle of the basin, with a drainage area of about 450 sq. miles above the station. The elevation at this point is about 5 000 ft.

The topography of the portion of the Sierra Nevadas drained by this stream is extremely rough and rugged. The formation is granite with very little soil covering, sparse timber growth, and scarcely any brush. Numerous lakes and marshes are found in the upper portions of this drainage area, above the gauging station, also a flat swampy country known as Long Valley. The precipitation is extremely light within the area of this basin, with the exception of the high elevations of the Sierra Nevadas, where there is a heavy fall of snow.

The record of the flow of these four streams is available for three years, 1904, 1905, and 1906. These include a normal season, a dry season, and a wet one, and show the flow under greatly varying seasonal rainfalls. The daily flow at the gauging station is shown in detail by the diagram, Fig. 7. It will be noted that the minimum flow of these streams is about the same, with the exception of Merced River which has much the smallest winter flow. Especial attention is called to the great fluctuations in the flow of Merced and Kings Rivers draining a timbered area; the lesser fluctuation of Kern River drain-

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FIG. 7.

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ing a partially timbered area; and the slight fluctuation of Owens River draining a practically untimbered area.

The yearly history of the flow of these streams is as follows: The rainfall from the first storms of the rainy season in the autumn is mainly absorbed by the dry ground in the foot-hills, and causes very little fluctuation in the flow, while, on the higher levels, it forms the lower layers of the snow fields. The heavy winter and spring storms cause a heavy run-off from the foot-hills, with some of the worst floods of the year. Above about the 5 000-ft. contour, all precipitation is retained as snow. The first warm weather of summer causes melting, and about half the total precipitation is discharged in six weeks. The middle and late summer flow comes from the perpetual snow fields of the high peaks, and gradually diminishes as the weather grows colder, until the beginning of the rainy season. There are a number of thunderstorms during the summer on the higher portions of the range, but they are not heavy enough to affect the general flow of the streams. The gauging station on Owens River being at an elevation of about 5 000 ft., the winter fluctuations are not found at that point, as in the case of the others.

Tables 10, 11, and 12, record the main features of the discharge and flow of these streams, and show many interesting conditions in the resulting flow from varying drainage areas and rainfalls.

The diagram and the tables show that Kings and Merced Rivers have very similar characteristics, though the drainage area of Kings River is nearly twice as great as that of the Merced. Kern River, in all its characteristics of stream flow, occupies an intermediate position between the two foregoing and Owens River, and the latter shows the least variation of all four. An examination of the diagram and tables shows that there is a remarkable similarity between certain percentages of flow from the same drainage area for different years. For example, on the Merced River the percentage of run-off during the first 10 warm days of summer was 12% of the total discharge in 1904, 12.2% in 1905, and 11.6% in 1906, although the total depth of run-off for the same years was 20.25, 13.26, and 35.92 in., respectively. Hence this early summer run-off appears to be directly proportional to the depth of snowfall as well as dependent upon the superficial area of the snow fields. The other streams show similar regularity of similar percentages. These percentages may be considered to represent the relative intensity of the floods of the different streams, and are practically the same for Kings and Merced Rivers, less intense on Kern River, and still less on Owens River, where the run-off during the early 10-day flood period is only 4.5% of the total flow for 3 years' average. Owens River, with a greater depth of run-off than Kern River, has about half the intensity of flood.

FIG. 1. LAKE GEORGE, IN EASTERN SIERRA NEVADAS NORTHWEST OF
LONG VALLEY. HEAD-WATERS OF OWENS RIVER.

FIG. 2.—EASTERN SLOPE OF SIERRA NEVADAS NEAR HEAD OF BISHOP
CREEK, A TRIBUTARY OF OWENS RIVER.

TABLE 10.

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1904.	Merced River, 1 090 sq. miles.	Kings River, 1 742 sq. miles.	Kern River, 2 345 sq. miles.	Owens River, 450 sq. miles.
Total discharge, in acre-feet	1 177 412	1 880 846	492 892	208 461
Maximum daily discharge, in second-feet.....	May 14 8 780	May 17 15 167	June 4 3 167	June 20 635
Minimum daily discharge, in second-feet.....	Sept. 16 80	Jan. 21 130	Jan. 21 156	Jan. 12 152
Ratio of minimum to maxi- mum daily discharge.....	1 to 110	1 to 121	1 to 20	1 to 4
Month of maximum dis- charge, and percentage of total.....	May 80%	May 84%	May 23%	June 15%
Month of minimum dis- charge, and percentage of total.....	Jan. 0.98%	Jan. 0.64%	Jan. 2.29%	Jan. 4.62%
Ratio of minimum to maxi- mum monthly discharge..	1 to 31	1 to 57	1 to 10	1 to 4
Total depth of run-off, in inches.....	20.25	20.26	3.93	8.78
Depth of run-off during first ten days of warm weather, and percentage of total...	May 9-18 2.46 12.0%	May 9-18 2.96 14.6%	May 12-21 0.36 9.2%	May 21-29 0.32 3.7%
Depth of run-off during month of minimum fall flow, and percentage of total.....	Sept. 0.33 1.63%	Dec. 0.23 1.18%	Sept. 0.12 3.06%	Dec. 0.56 6.42%

From the foregoing it would appear that we should look to conditions other than the amount of snowfall or the size of the drainage basin for an explanation of the varying flood intensity. The climate on opposite sides of the range is practically the same at equal elevations. Temperature changes occur on the same dates on all four drainage areas, but their effect on the stream flow is later on Kern and Owens Rivers than on Kings and Merced Rivers.

In searching for a cause for the difference in the character of the flow from these streams, the question naturally arises as to the condition of the forest cover. It is found that the drainage areas of Merced and Kings Rivers are covered with heavy timber below the 10 000-ft. contour; that the Kern River Basin, while it has considerable timber, has large areas which are bare or covered with a light growth of

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brush; that the Owens River Basin is bare soil or rock, except where there is a narrow fringe of timber between the northwest side of Long Valley and the timber line. From this it is seen that the fluctuations of the flow in these streams bear a striking relation, and apparently a direct proportion, to the amount of forest cover over their drainage areas, the fluctuations being greatest on Kings and Merced Rivers with the greatest forest cover, and least on Owens River with the least forest cover, with Kern River as an intermediate factor in both forest cover and stream fluctuation.

TABLE 11.

1905.	Merced River, 1 090 sq. miles.	Kings River, 1 742 sq. miles.	Kern River, 2 345 sq. miles.	Owens River, 450 sq. miles.
Total discharge, in acre-feet.	771 300	1 289 000	532 100	156 600
Maximum daily discharge, in second-feet.....	Mar. 19 8 020	June 13 9 795	June 15 3 039	June 20 533
Minimum daily discharge, in second-feet.....	Sept. 25 35	Oct. 22 150	Oct. 8 175	Aug. 20 146
Ratio of minimum to maxi- mum daily discharge....	1 to 229	1 to 65	1 to 17	1 to 4
Month of maximum dis- charge, and percentage of total.....	May 27%	June 30%	June 25%	June 15%
Month of minimum dis- charge, and percentage of total.....	Oct. 0.46%	Oct. 0.82%	Sept. 2.35%	Aug. 6.64%
Ratio of minimum to maxi- mum monthly discharge..	1 to 56	1 to 36	1 to 10	1 to 2
Total depth of run-off, in inches.....	13.26	13.89	4.25	6.60
Depth of run-off during first ten days of warm weather, and percentage of total...	May 16-25 1.62 12.2%	May 17-26 1.97 14.2%	May 19-28 0.40 9.4%	May 22-30 0.26 3.9%
Depth of run-off during month of minimum fall flow, and percentage of total.....	Oct. 0.06 0.46%	Oct. 0.12 0.82%	Sept. 0.10 2.35%	Oct. 0.47 7.01%

Another interesting condition of the Merced and Kings Rivers is their minimum flow. Their drainage basins, while having the maximum forest cover, give a still less absolute discharge in cubic feet per

FIG. 1.—EASTERN SLOPE OF SIERRA NEVADAS NEAR HEAD OF
BIG PINE CREEK, A TRIBUTARY OF OWENS RIVER.

FIG. 2.—EASTERN SLOPE OF SIERRA NEVADAS. GLACIER AT HEAD
OF BIG PINE CREEK, SHOWING CREVASSE.

second than even Owens River which has a drainage area from one-sixth to one-ninth as large, and no forest cover.

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TABLE 12.

1906.	Merced River, 1 090 sq. miles.	Kings River, 1 742 sq. miles.	Kern River, 2 345 sq. miles.	Owens River, 450 sq. miles.
Total discharge, in acre-feet.	2 090 000	3 920 000	1 900 000	260 000
Maximum daily discharge, in second-feet	Jan. 19 18 400	June 20 26 600	June 22 9 505	June 25 889
Minimum daily discharge, in second-feet	Oct. 30 62	Jan. 2 205	Jan. 8 230	Jan. 8 162
Ratio of minimum to maxi- mum daily discharge.....	1 to 297	1 to 129	1 to 41	1 to 5
Month of maximum dis- charge, and percentage of total	June 24%	June 26%	June 24%	July 16%
Month of minimum dis- charge, and percentage of total	Oct. 0.36%	Nov. 0.59%	Nov. 1.59%	Feb. 4.38%
Ratio of minimum to maxi- mum monthly discharge..	1 to 67	1 to 44	1 to 14	1 to 4
Total depth of run-off, in inches	35.92	42.26	15.18	10.97
Depth of run-off during first ten days of warm weather, and percentage of total...	June 16-25 3.93 10.6%	June 16-25 4.98 11.8%	June 15-24 1.46 9.6%	June 20-29 0.64 5.8%
Depth of run-off during month of minimum fall flow, and percentage of total	Oct. 0.13 0.36%	Nov. 0.25 0.59%	Nov. 0.24 1.59%	Nov. 0.60 5.47%

The present intention of the Forestry Bureau to plant forests on a large portion of the Owens River drainage area would seem to be unwise, in view of the foregoing conditions. This is particularly true as this stream is the intended source of the water supply of Los Angeles, and at no very distant day every drop of its water will be carefully hoarded.

Plates XLIV and XLV show the snow fields of the upper levels of the Owens River drainage on the east side of the Southern Sierras. Particular attention is drawn to the fact that all snow has melted from under the trees or around them and only remains in the drifts in the bare areas between the clumps of trees.

Mr. Willis. BAILEY WILLIS, ESQ. (by letter).—Four propositions are stated by Colonel Chittenden, and his argument is devoted chiefly to proving that they are not true. The writer holds that they are essentially true, provided that the limiting conditions, such as modify any general case, are appropriately considered. These propositions will be considered in order.

“The commonly accepted opinion is that forests have a beneficial influence on stream flow:

“(1) By storing the waters from rain and melting snow in the bed of humus that develops under forest cover, preventing their rapid rush to the streams and paying them out gradually afterward, thus acting as true reservoirs in equalizing the run-off.”

Forests do have a beneficial effect, although their capacity for such effect is not unlimited; neither are they in every location the most effective means of regulation. It is important to distinguish between level or very gentle slopes and steeper slopes, particularly those of mountainous districts. On the level, a forest-covered area and a well-tilled field compare closely in their capacity to absorb rain, but the forest prevents from 20 to 40% of the rain from reaching the ground (according to density of foliage, kind of trees, intensity of storms, and other conditions), and it transpires a large amount of moisture. Consequently the bare level field nearby receives more rain, and contributes more to ground-water. It also evaporates less than the forest transpires, and consequently it retains more from the same rain than the adjoining forest. The statement quoted from Mr. Zon* is strictly correct, as is shown by the experiments cited by Ernst Ebermayer,† who sums up the case as follows:

“In view of the exact investigations which have been cited above and which extend through 30 years, it is no longer possible to maintain the assumption so generally made, that forests increase the amount of ground-water, and constitute a storage reservoir for the supply of springs, at least not so far as plains are concerned. The draining effect of the forest is, on the contrary, so great that a much greater supply of water gathers in the depths beneath a treeless plain than beneath dense woods, provided that the underground conditions be the same in both cases. It follows that under these conditions the discharge of springs is not increased, but lessened by woods. Decided emphasis must, however, be laid upon the fact that these conclusions hold primarily only for the plains, and are not to be extended inconsiderately to uplands and mountains.

“Although the influence of the woods upon soil, moisture, percolation, and ground-water, under like soil conditions, must be the same in mountains as it is in lowlands, and only moderate differences are likely to appear, nevertheless the forest on the mountain differs very decidedly from that on the plain in regard to water control, inasmuch

* Page 251.

† Einfluss der Wälder auf die Bodenfeuchtigkeit, auf das Sickerwasser, auf das Grundwasser, und auf die Ergiebigkeit der Quellen, 1900, page 38.

as in mountain regions, in consequence of the surface run-off of rain Mr. Willis. and snow water from the slopes, a factor is introduced through which wooded mountain slopes receive a much larger amount of water than bare unwooded water-sheds."

Any one who will examine the data, derived from 30 years of observation and experiment, on which Ebermayer bases his conclusion, will hardly think that "*post hoc, ergo propter hoc* is the argumentative process relied upon."

The question of regulation of floods from mountain valleys by forests cannot be allowed to pass without a discussion of Colonel Chittenden's argument. In assuming "an inclined-plane surface, practically impervious to water," he introduces a special condition that may arise under a forest, but only as a limiting case, namely, when the forest has stored all the water possible and can do no more. On slopes which facilitate run-off, no other agent can do as much.

Contrasting the division of rainfall on forest slopes with that on bare slopes, there is, in each case, water which is lost to use, a minus quantity, and water which is gained for use, a plus quantity. The loss on the forest slope is: (1) That which stays in the tree tops; (2) that which is held by litter and evaporated from it and from the soil; (3) that which is transpired through roots and leaves. The loss from a bare slope is evaporation plus run-off. The gain in either case is through percolation and ground storage for a longer or shorter period.

During a period of little or no precipitation, the chief loss from the forest is by transpiration; on the level, as determined by observation in Russia, France, and Germany, it is greater than that by evaporation from a bare surface, and lowers the water table relatively to that in an adjoining field; on mountain slopes, it no doubt has a similar effect, which is, however, in considering the losses from forested slopes, to be balanced against quick run-off from bare hills. At the end of a dry period the ground reservoir beneath the forest, on plain or mountain, is in a condition to receive more water than that beneath a bare slope.

During a period of precipitation the chief loss from the forest is in the tree tops. As already stated, it varies greatly in amount, but, whatever it comes to, it is, in the limiting case of an excessive rain, a beneficial because a minus quantity.

At the end of a dry period, the layer of leaves, rotten wood, and humus beneath a forest has a capacity to absorb as much as 50% of its volume of water. When rains come, this amount is retained from run-off or ground storage and later evaporated. So retentive is the humus that, while it serves as a sponge to prevent run-off and transmit water to the ground reservoir, it does not give up much to storage, and yields its water-content only slowly to the moderate influences of

Mr. Willis. evaporation in the shade. The amount thus retained is small as compared with that which is transmitted through wet litter to ground storage, but it is an amount which can be controlled by regulating the litter. The proportion of precipitation absorbed by forest litter, therefore, need not be an injurious minus quantity if the water is wanted in the stream; but it is a beneficial minus quantity when there is more water than can be handled. The algebraic sum of these opposite results depends on climate, topography, and water service, and, under conditions of good forestry, determines what proportion of litter shall remain beneath the trees, and to what extent measures shall be taken to substitute an open soil for it at the surface. He reasons without thought who reasons without reference to forestry in regard to forest conditions.

Thus considering the limiting case of great precipitation, it must be recognized that the forest on a slope holds back the most water, unless it can be shown that percolation into a bare slope exceeds loss from tree tops, loss in the forest litter, if any, and percolation into the ground under the forest. There are cases where percolation into bare ground on a slope reaches this surprising proportion, as on sand hills, and on some very coarse granite soils of equally open texture; but it does not reach this proportion in loams and clay soils; on the contrary, on these quick-spilling soils, percolation is a very small part of precipitation.

Statistics of comparative run-off from bare and forested slopes, which are observed in such a way as to yield data for close comparison, are not known to the writer. It is probably safe to say that they have not been observed in the United States. To obtain them, one must observe the same precipitation on adjoining areas, of like slope, soil, and geological structure. Only in this way can the forest influence be isolated, and its effect ascertained statistically. The writer, however, has before him the results of three years' investigation by Professor L. C. Glenn, of Nashville, Tenn., in the Southern Appalachians, the most critical region of the United States, and has gathered from Professor Glenn's manuscript report to the Forest Service the following summation of details which bear on this question.

Forty-six creeks and small rivers, the water-sheds of which may be described as timbered rather than cleared, are known, according to observation and local repute, to rise gradually in times of flood, to continue high for several days, and to subside slowly. They carry but little sediment, and they maintain a good volume of water during dry seasons.

Thirty-eight creeks and small rivers in the same water-sheds, having slopes which may be described as cleared rather than timbered, are known, according to observation and local repute, to rise rapidly in times of flood to extreme flood height, to carry excessive quantities

of mud, sand, and gravel, and to fall quickly. In dry seasons they are very low, and the range from lowest to highest stages has increased, and has inflicted much damage in very recent years.

Two other classes of conditions may be recognized in Professor Glenn's descriptions: One, of valleys which are still timbered, but which are being damaged by the commencement of logging operations, and particularly by the erosion of logging chutes; the other, of watersheds which are largely cleared, but grassed, and which the grass protects from erosion, though not in the same degree from rapid run-off.

Such evidence as this, collected by a qualified and impartial observer, with reference to individual water-sheds, establishes, for the region in question, comprising the mountains of North Carolina, Tennessee, and Georgia, the fact "that forests do exert a beneficial influence on stream flow by storing the waters from rain and melting snow, preventing their rapid rush to the streams, and paying them out gradually afterward, thus acting as true reservoirs in equalizing the run-off."

As compared with these direct observations on limited water-sheds, the statistical data of precipitation and run-off on large streams, as presented by Colonel Chittenden, have a minus value for consideration of the question at issue. The stations of the Hydrographic Service and of the Weather Bureau are too few in number and too widely scattered. The method of analysis does not take account of the great diversity of conditions in an extensive water-shed, to which Colonel Chittenden calls attention.* Engineers know that a circuit of approximate observations may be run and close fairly well if the number of observations be sufficiently large, the result being the mean of many balancing errors; this is also true in the observation of flood stages or low-water stages, on the Ohio, for instance. In any case the stage is a mean of balancing conditions on hundreds of small water-sheds, some of which are forested and some deforested, some of which are and some of which are not cultivated. In that mean, the effect of the individual water-shed is so obscured as to be quite indistinguishable. Conclusions based on inferences from such data have not the value which they should have, in order to carry weight with the engineering profession.

Colonel Chittenden, further, says:

"The commonly accepted opinion is that forests have a beneficial influence on stream flow:

"(2) By retarding the snow-melting in the spring and prolonging the run-off from that source."

In regard to the influence of forests on melting snow, Colonel Chittenden argues "that the effect of forests upon the run-off from

Mr. Willis. snow is invariably to increase its intensity. This results from two causes, one affecting the falling of the snow and the other its melting."

Following Colonel Chittenden, snow which falls in the open may be divided into that which remains evenly spread and that which is gathered into drifts; and snow which falls in the forest may be divided also into two parts, namely, that which reaches the ground and that which hangs in the branches. The snow which is held back in drifts and that which is hung up in the branches of the trees and returned to the air by evaporation may be said to be withdrawn from immediate run-off. The statement is not quite correct in either case, but the qualifying considerations are not such as to modify the balance which may be roughly struck between the two quantities, when each approaches a maximum. There remains in the open an uncertain but large proportion which is melted, as all agree, early in the spring, and there remains in the forest a considerable proportion which is held in the protection of the trees until later in the spring and early summer. From any such snow-covered region of moderate altitude, we commonly have spring floods, which are produced chiefly by the melting of the snow in the open, both from the areas that are evenly covered and from the surfaces of the drifts, and subordinately by a contribution from the snow that is melting more slowly under the trees. Were all the snow in the open, the proportion which would be contributed as run-off to the early spring floods would be much larger, and these floods would be much more disastrous. Later in the season, the forested parts of such regions sometimes occasion severe floods in consequence of a large body of snow lingering until the warm winds strike it. This effect is undoubtedly unfortunate, but the question may well be asked whether it were better to have the June flood on top of that of April, rather than divided, as they are likely to be in consequence of the presence of the forest. The condition is one in which excessive precipitation results in run-off which is beyond the control of any natural agency, and high waters will ensue whether or not there be any forest.

In the Northwest there is a special condition prevailing on the higher ranges which rise above the tree-line and even into the region of perpetual snow, a condition which is described by Colonel Chittenden, and has the effect that he regards as general. The writer is familiar with it in the high mountains of Western Montana, Idaho, Washington, and Oregon. The deeply sculptured crags and peaks of the mountains above the tree-line produce such eddies in the strong winds, that a very large part of the heavy snowfall is gathered into drifts. At these altitudes even "chinook" winds are cooled by expansion as the air currents push upward along the mountain sides, and they melt less snow than on lower slopes. Therefore the drifted snow banks linger far into or through the summer, continuously feeding

the lakes and streams. The special condition is one of incipient glaciation. From the glaciers of Mount Rainier one may learn what happens when this condition develops extensive bodies of ice and snow, and Colonel Chittenden has kindly furnished an illustration—that of the White River (Fig. 1, Plate CX). This particular White River flows from the Emmons and White River glaciers which cover the eastern and north-eastern side of Mount Rainier, and its well-earned character of a bad stream is due to this fact, and not to the forest which once densely covered its lower course, but which is now severely cut and burned. Colonel Chittenden is unfortunate in not being acquainted, apparently, with the real character of the river. The writer was well acquainted with it at one time; he spent four years in these forests before they were touched by axe or fire (1881-84), and became familiar with the glacial and non-glacial streams by personal contact. The former are subject to well-known daily fluctuations, rising in the morning and falling at night; the writer preferred to wade them early in the day. They also rise sharply under warm winds, and fall quickly when the air is chilled. The non-glacial brooks were uncompromisingly high and comparatively steady day and night, from some time in March until the snow was gone from under the forest cover.

Thus the writer's conclusion, based upon experience of snow conditions ranging from the mountains of North Carolina to the glaciers of Mount Rainier, is that the forest does exert a beneficial influence in retarding the melting and run-off of snows, even though, as happens in certain areas, the snowfall is so great as to produce floods in spite of the forest's influence.

Colonel Chittenden maintains that:

"In periods of extreme summer heat, forests operate to diminish the run-off, because they absorb almost completely and give off in evaporation ordinary showers which, in the open country, produce a considerable temporary increase in the streams."

This fact, regarding the influence of forests upon light summer showers, might have been supplemented and the argument strengthened by stating that during the hot seasons forests also transpire a large amount of water which is taken from soil moisture, and these two facts together set a limit to the value of forests in regions of meager rainfall. For instance, it is established by experience on the Great Plains, as well as in the orchards of Southern California, that wind-breaks may take more moisture from the soil than the crops near them can afford to lose, and the effect on the crops would be the effect on any spring in equally close proximity; but against this demand of the plant for moisture to carry on its physiological processes, must be set the contribution which it has made at an earlier season to ground-water storage in excess of the contribution which would have resulted from bare ground. Here again recurs the question of slope and the

Mr. Willis. proportion of run-off, and it must be recognized that, in the semi-arid plain, narrow limitations are placed upon the advantageous growth of trees, which do not hold for the mountains under humid conditions. There, more water is stored by the slow-spilling surface and retained by the ground under the forest than by that under the quick-spilling slope of bare ground. The stored water in the ground is the principal source of low-water supply, and thus, in times of precipitation, the forest performs a service which inures to the advantage of low water in times of drought.

The ideal condition for ground-water storage, in order to maintain stream flow, is an even plain covered by a receptive soil, that is, by a soil which is in the best state of preparation for growing crops. Such a soil is maintained by deep plowing, by culture during the growing season, by keeping the fallow ground broken up, and by crop rotation; that is, by methods which increase the productiveness of the fields. The one essential condition, however, to make this surface more retentive than a forest-covered surface, is that it shall be so nearly level that run-off will not be a notable factor. To establish this condition on gentle slopes, the farmer may resort to contour plowing and harrowing, but to establish it on steep slopes, it is necessary to build terraces. All the older nations of the world have had to build terraces in order to extend the cultivated areas far enough up the mountain slopes to supply, in some measure, the demand of growing populations for food. We are still a long way from that condition, but nevertheless it should be recognized that terraces have a place in systems for the conservation of waters for city supply, power, or navigation. In a region where the conditions are so difficult and so critical as they are in the Southern Appalachians, farming should be carried on only as far as terracing can be adopted economically. Beyond that area, wherever terracing would be so costly as to prohibit farming, the surface should be covered with a vigorous forest.

The writer cannot leave this subject without commenting on the oft-repeated statement that natural re-forestation restores the conditions of water control, which existed under virgin forests. No one will deny that natural re-forestation is a general result of the initial cutting of the forest. No one can reasonably affirm, however, that the second growth which springs up behind the American lumberman possesses the character of the virgin forest. Its roots are weaker, its branches afford less protection, and its influence upon water storage is different. In some cases, the young forest being more open than the old, and its demand for water less great, a larger proportion of water will appear in the springs, and the rivers will run fuller for a time. This is particularly true of the densely forested ranges of the Northwest, and Colonel Chittenden cites a special case

in a region of moderate rainfall and porous soils (Nevada), where Mr. Willis. this effect was a maximum before the new growth used much water. If the young forest were vigorous enough and could be given time enough to grow to the stature and density of the old stand, it would eventually re-establish the conditions that existed under the virgin forest; but in any case, during the growth of the young forest, even under the best conditions, erosion has begun its insidious work. The gully that is cut in the forest cover may be but a few inches deep, or, as frequently the case in the Southern Appalachians, many feet deep; it may be covered by logs, brambles, and weeds; but it lowers the level of discharge by a corresponding amount and gains an advantage for attack upon the entire slope. That advantage it never loses, and the effect is the removal of the superficial soil at first and ultimately of all the soil which is above the level of discharge of the mouth of the gully. Though this ultimate effect be deferred for a long term of years, it will certainly be reached. In the high mountains one has only to climb the crags above the tree-line to see the result. In the Southern Appalachians, where the soil is decomposed rock, of impervious texture and great depth, one has only to consider the logging chute and the old field. There, from virgin forest to abandoned field is frequently an interval of but five years, and, while it is true that the farmer has a worse record than the lumberman, the difference will not be material fifty years hence. In China, where the precipitation is much less and the conditions, consequently, less favorable to erosion, the writer has seen several thousand square miles of mountainous country like the Appalachians, which has been completely deforested, denuded to the bare rock, and depopulated, in the last century and a half. There is great reason to protest earnestly against any superficial observation which leads to the conclusion that no harm is done by reckless lumbering and ill-judged agriculture, because Nature with her wonderful recuperative power in some measure conceals the scars.

"The commonly accepted opinion is that forests have a beneficial influence on stream flow:

"(3) By increasing precipitation."

In opposition to views which are frequently supported by general rainfall statistics, and are endorsed by Colonel Chittenden, the writer holds that forests do affect precipitation; that they increase it slightly over that which falls upon green fields, and that they increase it notably over the amount received by bare plains under critical atmospheric conditions. He holds that these relations may be perceived over sufficiently wide level lands, but that they are particularly perceptible in the case of mountain ranges. More important, however, is the influence of the forest or rock of a mountain range, because there the

Mr. Willis. effect of deforestation is to increase conspicuously the irregularity of precipitation.

The principle which underlies the effect of forests on precipitation is very simple. Moist air currents rising into the upper strata of the atmosphere are dilated and cooled. Their vapor is condensed and falls as rain. Any effect which increases the proportion of moisture and lowers the temperature promotes precipitation; any effect which decreases the proportion of moisture or raises the temperature lessens precipitation.

It has been shown that forests transpire more water than is evaporated from the bare ground, and the experiences of balloonists, particularly in France, show that the air is cooler over a large forest, even at a height of 1500 m. Sometimes, over hot plains, a shower may be seen to begin to fall, but to evaporate before it reaches the ground. While these effects are certainly subsidiary to the great movements of moisture along the cyclonic tracts from the west and south toward the northeast across North America, they cannot be said to be negligible.

Man cannot readily change a great plain from a forested region to one bare of soil, and when he substitutes for the trees a vast stretch of grain, as has been done in the Upper Mississippi Valley, he does not change the conditions of radiation so seriously as to affect the powerful rain-bearing currents which sweep up from Texas and the Gulf. The case is entirely different, however, in regard to mountain ranges. It is easy, with the aid of the rills and torrents, to remove their covering of vegetation, and they can be denuded so completely that the radiation from bare rock replaces that of forest for an entire mountain range. The precipitation over mountains is always less regular than that over plains, for the irregularities of the mountain slopes cause the air-currents to rise and expand and cool very unequally; and when these conditions are exaggerated by removing the regulating effect of the tree surface and by substituting the aggravating effect of the bare surface, conditions are produced that result in more violent floods and more excessive drought than existed before Man did his irrevocable work.

"The commonly accepted opinion is that forests have a beneficial influence on stream flow:

"(4) By preventing erosion of the soil on steep slopes * * *."

It is difficult for the writer to understand how any observer can say, as Colonel Chittenden does,* that there is a deficiency of evidence to support this view. As a geologist, the writer's attention has been constantly drawn to the evidences of erosion under the varied conditions of relief and climate in nearly all parts of the United States

and also throughout Europe and not a small part of China. There Mr. Willis. is, according to his observation, a definite relation between the different valley deposits and forest-covered hills on the one hand or denuded hills on the other. He cannot recall an exception to the fact that streams flowing from hills which have been denuded of forests have filled their lower valleys with broad flats of sand and gravel through which the waters meander in shifting, uncertain channels. Equally closely related are forested mountains and clear streams, which flow through valleys with well-established channels and more or less extensively developed flood planes that are covered with appropriate vegetation.

In all regions where precipitation is sufficient to maintain a forest cover, a certain equilibrium is reached between the rate of soil production and soil erosion. Streams of a certain size, on a certain slope, are able to keep their bottoms clean and slowly to erode them. Less efficient rills are unable to penetrate the protective cover and cannot effectively begin the task of corrasion. This limit varies according to climate, vegetation, and soil conditions, and is not the same throughout any one district, much less in regions so different as the Appalachians and the Cascade Mountains; but wherever virgin forests have persisted during a geologic age, as they have over a great part of the United States, the processes of Nature have brought about the adjustment, and have reduced the progress of erosion to a slow rate.

This adjustment is gravely disturbed when Man cuts a forest. No material damage need ensue if he does so intelligently and protects the surface until vegetation can recover from the relatively slight injury that is done by forest cutting under good methods; but the methods of the American lumberman, followed by fire, as they too often are, result in such a disturbance of the adjustment as to make recovery extremely difficult, even if possible.

The effect of the disturbance is seen in the vigorous growth of thousands of little gullies, which are scarcely noticeable at first, but which grow like the branches of a tree, and spread far out into the previously uneroded surface. Vegetation always makes a brave fight, but unless aided by Man it can never recover the position which it originally held.

As stated by Colonel Chittenden, Man too often does not aid vegetation, but carelessly establishes fresh channels of erosion in wheel ruts, logging chutes, etc.; he cultivates the ground under conditions that promote the gathering of the rills and the washing of the soil. Thus, he proceeds with criminal negligence to accelerate the process which, if continued, will eventually make such districts as the Appalachian Mountains uninhabitable.

Any one who takes a broad view of this vital question of the

Mr. Willis..control of the waters in their circulation over and through the land must recognize that the forces of Nature, involved in rainfall and sunshine, in the quiet stream and in the great flood, can be regulated and brought to serve Man, but only through the co-operation of all the forces that he can bring to bear. The farmer who before long will cultivate more than one-half of our country, the herdsman who will graze his flocks over one-fourth, and the forester who, to supply our needs, must raise his crop of trees on one-fifth, must all co-operate to control the Genii of the waters. The opportunity to make them our servants is where we can turn them from the paths of the air or the channels of the rills to the dark courses underground in the recesses of the rocks. Every method of agriculture, grazing, and forestry must be used to promote ground storage and reduce run-off. Even then there will remain a certain surplus of flood waters, the immediate gathering of which cannot be prevented. These and all other waters that join in our rivers in their course from the mountains to the sea, must be committed to the care of the engineer, whose duty it is to store, to divert, to regulate them, so that they shall be made to serve every purpose to which civilization can put them.

Leighton. M. O. LEIGHTON, Assoc. M. Am. Soc. C. E.—This paper is so admirable a literary composition and so persuasive in its presentation that one is well-nigh beguiled into acceptance of the author's precepts. It is only after critical review and the application of fundamental principles that one is prepared to appreciate how erroneous are the premises, how mistaken the deductions. Such a consideration reveals several points of peculiarity, which may be summarized as follows:

1. A large number of the premises and observations on which the author's conclusions are based are in error;

2. Nearly all his difficulties with reference to the relation of forests to stream run-off would be solved if he had not misconceived certain fundamental principles;

3. In the progress of his argument he presents contradictory views;

4. He rejects many generally accepted ideas, because little or no evidence has been brought forward in their support, and then he substitutes concepts of his own without any accompanying demonstration.

An attempt will be made to reveal all these peculiarities in the following discussion. No effort will be made to treat them in categorical order, because such is not the prime purpose of this rejoinder. The points will be indicated incidentally in the discussion of the principles involved.

At the very outset there is revealed a fundamental misconception which largely explains many of the adverse deductions in relation to

forest control of run-off, viz.: "By storing the waters from rain and Mr. Leighton. melting snow in the bed of humus that develops under forest cover, preventing their rapid rush, * * * ." If this means strictly what it says, the author believes that the bed of humus is the agent of storage. The impression here conveyed is intensified by the practical illustration given under the caption "Effect of Forests Upon the Run-Off from Rainfall," in which an inclined-plane surface is used, "practically impervious to water, with a layer of sand covering some small portion of it." The author has forgotten the greatest reservoir, namely, the ground. When he assumes an inclined-plane surface, impervious to water, he denies the existence of ground storage. The speaker has never before heard the principle of forest cover so applied. The common understanding is that the forest mulch is not the storage agent in any except a merely nominal sense. Its whole function is to protect the ground, so that its surface will not become hard and impervious, and to conduct the water of precipitation into the interstices of the underlying soil. The effects of this fundamental misconception are apparent in many parts of the paper, and, in fact, the whole argument relative to the inefficiency of forests in conserving water is based upon it. Were the author's original conception correct, then indeed would his conclusions have a measure of justification, but not otherwise.

Although Colonel Chittenden denies that there is a pervious soil under the forest, he readily grants that there is a marked retentive capacity in bare soil. The reader must infer, either that there is no soil under the forest, or that soil covered by forest must in some way remain impervious. The really fatal admission, however, is in the sentence: "In newly plowed ground it (the retentive capacity) is probably greater than in the forest." There is a reason why newly plowed ground is, as the author implies, more retentive than unplowed, bare soil. This reason is that the compacted surface crust has been broken, the underlying earth has been disturbed and loosened, and thereby made absorbent to the precipitated water that falls upon it. After the rains have descended, and the sun has shone on this plowed ground for a period, a compact surface is gradually formed. The result is that the water is less easily absorbed and the retentive capacity of that particular piece of ground constantly decreases, as the date of plowing recedes.

What now is the effect of the forest-mulch cover? It protects the ground from the direct pelting of the rain and the resulting process by which the earth's crust becomes compact, and keeps it in a condition that is always equivalent to that of a newly plowed field. No one who has ever scratched away the mulch cover in a forest can deny this. The earth below is always found in an open and porous condition. How, then, can the retentive capacity of a newly plowed field be

Mr. Leighton. greater than that of the soil beneath the forest, provided, of course, the two soils are of the same character? With physical conditions identical, the retentive capacity must be the same; but, when one recalls that the forest mulch must assist in this absorption by retarding the water that would otherwise run over the ground, the superiority of forest-covered soil for modifying run-off would seem hardly to be susceptible of more complete demonstration. It is readily admitted that there are some soils which, even under forest cover, will not retain as much of the precipitation as some others which are kept bare; but, in making comparisons of this kind, one is assuming, of course, that the conditions are comparable. It is assumed that the soils are the same in point of texture and retentive capacity. In the beginning of his paper Colonel Chittenden implies that the soil beneath the forest must be impervious. Later, in the paragraph quoted, he implies that it may be somewhat pervious, but not to as great a degree as the soil unprotected by forests; all of which indicates that the original conception, as well as the deductions, are unfortunate, from his point of view.

In the pursuit of his argument, a contradiction is presented.* The regulative effect of the forest bed in moderate storms is clearly admitted. It is then stated that, by reason of later and heavier storms, this forest bed gives up what it had originally retained. Of course, the forest bed does not store the floods, as the author claims, and equally, of course, it does not prolong the run-off after the storms have passed, this being the function of the great ground-storage reservoir; but, assuming for purposes of illustration that his contentions are true, how can it be possible that this forest mulch may contribute to a later flood, and produce a devastation greater than would occur if the area had been bare? Assume that a rainfall has occurred, which has just saturated the forest mulch, and that it can store no more. Let a later and heavier rain follow. Is not this forest mulch going to retain its retentive capacity, irrespective of later rains? If so, how is it possible that merely by reason of a later rain the forest mulch is going to shed all that later rain and, in addition, the water which it had received from the previous rain? Under such a conception, the second rain must have an effect of desiccation on the mulch. If the contention were that the forest mulch would have no effect on the run-off from the second rain, admitting for the moment that the author had not misconceived the fundamental idea, then his conclusions would be justified; but, in order to contend that this forest mulch is going to increase the flood, the assumption must be made that it will give up gratuitously that which it had previously collected. It is hardly likely that so able a man as Colonel Chittenden will, on taking thought, subscribe to such an assumption.

The paragraph on pages 250 and 251 contains another contradictory Mr. Leighton statement, and presents certain new concepts, unsupported by supplementary evidence. The first sentence is an admission that, in periods of extreme drought, springs and little streams dry up more completely under deforested than under forest conditions. It is then stated that the difference is exaggerated in the popular mind. On the contrary, it is very doubtful if the difference between the two conditions could be exaggerated. One could hardly exaggerate a difference between flowing water and a dry spring or rivulet. The margin must be 100% in all cases. The exception noted by the author in the foot-note,* with reference to the drainage of low swamp lands, while true, has not even a remote relation to the conditions under discussion. The drainage of a swamp area is essentially the tapping of a reservoir. It bears the same relation to spring and rivulet flow as would an artificial storage reservoir. The water released during dry seasons must prolong the flow, of course, whether the release be effected by raising a gate or digging a trench. The author then states that, because springs and streams are dried up, there is no reason why there should be any appreciable diminution in the flow of the great river. This idea is strange and new, and brings up a question as to the sources of supply in a great river during a period of extreme drought. No one can well deny that rivers are supplied during such periods from ground storage, which collects almost entirely in the small streams and rivulets, and unites ultimately to form the great river. The immediate drainage on any great river, which contributes seepage directly to the main artery, is always comparatively small and sometimes negligible. Why, for example, has there been any water whatsoever in the Ohio between Pittsburg and Cairo during the summer and fall of 1908? No one believes that, had the immediate drainage area contributing to this main artery been depended on, the Ohio channel would have been anything but a dry bed. The supply that has been contributed to this river has come from the millions of small rivulets, each of which has drawn on its immediate ground storage, and, by uniting, has formed the brook which, also drawing upon its immediate storage, has formed the larger tributary, and these, supplemented to some extent by immediate ground storage, unite to form the river which, in spite of the lack of rain, has persisted. In other words, the great ultimate sources of supply for any river lie in these small rivulets, and the discharge of any river is but the result of their union. This is a matter of elementary physiography, long ago enunciated, repeatedly confirmed, and, as far as the speaker knows, undenied up to the present instance. Admitting, therefore, the truth of the proposition and, in view of the author's admission that springs and rivulets dry up more completely under deforested than under forest conditions, what becomes

* Page 250.

Leighton. of the contention that forests do not sustain stream flow during dry seasons?

It is of interest to pursue further the author's reasoning. He contends that if all these small rivulets become dry the river will nevertheless, somehow, somewhere, get its water supply. Moreover, the conception implies that the normal supply of water in these rivers must appear suddenly, as if in response to the smite of Moses' staff. If the course is followed, it will lead out of dry rivulets and brooks into a normally flowing stream. The transition from dry conditions to those of normal flow must be abrupt. Whence comes this providential supply? The facts are that the drying up of springs and little streams means simply that the ground storage has been drawn down or exhausted. The concept of the author is hopelessly involved. Between his admission of dry springs and little streams, and his assumption of normally flowing rivers, his argument is ground to pieces, as it were, between the upper and the nether millstones.

The author further states that heavier showers, which make freshets in the open, are largely "absorbed in the leaves and forest bed and pass off in evaporation." This concept is advanced without demonstrated proof; how does the author know that this is true? The demonstrated facts are all to the contrary. The showers which, falling in the open country, make freshets, must, when they fall on the forest, pass through the "leaves and forest bed" and enter the ground, merely because they have the opportunity, which opportunity is largely denied them in the open. The water which is absorbed in the leaves and forest bed from heavier showers is but an insignificant part of the total precipitation.

Further along it is stated that it is better to have a good than a uniform flow in a river. It is difficult to imagine how one can be attained without the other. In order to have a good flow, it is necessary that the low extreme be prevented, and this very prevention means comparative uniformity. Good flow (and by this it is assumed that the author means abundant flow) is attained quite as much by the prevention of low periods as by the production of high ones.

The final sentences of the paragraph* enunciate a curious doctrine. It is stated that "great rivers swallow up and equalize the small irregularities of their head-waters and actually experience somewhat larger low-water flow than if their water-sheds were still thickly forested." This is not uniformly borne out by experience; but only the logic of the argument will now be considered. If it be true that the source of supply of great rivers is ultimately in the small rivulets, how is it possible, with lack of uniformity in those small rivulets, to secure uniformity in the large ones? Of course, if the lack of uniformity took place in successive periods over an entire drainage area,

there might be uniformity in the stream below, because, after one small unit of the supply had exhausted itself, the next would supply the deficiency, and so on to the end; but, as the author forcibly states, natural run-off cannot be controlled with such mathematical accuracy. Uniformity in small rivulets begets uniformity in the main artery supplied by those rivulets. The cause and effect are so clear as to become axiomatic. If, as the author contends, deforestation assists in the drying up of springs and rivulets, then, as a necessary consequence, the flow of the main affluent must become less, and the effect will be more and more pronounced as the proportionate amount of deforested area decreases, until finally, when there is absolute deforestation, there must be this tendency of small rivulets and springs to dry up over the entire area. If the author would give consideration to the all-important matter of ground storage and apply thereto some of the fundamentals of geology and physics, he could readily see the fallacy of his argument.

With reference to the section concerning the influence of forests on snow-melting, it appears that the author's observations have been confined to a comparatively limited area in a high altitude. Several of his observations are faulty for the areas which he is considering. He has apparently neglected all consideration of the physical principle of diathermancy. His premises will be considered in their order of presentation.

The statement that forests prevent the formation of drifts, and distribute the snow in an even blanket over the ground is, of course, quite erroneous. Every country boy has floundered through drifts in the forest, and Dr. George Otis Smith, in his discussion on this paper, testifies that in the very region concerning which Colonel Chitenden appears to be most familiar, and in the same year in which the latter made some of his observations, his (Dr. Smith's) horse became stalled in a snowdrift in a dense forest on or about July 1st. Further, the author states that, "in the open country, the snow is largely heaped into drifts," which is quite as erroneous as the first statement. On the tops of peaks and in extremely high altitudes, constantly subject to great winds, this may be true at times; but it is certainly untrue for the greater part of the country, the quantity of snow in the drifts being but an exceedingly small part of the total accumulation. Even in high altitudes, the heavy and uniform blanket of snow is common, as can be shown by hundreds of photographs on file in the Geological Survey.

Consider this, together with the author's admission that the period of snow-melting in the open country begins much earlier than in the forest; and consider further the well-known physical fact that the melting of snow takes place at the bottom and not at the top, except, of course, in the event of warm melting rains. This is a point

Mr. Leighton, entirely overlooked by the author. The blanket of snow in the open, not heaped into drifts, melts first, and the water naturally seeks to percolate into the ground. Bare soil will not absorb this water to the maximum extent. In many cases, in northern latitudes, the surface is frozen before the snow falls upon it, and it thereby becomes practically impervious. The first rush of melted water goes directly into the streams and, as it is a quick melting, as Colonel Chittenden contends with so much truth, it follows that there must be a gorging of the rivers. Now, of course, these freshets would be considerably less if the greater part of the snow were concentrated into drifts, as claimed by the author; but, inasmuch as over the greater part of our snow-covered country this is not the case, the saving element does not apply. Consider now a drainage area, one half bare and the other half forested, and apply these principles to it. The snow covering the ground in the open, exclusive of drift, melts rapidly and rushes into the watercourses, filling them to a certain height. With this in mind, assume that the forest has been removed, and that the whole area is bare; does it not follow that, where formerly the 50% bare country contributed its melted snows to the river channels and filled them to a certain height, 100% of the same area would fill them to a greater height, or, in fact, would practically double the discharge? Under the forest condition, there is a division of floods. One-half the area would discharge its flood-waters, and then subsequently the other half, which is quite different from the condition in which the whole area discharges practically simultaneously.

In the foregoing assumptions liberties have been taken with facts concerning forests. It has been assumed that, while the melting is going on in the open, none is taking place in the forest. This is not true. By diathermanous effect, the sun's rays, which, according to Colonel Chittenden, melt the snows in the open, begin to melt the snow in the forest quite as early, the difference being that the forest melting is much slower. And what takes place there? The layer in the forest begins to melt at the bottom. Beneath it is not a compact and frequently frozen layer of ground, but a litter of mulch, and beneath that an open, porous soil, protected from the early winter cold which freezes the ground in the open. The forest litter conducts this melted snow into ground which is eager to receive it; but Colonel Chittenden cites the fact that later warm rains will hasten this melting. This is true, but why confine this effect to the later warm rains? Early warm rains are not uncommon. When they fall over the snow on the open land, would not the effects be even greater than in the forest? The author then contends that the snow in the open is melted by the rays of the sun before the air has become warm. However true this may be in high altitudes which he cites as examples, one must know that it is not true in the lower altitudes. The

severest floods which have been experienced have been caused by Mr. Leighton. warm rain falling upon hitherto unmelted accumulations of snow. In the lower altitudes warm rains sometimes occur in midwinter. They fall "on the just and on the unjust," on forested as well as on deforested areas, and if Colonel Chittenden's reasoning be correct, then would the melting in the open be much faster than in the forest.

It is true, as Colonel Chittenden states, that a drift in the open in the high Sierras and Rocky Mountains remains long after the snow in the forest is gone. There is a reason for this, which is peculiar to such country. This is not always true in the lower countries, Colonel Chittenden's experience in Western New York to the contrary notwithstanding. Inasmuch as the author has referred in an attractive way to his experiences as a boy on the farm, the speaker will assert that he, too, "was once a bare-foot boy," and that in the woods of Maine when he desired to find snow in June or July, he went to the forest, as did other boys. In the open country crops were approaching maturity at that time.

Generalizations based on observations in a limited area are dangerous, and it is a fact that, if one travels along the Sierras from south to north, he can find exemplified practically every condition of snow-melting and run-off, some of which conform to the conditions stated by Colonel Chittenden and others to the conditions which he declares never exist. Let him take a wider range of observation in the matter of snow-melting and consequent run-off, and out of his own mouth will he disprove his assertion.

The speaker will not discuss the obvious errors shown by Fig. 1. In view of the foregoing, it should be clear that, for the greater part of the United States, the legends on the two curves should be transposed.

From pages 254 to 256 the implication seems to be that the greater part of the snow in the forest is lodged on the branches of trees, and that the part which passes through to the ground is of a light and feathery nature, the whole presenting an admirable focus for quick melting by subsequent rains. It is stated that "of an 18-in. fall, perhaps 12 in. is on the trees and the rest spread evenly on the ground." The whole picture is deceptive. If the author will visit the forests of the Northwest, with which he appears to be most familiar, he will find, in some sections, two sets of trail marks on the trees, one close to the ground for summer guidance, and the other from 10 to 15 ft. above the ground for the guidance of the winter traveler, who is walking at approximately that height on the top of the snow. Of course, during any snow storm a large amount of snow will accumulate on the trees; but it is undeniable that the first sweeping wind which rushes through the forest, after the snow has fallen, will blow off the greater part thereof, and it will find lodgment on the ground. Therefore, the

Mr. Leighton. fanciful presentation of a light and fleecy snow, two-thirds of which is held aloft for the greedy melting of the spring rains, finds no justification in actual experience. What proportion, for example, of a total snowfall could the trees sustain, when the layer on the ground is from 10 to 15 ft. deep?

The author's comparison of the run-off from Puta Creek and American River is unfortunate, for he has given a total mis-statement of relative rainfall and run-off on the two areas, as is shown unmistakably in Mr. Pinchot's discussion and diagram, Fig. 16.

In the author's discussion of practical effects, it will be of interest to consider the hypothesis that records of 200 years are necessary to establish the trend of run-off as affected by forest cover and deforestation. It has been demonstrated by the work of the Geological Survey that, in a period of 10 years, run-off conditions, in practically all parts of the country, are comprehended, from one extreme to the other. It may be that, here and there, an extreme low or an extreme high water may occur in one decade which is not reached in another; but this is of no consequence in summing up the tendencies of the river to floods and to low waters. These extreme conditions are mere sports, due to unusual occurrences, and it is as illogical to consider them as representative of general tendencies, as it would be to accept the physiological and anatomical freaks in a museum as representative of the human race. The comparison of run-off conditions in 10-year periods has been well set forth in an article* by John C. Hoyt, Assoc. M. Am. Soc. C. E. Therefore one need not despair because the records do not comprehend the 200 years which have been prescribed by certain engineers.

The claim that a 200-year record is necessary arises from the fact that the investigators are looking for freak conditions, in order to endeavor to substantiate certain hypotheses. If the details leading up to the floods and low waters be examined, the whole matter resolves itself into the task of ascertaining cause and effect. The real question to be solved is: Does a rainfall of a certain depth, at a certain season of the year, cause a greater flood since deforestation than it did formerly under well forested conditions? Now, the answer to this question can be ascertained from recent records. Cyclical changes, so-called, in precipitation do not enter into the question, because the whole record is reduced to a common basis, irrespective of cycles, but depending solely on actual depth of rainfall and comparative conditions of ground surface. The author, in presenting Table 1—extreme gauge records on various streams—merely reveals a fundamental misconception. It is not the contention of well-informed persons, as far as the speaker is aware, that deforestation produces higher floods. The real effect is to cause more frequent and more prolonged floods.

* *Engineering News*, April 23d, 1908.

Especially high floods are the direct result of excessive rainfall Mr. Leighton. which continues after the ground has become saturated. In such a case the forest is merely an assurance that all available ground-storage capacity shall be used. Therefore, the presentation of highest and lowest gauge heights is gratuitous. No one who has given deep consideration to the matter expects them to be productive of any definite conclusion.

There is another curious error revealed by Table 1, namely, consideration is not given to the depth of rain that produced the high stages. This is an all-important element in the matter. There are rivers in the United States in which there has been a decided diminution in flood occurrence and flood frequency, and if these two items were taken alone the result would mislead. Examination of the rainfall records for these river basins shows that there has been a greater proportionate diminution in rainfall, and especially in flood-producing storms, than in actual floods. Therefore, when the two are compared, it is apparent that there is an actual increase in flood tendency in the river. Further elucidation of this will be taken up in connection with the Tennessee basin.

In a foot-note on page 263 the author has approached the crux of the matter in some observations concerning the Ohio and Connecticut Rivers. Had he realized the importance of these two cases, he would not have relegated them to a foot-note. In contradistinction to the facts there given, the author asserts that there has been no change in forest conditions on the drainage areas mentioned during the period of record. Fortunately, the speaker has been able to make an examination into the situation. Only a few days ago, he observed a large amount of timber-cutting taking place on the Monongahela drainage. Credible testimony further assures us that deforestation is still going on over this basin. This is verified by the report of the Bureau of Statistics, Department of Commerce and Labor, for 1907. Pennsylvania is the ninth State in the Union in timber production, the yield for 1906 being valued at nearly \$30 000 000. According to the Forest Service, the bulk of this is cut in the central and western parts of the State, a large amount coming from the Allegheny basin.

Again, with reference to the Connecticut drainage area, it is true that small timber is growing up on abandoned farms and that the total forest area may be as great or even greater than it was twenty years ago; but it is new forest, without the accumulated mulch. It will not render the same service to ground storage as the primeval forest.

On the other hand, original timber-cutting is going on. One of the parties financially interested in Turners Falls Dam, in Massachusetts, recently assured the speaker that, for the past quarter of a century, from 50 000 000 to 80 000 000 ft. b. m. of timber had been allowed to pass over the crest thereof each year. This certainly does

Mr. Leighton, not appear like a cessation of timber-cutting. On the contrary, Turners Falls is well down on the river, and, if the observations of lumbermen be true, and if the statistics of the Forest Service be justified, this amount of timber does not represent the extent of actual deforestation. This quantity of timber, from 50 000 000 to 80 000 000 ft. b. m., represents an enormous and constant drain on the primeval forest on the Upper Connecticut. So much for the facts. The line of inquiry suggested in Colonel Chittenden's foot-note will now be developed.

The diagrams, Figs. 8 to 15, inclusive, have been prepared to show:

First, the record of rainfall in each place for the period of observation;

Second, the number of days in each year during which the gauge stood at or above a certain designated point which may be considered as the flood point. (The point chosen in these cases may or may not be the true flood point; but the fact is immaterial. The presentation of data in this way is, in its essential result, merely the cutting off of the top of the hydrograph and the summing up of the number of days. As long as the same point is used throughout the record on each river, the exact location thereof is of little consequence, because it is the relative flood duration, rather than an actual numerical record of total height, that is desired);

Third, the expression of the number of days in terms of precipitation. Each diagram is the expression of precipitation as a straight line, and the further expression of the number of days of flood in terms thereof. It will be observed that such a record obviates the necessity for a two-century record of observation, because it gives the actual results of a unit's precipitation.

The fourth diagram on each sheet is the expression of the total rainfall in each 10- or 5-year period, such periods being progressive. Thus, the first period may be 1880-89, inclusive, the second 1881-90, inclusive, and so on. Such an expression gives the concrete view of progressive flood tendencies. The wide annual variations in precipitation and the resultant run-off effects thereof, by this method of expression, are smoothed out and compensated, and afford a less involved idea of the actual trend of events. The fifth and sixth expressions are those of total days of flood and the relation of one to the other, all in progressive periods, as in the fourth expression. It will be appreciated that the last three are composed of the same original data as the first three, the only change being the method of assembling the facts. A mere glance will show that flood tendency on all these basins is increasing, and an examination of their history will prove that while, in some cases, a part of the change may be due to other factors, still the relative importance of those factors is insignificant in comparison

FLOODS ON OHIO RIVER AT WHEELING, W. VA. 1885-1907

FIG. 8.

Mr. Leighton.

FLOODS ON ALLEGHENY RIVER AT FREEPORT, PA. 1874-1907

Fig. 9.

FLOODS ON MONONGAHELA RIVER AT LOCK No. 4, PA. 1886-1907

FIG. 10.

Mr. Leighton.

FLOODS ON YOUGHIOGHENY RIVER AT CONFLUENCE, PA. 1875-1906

FIG. 11.

FLOODS ON WATEREE RIVER AT CAMDEN, S.C. 1892-1907

FIG. 12.

Leighton.

FLOODS ON SAVANNAH RIVER AT AUGUSTA, GA. 1876-1906

FIG. 13.

FLOODS ON ALABAMA RIVER AT SELMA, ALA. 1892-1907

FIG. 14.

Leighton.

FLOODS ON CONNECTICUT RIVER AT HOLYOKE, MASS. 1874-1907

FIG. 15.

with the deforestation. In other words, the one great, predominating change in the character of the drainage areas during the period of record is deforestation. The history is clear, and the deductions are not subject to serious dispute. Mr. Leighton.

One of the interesting features brought out by these diagrams is the remarkable agreement in the progressive trend of the record on the Ohio at Wheeling, and those on the Allegheny at Freeport, the Monongahela at Lock No. 4, and the Youghiogheny at Confluence. The earlier lumbering operations of the Allegheny basin are shown clearly by the earlier initial increase in flood tendency. Examples like those presented by Figs. 8 to 15, inclusive, might be multiplied several times, and they would have been presented were it not for the excessive time and labor required in preparing the diagrams.

There is one point of objection to these diagrams which may reasonably be taken: It is that they draw comparison between annual precipitation and the number of days of flood. A better comparison would apply between the number and depth of flood-producing rains and the number of flood days. Such a comparison has been made on the Tennessee basin above Chattanooga. No other basins are here dealt with in this way, because of the enormous amount of labor involved.

In addition to proving beyond controversy the increase in floods due to deforestation, the record is of interest because it shows how futile and misleading is the attempt to derive conclusions from flood records without taking into account records of precipitation. Inspection of the Chattanooga flood record shows a decided decrease in the number and duration of floods during the period of record. If this were taken alone, it would controvert the forest-control idea. A comparison of the precipitation records on the drainage area, however, assures us that the rainfall has decreased, even to a greater relative extent than the floods. The final result is that the flood tendencies have increased.

The results for the Tennessee basin cover 24 years, from 1884 to 1907, inclusive. Although the records of gauge height extend farther back than the earlier date, the number of rainfall stations maintained on the basin previous thereto is not sufficient to render safe any conclusions with reference to precipitation. It is appreciated that a given depth of rainfall precipitated during the winter months will generally produce a greater run-off than the same depth would produce in August or September. Therefore, an effort has been made to eliminate this source of error. Summing up the flood-producing rains for the 24-year period, it is found that the total is 335, of which 313 occurred from December to May, inclusive, and the remaining 22 during the other portion of the year. It is apparent that the number of such rains from June to November is not sufficient to afford a basis

Mr. Leighton.

TABLE 13.—THE RELATION BETWEEN STORMS AND FLOODS IN THE TENNESSEE BASIN DURING THE PERIODS DECEMBER-MAY, INCLUSIVE, 1884-1895, AND 1896-1907.

STORMS, IN INCHES PRECIPITATED.									
Period.	1-1.5	Storms.	7 8						
		Days of Flood.	5 3						
	1.5-2	Storms.	12 11						
		Days of Flood.	6 10						
	2-2.5	Storms.	6 9						
		Days of Flood.	15 23						
	2.5-3	Storms.	5 5						
		Days of Flood.	9 30						
	3-3.5	Storms.	5 4						
		Days of Flood.	13 13						
	3.5-4	Storms.	6 1						
		Days of Flood.	30 6						
	4-4.5	Storms.	1 1						
		Days of Flood.	6 8						
	4.5-5	Storms.	2 3						
		Days of Flood.	17 20						
5-5.5	Storms.	2 ..							
	Days of Flood.	18 ..							
6-6.5	Storms.	. 1							
	Days of Flood.	11 11							
7-7.5	Storms.	2 ..							
	Days of Flood.	28 ..							
8-8.5	Storms.	1							
	Days of Flood.	17							
1884-1885.....									
1886-1887.....									
1888-1889.....									
1890-1891.....									
1892-1893.....									
1894-1895.....									
1896-1897.....									

of comparison. Therefore, only the December to May floods will be considered. In making this comparison, the ideal condition would be to compare the rainfalls and floods during identical conditions of climate, but such a refinement is impossible. On the other hand, the multiplication of data afforded by the large number of flood-producing storms in the December-May period warrants the conclusion that the varying climatic conditions in this period are compensated, and the final conclusions which are drawn from the result must be worthy of confidence. Dividing the period covered by these 313 floods equally, two consecutive 12-year periods are afforded, which give a basis of comparison. The floods in the later period, resulting from a given depth of storm precipitation, are shown clearly to be more severe than in the earlier period. The method of presentation further makes it possible to compute the increase in flood tendency due to deforestation. In the Tennessee basin it is 18.75 per cent.

If the number of flood days is divided by the number of storms, the result will be the number of days per storm. Applying this to each of the series in Table 13, the result given in Table 14 is reached.

TABLE 14.—DAYS OF FLOOD PER STORM, 1884-1895 AND 1896-1907.

Period.	Storms, in inches precipitated.							
	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5
1884-1895	0.7	0.5	2.5	1.8	2.6	5	6	8.1
1896-1907	0.4	0.9	2.6	2.7	3.2	6	8	6.7
Percentage of increase.	-43	80	4	50	22	20	33	-17

The algebraic sum of these percentages is 149.00 and the average is 18.75, which sums up the effect of deforestation on run-off from 1884 to 1907, inclusive.

The author devotes some space to a discussion of the effects of forests on rainfall, and concludes that there is little or none. For the purposes of the present discussion, the question is in no wise involved. The requirements are satisfied with the record of actual precipitation, be it decreasing or increasing. Colonel Chittenden, however, oversteps the bounds of conservatism when he asserts:

"Coincident with our recent high waters, which are attributed so largely to deforestation, there has been an increase in precipitation, where there should, apparently, have been a decrease."

Let the author examine the precipitation records over the basins of the Tennessee, Cumberland, Kentucky, Pemigewasset, and Catawba Rivers, and he will be convinced that his generalization, in these important instances at least, is quite the reverse of the truth.

Mr. Leighton.

The author expresses a preference for floods over dry years, and he assures the reader that dry seasons are sure to follow floods.* The sequence is hardly obvious in the light of past experience. The present year, 1908, for example, has been one of the severest in our history, from the flood-damage standpoint, and yet the rivers have been extremely low a great part of the time. The Ohio has been visited by no great floods; yet the drought has been the worst in the last half century. On the other hand, the Ohio was visited by disastrous floods in January and March, 1907; yet, during the following summer, the river was not abnormally low. The author's generalizations are precarious.

The expressed preference of the author for floods over dry seasons suggests the query whether or not he has ever considered the extent of the country's flood damage. It is plain, from the statement quoted, that he has disregarded the worst element of loss, viz., the flood-water itself. A flood is essentially a waste of water which might be put to a useful purpose; but, apparently, he does not realize that floods, during 1908, have caused a physical damage of \$260 000 000, and the end is not yet. Nor does this figure take account of the property depreciation resulting from flood menace, which would more than double the total.

There still remains much to be said, but the speaker will forbear discussion of Colonel Chittenden's statements concerning forest control of erosion, except to state that, if he will accompany the speaker on a journey of one week to portions of this country with which he is evidently now unfamiliar, he will willingly withdraw this section on erosion. His fundamental misconceptions concerning erosion may be explained by a little consideration of dynamic geology.

The speaker, at his solicitation, has received from Dr. W J McGee,† a comment upon certain features of Colonel Chittenden's paper, in which he remarks that Colonel Chittenden errs in that he assumes that there is no connection between rivers considered with respect to improvement and the sediment that they carry, and again when he holds that water is the object matter of engineering art and sediment the object matter of scientific farming. Such misconceptions explain the erroneous deductions respecting the Missouri River. Dr. McGee notes Colonel Chittenden's declaration in one sentence that the Lower Missouri takes its sediment from the Bad Lands and his equally emphatic utterance in another sentence that the sediment carried by the Missouri and other rivers is merely local freight. Dr. McGee then testifies that the Missouri is still a clear river after passing the Montana Bad Lands. He observes, further, that the Missouri normally gathers by bank caving nearly twice as much sediment in the State of Missouri alone as it pours into the Mississippi. "The only

* Page 269.

† Erosion Expert of the Bureau of Soils, United States Department of Agriculture.

sound basis for thought concerning streams," writes Dr. McGee, "is Mr. Leighton. that of geology, in which running water is viewed as an agency, indeed as the most energetic and effective agency in earth making; and this property of water arises in the extraneous matter carried within it. Sediment-bearing water is fundamentally distinct in its behavior from clear water." Dr. McGee further contends that if these principles are borne in mind the conclusions at which Colonel Chittenden arrives would be impossible.

With reference to the assertion that our rivers are not shoaling by reason of erosion, it may be remarked that, if the author will review the reports of the Chief of Engineers, U. S. Army, he will find ample evidence to the contrary. Of course, erosion does not mean uniform shoaling throughout the entire course of a river. It means rather additional bar formation. The schedule of dredging on the Ohio shows a fairly constant increase since 1875, and it is significant that, in the recent report on the 9-ft. canalization of this river, the Board of Engineers for Rivers and Harbors recommended that \$1 000 000 per year be provided for dredging. While it is recognized that the need for this great sum arises from the cessation of bar cutting that would be occasioned by the erection of locks and dams, it indicates, nevertheless, that the United States Engineers have recognized that the débris problem is of far more consequence than Colonel Chittenden would have us infer.

The speaker will pass over the author's discussion of forest policies. Here again, his mistakes are fundamental, and his contentions contradictory; but a reply will undoubtedly be forthcoming from some persons better qualified than the speaker.

In reference to the section on artificial reservoirs, as the speaker has already replied to many of the objections,* he will merely refer to them.

It is evident that Colonel Chittenden recognizes fully the possibilities of the reservoir, and accepts the principle of conservation. Indeed, were one desirous of establishing this principle beyond all controversy, he would need but to take the report of the Board of Engineers on the Upper Mississippi Reservoirs,† of which Colonel Chittenden was a member, and, to demonstrate the absolute soundness of the reservoir principle, would have only to hold this report aloft and stand mute.

It is stated that Fig. 2 illustrates a contingency which nearly happened on the Upper Mississippi in the flood of 1905, namely, the operation of reservoirs to increase floods. The speaker is unable to concede the correctness of this deduction. Fig. 2 shows that the maximum flood height at Aitkin occurred from the 1st to the 15th

* *Engineering News*, November 5th, 1908, pp. 504-507.

† Pages 290 and 292.

Mr. Leighton. of July. On July 1st, the Aitkin gauge was more than 6 ft. above full-bank stage; yet the controlled flow from Pokegama was about 1 200 cu. ft. per sec., or less than one-half full-bank capacity. The Aitkin flood on July 1st was due, therefore, to the discharge from the uncontrolled area above Aitkin. Supposing, now, that the Pokegama area had been uncontrolled, the discharge on July 1st, according to Fig. 2, would have been 2 700 cu. ft. per sec. greater, which is equivalent to an increase of nearly 200% in excess of discharge over bank-full capacity at that time. The high point at Aitkin appears to have occurred on or about July 5th, at which time the reservoir discharge was approximately 2 200 cu. ft. per sec., or nearly 2 000 cu. ft. per sec. less than it would have been without the Pokegama control.

The sharp increase in the controlled Pokegama discharge which took place between July 5th and 31st, is accompanied by an equally sharp decrease in gauge height at Aitkin. When the gauge again began to increase on August 1st, the controlled discharge was 1 500 cu. ft. per sec. less than it would have been under natural flow, and, on or about August 10th, the date of the secondary flood crest at Aitkin, the natural flow would have still been teeming on, reaching its maximum some 10 days later; yet, in spite of the fact that the controlled flow continued to increase from that date until about September 12th, the flood at Aitkin showed practically continuous subsidence. Now, this secondary flood, culminating on or about August 10th, indicates a discharge of nearly 800 cu. ft. per sec. less than that culminating on July 5th; yet the natural flow at Pokegama would have been about 800 cu. ft. per sec. greater than is indicated at the height of the July flood.

The defect in Fig. 2 is that, while the author has introduced an hypothetical curve for the natural flow at Pokegama, he has not balanced it by a similar hypothetical gauge record for Aitkin, but has attempted to draw deductions by basing his computed natural-flow curve upon his controlled Aitkin gauge-height record. He observes that the sharp increase in controlled Pokegama discharge from August 1st to 10th, is accompanied by a sharp increase in gauge height at Aitkin for the same period, and, inasmuch as the controlled flow at Pokegama on August 10th is only about 350 cu. ft. per sec. less than it would have been under conditions of natural flow, he believes that the reservoirs nearly operated to increase the flood. Of course, this is a fallacy, because, under natural flow conditions at Pokegama, the Aitkin gauge record would have been entirely different.

The excess of computed natural flow over controlled flow at Pokegama between July 1st and August 10th (the crucial point at which the reservoirs seem to have become nearly inefficient) is approximately 5 230 000 000 cu. ft., and it is unquestionable that this would have changed the flood occurrences at Aitkin by carrying the highest gauge

point farther along in July, and affording thereafter a subsidence at Mr. Leighton, a rate somewhat approximating the subsidence of the computed natural-flow curve. It is apparent, therefore, that, although the controlled flow at Pokegama is in one point actually greater than the maximum natural flow would have been, there is not the slightest reason for believing that this controlled flow came anywhere near adding to the severity of the flood which would have occurred without reservoir control.

The author has based his conclusions on the relative natural and controlled flows at Pokegama, whereas the actual test of the matter lies in the record of the Aitkin gauge. His apparent tendency to regard the actual discharge from the reservoir as the important feature, rather than the actual effect on the river below, is further indicated by Fig. 3.

Fig. 3 certainly shows, as the author contends, that the controlled flow at Pokegama was not as uniform as the natural flow would have been; but is this not the whole purpose of the reservoir system? In the practical operation of reservoirs one does not seek to secure uniform discharge from those reservoirs, but rather to adapt the discharge so that, in connection with the uncontrolled discharge from lower tributaries, it may finally produce a condition of uniformity in the river many miles below, and not, indeed, in the river just below the reservoir outlet. It would have been eminently fair, in presenting Fig. 3, to have added thereto two more curves, one showing the discharge at Aitkin, Brainerd, Little Falls, or St. Cloud, as controlled by the upper reservoirs, and the other, a computation of what that flow would have been had the reservoirs not been installed. The reason reservoirs are installed may be, in some cases, that the flow at the point of installation is too uniform to combine satisfactorily with conditions in lower tributaries. Therefore, uniformity of reservoir-discharge flow is decidedly not the sole object. The fact that such discharge is not as uniform as the natural flow would have been is of no consequence in summing up the usefulness of the reservoir system.

The difficulties that Colonel Chittenden expresses, with reference to the effective operation of a system of reservoirs like that proposed by the speaker on the Ohio basin, apparently arise from the fact that he has not considered the great capacity of these reservoirs. Their effective capacity, in every case, is computed upon a total conservation of the water on 100% of a certain area. This is discussed at length in the paper. Of course, exceptional seasons would come when the floods would fill these reservoirs higher than at other seasons; but, if we take the actual records of such exceptional seasons, we shall find it very rare indeed when the flood run-off in any season, however prolonged, is as great as the total mean run-off of that area for an entire year. Therefore, before a reservoir, the capacity of which has been

Mr. Leighton, adjusted to hold the entire mean run-off, has been overtaxed, dry seasons would intervene, during which the reservoirs would be needed to supplement the low-water discharge. But, supposing this were not always true; admitting for purposes of argument that there would be times, at rare intervals, when the reservoirs were overtaxed and a flood would descend on the valley below, does this make the proposition valueless? Is there not virtue in a project that will render floods extremely infrequent, instead of extremely common, as they are at present? The speaker believes that the proposed reservoir system could be operated always to control floods, but he contends that, even if now and then a portion of a flood should get past the reservoir system, there would still be ample benefits accruing from that system. Colonel Chittenden surely will not contend that because benefits are not 100% it is not well to secure 90 or even 80 per cent.

The same observation holds good for the low-water conditions. A storage of 100% begets confidence, and properly so; but, supposing there would be times when the reservoirs would be "too empty" to afford full supplementary flow during dry seasons, would there not still be a large measure of benefit for water-power purposes in a partial flow, and would not the condition be infinitely better than that which prevails to-day? Let us not be petulant. If we cannot secure a whole loaf, let us take three-quarters or even a half, remembering that the half is sometimes the sole arbiter between a dead man and a live one.

The observation that the proposed reservoir system would not, in the case of the flood of 1907, have helped the situation at Cincinnati indicates that Colonel Chittenden has fallen into the same error that Major Newcomer did in assuming that it was expected that the Upper Ohio reservoirs were to control the situation all the way from Pittsburgh to Cairo. If, as stated, the maximum at Cincinnati and that at Pittsburgh occurred about the same time, it ought to be plain that the flood-waters which furnished the maximum at Cincinnati did not come from the Pittsburgh district. They came from lower tributaries, and the proposed system of reservoirs covers these lower tributaries.*

The author's river hydraulics become somewhat involved when he undertakes to discuss flood-wave propagation. The effect of flood-wave prolongation that he describes would be favorable, rather than detrimental, to reservoir control. In fact, the whole paragraph presents a symmetrical contradiction, and the speaker will endeavor to analyze the conditions.

There is established, in the Ohio River, a certain flood regimen in which are comprehended all the flood phenomena, including progress of crest, prolongation of wave, etc. When, in his original report, the speaker discussed the effect of reservoirs, he did not start at Pittsburgh with a certain crest and volume, and compute what the effect would

* Further discussion of this point may be found in *Engineering News*, November 5th, 1908, pp. 504-507.

be at Cincinnati and other points along the river. Had he done so, Mr. Leighton. then, indeed, would it have been necessary to account for all the phenomena of flood transmission. Fortunately, observations at lower points rendered this unnecessary. The regimen has been observed; what happened at Wheeling, Cincinnati, etc., is known and also what contributed to the conditions there. Now, what is the effect of the reservoir system as proposed? It is not that of prolongation of flow; no attempt is made to flatten the wave by allowing the same amount of water to discharge in a longer space of time. The element of time remains unaffected, save that which results from change of head. The real effect is to cut out from the drainage area a certain portion which otherwise would contribute to the flood. A flood wave at Pittsburgh would contain equivalently less water; and, knowing what actually happened there without flood storage, one can compute approximately what would take place as a result of the reduction. This reduction would not be the equivalent of the area cut off; it would be greater, because this area is steeper than the average for the whole, and, therefore, its flood wave is the more quickly transmitted to the lower valley, as demonstrated by Colonel Chittenden. The special point that he makes, by the way, is not involved in the discussion, for no one is contending that upland streams are subject to over-bank floods. In establishing storage reservoirs, efforts are made to protect the lowlands, not the uplands, and it is self-evident that they are most in need of protection from these upland streams, which are of so large a unit discharge capacity and so swift in flow that they do not inundate their own lands, but quickly deliver their floods into the lower rivers of relatively small capacity.

Proceeding now with the matter of flood propagation, let it be assumed that the problem has these elements in it. Colonel Chittenden starts with a flood at Pittsburgh increasing from 100 000 to 200 000 cu. ft. per sec. It is asserted that this would not produce a similar increase at Cincinnati. Very well, but is this not in our favor, and are we not on the safe side, as far as flood damage is concerned, if we assume that the increase will be as great in one case as in the other? The rule should work both ways. If an increase of 50% in the discharge at Pittsburgh does not produce a similar increase at Cincinnati, should not a decrease of 50% at the one place effect a greater decrease at the other?

Carry the matter up past Pittsburgh, even to the reservoirs. If, by manipulating the gates, 50% of the flood is conserved, a reduction equivalent to that assured by the author would take place when the crest had reached Pittsburgh, and, in proceeding down the Ohio Valley, it will be reduced still further by the time it reaches Cincinnati. Why, then, would not the reservoirs have 125% of the predicted results, instead of 75%, as Colonel Chittenden suggests?

Mr. Leighton. With reference to the matters of cost, local obstruction of highways, communication, safety of dams, and overflow damages, the speaker will refer to his article above referred to.* The speaker will accept Colonel Chittenden's estimate of cost, \$500 000 000, and will still insist that the investment will be eminently wise. The author has made a distribution of expenditures covering the Mississippi and Ohio Rivers, including navigation and flood protection; but, with all this accomplished, still would we be wasting the flood-water which is so much needed; still would we have low water and foul streams, with unspeakable conditions on the Ohio, like those of the past summer and fall; still would we be obliged to provide for water-power, our sole hope as a source of energy in the future; still would we be wasting our precious and fast-disappearing supply of coal. Why is it that we refuse to take the long, broad, comprehensive view ahead, and provide manfully for all future contingencies and economic demands? Is the old, the narrow, the conventional road, the course of which traverses a circle, always to confine our steps?

The final point of error on the part of Colonel Chittenden is that of the speaker's alleged estimate of returns to the Government by reason of additional water-power made possible by reservoir construction. The fact that three good men have successively published comments thereon, under the assumption that the speaker has estimated a return of \$20 per horse-power-year, leads him to believe that there must be some statement or turn of phrase in his report that warrants such an inference. He has been unable to find it, and refers those interested to his statement in *Engineering News* above cited. Throughout his whole consideration of water-power, the speaker has used \$20 per horse-power-year merely as a factor to indicate approximately the value of the power, and not the Government rental.

One more word, and that with reference to the author's strictures concerning the speaker's "reversal of obligation." It is in testimony of Colonel Chittenden's progressive attitude that he makes this stricture. He asserts that the reservoir principle is accepted, and that the cost is the only remaining bone of contention. Would that this were so! The principle is still widely doubted, in testimony of which the author should review recent utterances and writings of some of his brother officers. The existence of suitable reservoir sites in the Ohio basin is not accepted universally, in testimony of which see same utterances and writings of same parties. The original report, presented by the speaker to the Inland Waterways Commission, was designed to defend the principle and to announce the existence of reservoir sites, and, finally, to make a plea for a worthy examination which would include this matter of cost as well as all other uncertain items.

* *Engineering News*, November 5th, 1908.

W. D. PICKETT, M. AM. SOC. C. E. (by letter).—Colonel Chittenden's paper and the paper by the writer entitled "The Floods of the Mississippi Delta: Their Causes, and Suggestions as to Their Control,"* indicate to the casual reader a radical antagonism, apparently, as to the effect of the shade of forests on the melting of snow; also, as to the effect of forests in retarding the flow of rain or snow water on mountain or hill sides. It would seem that the first question is whether snow will melt faster (especially at elevations of 8 000 or 10 000 ft. above sea level) under the direct rays of the sun, or when protected by shade, such as pine forests afford.

The second question is whether rain or snow water will reach a stream when flowing over a comparatively smooth surface, such as cultivated fields, in less time than when flowing over a surface obstructed by the roots and trunks of forest trees and by the brush and other impedimenta common to all forests.

It would seem that there is but one answer to these two propositions, and that between two engineers, each with exceptionally good opportunities for observation of the themes of which they write, this antagonism must be more apparent than real, if their views are elaborated and explained.

The object of this discussion is to explain and particularize the writer's views on the subject. In the writer's paper the cause assigned for the disastrous floods of the Mississippi Delta was the merging, near the mouth of the Ohio, of the "Spring Rise" from that stream with the "June Rise" from the Missouri, and the passage of the combined flood toward the Gulf. It was also pointed out that the only means of preventing the coincidence of these floods at or near the mouth of the Ohio was by the construction of reservoirs of the requisite capacity, at the head-waters of the Missouri, to hold back the annual floods a sufficient length of time to allow the spring flood from the Ohio to pass down and out of reach, without peradventure, of the later "June Rise" from the Missouri.

It was suggested that Nature had already pointed out the most feasible and effective reservoirs, by the creation of those vast pine forests at the head-waters of the Missouri, and that these are vast storage reservoirs in which the accumulated snows of winter are preserved until gradually turned into water in summer. These forests are usually found in that portion of the Great Continental Divide between elevations of 7 700 and 9 200 ft. above sea level, usually designated the "Timber Belt." It was pointed out that within this timber belt there are vast areas of open land, which were formerly covered with pine forests, but which, from unknown causes (supposed to be from fire), had become denuded, thereby exposing the snow to the direct rays of the sun. The area of these open mountain plateaus

* *Proceedings*, Am. Soc. C. E., November, 1908, Vol. XXXIV.

Mr. Pickett. was estimated as about equal to that of the pine forests already existing on the timber belt.

It was also pointed out that, from the writer's 15 or 20 years' observations, the snow in these open areas usually melted and flowed to the valleys during May or the first days of June, a month or six weeks earlier than the snows stored up in the forest reservoirs. These remarks are confined to localities within the timber belt.

The writer also stated his belief that the early melting of the snows on these open plateaus around the higher portion of the entire Missouri River water-shed is the principal cause of the "June Rise" in that stream.

Evidently these plateaus were once clothed with forests, and Nature teaches that these areas, with few exceptions, can be re-clothed with forests by using the means that Science prescribes. When that is accomplished, the winter's snows will melt so gradually during the early summer as to prevent those spasmodic floods of the local streams which, when finally combined in the main stream, become known at its mouth as the "June Rise."

By the remedies advocated this flood will be held back at least a month, and considerably modified in intensity and volume.

It was also pointed out that one factor in retarding the melting of snow during the first warm months is the comparatively low temperature of the air at such elevations as the timber belt; that after the snow commences melting in the forests there are few nights in June, July, or August when the temperature is not low enough to form a snow crust firm enough to bear the weight of a man or even a horse. The actual melting of the snow occurs during about one-quarter of the 24 hours. The warm currents of air circulating through the timber cause the surface of the snow to soften, and hence the crusting at night.

In open areas, on account of the radiation of the heat given out during the day, the temperature is not as low as in the timber, the crusting of the snow is not as effectual, and its melting goes on during at least three-fourths of the 24 hours, and in the direct rays of the sun is much more rapid, and at times continues during the entire night.

Another consideration affects the melting of snow in the timber belt: The accumulated snows of winter represent what has fallen in different layers or storms from September to May. With the rain or melted snow that falls in May, June, and July, the water used during the irrigating season represents, as before explained, the entire precipitation, practically, for the year ending September 1st. The layers of snow that fall in December, January, February, and March are deposited, and, before the subsequent layer falls, are subjected to temperatures ranging from 20 to 40° below zero, depending on the winter conditions.

These are the temperatures recorded at an elevation of 6 500 ft.; Mr. Pickett. at the altitude of the timber belt, they must have been much lower. with the gradual settling and compacting of the snow during the winter these temperatures must have been stored up, to a considerable extent, under the protection of the forests.

In the open areas, however, the snows, after successive layers have been deposited by winter storms, are exposed more or less to the direct rays of the sun (for in the winter clear skies are the rule in the timber belt), and the temperature of each layer of snow must have been higher than when first deposited. From these causes alone the snow in the open areas would melt sooner.

The foregoing gives the writer's views and the reasons for the much more rapid snow-melting in the open areas of the high mountain plateaus, the re-clothing of which with forests is considered so important for irrigation as well as for the prevention of floods in the Mississippi.

These views have been impressed upon the writer by a residence of 15 or 20 years in the valley of the Grey Bull, during which cattle interests compelled him to study climatic conditions. Previous to 1883 seven or eight months of each year (for seven years) were spent on the head-waters of the rivers radiating from the Yellowstone National Park. During these explorations the writer obtained an intimate knowledge of the topography of about 100 miles in length of the Continental Divide and of the extensive groups of mountains on each side. Within four miles to the south of his ranch there was an elevation of more than 8 000 ft. on the northern border of an extensive mountain plateau containing one peak of 13 300 ft. elevation, and others of 10 000 and 11 000 ft. elevation. To the north, within 10 miles, there was a similar plateau of less extent, each being a good summer range for cattle. The writer and a neighbor secured, and, for years utilized, the mountain plateaus to the south as a cattle range. The importance of placing herds of cattle on this range at as early a date as possible, in order to reserve the "fenced-in" pastures for winter range, necessitated many trips to the top of the mountain to determine how much of the plateau was free from snow and had sufficient new grass to sustain stock. In these trips the marked difference as to snow-melting in the pine forests and in the open areas was forced on the writer's attention.

In several seasons there was sufficient grass in the open areas to permit moving the cattle to the mountain as early as June 10th; sometimes, in backward seasons, this was not done until toward July 1st.

In carefully reading Colonel Chittenden's views as to snow-melting, the points wherein he differs from the writer may admit of explanation. While conceding that snow melts faster in open areas, the author claims that when the snow in forests commences melting it

Mr. Pickett goes faster than if in open areas. In the timber belt this does not hold good in June, July, or the first weeks of August. The snow in the forest that softens on top, or perhaps partly melts, is crusted over or frozen at night, so that the melting or softening is not resumed until noon or later the next day.

His view is correct when referring to the valleys of 5 000 or 6 000 ft. elevation, and there the drifts he mentions go very rapidly. These drifts commence to melt in April and disappear very rapidly during the wet snows and rains not infrequent in April and May. The writer thinks he has an exaggerated impression of the value of the small gulches or depressions in the plains below the mountains. The writer's observation is that sage brush (in evidence everywhere except on the high ridges which have been denuded of soil by high winds) effectually prevents the drifting of the snow when of ordinary density.

Twice (1881 and 1882) the writer crossed the Yellowstone about May 1st at Benson's Landing and passed around the foot-hills bordering the Yellowstone Valley on the south, by the Upper Indian Lodge Pole trail, to Clark's Fork, a distance of 60 or 75 miles. Though crossing on each trip numerous small gulches, that earlier were full of snow, there was no snow anywhere, but the streams of any size were high from the melted snows. The writer differs with Colonel Chittenden, as to the efficacy of snowdrifts in preserving snow at any altitude when subject to the direct rays of the sun. Pine forests, even at high altitudes, are more efficacious.

Figs. 1 and 2, Plate XXXVII, confirm the writer's ideas in reference to snow. The photograph of the forest shown on Plate XXXIX was evidently taken just after a snowstorm. A wind of greater or less power always follows such storms, and soon deposits the snow on the ground. The temperature of the air is usually too low to permit the snow to melt, even should the wind fail to dislodge it. If the wind blows parallel to the lay of the forest during a snowstorm, the forest will retain only its share of the snow; but in the high mountains it frequently happens that a forest is on the windward slope, and in that case the wind will drift the snow under the limbs of the trees and form large drifts well up into the timber. At the end of winter, such drifts are sometimes 6 ft. deep. In one locality the wind has such velocity in passing over a mountain, above the timber line, that snow is taken up and drifted a mile or more and deposited in forests at lower altitudes. This occurs every winter.

The following is an index of the effects of the sun's direct rays on snowdrifts in the plains below the mountains: On April 1st, 1893, the writer was delayed by the washing away of a bridge and trestle on Heart River near Mandan on the Northern Pacific Railroad. In passing over the reconstructed bridge the cultivated field in the river

bottom was partially covered with blocks of ice from 2 to 3 ft. thick, Mr. Pickett. which had been brought down on the flooded river. This stream had its rise about 100 miles westward in the famous "Bad Lands," the deep gorges in which are conducive to the formation of extensive snowdrifts. In this instance the sun's rays had quickly done their work. The Missouri River at Bismarck had been free of ice for some time previous to that date.

It seems to the writer that there can be only one opinion in regard to the effect of forests in retarding the flow of rain to the streams below, thereby preventing sudden floods. Applying the illustration to the water-shed of the Ohio, suppose there is on a hillside a forest of average density, with all its impedimenta of roots and trunks of trees, underbrush, old logs, dead leaves, etc. On another part of the same hillside are cultivated fields, each portion extending to the stream at the foot of the hill. Suppose now a steady rain of average flow is falling on these two areas. Can there be any doubt which section of that stream will first receive the water, that flowing over the cultivated field, or that flowing through the forests?

Leaving out of the question the obstructions offered by the roots and stumps, the increased friction of the water in running over the leaves and other smaller obstacles would decide the question. The parallel between the cleared fields and the forests is drawn because the disappearance of the timber is usually followed by the cleared fields. This occurs especially in those portions of the Ohio River water-shed in Ohio, Indiana, and Illinois. The destructive floods usually occur before the land is plowed for the coming crops.

Omitting all reasoning, these facts stare us in the face each spring; the much earlier floods from the Monongahela and Allegheny Rivers at Pittsburg; the greater volume and intensity of the floods; and the destruction of millions of dollars' worth of property in and around that city, and the devastation as far as the mouth of the Ohio. This did not occur fifty or sixty years ago, before this water-shed was denuded of its forests.

Civil engineers and planters state that below Memphis they watch with greater dread the floods from the Tennessee and Cumberland than those from the main stream, because the floods from those streams come earlier and with greater intensity and volume than was the case forty or fifty years ago.

The importance attached by the writer to reforesting the areas of the high mountain plateaus at the head of the Missouri River water-shed tempts him to recount the other benefits to the nation, besides those mentioned in his paper "The Floods of the Mississippi River Delta."

There are no records as to the extent of the forests and the adjoining open areas in the timber belt, but the writer feels confident that

Mr. Pickett. the areas of open land are as great as those which are forested, and, with few exceptions, these areas can be reforested.

There is a great length of the Continental Divide whose summits are not above the timber line, and are not as well adapted for the storage of snow as the mountain spurs making out from the main range and forming dividing ranges between the numerous streams having their origin in the main divide. These spurs are almost invariably high, and their numerous gulches are suitable for the storage of snow. That part of this divide between the heads of the Jefferson and Wind Rivers, with its mountain spurs branching eastward, is an example. These mountain ranges separate the West Gallatin, the Yellowstone, the Clark's Fork of the latter stream, and the North and South Forks of the Stinking Water and Wind Rivers. There are many portions of these subsidiary mountain ranges above the timber line with their summits topped off by peaks from 10 000 to 13 300 ft. high, such as Emigrant Peak, Bear Tooth, Pilot, Index, Franks Peaks, and the Washakie Needle, a mass of mountains about 100 miles in length and opposite the Yellowstone Lake, extending about 80 miles eastward. The valleys between these streams are narrow, sometimes partaking of the nature of cañons, with the dividing ranges on each side from 3 000 to 4 000 ft., above the valleys. These mountains have been explored by the writer and are probably more suitably fashioned for the storage of the winter's snows than any similar groups along the Continental Divide, but there are many others of somewhat less merit. There are also several groups of mountains, detached from the main range, that store up a great deal of snow. The Big Horn Range, about 100 miles in length, crowned with Cloud Peak, more than 11 000 ft. high, is the most extensive. North of the Missouri are the Bear Paw and Little Rocky groups, and these, though not of great elevation, are well adapted for the storage of snow.

The benefits to be derived from reforesting portions of the timber belt are: First, its importance for the irrigation of the arid belt contiguous to the tributaries of the Missouri. Secondly, its benefits, as a factor, in keeping apart the annual spring floods of the Ohio and the June rise from the Missouri. In his paper, previously quoted, the writer gives an estimate of the annual yield, in dollars and cents, of the land which will be reclaimed by the prevention of such floods. The data on which this estimate is based are given, so that any one can correct it according to his views. The estimate totals \$376 200 annually. Thirdly, its favorable effects in controlling the floods of the Mississippi, by enabling the Mississippi River Commission to confine the stream to a fixed channel, thereby making safe the levees already constructed. If the writer's views and the reasoning sustaining them are correct, it is evident that one dollar spent in reforesting at its head-waters will save two or more dollars in the lower

part of this great river. Fourthly, its directly beneficial effect in the construction of that grand work "The Lakes to Gulf Waterway," a work of such national importance that the public already appears to have decided that it shall be constructed. Mr. Pickett.

Once confine the channel of this mighty river to fixed bounds, by such works as the River Commission has devised, and the solution of the problem would seem to be easy. The writer believes that there has always been a navigable depth of 5 ft. over the bars below Cairo. It is understood that by certain works to confine the channel, and by vigorous dredging, the Mississippi River Commission will be enabled to increase this depth to 10 ft. It would seem that by using all the appliances of modern engineering, and by forcing the river to assist in scouring out its channel, the additional cost of increasing the depth to 14 or 16 ft. would be inconsiderable when compared with the immense benefit to be derived by the commerce of the nation.

The essential part of the problem is the prevention of the merging of the spring floods of the Ohio with the June rise of the Missouri. That being accomplished, the third and fourth problems are easily solved, as far as engineering questions are involved.

As to the benefits from irrigation to be derived by the arid belt by this reforestation, the writer, from personal knowledge of the lands to be reclaimed, is confident that every gallon of water that may go to waste during the irrigating season could be used beneficially in the various parts of the belt.

The financial benefit to the nation, together with increased population and numerous other advantages, will make it certain that within a reasonable time every acre of this part of the arid belt, susceptible of crops, below an elevation of 6 500 ft., will be brought under cultivation.

According to a report of Elwood Mead, M. Am. Soc. C. E., in regard to irrigating works in the valley of the Po, in Northern Italy, that kingdom has expended millions of dollars in the construction of immense dams, reservoirs, and ditches for irrigation. The annual rainfall of that valley is about 43 in., or slightly more than that in the valleys of the Ohio and the Mississippi. When a nation like Italy can afford to expend millions on a part of that kingdom in which the rainfall is greater than in the States east of the Missouri, this great and wealthy nation will certainly, within a seasonable time, reclaim this extensive arid belt which, 60 or 70 years ago, was called "The Great American Desert" and was believed by some statesmen to be the western boundary of the country, as fixed by Nature.

In October, 1908, when in Montana and Northern Wyoming, the writer investigated the value of the lands in the arid belt when brought under the influence of irrigation and when there was a ready sale for the products of the soil. In Billings, Montana, in connection by rail

Mr. Pickett. with Northern Wyoming, a sugar beet factory, with all modern improvements, has recently been finished at a cost of \$1 000 000. The superintendent stated that the factory was in operation and had just commenced receiving the present season's crop of sugar beets. He also stated that his company was paying from \$4.50 to \$5 per ton for the beets delivered at the nearest railway station, the price being regulated by the haul. He also stated that 15 tons per acre was about the average yield and that the cost per acre to ranchmen was about \$30, making a profit of from \$37.50 to \$45 per acre to the ranchmen.

As the yield and profit per acre appeared to be very liberal, the writer obtained information from ranchmen and others who corroborated the figures given above; and the writer is informed that the best lands in Missouri, Iowa, Illinois, Indiana, Ohio, Kentucky, or Tennessee cannot make as good an exhibit.

There is every prospect that there will always be a good price for the sugar beet. The United States is now importing from 2 500 000 to 3 000 000 tons of sugar annually. The railway system of the West is gradually extending, so that in a few years every agricultural neighborhood will be reached.

All land under irrigation in Wyoming or Montana below an elevation of 6 500 ft. will bring forth a large yield of the beet. With the extension of the railway system, sugar beet factories will follow as soon as the length of haul becomes excessive, and it is certain that the railways will encourage the industry by proper rates, for they will have the advantage of handling the product twice.

The yield per acre mentioned above is not excessive. Without special pains, ordinary potatoes have been raised at the rate of 16 tons per acre, and this yield is not uncommon. A few years ago an agricultural paper offered a prize for the largest yield of ordinary potatoes; the prize was won by a ranchman of Sheridan County, Wyoming, with 940 bushels or 28 tons per acre. An experienced cattleman, instead of selling the sugar beet, considered it more profitable to feed them to his beef cattle.

These same lands will produce from 1 ton per acre at altitudes of 6 000 ft. to 5 tons at lower altitudes where three cuttings can be had during the season. Alfalfa brings from \$5 to \$8 per ton.

These statistics are authentic, and are repeated to indicate that the Government can make no mistake in expending liberally for storing up all the surplus water from the Missouri River water-shed that goes to waste during the irrigating season.

Mr. McMath. ROBERT E. McMATH, M. AM. SOC. C. E. (by letter).—The author, by the title of his paper, has invited his readers to make an excursion into a boundless forest, in which many trails lead in many directions. He, in a measure, sets out to open and improve one trail, and very wisely suggests that members of the Society give "The results of their

observation and experience touching the important and vital features Mr. McMath. of one of the chief living questions of the day."

The writer feels disposed to protest mildly against the limiting clause of the title, "Reference to navigable rivers," because he knows no definition for navigable rivers, nor where to draw the line between the flotation of a chip and the largest ship. In the conservation and utilization of stream flow, as one of Nature's beneficencies, navigation comes last, but is not chief.

In discussing the paper, the writer would amend the title to read, "Reservoirs and forests in their relation to stream flow." Nature has determined the question of precedence by the fact that reservoirs are one of the controlling elements of stream flow, and has located reservoirs at every step from the hilltop to the ocean, and supplies water to fill the entire system from the great reservoir, whose importance in the administrative economy justifies the fact that three-quarters of the earth's surface is ocean. Incidentally, the oceans are useful for navigation, and the same is true, to greater or less degree, of the rivers emptying into them. The chief end of rivers is not navigation, but the conveyance of waters from higher to lower levels.

Nature has provided a goodly number of possible sites for artificial reservoirs to supplement the natural sites. The engineer who belittles reservoirs, their uses and possibilities, has not grasped the fundamental principle of river engineering.

In the final analysis it will be found that the possibility of reservoir extension is the measure of the success that may be hoped for in the way of a permanently improved Lower Mississippi, and a permanently protected delta, from the Ohio to the Gulf. This is a large assertion, but the proof is at hand.

Water at a high level represents potential energy, mass into head, $Q \times H$. In the passage of water from mountain top to ocean this potential energy must be expended in work.

If we assume the average volume of the Mississippi below the Ohio to be 500 000 cu. ft. per sec., and the elevation at that point to be 250 ft., there is a potency of about 20 000 000 h. p. to be expended in work each minute along some 800 miles of river.

If men load the stream with 100 000 tons of freight and let it float with the current, the load increases the mass, but the head is still H . The potency is $(Q + q) H$.

If Nature loads the stream with mud, silt, sand, and gravel to an aggregate of q_1 , the capacity for work is represented by $F (Q + q_1) \frac{H}{l}$, l being distance.

As a matter of fact, Nature does not give a through bill of lading for the freight it commits to the river, but the load is dropped at way stations, as bars and accretions, and is replaced, in a measure, by scour

Mr. McMath. and erosion at other places. The interruptions of silt movement congest and obstruct the main line.

The conclusion is unavoidable, the potential energy of the river must be expended in internal work, attrition of moving gravel and sand, friction, boils, eddies, etc., in the stream, and in scour of the bottom and erosion of banks.

This view of river dynamics gives a clue to the difficulties attending attempts to improve great rivers by fixation of channel and banks. The old tradition of the housewife who fought the North Sea with her mop is not far from a parallel case.

The improvement problem may be fairly stated to be, How to give the potential energy, which Man cannot materially increase or diminish, something more to do than destructive work. We know that floods destroy, but we do not fully know and appreciate the fact that the work done at low stages is largely reparative. Reparative work is the re-adjusting and removing of high-stage, or flood, deposits so as to restore the efficiency of the river bed which is always impaired by flood waves. Assuming that such reparation is the fact, the practical solution of the improvement problem is to subtract from the flood and add to the low-stage energies. This brings reservoirs to the front, for they effect this exchange, and nothing else is known that will. The argument that they will not prevent all floods is not worthy of attention. The question is, how much can they be made to do?

From 1880 to 1883 the writer was employed by the then newly created Mississippi River Commission to make a special study of reservoirs, their possibilities, and their relations to river physics. He progressed far enough to realize that reservoirs were the natural and logical remedy for many physical ills, capable of ameliorating, if not curing.

He became convinced that the dynamic view of river physics, outlined above, was true beyond controversy, and that the first practical lesson was the futility of fighting against natural law when it is possible to work in harmony with it, by extending and especially by perpetuating Nature's reservoir system. Levees, revetments, and dikes, while locally useful and temporarily effective, should have a subordinate place.

It was then argued that concentration of flood waters between levees would "lower the Mississippi in its bed" and "set Cairo on a hill." When this idea gained official ascendancy, the writer resigned his position and turned to another line of professional work.

Twenty-five years have passed, levees have been built and maintained along the whole delta course of the river; and millions have been spent. Has the river bed been lowered? Has Cairo, relatively to high waters, been elevated? Has any stretch of river of considerable length yielded to control and been permanently improved? The writer appeals to the records.

The reservoirs already constructed and being operated at the head-Mr. McMath. waters of the Mississippi afford a very useful object lesson, if studied and the lesson applied intelligently. So far as the writer knows no such study and application have been made.*

The formal perfunctory Annual Reports to the Chief of Engineers drop a fact here and there, but are chary of giving interpretations. The following explicit statement is made in the Report for 1905, Vol. VI, page 1675:

"Without the reservoirs the discharge of the river at St. Paul is liable to fall to 1 700 cubic feet per second, as it has in the past, while with them the discharge can be readily held throughout the navigation season at or above 6 000 cubic feet per second."

That is, the present reservoirs are entitled to credit for a contribution of 4 300 cu. ft. per sec. to the Mississippi from below St. Paul to the Gulf of Mexico. For it must be borne in mind that a contribution to maintain a flow is subject to loss from absorption or evaporation only in the proportion that the augment increases the surface, which is very small. If delivery of the augment is delayed, and it be expected to fill a depleted bed, the losses by absorption and evaporation will easily consume the augment.

For this reason, the writer credits the reservoirs with the full amount of their contribution from St. Paul to the Gulf. A further contribution from the Great Lakes Reservoirs, *via* the Chicago Drainage Canal, is added to the Middle Mississippi at Grafton. The minimum discharge at St. Louis has been said to be about 40 000 cu. ft. per sec. A 10% increment from St. Paul and 20% more from Chicago is a material increase, and certainly assists in the formation and maintenance of the low-stage channel; but, from the writer's point of view, a more important result is the general condition of the river bed due to low-stage scour. Nothing will be said about bank erosions because they are not perceptibly affected by contributions.

Suppose this prepared condition, which ordinarily will last and progress during the winter months, is followed by a heavily silt-laden flood from the Missouri River. The water flood-wave will outrun the silt load which drops on and elevates bars; not only is the low-water channel obliterated, but the elevated bars are obstructions left by the flood-wave to impede the flow of subsequent flood-waves, which, to pass equal volumes, must rise higher on the gauge. In other words, flood-waves impair the efficiency of the regular river bed. Here lies the weakness of levees as a protection against extreme floods. There is not only no way of arriving at the volume that may come as a result of combinations of discharge from numerous tributaries, but in case of a

* The author in a foot-note refers to a report of a Board as containing "exhaustive data upon the system and its operation"; the writer has not seen the report.

Mr. McMath. succession of flood-waves, as the season advances, it is impossible to foresee what height on the gauge may be reached by a known volume.

When the Government undertakes to construct and maintain a levee system covering a long extent of river, the fact is accepted as a guaranty that complete protection will be furnished, and that the protected areas will invite occupancy and cultivation. If the levees are overtopped by unforeseen combinations of floods or are extensively breached by any of several forms of attack, the dire disaster to life and property will be greater as the levees are higher and as the sense of Government assurance of security is stronger.

The author has favored us with quite a long list of lions which may lie in wait in a reservoir system. The writer merely uncovers the existence of very savage lions along the levees' track as well. The moral is, use levees, reservoirs, and other methods of improvement within their appropriate limits and for proper purposes.

The appropriate limits and purposes of reservoirs depend upon conditions which vary with latitude, climate, topography, elevation, seasons of excess and deficiency of precipitation, the use made of impounded waters, the unreasonableness of men, and, the writer deems it necessary to add, to administrative action under defective legislation or want of legislation.

The latitude and climatic conditions of the Upper Mississippi differ radically from those of the Ohio Valley. The topography conditions of flat and hilly gathering grounds, season, and rate and quantity of precipitation are also very unlike. If there should be an Ohio system of reservoirs, there is little doubt but the leading or primary use would be for power, and so the executive in charge of operation, and there must be a supervising executive, may be relieved from the embarrassment of the Upper Mississippi executive, who tries to satisfy seven different and often conflicting interests (town water supply and irrigation might have added two more) without authority to decide which is entitled to preference or precedence.*

The shadow of the author's official experience in this connection is noticeable in the later pages of the paper. The whole story could not be told by an officer of Engineers, because it might be construed as criticism of "Official Superiors." A civilian is at liberty to say that the fault lies, with many others, at the door of The Congress.

To sum up the reservoir part of the writer's discussion:

1. Artificial reservoirs do have and will have a considerable moderating influence on floods, but that influence cannot control extreme cases; extremes, however, are exceptions.
2. Artificial reservoirs have many beneficial uses and, in comparison, few drawbacks.
3. Whether a possible reservoir site is or is not available, is a local

*Report, Chief of Engineers, U. S. A., 1905, Vol. VI, p. 1676.

question to be determined by an algebraic sum of "plus" and "minus" Mr. McMath. quantities, in which time is a variable factor. What was once easy is not difficult; what is now difficult will be more difficult later.

4. Passing from the Ohio and Upper Mississippi water-sheds, it is a reasonable expectation that the floods from the Upper Missouri, Yellowstone, Platte, Kaw, Arkansas, Cimarron, Cottonwood, North and South Canadian, and Red Rivers will sooner or later be held in reserve for the benefit of the arid and semi-arid regions of the Middle West. The aggregate of flood decrease, not so much as to height as duration, is tremendous. This, in the writer's opinion, is the chief hope for the Lower Mississippi for flood control, navigation, and security.

5. A river from source to mouth is an indivisible unit, though it has many branches and serves many uses.

The author's treatment of the influence of forests on stream flow is weakened by his omission of the very great and almost universally present fact of ground storage.

"The inclined-plane surface, practically impervious to water, with a layer of sand covering some small portion of it" with a uniform spray of water applied to the entire surface, has but little similarity to natural conditions.

Some years ago the writer visited the head-waters of the Meramec River, Missouri. A heavy fall of wet snow, about 9 in. deep, had covered the country with practical uniformity. After two days of bright sun and warm wind the snow was all melted, and the streams were running full.

The territory visited was near the junction of three streams, the drainage areas of which may be roughly estimated as being in the proportion of 1:3:4, with an aggregate area of about 2 500 sq. miles.

The smallest area has largely a clay subsoil of considerable depth, which is about as near an approach to an impervious surface as Nature makes; the underlying rock is sand and limestone. The slopes are moderately steep, largely cleared, and under cultivation. Conditions are favorable to active soil wash. The outlet stream is extremely turbid, the water being a dull brick-red in color, and the volume may be estimated at 150 000 000 gal. per 24 hours. Topographically, this stream should be the outlet for the second area as well as the first. It is known as the "Dry Fork of the Meramec," and is well named, for normally it is dry. The first area has no springs fed by stored water, but, as the area bears crops, a part of the precipitation, say 15%, must be absorbed.

The middle area is largely a sandstone formation with a porous top soil. The valley has a stream bed for emergencies, but it is normally dry; the stream bed practically ends at a cavern in the hill-side. There is plenty of evidence in the shape of drift that water

Mr. McMath. occasionally enters the cavern, and there is no doubt that the Big Spring of the Meramec, several miles distant and on the other side of a high rock ridge, is the chief water outlet of the second area.

The normal flow of the spring is about 60 000 000 gal. per 24 hours. A year's daily record of temperature showed a variation of about 2° Fahr., which proves that it is ground-water. At the time of the visit, about an hour after the first stream was forded, several engineers agreed to estimate the flow at 250 000 000 gal. per 24 hours. The water was roily, but fairly potable, being much the same as the water then supplied the citizens of St. Louis after sedimentation (since 1904, the St. Louis water has been clarified). The original forest, which was not dense, was cut 25 years or more ago for timber and for smelting-furnace fuel. Nature seems to be indifferent as to reforestation. The humus is very thin, but the soil and subsoil are absorptive sponges, probably not less than 60% of the precipitation being stored.

The third stream, known as the "Water Fork of the Meramec," has no special feature to distinguish it from other streams coming from a rugged country whose hilltops are the remnants of a denuded plateau. The valleys are narrow, with numerous springs, the rivulet tributaries bring in fragments of disintegrated rock to be worn down by attrition into gravel and sand for the big city below. At the time of the visit, two hours after the spring was reached, the flow was taken to be about 400 000 000 gal. The water was of a gray turbidity, but became potable after 5 min. subsidence in a vessel. Soil wash was not seriously in evidence. This area has been deforested for timber and furnace fuel. The land ownership being largely held by the Iron Company, the population is sparse and not given to agriculture. The place rock is sandstone above and flinty limestone below, readily disintegrated. The humus is of fair depth on the plateaus and thin on the hillsides. The conditions are favorable to absorption; probably 50% of the precipitation would be a fair estimate.

The intensity of rainfall may be said to vary from a Scotch mist to a cloudburst; the run-off varies accordingly. The absorptive power of subsoil and rocks may vary from nothing to totality, and the run-off inversely. If the subsoil below the humus is impervious, crops may start, but must perish; if pervious, capillary action and roots of plants recall much moisture from underground storage, but a very large part sinks below reach and feeds springs more or less remote.

If one regards local run-off as the end, underground water is to him a dead loss; if he takes a broader view, it comes back to its place among available resources.

In the locality used by the writer as an illustration, there is fairly good basis for the idea that the ground-water gets back to the streams within the areas. The locality is in the "Ozarks," and probably is fairly representative of broken country in low mountain districts.

The writer does not belittle evaporation and local run-off. He brings Mr. McMath. underground storage forward that it may have its proper place in the consideration of the vital question.

Considering the subsoil and underlying rocks as a sponge lying below the humus, the influence of forests on stream flow depends at least partly on whether they hold the water of rains and melted snow within reach of the sponge longer than denuded waste lands or cultivated fields. An infinite variety of conditions must affect the question; the only answer that may be given is an averaged result.

The author, in the first of his seven summing-up propositions, says:

"The bed of humus and débris that develops under forest cover retains precipitation during the summer season, or moderately dry periods at any time of the year, more effectually than do the soil and rocks of deforested areas similarly situated."

The writer is content to accept this statement as the grand averaged fact, and thinks it a verdict in favor of forests.

The conservation and utilization of Nature's resources are the special province of engineers. Now that the subject has come to the front, engineers would be very remiss if they failed to press forward in the discussion. They should not surrender the field to the horde of fakirs who rush into any discussion which promises to receive popular attention.

As a check and antidote to the follies of fakirs, Colonel Chittenden's paper and its discussion are valuable and timely.

H. F. LABELLE, M. AM. SOC. C. E. (by letter).—In point of timeli- Mr. Labelle. ness and completeness this paper is *facile princeps*; the question of the influence of forests on the regimen of rivers through the control of rainfall has been presented to the Society in a most exhaustive manner. The paper brings this matter, which has assumed a national importance, before a body of men who, it is to be hoped, will discuss it exhaustively, and there is no doubt that the net result will be a clearer understanding of the complicated problems involved, which, so far, have for the most part remained without adequate solution.

The most natural thing to do, in investigating the value of this theory, as advanced by the votaries of reforestation, is to confront it with the facts; if it explains all or a great majority of them, it can be confidently accepted; if it does not, it is not tenable. In order to investigate the matter the writer submits Table 15, in which he has arranged by decades the high waters given by the author in Table 1. The available data from the Susquehanna and Schuylkill water-sheds have been added. The last two water-sheds have been selected because, in the first, deforestation has been progressing at a high rate since the Fifties; in the second, little or no deforestation has occurred during the last 40 years. The figures in Table 15 are the means of the author's figures for each successive decade; other periods are shown in brackets.

Mr. Labelle.

TABLE 15.

All Figures are in Feet, Except for the Schuylkill, where Inches Over the Reading Dam are Given.

Decade.	Years.	MISSISSIPPI.		OHIO.			TENNESSEE.	MISSOURI.	CONNECTICUT.	SUSQUEHANNA.		SCHUYLKILL.	
		St. Paul.	St. Louis.	Pittsburg.	Cincinnati.	Louisville.	Chattanooga.	Florence.	Kansas City.	Springfield.	Harrisburg.		Reading.
											High water.	Low water.		High water.
1st.....	1848-1857	.....	(1898-55) 31.2 (1856-97) 26.8	25.1	.....	.....	.....	.....	.....	.....	.....	.....	
2d.....	1858-1867	.....	.....	24.8	49.7	27.3	.....	.....	.....	.....	.....	.....	
3d.....	1868-1877	12.6	25.6	22.2	48.7	25.1	.....	24.3	(1844-78) 21.3	16.1	.....	.....	
4th.....	1878-1887	11.4	27.6	24.6	54.1	30.3	35.0	22.0	19.8	14.4	.....	.....	
5th.....	1888-1897	10.5	27.1	25.4	48.6	23.9	33.5	20.4	19.8	15.3	(1891-95) 10.4	0.58	
6th.....	1898-1907	10.8	25.5	28.0	53.1	23.8	31.5	20.0	24.1	16.9	15.9	0.89	

From the Fifties to the early Nineties the lumbering operations on the Susquehanna were very brisk, and enormous quantities of square timber were taken down to tide-water. Many mills, especially in the Williamsport district on the West Branch of the Susquehanna, have also been busy transforming the forests into lumber. The flood of June 2d, 1889, which coincided with the flood at Johnstown, Pa., brought to tide-water millions of logs, which occurrence made clear the vast extent of lumber cutting in progress in the upper part of the water-shed. Since 1895 square timber rafting has ceased on the river, but the manufacturing of lumber and the consequent deforestation are still progressing at a rapid rate.

As to the Schuylkill River, E. F. Smith, M. Am. Soc. C. E., General Manager of the Schuylkill Navigation Company since 1865, states that little or no deforestation has taken place in the water-shed during the last 40 years, and that the Schuylkill valley is largely a farming and not a densely wooded district.

As the low water at Harrisburg, on the Susquehanna, has not been influenced by engineering works, the average low water for the last two decades (1891-1908) has been introduced in Table 15.

Bearing in mind that deforestation has progressed in all the water-sheds except the Schuylkill from the early decades to the present time, it will be seen from Table 15 that the floods have increased in some rivers and decreased in others. In the case of the Ohio, at Pittsburg, the mean of the floods (retrogressing from the third to the first period and progressing from the third to the sixth) has increased in about the same ratio. Comparing the Schuylkill for the fourth and fifth decades with the Ohio for the fifth and sixth decades, there is a greater increase in the first than in the second case; now, if the increase in the former cannot be attributed to deforestation, because no deforestation has taken place, why should it be in the second case? There is certainly no uniformity in the figures: they tend to show that deforestation is not the paramount factor in the causation of floods.

As already stated, the natural features of the low water on the Susquehanna have not been disturbed. The zero point of the Harrisburg gauge was placed at the low-water mark of 1804. This gauge was established in 1890. According to the theory here discussed, and after extensive deforestation of the water-shed, low waters should be much lower than they were 100 years ago. The fact is that the water at Harrisburg went below zero of the gauge only once since 1891 (-0.04 in 1900); in 1895 it went down to $+0.04$; all the other readings are above 0.16, and the means for the last two decades are as shown in Table 15. The low water since 1891 has apparently been on the increase. Here also, at first sight, the theory fails to explain the facts. The writer says "at first sight" because it is quite evident

Mr. Labelle. that other factors, like rainfall, its distribution, and the condition of the ground-water, may mask the effect of forests, and that a thorough analysis of these other factors is necessary before the real effect of deforestation becomes apparent.

It is believed that Mr. Leighton, in his remarks on the Tennessee River, has gone to the heart of the whole question, and that rainfall has to be considered in conjunction with deforestation. The writer also believes that the condition of the ground-water is the governing factor in low stages. This question has already been taken up by the Forestry Bureau, and diagrams have been made for a number of streams. If these diagrams show that neither the rainfall nor the condition of the ground-water can account for changes in the run-off, the theory of forests and stream flow will be materially strengthened. It is to be hoped that these diagrams, or, at least, the results obtained from them, will soon be published, and that they will be for a great variety of rivers in different parts of the country, including rivers having water-sheds which have suffered little or no deforestation. It is much to be desired, however, that this work be done by disinterested parties. The question of obtaining correctly the total daily or monthly rainfall in a water-shed from a few widely scattered stations is no easy task; it is strongly dependent on the judgment and experience of the computer, and, obviously, he should be free from preconceived ideas.

Mr. Pinchot has mentioned the importance of forest cover as increasing ground-water storage and the consequent increasing of low-water stages. It is believed that there are other factors of much greater importance than forest cover in the creation and conservation of ground-water. A comparison of the minimum run-off of that part of the Susquehanna water-shed above Harrisburg with the minimum run-off of the Octoraro Creek, a tributary of the Susquehanna, draining a water-shed of 217 sq. miles near tide-water, devoid of forests and under a high state of cultivation, while the country above Harrisburg is only partly deforested, gives the following results:

Year.	Susquehanna River above Harrisburg.	Octoraro Basin.
	Minimum run-off per square mile.	Minimum run-off per square mile.
1897	0.19 sec-ft.	0.63 sec-ft.
1898	0.21 " "	0.83 " "
1899	0.15 " "	0.80 " "

The factors favoring the Octoraro Basin, which is in the alluvial plain at the head of Chesapeake Bay, are porosity of ground and flat slopes, while the water-shed above Harrisburg is in the hills and the ground has less retentivity. Even if the forests above Harrisburg had remained intact, it is difficult to conceive that low-water run-off

per unit of area in that part of the water-shed would have reached Mr. Labelle. the figures given for the Octoraro Basin. The foregoing statement would corroborate the author's 7th proposition.*

The Bureau of Forestry has investigated different water-sheds, from time to time, for the purpose of ascertaining the effect of forests on stream flow. These investigations can be divided into two classes: (1) Those carried out in adjoining water-sheds, both forested and deforested; (2) those carried out in a given water-shed before and after deforestation.

The investigations carried out in the San Bernardino Mountains, California, belong to the first type. Mr. James W. Toumey,† in recording the results of the above, prefaces his tabulation as follows:

"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.'"

The results of his investigations are summarized in Table 16.

TABLE 16.

Area of catchment basin, in square miles.	Condition as to cover.	RUN-OFF IN PERCENTAGE OF PRECIPITATION:			Run-off in June, in acre-feet per square mile.
		In December, 1899.	In January, February, and March, 1900.	Annual.	
0.70	Forested.	3	35	28	25 —
1.05	"	6	33	30	30 —
1.47	"	6	43	36	30 +
0.53	Non-forested.	40	95	69	0

The rainy season begins in December and ends in March. The precipitation is 46 in. for the forested and 33 in. for the non-forested areas. At first sight the results are all in favor of forests, except as to the total annual run-off, which is 69% for the non-forested and

* Page 281.

† "The Relation of Forests to Stream Flow," by James W. Toumey; a reprint from the Yearbook of the Dept. of Agriculture, 1903.

Mr. Labelle, only 33% for the forested areas. From the results Mr. Toumey concludes that the forests are beneficial, inasmuch as they tend to equalize the flow throughout the year. He does not say a word about the relative slope and porosity of the water-sheds; the precipitation is given, but its character is not mentioned. The influence of the different factors producing run-off should have been found before the percentage of influence due to forests could have been determined. This procedure in the above experiments would have made the results more convincing.

The investigation of the causes of the decreased flow of Rock River, Wisconsin, belongs to the second class.* The water-shed has an area of about 3 600 sq. miles, is slow-spilling, and has a comparatively high retentivity.

A good proportion of its swampy lands and small lakes has been drained; and the custom of laying tile and other drains and of cutting ditches prevails throughout the region. This has resulted in a more rapid delivery of the rain water into the streams. The rainfall has been decreasing since 1885. The forests have decreased from 75% to 30% of the whole area. Mr. Schwarz, the author of the pamphlet, states that the most obvious explanation for the smaller quantity of water annually carried by Rock River is the diminution of rainfall; he ascribes also a certain amount of influence to the draining operations above mentioned. The principal body of water which has been drained is the Horicon Marsh, at the upper end of the main branch of the river. This marsh was dammed in 1846 for water-power; it has an area of 73 sq. miles, and its catchment amounts to approximately 400 sq. miles, or one-ninth of the water-shed. Later, the dam was removed, and the tract was allowed to revert to its original state and was put under cultivation. In spite of the conditions just described, the pamphlet attributes largely to deforestation the reduction in the stream flow.

It seems to the writer that the conditions obtaining in the water-shed were well enough known to permit of making some kind of an estimate of the percentage of decrease of run-off due to:

- 1.—Smaller rainfall;
- 2.—Drainage of swamps, low lands, and the Horicon Marsh;
- 3.—Increased demand of cultivated lands;
- 4.—Deforestation.

The sum of the first three factors subtracted from the total decrease in run-off as computed from gauging operations would give the fourth factor, or the percentage of decrease due to deforestation. Until this computation is made, all estimates of this fourth factor are mere speculation.

* "The Diminished Flow of Rock River in Wisconsin and Illinois," by G. F. Schwarz; Bulletin No. 44, Bureau of Forestry.

Both Colonel Chittenden and Mr. Pinchot have gone to the water-shed of the Sacramento River* to secure evidence in favor of their views. Their conclusions are divergent. In the paper on the flood of March, 1907, on pages 296 and 297, is found the rainfall for both the American River and Puta Creek, the two streams selected for comparison. The divergence in the conclusions is caused by the use of different rain stations in the columns headed March 17th-26th. The author derives his average rainfall for Puta Creek from Stations 76 and 77, excluding the two others as not representing territory tributary to the run-off gauging stations. Mr. Pinchot objects to this, and by taking in Stations 74 and 78 and some stations outside of the water-shed (a procedure of doubtful orthodoxy, but the figures on the Cache Creek Basin were very tempting) he manages to get an average much lower than the author's, thereby turning the tables on the latter. The writer does not think it necessary to go outside of the Puta Creek water-shed for rainfall data. If the period from March 17th to 26th does not furnish sufficient information, the two water-sheds may be compared for the whole month of March, which is preferable for our purpose for it represents a greater percentage (70%) of the yearly rainfall. Table 4 of the paper cited gives the precipitation of both water-sheds for March, 1907. From Tables 13 and 14 of the same paper the total discharge for the month can be obtained. Table 17 gives the precipitation and run-off for each water-shed.

TABLE 17.

	Precipitation, in inches.	Drainage area, in square miles.	Total rainfall, in billions of cubic feet.	Total run-off, in billions of cubic feet.	Percentage of run-off.
American River.....	25.67	1 910	114	62	54.5
Puta Creek.....	19.12	805	36	18.45	37.4

The figures in Table 17 certainly do not favor forestation. It is fair to say, however, that they are not an argument against forests, because the percentage of snow in the American River water-shed is not known and cannot be estimated owing to the non-existence of rain and snow gauges in the upper part of the basin.

In his 5th proposition the author gives an important place to second growth; there is no doubt that second growth in Eastern forests tends to perpetuate or at least restore the conditions obtaining before the removal of the virgin forest, whether these conditions be favorable or not to the uniformity of stream flow. In the Southwest, however, in places, coniferæ compose the bulk of the forests, and deforesta-

* "The Flood of March, 1907, in the Sacramento and San Joaquin River Basins, California," *Transactions, Am. Soc. C. E.*, Vol. LXI, p. 281.

Mr. Labelle. tion leaves the country as bare as the bluffs of Eastern Nebraska. On some of the hills, where thick forests existed 25 years ago, not a tree nor a bush can be seen; the second growth, owing no doubt to the scarcity of rainfall, has not materialized; there is almost no grass, and the ground is bare and sun-baked. Still the erosion is not remarkable from year to year, and is almost entirely confined to the stream beds. It is true to say, however, that floods have more violence now than before deforestation.

Silver City, a town in Southwestern New Mexico, about 8 miles from and on the eastern slope of the Continental Divide, was founded about 1870. Although the business part of the town was often flooded during the rainy season, no material damage was done until about 13 years ago. At that time the forests in the water-shed had been considerably reduced and a flood of unusual severity coming then destroyed several buildings on the main street, including a large hotel, and started to cut a new channel on the line of that street. The gully is now about 50 ft. deep and 100 ft. wide in some places. The people of Silver City consider the occurrence a blessing in disguise, for it has confined the floods, and the town is now free from further damage. The people also believe that the deforestation of the water-shed has been the primary cause of the erosion, and it is really hard to believe that any other cause could have produced it. It is believed that this part of New Mexico is eminently well adapted to the gathering of evidence in the matter discussed herewith, especially as to erosion, owing to the favorable conditions of rainfall, slope, and soil, surface and subsurface.

We must not, however, give to soil erosion an importance so great as to induce us to believe that our highlands are surely, if slowly, being washed to the ocean. We can permit ourselves to doubt the imminence of this peril if we consider for a moment the Chinese Empire and its vast area feeding its millions of mouths. In spite of the fact that China has been deforested for hundreds, nay, perhaps for thousands of years; in spite of the fact that the quantity of material eroded from its surface has been sufficient partly to fill and discolor the waters of the Yellow Sea, without mentioning the enormous quantity of deposits brought into the China Sea; in spite of the high rate of rainfall and the destructive floods occurring in the basins of its rivers, the land is still able to feed a population five times as large as ours, and the end is not yet. No, let us rather believe that the husbandman, with the help of fertilizers, proper rotation of crops, and other scientific modes of culture, will be able to work faster than the destructive forces of Nature, and stay the progress of erosion. With the example of China under our eyes we are warranted in believing that our highlands will not cease to be productive for three or four thousand years; this should satisfy the most rabid devotees of the great-grandchildren

cult. The Chinese and also the Igorrotes of Northern Luzon prevent Mr. Labelle. the erosion of their sidehills by building against them a system of terraces; some fine examples of this mode of construction can be seen in the Province of Lepanto-Bontoc, Island of Luzon.

Enough has been said to show how insecure the foundation underlying the theory of forest and stream flow is at present. Further studies will probably bring out classes and indicate the kind of watersheds where forestation is beneficial. To accept the theory as it now stands, with its sweeping claims, would be both illogical and unwise. If the acceptance of this theory means the spending of millions in time and money, the country should be sure that failure to accomplish results will not confront future generations.

In reference to the system of reservoirs proposed on the Ohio River and its tributaries: If the advocates of the scheme expect to get revenue from the sale of water-power in the Ohio Valley, they will certainly meet with disappointment. This section of the country is blessed with an abundance of good coal, and it would be difficult to find anywhere a district where water-power is in less demand and will remain so for so many years. Should our Government wish to elucidate this matter, let a power survey be made of the whole valley and it will soon be found that the proposition is hopeless.

As regards the enterprise as a whole, the writer hopes that it will be agreed that nobody knows whether or not it is practicable, because nobody has ever tried to find out and gather the physical facts necessary to form an intelligent opinion.

The writer finds only one fault with the investigation of this matter which was initiated by the last Congress; the appropriations for this work should be largely increased to push it rapidly to completion. The whole water-shed of the Ohio should be investigated, proper structures designed, and different combinations of reservoirs effected; then the whole proposition should be submitted to engineers of national, if not international, reputation, and its merits and practicability determined on a basis of indisputable facts and data. The more complete and exhaustive are the studies, the less speculation will be required. If the scheme has to be rejected, let it be done as quickly as practicable, in order that local means may be adopted for the protection of flood-swept districts and the amelioration of rivers.

EMIL KUICHLING, M. AM. SOC. C. E. (by letter).—This difficult Mr. Kuichling. subject has been presented by the author in a very clear and forcible manner, and gives the results of his careful observations and long experience with extensive projects for the conservation and regulation of the discharge of many natural streams. The ground covered, however, is so broad that discussion must necessarily be limited to the consideration of only a few of the various features involved.

Much has been written during the past fifty years on the meteor-

Mr. Kuichling. logical influence of forests, but the conclusions reached are often discordant, owing to the obscurity of our knowledge of the various factors that enter into the problem. Some writers have laid stress on the mysterious properties of trees, singly and in groups, as exciters or conductors of electricity; others have given attention to the complex thermal influences of vegetable life; another class has studied the purely chemical actions of foliage; while a fourth class considers only the geological and hydrological relations, or the rainfall and run-off as commonly expressed and understood. These latter relations, however, involve all the others, so that in reality run-off is the resultant of a variety of physical forces, most of which are still almost unknown.

The familiar factor called rainfall or precipitation is by no means easy to measure, or even estimate, with accuracy on a large drainage area. Its magnitude varies in almost every storm, both with the position and altitude of the rain-gauge and with the direction of the wind. Gauges placed only a few miles apart at the same altitude usually exhibit very considerable differences in the quantity of water caught, and these differences increase greatly in a mountainous region, especially on opposite sides of a high range. Still greater do such differences become when dealing with snow. In conjunction with one of the most skilful observers in the U. S. Weather Bureau, the writer once undertook to measure the depth of snowfall during two winters, but in no instance did the observations agree, either in respect to depth or weight, at several different points in the same city; neither did the differences balance even approximately in the course of several consecutive months.

In view of these difficulties of estimating the approximate depth of atmospheric precipitation on a relatively small and nearly level urban area with a number of favorably located gauges, it is easy to understand how much more difficult the task becomes in the case of large drainage basins presenting a great variety of surface and altitude, and having thereon only a few places of observation.

Numerous cases might be cited in our oldest and most densely populated States, where important river basins with areas of several thousand square miles have only two or three rain-gauges, whose records embrace less than twenty years; and plenty of cases occur where the observed run-off from adjacent tributary water-sheds of similar character in the same basin is widely different during a season of several months from apparently equal amounts of precipitation. Other instances also occur where the aggregate observed run-off during twelve consecutive months, from a mountainous drainage area of several hundred square miles, is greater than the reported precipitation thereon, measured at one or two stations.

But while there are probably serious errors in the estimates of our rainfall, as well as a woful deficiency in the number of places of obser-

vation, the available data for run-off are generally not in much better condition, due to difficulties of measurement and observation. It is rarely the case that the gaugings of a stream at the same stage of flow agree with each other in the course of several years, even when the channel remains unchanged, and in but few instances are accurate measurements made of high floods. It also seems to be necessary to change the rating tables of many river stations from time to time in consequence of altered channel or more reliable gaugings, so that comparisons of discharge at some particular stage in different years cannot be made without much tedious study. Such work is usually impracticable in the case of private enterprises and is seldom done for public purposes, but it is indispensable when endeavoring to ascertain the cause of variations in discharge.

It seems to the writer, therefore, that, with the scanty data now available in the United States, a sound conclusion cannot be reached in regard to the influence of forests on either rainfall or run-off; and that, until a much larger volume of accurate observations has been acquired, we must content ourselves with the more or less imperfect studies of the subject that have been made abroad. There is, however, no question about its importance from the point of view of national economics, and the writer hopes that the public interest taken in it will quickly lead to the needed enlargement of our Weather and Hydrographic Bureaus.

ROBERT FLETCHER, ASSOC. AM. SOC. C. E. (by letter).—The following facts have come within the range of the writer's personal experience and observation: Region: the upper Connecticut Valley at a point where there is a tributary area of about 3 250 sq. miles, north of Dartmouth College. Altitude of the country: from 380 ft. above the sea at the river level to 6 000 ft. in the White Mountains. Annual rainfall: between 30 and 40 in. Winter conditions: ground frozen from late November to the middle of April. Surface of the country: river bottoms, narrow valleys, generally steep hillsides; probably one-quarter or more in forest which is mostly recent growth excepting about the head-waters of streams in the extreme north. Furthermore, the writer is interested in the work being done by Dartmouth College, under the supervision of its forester, in systematic forestry applied to the College Grant which comprises about 40 sq. miles near the head-waters of the Connecticut River. Also, as an official of the Hanover Water-Works Company (which is the College and Village precinct in a joint corporation), he has supervision of about 2 sq. miles, the entire drainage area tributary to the reservoir which furnishes the water supply. His period of personal observation extends over thirty-six years.

As to forestry conditions in this region, the following facts are undisputed: The primeval forest has long since disappeared, excepting

Mr. Fletcher. on the slopes of the northern mountains and in some very rare small holdings farther south. Lumbering has been going on incessantly for two or three generations, resulting in "drives" of logs down the river amounting annually to 60 000 000 ft. or more. Every farm, since the settlement, has had its "wood lot" as the source of fuel. Since the railroad era, 75 years ago, the demands on the forests for locomotive fuel have been very great, until, within 25 years, the coal-bin has displaced the railroad wood-pile. Latterly, to the great cuttings of the lumber companies have been added also the large cuttings made by owners of paper mills for the manufacture of wood pulp. Both of the latter were principally concerned in getting out the pine, poplar, basswood, and spruce, leaving a large amount of the hardwood undisturbed excepting for the inevitable breaking down of trees and the accumulation of great quantities of slash. Last of all have come the agents of a great concern (one or more?), the so-called "Match Company," who, offering to the farmer, for the growth on his woodland, a cash price (which is often far less than its real value, but is a goodly sum to the rural owner), buys it all and makes a clean sweep. The farmer, to be sure, has his land left, but most of it will be worthless, until, in perhaps 80 or 100 years, it may produce another forest. Within the last 5 years it has become a familiar sight to see prominent hillsides up and down the Connecticut Valley almost entirely denuded of their timber growth.

With regard to the erosion in such cases, it may be said that all depends on the nature of the soil and the slope. Heavy rains undoubtedly make the rocky slopes more bare, because the thin soil dries out quickly without the protection of the foliage. The heavy soils are more tenacious, and allow the rapid development of new growth. The sandy terraces are frequently badly washed by rain and scored by wind, because they dry so quickly without the protecting cover.

According to the testimony of the oldest inhabitants, there is probably more woodland throughout this section of country than there was fifty years ago. In all directions, old pastures are growing up to white pine, whenever "seed-trees" are favorably situated, and it is surprising how rapidly these trees grow—when they have made a good start—from the sixth year after seeding. Young pines will increase in height from $1\frac{1}{2}$ to 2 ft. annually, and, after the twentieth year, have been known to add 4 ft. to their height in a single year. After that period, also, the annual increase of bulk is about 10 per cent. By systematic work and some outlay, an individual, if he has patience and years enough before him, may do considerable reforestation by raising and setting seedlings; but it is the writer's experience that Nature, if left to herself under favorable conditions, will easily out-strip him three or four acres to one, especially with a little assistance in transplanting, where the natural seedlings are bunched too much.

Noting briefly now the author's numbered conclusions:

(1) The moderating and equalizing influence of forests on the run-off of ordinary rainstorms is a fact too obvious to be questioned. We must not, however, belittle the absorbent and retentive power of tillage and grass land under proper conditions of cultivation and slope.

(2) The author's second proposition is quite confirmed by the writer, who has tramped for miles over the drainage area of the reservoir in the height of heavy rainstorms, and found the saturated woodland shedding the rainfall in swift and furious streams, even more rapidly than the meadows where grass was growing.

(3) The author's proposition concerning run-off in summer the writer would apply to woodland and open country alike. Throughout the summer and autumn, when the grass, and crops, and trees, alike absorb moisture from the soil, heavy rains in the reservoir district produce but little effect on the level of the pond. In this case, the area of the reservoir (34 acres) is about one thirty-eighth part of the drainage basin, and the whole district is underlaid by an impervious boulder clay, so that nearly all the seepage eventually reaches the pond. In winter, however, the pond level rises quickly, even with moderate thaws or small rainfalls.

(4) The author's proposition concerning the effect of forests on snowfall to aggravate the flood discharge of rivers is not true in this region. Snow always remains in the woods late in the spring (except among young deciduous growth on the south exposure), and disappears gradually during April and May. Furthermore, the ground in the woods freezes much less than that in the open, and probably in spots allows percolation of water from the snow more or less throughout the winter; for, in the reservoir under observation, the surface level has been known to rise throughout the winter notwithstanding the draft upon the reservoir. (A temperature of 20° below zero is commonly experienced during three months of the winter.)

(5) Soil erosion depends so much upon circumstances, as already noted, that we may pass the question here.

(6) As to climatic conditions in this region, there has been no marked change in the mean annual precipitation since 1835, when the keeping of systematic records began. Of course, after the past season of phenomenal drought, by which we are more than 10 in. short of the average during the past year, the most ardent faith in statistics is likely to waver a little, as though some change were impending; but the records show that our forefathers had similar experiences and probably similar misgivings.

Period of 21 years.	Mean annual precipitation.
1835 to 1855	40.77 in.
1866 to 1886	30.63 "
1887 to 1907	36.43 "

Apparently, there is a gradual decrease, in the long run(?), but we can judge better 20 years hence.

Mr. Fletcher. Furthermore, as to river floods, there has been no noticeable increase. In fact, the highest flood that the writer has ever seen occurred about 25 years ago, and was considerably short of the height of the record flood of 1869, which wrought destruction throughout New England. Mill operators along the Connecticut also testify that there has been no noticeable change in the flood extremes. If anything, the flow has been more uniform in recent years. This last statement is the only comment the writer cares to make on Proposition 7.

For another case in point, it is proper to cite the experience of a private water company which supplies the village with a very pure spring-water drawn from a series of wells on a wooded hillside about 2 miles distant, and delivered through a 2-in. pipe to about 160 takers. This supply has not failed throughout the phenomenal drought of the last six months, and it is believed that it has been conserved by carefully maintaining the forest growth on the company's reservation.

Finally, extreme statements on both sides should be avoided, and the facts, when carefully ascertained, should be rightly interpreted. If it is true, as has been stated, that the fire gets more than the axe, then the lumberman naturally wishes to rescue the wood for the use of man. On the other hand, in virgin forest, the fire is not so apt to make headway, especially with a little care; but the vast areas obstructed by slash will always be subject to permanent destruction, until decay has done its work.

As to the question of cause and effect, the distinguished curator of the Arnold Arboretum has said, "If you have rainfall, you will have forest; no rainfall, no forest." It is an incontestable fact that the smaller streams of our side valleys not only have less regular flow, but have less annual discharge than in the days of the grandfathers. Ruins of mills and dams may be found on mountain streams where the attempt to establish a water-power to-day would be ridiculous. It is a fair question whether the country has been undergoing a gradual desiccation since the glacial period, irrespective of the question of annual rainfall. A fair interpretation of experience and observed facts leads to the inevitable conclusion that extensive and continued denudation of our forest-clad hills and mountains without continual and successful reforestation would be an immeasurable calamity, and that, putting aside argument or disputed points, we will make no mistake in all reasonable endeavor to conserve to the utmost the protected conditions about the head-waters of our streams and in the higher valleys, which we have inherited from the past.

Mr. Snow. J. P. SNOW, M. AM. SOC. C. E. (by letter).—The paper is timely as an offset to the present absurd statements in regard to the calamities overshadowing us on account of changing forests to cleared land. An experience of more than 40 years in Central and Northern New England leads the writer to agree, in the main, with the essence of

Colonel Chittenden's position. Some features of the paper, however, Mr. Snow may, perhaps, be made to mean more than was intended.

Conditions vary for each locality, and a statement that is true for one place may not hold in another. The author well says that no fixed rule can be upheld for all localities and conditions. What follows must be considered as pertaining only to that portion of New England between the latitude of Boston and the Canadian line.

Certain vital elements of the problem have not been mentioned in recent discussions, as far as the writer has observed. That forests evaporate an enormous quantity of water from foliage is proved by the water level in swamps becoming higher after a heavy growth has been cut off. On ordinary upland forest this evaporation tends to lower the subsoil water more than the growth on open land. Surface springs and running streamlets, on the other hand, are protected from evaporation by the shade of the forest, and stand a better chance to persist through a hot summer than if in the open. It is not surface water, however, that principally feeds our streams during ordinary or low-water periods. It is subsoil water reaching the streams below the water surface. Many times wells and pits have been sunk near streams with the idea of getting the advantage of filtration through a few feet of earth, and, behold, the supply was all from the side farthest from the stream. The greater part of New England is covered with a blanket, from 5 to 15 ft. thick, of interglacial gravel resting on subglacial till or ledge. Deep bank cuttings all over the region show water oozing out at the top of the impervious stratum below the gravel blanket. This natural reservoir is practically independent of surface cover.

In long-continued rains, when the ground is not frozen, the run-off is practically the same from open as from forest-covered land, with the following exception, in connection with freshet effects: Forest streams are generally choked with driftwood, and sometimes very formidable jams occur, which spread devastation when they break. A stream may even be turned from its course when one of these jams holds permanently, as is indicated on the Ammonoosuc River, in New Hampshire, a few miles above the Village of Littleton. These obstructions do not increase or decrease the total run-off, but they do have a marked effect on the possible amount of damage that high water may do.

In the case of moderate rains, the absorbent action of open and wooded land is probably very nearly equal, as a whole, with the balance in favor of the open land, if the ground is not frozen. New England grass-land, with its thick mat close to the surface, and with stalks and roots leading down into the soil, is certainly almost ideal as an absorbent. Deciduous forest, on the other hand, covers the ground with broad leaves that act like shingles to keep the water

Mr. Snow. from the soil. Fine needles act in much the same manner. Spruce, hemlock, cedar, fir, and larch furnish an absorbent bed, but it takes more than a gentle rain or common shower to get through the dense foliage of these trees before it is dissipated by evaporation; but little water reaches the ground, under these conditions, except that which runs down the trunks. Where the surface is covered with a thick moss growth, water is absorbed and retained better than on grass-land, but this condition obtains but sparingly in true forest.

As to forest effects on snow-melting: The author's position is certainly correct under certain conditions that are always possible, but seldom occur in the region here considered. Those who are responsible for railroad way and structures always dread a heavy burden of snow in the woods during late spring. If there is much snowfall, the normal condition is that a heavy burden will remain in the forest after the open ground is bare, except for drifts. If, under these conditions, a long rain occurs after a day or two of cloudy warm weather, the whole burden in the woods will go. Frequently the quiet reaches of the streams will still be covered with heavy ice, and all sorts of things may happen.

Snow upon open land frequently melts largely from the bottom, if the snow blanket comes on early enough to prevent deep freezing of the ground and remains on continuously through the winter. In this case the water is very largely absorbed by the ground. In heavy forest, on the other hand, this does not occur to nearly the same extent. Although the ground seldom freezes at all, the bed of humus, leaves, or moss, seems to act as an insulator to prevent the ground heat from melting the snow. Snow sometimes evaporates without melting, if the air is unusually dry for a long period. Water, as we know it, is a meteorological phenomenon, and meteorological conditions govern the whole problem. Forest effects are very subordinate and occasional, as far as ordinary run-off is concerned; under special conditions, such as described, the effect of large forest areas is distinctly bad.

In one way, not noted by the author, forests conserve the low-water flow of streams of moderate size, especially that of mountain streams on rocky beds. The evaporation on a hot summer day from a stream flowing over a bed paved with cobbles exposed to the full glare of the sun is very great. The cobbles and boulders are alternately wet and dry from the splashing of the water and the drying effect of the sun. Many miles of streams exist in New England that are now exposed to these conditions, whereas a century and a half ago they were largely protected from the sun's pumping effect by overhanging trees and water-loving bushes along their banks. This feature of shade and exposure probably measures the principal advantage of forest cover over open land in conserving stream flow.

Soil wash may be due to gullyng the surface, or bank erosion by streams. The first, such as is common in the Piedmont Section of the Southern States, is almost unknown in New England. The latter occurs both in forest and open land. Torrential streams generally keep their banks intact in both forest and open, except when jams occur in the timber. On quiet reaches the bottom land in heavy timber is usually a network of sloughs, sand-bars, snags, and swamps due to drift. In the open, banks are frequently cut at the bends, and disastrous cut-offs sometimes occur. A fringe of small-growth trees and bushes along the banks of the streams, through level land, is a great protection against this class of damage.

The greatest damage from erosion is due to sediment deposited on arable land or in bars which tend to divert the stream and spread it out into shallows. Without doubt the sudden removal of forest growth from a water-shed may result in erosion that will be pernicious to the land below, as will any disturbance of the existing equilibrium. Sawdust from lumber mills, poisonous sediment from paper and woolen mills, waste from tanneries, drainage from cities, wash from highways and streets, and the various encroachments of grasping abutters will destroy the regimen of a stream unless it is properly controlled by competent authority. Once a stream in the open is choked and spread out into shallows, its waters are exposed to the pumping effect of the summer sun, and a small dry-season run-off will follow.

Serious erosion sometimes occurs from the undercutting by sub-soil water from adjoining land when timber fringes are removed from stream banks. Such removal can hardly be called deforestation, but some of the minor features of the relation of wood growth to streams have more actual influence on the question at issue than the sponge theories of our friends, the lecturers. The sponginess of the thin-soiled rocky hillsides of New England is a negligible quantity.

As the author states, the amount of stream flow depends on the amount of precipitation, and forests are not the cause, but the natural effect, of abundant precipitation. This effect, if correctly spelled out, will read that mighty forests are produced by heavy precipitation because they are the most rapid dissipators of the superabundant moisture. Replace the tree growth of the Coast Range in Washington and British Columbia with close-cropped lawn grass, and the streams and rivers will carry much more water than they do now.

In a half century the streams, springs, and wells of New England have not been as low as they have been in 1908, although the area in tree growth is much greater now than 50 years ago. The reason of the low water, however, is simply the lack of rain.

The proper objects of forest conservation are well set forth by the author. His views accord with those of the writer except, perhaps, in the matter of devoting convenient lowlands to timber growth.

Mr. Snow. The scheme, advocated by many, of reserving enormous tracts of land for forest growth exclusively is all wrong. To prevent cutting in primeval forests is still worse. Matured trees make but little growth, and nearly all timber native in Appalachian regions is better in second than in old growth. Primeval forest shows lack of civilization, and large areas of it will lead back to uncivilized conditions among its denizens, be they men or beasts.

The true way to make forest conservation a benefit to the people is to encourage the growth of valuable timber in small areas scattered all over the farming section. In New England the northerly slopes are almost invariably better adapted to tree growth than to pasture or to cultivation. Add to these the high lands too rocky or thin-soiled for farm use, and we have a sufficient area for timber. It is probable that this is just what the author means, but his statement is capable of being interpreted differently.

Land that can be cultivated profitably for field crops should not be wasted on forests. There is an abundant area in New England that cannot be so cultivated without going to the high peaks of the White Mountains or their slopes, which, forsooth, are mostly above the tree-line or too near it for the profitable growth of timber. Small areas, as advocated above, will not endanger streams by driftwood or quick spring floods; nor will they foster such awful fires as large tracts actually invite.

Reforestation, to be successful, must rest on an economic basis. The greatest handicap to forest raising to-day is taxation. In the region considered, real estate is heavily taxed, especially that controlled by non-resident owners. If taxes on land devoted entirely to tree growing—where an earnest effort is made by the owners to grow suitable trees—could be assumed by the State or Nation until revenue of some kind is derived from the land, a substantial and wholesome impetus would be given to the work.

Mr. Johnston. CLARENCE T. JOHNSTON, M. AM. SOC. C. E. (by letter).—All who are familiar with the forested mountain regions of the West will agree with Colonel Chittenden in his conclusions. Possibly there are localities in the East where forests have the influence on stream-flow which has been attributed to them by popular rather than scientific authorities. Several discussors refer to the days of their childhood when forests were found on every hand, when streams furnished a steady flow, and when floods were not common; but they do not supply any data from which to judge as to how much cultivation has taken place since the forests disappeared, and what kind of vegetable growth has taken the place of the forests. Neither do they furnish any information relative to the rainfall during the years covered by their observations, the character of the drainage area, the kind of soil, the slope, etc. In the absence of this information, it is difficult to understand how

those who read are to ascertain whether or not such conclusions are based on fact or fancy.

Precipitation problems have been studied by the officers of the United States Weather Bureau for many years, yet the writer has been unable to find, in any of their reports, anything which would lead to the belief that forests have any appreciable effect on rainfall. Until this important branch of the Government service shows that there is some relation between forests and precipitation, men with scientific attainments will not be in haste to conclude that forests are a great factor in influencing rain and snowfall.

The writer has spent many months in the mountains of the West, and there the great problem is, not to prevent floods, because these are always of but local importance and of no great consequence, but to obtain the largest volume of water possible during the season when it is needed most for irrigation. Eastern streams are utilized for navigation and for power, as well as to furnish water for domestic purposes, but the problems in the West are different, because the needs and purposes there are different.

The writer's convictions have been established by observations and measurements covering a period of twenty years, and any one who doubts the truth of Colonel Chittenden's conclusions in reference to the timbered areas in the mountains of the West, should visit any of the numerous ranges in the spring before the snows begin to melt. He will find the timbered areas covered with a blanket of snow. The bleak mountain tops above the timber line will also appear to be covered, but as he ascends the mountains he will find that the snow on the high rocky slopes lies in depths varying from a few inches to 30 ft. and more. It will be found that it is warmer on the treeless slopes than it is in the forests while the sun is shining directly upon them; and when the sun is obscured, it is warmer under and among the trees.

As the weather grows warmer, it will be found that the snow lying thinly on the exposed treeless areas disappears first, and the great drifts surrounding these areas of light snowfall above the timber line show but little tendency to change. The snows in the forests, being distributed in uniform depth, gradually settle, absorbing the water that results from melting, and freezing at the surface each night. Later in the season, the great drifts above the forests settle gradually and the streams are largely supplied from areas where the snowfall has been from 1 to 3 ft. in depth and where melting is not delayed by the shade of the trees. As the season advances, and some time between May 1st and June 15th, depending on the lateness of the spring, the snow in the forested areas begins to melt, and, as it is practically uniform in depth, the entire timbered area furnishes water to a stream and its tributaries at the same time, and,

Mr. Johnston. owing to the saturated condition of the snow, it disappears within a few days. The floods which occur in the West come from the forested areas regularly each year. They do more damage to irrigation works by carrying timber which lodges in dams and head-gates than by high water alone.

If one considers the character of the timber grown on the mountains of the inter-mountain region, and estimates the volume of water necessary for the production of this timber, it becomes an economic question whether or not the farmers can afford, ultimately, to permit the growth of trees to the injury of the total available water supply. Before many years, all the water of our streams will be stored and held until the irrigation season begins. When this occurs, agricultural growth will be hampered unless all the water that can be obtained for this higher use can be made available. As every irrigator plants trees, this transition will tend to increase rather than to diminish the forest area and the available timber supply.

By July 1st, the snow has disappeared from the forested areas, and the water supply thereafter is derived from occasional rains and the great snow banks in the mountains. Later than July 1st, it is possible to find small quantities of snow here and there in the forests, but, although the writer, for twenty years, has been searching for snow in the forests during August, the month when water is needed most for irrigation, he has failed to find it.

It is fortunate that this important subject is receiving some intelligent study, and that discussions are being submitted which deal with facts rather than with boyhood dreams and theories unsupported by experiment or scientific observation. The Government's forestry work should not be affected in any way by the solution of the problems considered in this investigation. If the forestry service rightly has a place under the National Government, this place is assured, because its value to the public must depend on the protection it affords to forests and the timber supply. It is not necessary for that department to attempt to perform everything, and particularly to make claims which would lead one to believe that trees do not belong to the vegetable kingdom, in that they conserve more water than they need in their growth and development.

Mr. Pinchot. GIFFORD PINCHOT, ASSOC. AM. SOC. C. E.—In discussing the influence of forests on stream flow, it is unlikely that we will ever have a better statement, in certain respects, of the case against the forests than that which Colonel Chittenden has made. It has been restated time after time, under different conditions and by writers of different nations. This is, perhaps, the best statement ever made in America; therefore, it is particularly important, as far as facts are known, that the discussion should be as complete as possible.

The essential point to be considered in the discussion of the relation of forests to stream flow is this: What are the functions of the forest floor in the distribution of fallen rain? Mr. Pinchot.

Colonel Chittenden quotes at some length from the testimony of the speaker before the House Committee on the Judiciary, given February 27th, 1908, as follows:

"I have in my hand here a photograph of a denuded hillside. After the forest has been removed rain falls on that hillside and runs off rapidly, as the water I drop upon the photograph does now, and disappears instantly (illustrating). If, on the other hand, I place a forest cover on the hillside, that is exactly analogous in texture and effect with this piece of blotting paper, and drop the water slowly upon it, we would find that, instead of running off slowly at the bottom, the water is held (illustrating with blotting paper). Part of it runs off, but, as soon as the absorbent quality of the paper or the forest floor has time to take effect, the water is kept and drips gradually for a considerable length of time off the hill into the stream. This is an exact illustration of the way in which the forest controls the stream flow on that hillside."

He continues:

"Mr. Pinchot should have completed his illustration. He should have continued to sprinkle the paper long enough and heavily enough to have saturated the paper completely in order to show that the water would then flow from the paper as rapidly as from the uncovered area; and he should then have explained that this condition represents what always happens in the forest in times of great flood. Then he should have sprinkled the paper intermittently in small quantities, and at such long intervals that the warm air of the room would evaporate all of the absorbed water, and that none whatever would flow away. He should then have explained that this condition represents what always takes place in the forest in times of great drought."

It is unfortunate that Colonel Chittenden should have stopped his quotation where he did. The paragraph continues unbroken:

"The water which was in this piece of blotting paper on that steep slope remaining on the surface in this way for a considerable length of time, has an opportunity to run down into the soil, which is made permeable on the surface by the decay from the trees. One of the best-known effects of the humus under a forest is to render the top layer of the soil permeable and therefore to allow the water to sink into this forest reservoir. Experiments made with the greatest care show that even a moderate bed of humus is able to hold some five times its own weight of water, and the water, being retained in that way, sinks gradually into the ground, and in this way the streams, instead of being made torrential, are made to flow much more regularly during the summer months. In other words, the effect of the forests, theoretically, from this experiment should be to diminish floods and maintain the low-water supply."

The speaker, on the preceding page of his testimony, had already

Mr. Pinchot. explained the function of the forest and the purpose of his illustration as follows:

"The effect of a forest on a steep slope is to cover that slope with leaves, rotten and half-rotten sticks, and other mechanical obstructions which prevent the water which falls upon that slope from running straight down below as rapidly as it would otherwise. In this connection it has, in the second place, the effect of permitting the water which falls on that slope, instead of rushing off rapidly, to sink into the mountains.

"Now the mountains are substantially great reservoirs of water, which cannot operate unless they are renewed from time to time by the rain that falls upon them; and the rain that falls upon them cannot get into the mountain reservoirs unless the surface of these reservoirs is in an absorbent condition. I can illustrate that to the members of the committee in a moment with a glass of water and a piece of blotting paper, as a definite illustration."

The illustration quoted above then follows.

Unfortunately, Colonel Chittenden has failed to gather from these statements what seems to the speaker to be their obvious meaning.

The illustration used is a fair description of one, but only one, of the essential functions of the forest floor, and due notice was given to that effect. The forest floor offers a physical obstruction to the rapid escape of water over the surface, and thus itself provides to some extent a small storage reservoir. Colonel Chittenden admits this influence for average conditions; indeed, it is a matter of such common observation as to be indisputable. The practical value of this influence may be little or much, depending on the character and amount of precipitation and the thickness of the undergrowth, decaying litter and humus on the ground.

There is, however, another function of the forest floor which in practical value far surpasses this one. The forest floor acts on the soil itself to multiply its absorptive capacity. The humus, which by natural action is being constantly mixed with the upper layers of mineral soil, greatly increases its receptive and retentive power, while the deep-penetrating roots also open passages through which water readily passes into the great reservoir of ground-water.

That Colonel Chittenden has failed, however, to consider this function is evident throughout his discussion. In giving an illustration, he says:* "Consider an inclined-plane surface, practically impervious to water." When it is understood that under the forest the surface is very far from impervious, and that, on the contrary, it is absorbent in a high degree, the argument is seen to be fallacious.

Failing to note this function of the forest floor, Colonel Chittenden misses entirely the greatest influence which the forest exerts on fallen moisture—that of changing surface drainage to underground drainage,

* Page 247.

and of replenishing the great underground reservoir from which the Mr. Pinchot, springs and streams are fed.

What is the importance of ground storage, which is so lightly passed over? Professor King has found that ordinary soils have a capacity of from 4 to 5 in. of water per foot of depth, or even more.* Ground-water extends to a considerable depth. Considering the earth masses which lie above the stream levels in mountainous regions, one may form an idea of what ground storage means to the permanency of stream flow. The ground-water is constantly in motion, is replenished entirely from the surface, and is easily disturbed by any change in surface conditions.

In certain regions where there is a very thick humus, reaching occasionally, as in the Adirondacks, a depth of 3 ft., it has an important storage capacity; but the capacity of the humus is always insignificant compared with that of the ground. The mountains themselves are the chief reservoirs, and the principal function of the forest, so far as water is concerned, is to keep the surface soil permeable, so that these reservoirs of ground-water may be regularly and bountifully replenished. When the importance of the forest to ground storage is once realized, a very large part of Colonel Chittenden's argument is seen to rest on a fundamental misconception.

While admitting that for average conditions the forest bed has some retentive influence, the author hastens to say emphatically that "it is not true for extreme conditions—great floods and excessively low waters."† He further says:‡

"When a period of heavy storms occurs, spreading over a great area, continually increasing in intensity, the forests, by retaining some portions of the earlier showers and paying them out afterward, do produce a general high condition of the river which may greatly aggravate a sudden flood arising later from some portion of the watershed."

This curious conception seems to have taken root: Assuming, for example, that the humus is able to hold 1 in. of rainfall; then, when a later storm of 4 or 5 in. comes on, not only the 4 or 5 in. of the storm runs into the streams, but also the 1 in. which was there before. Thus the storm itself would have destroyed the storage capacity of the forest floor; an assumption which doubtless Colonel Chittenden will repudiate at once, when his attention is called to it.

The speaker was quoted as saying that the increase of rainfall due to the forest is about 10 per cent. That figure was taken from the estimate of Dr. Ebermeyer who, perhaps, has studied the influence of mountain forests on precipitation as carefully as any one else.

* F. H. King, Nineteenth Annual Report, U. S. Geological Survey, Part II.

† Page 247.

‡ Page 249.

Mr. Pinchot. The theoretical argument is overwhelmingly in favor of the contention that mountain forests do cause rain; and a reasonably correct view of that contention may be reached by taking an extreme case.

Take a heavily wooded water-shed, rising from the sea, as for instance in California, with prevailing on-shore winds during certain seasons. There are two things which lead one to suppose theoretically that the rain which does fall, under these conditions, should fall. One is the progressive cooling due to the air being forced into a higher altitude, resulting in a change in the amount of water vapor which the air will hold. The other is the fact that over the forest there exists a comparatively cool stratum of air, for some distance up, as has been ascertained by definite observations. We should, therefore, expect that a rain-cloud, passing from the sea over such a mountain range, would be inclined to drop its rain; first, because it was forced to cool itself by rising in height, and, second, because it met cool air above the forest. What would be the case if that same slope were deforested? The same influence of height would be observed, but, instead of the cool air above the forest, there would be a body of heated air rising from barren rocks and slopes, the whole effect of which naturally would be to prevent the cooling, and so to discourage precipitation.

This extreme case gives the argument as to the effect of mountain forests in causing rain. Many observations, some favorable, some unfavorable, and some neutral, to this theory, have been taken all over the world; but the best prevailing opinion of the men who have studied the matter most carefully seems to be that an effect of the forest on rainfall does exist, and that it increases rapidly with the altitude at which the forest grows. However that may be, the influence of the forest in causing rain, whatever it may be, is a matter of comparatively small importance compared with its influence upon the distribution of water after it reaches the surface.

Colonel Chittenden has made an unfortunate choice in comparing the floods of March 17th to 26th, 1907, in Puta Creek and the American River, California. His figures of precipitation for the American water-shed on the east are approximately a correct average of the various gauging stations of the water-shed. But his average precipitation of 22.7 in. for the water-shed of Puta Creek was taken apparently from only two stations, both on the extreme summit of the Coast Range. One station is not on the water-shed of Puta Creek at all, but across the main divide of the Coast Range on the west or rainy side, and the other is just inside the water-shed, but at its highest point. The larger part of the water-shed which lies below is wholly neglected. Fig. 16 is a diagram of these two water-sheds.

Those who are familiar with California understand that the rain clouds from the sea come to the crest of the Coast Range with a con-

Mr. Pinchot.

FIG. 16.

Mr. Pinchot. siderable burden of water vapor, and drop it rapidly before and after reaching the crest; as the clouds pass eastward over the Sacramento Valley, the rainfall diminishes with great rapidity.

The other rainfall stations on Puta Creek water-shed or in its neighborhood have been given their due weight, and the results have been worked out in two ways. One is by simply taking the arithmetical average of the stations, from which we get the following results: Puta Creek, instead of having 22.7 in. of rainfall, has 9.44 in.; while the American River has 14.6 in., as given by the author. Calculated in this way, it appears that, although the rainfall on the timbered American River water-shed—and a very much steeper water-shed—exceeded that on the Puta Creek water-shed by 55%, the run-off exceeded that of the Puta Creek water-shed by only 23 per cent.

Calculating by isohyetal lines, we get, instead of 22.7 in. on the Puta Creek water-shed, 10.89 in., with the same result, or 14.69 instead of 14.60 in., for the American River water-shed. From these figures, the rainfall on the American River water-shed exceeded that on Puta Creek water-shed by 53.3%, while the run-off exceeded it by only 23 per cent.

Colonel Chittenden says: "If the forest theory be true, these smooth western slopes should send down a greater flow for the same precipitation than the eastern slope. This is exactly what did happen. When the facts are correctly stated, the forest theory is absolutely sustained.

Passing to the question of flood height and flood frequency, it is perhaps unnecessary to insist that flood height is not the critical factor. As far as the influence of the forest is concerned, flood frequency and duration and the frequency and duration of low waters are the essential considerations.

The statement is made that "the constantly reiterated statement that floods are increasing in frequency and intensity, as compared with former times, has nothing to support it."

There are no long-time figures of stream flow in the United States; but, taking the rivers of which we have definite measures, dividing the time for those figures in two equal parts, and ascertaining for those parts the frequency of floods, the number of days of floods, and the number of days of low water, it is found, in by far the majority of cases, that floods are increasing in frequency, and low waters likewise. In other words, such records as there are for streams with mountain water-sheds, where heavy cutting has been going on, directly support the view that the forest has influence on stream flow.

Figures covering from 15 to 34 years for those streams whose water-sheds lie in the Appalachian Mountains and which have been heavily cut over within the period of measurement, refute the claim that there has been no change in flow during that time. In the report of the

hearing on House Resolution 208, before the Committee on the Mr. Pinchot. Judiciary, 60th Congress, 1st Session, it is shown that the Ohio, Cumberland, Wateree, Congaree, Savannah, and Alabama Rivers, disclose a marked increase of floods and flood duration. A more recent examination of the records of flow for the Allegheny, Monongahela, Muskingum, and Potomac Rivers shows precisely the same trend. These streams do not show general increases in the extreme height of floods, but rather a marked tendency of the waters to rush away in many sudden violent floods of short duration, which is to be expected in the case of barren slopes. Most streams of which we have records show a longer low-water period now than formerly, though the tendency is not so marked as the tendency toward increased floods. Where such a tendency is not in evidence, it may possibly be due to the geological formation of the water-shed, or to the filling of the stream channels, so that the general water level is raised.

In contradistinction to these streams, which have mountainous or hilly water-sheds, the Red River, whose upper basin is entirely in the plains and in a region which has largely been brought under the plow in the last 15 years, shows both diminished floods and greatly improved low-water conditions during the past 16 years. This proves the case over again, only from another point of view. Surface conditions over a water-shed clearly have great influence on the flow of the stream which drains it.

Fundamental errors appear to underlie the author's discussion of influence of forests on snow-melting. The first is that the ground does not take up the water from the first melting of snow. The author says: "The water from the first melting of the snow blanket does not sink into the ground, but into itself. * * * The author has seen an 8-ft. covering of snow dwindle to 2 ft., with the ground beneath it still comparatively dry." Does not evaporation and rapid drainage into the ground account for this? In a forest, especially in a mountain forest, the snow usually falls on unfrozen ground, and the natural warmth of the ground hastens the melting of the snow at the bottom. Whatever free water appears soaks at once into the earth.

It is true that, because the sun is excluded in a dense forest, melting begins later than in the open, and Colonel Chittenden correctly states a universally known fact when he says that, "even after the ground in the open is entirely bare, except under the drifts, the forest areas may still be covered with an unbroken layer of snow." Why? Simply because it is colder in the forest. It is colder when the process of melting begins, it is colder until the snow is gone in the open. The forest consequently acts in exactly the same way as the gulch on the north mountain exposure. It catches the average amount, or in some cases more than the average amount, of snow, and holds it till the melting time in the open is past. If the melting went on as fast in the

Mr. Pinchot. forest as it does in the open, the discharge of water would be greater, considering the whole water-shed, and floods would thereby be intensified.

The only condition under which the melting, for like conditions, is anything like as fast as in the open is during a warm rain, such as often accompanies the "chinook" winds in the western part of the United States. When this happens, the effect is the same on the snow-drift in the gulch and on the snow blanket in the forest. It melts at a most rapid rate. Once melted, there is this difference: Water from the snowdrift is at once in the channel ready to swell the floods, while water from the snow blanket is caught up in the layer of leaves and humus overlying a porous soil, and is retarded at every moment in its downhill course. A portion seeps down through the humus into the stream, a large or even larger part goes into the earth and does not reappear for weeks or months.

The assumption that, "of an 18-in. fall (of snow), perhaps 12 in. is on the trees and the rest spread evenly on the ground," is one which will be disputed at once by anyone who has made a habit of frequenting and observing the forests in winter. Such heavy retention of snow is seldom seen elsewhere as may be found in the cedar forests and swamps of the Northeast; yet even there the speaker, in some considerable experience, has never seen a condition which began to approach the proportion of two-thirds of the snow on the branches and one-third on the ground.

The foregoing is but a partial statement of the relations of the forest to snow. Unfortunately, time is lacking to elaborate it.

Turning to the influence of forests in preventing erosion, Colonel Chittenden says that "he has still to see a single example where the mere cutting off of forest trees has led to an extensive erosion of the soil." He further says that "a soil that will sustain a heavy forest growth will immediately put forth, when the forest is cut down (or even burned down), a new growth, generally in part different from the first, but forming an equally effective cover to the soil."

Those who have studied the forests know that the value of young growth, so far as water supply is concerned, is vastly less than that of the old first growth. If Colonel Chittenden had followed the literature of forestry somewhat further, he would have learned that the destruction of the old forest immediately has the effect of dissipating the humus which is the accumulation of tens and sometimes of hundreds of years. He would have learned, further, that the removal of old trees, however effected, reduces the value of the forest floor in promoting the permeability of the soil. There are endless illustrations which might be used, as in the Adirondacks, in Maine, and in California, where the type of growth which follows the destruction of the old forest is far less favorable to absorption than that which has been destroyed.

Colonel Chittenden has been unfortunate in the case of Fig. 2, Mr. Pinchot. Plate XL, which, he says, "shows one of the best examples of this class of timbered land; * * * and no large amount of soil erosion has resulted."

A perfectly flat place is chosen as an example, on which no erosion will be expected; but on the only slope shown in the photograph, the edge of a ditch, erosion is actually taking place.

Similarly, he says:

"In the forest areas of the East, the growth that follows tree-cutting, consisting not only of new trees, but of briars and small brush of every description, accumulates very rapidly, and forms a more effective mat against erosion than the original forest itself, and is equally effective in storing water."

The mistake is a fundamental one, every woodsman knows or should know, and it can be checked by anyone who will take the trouble to compare the quality of the forest floor in the two kinds of forest.

Colonel Chittenden goes on to say: "Certainly, the ground in a forest under culture, with the *débris* raked up, is more easily eroded than that of a slashing or second-growth area, or even good meadow or pasture."

Where Colonel Chittenden could have gathered the idea that in any cultivated forest whatsoever, and least of all in the United States, it is the habit to rake up the *débris*, the speaker is unable to say. But it must be said, with regret, that the statement shows so complete and thorough a misunderstanding of the most elementary foundations of forestry as to invalidate at once in the mind of any man acquainted with the forest, the author's observations or conclusions on all matters relating to the practical management of the forest, or its results.

It is unnecessary to dwell on the statement that it is not forest destruction, but agriculture, which has the effect of causing soil erosion. Whether one destroys the forest to cultivate the soil, or cultivates the soil after the forest is destroyed, makes no difference. In either case, the forest is gone, and its cover has been removed. But the effect of any good cultivation is directly the opposite to Colonel Chittenden's contention, as is shown in the case of the Red River.

The author suggests that we cease devoting the mountain slopes to forests, and take up their cultivation on the lowlands. The failure to conceive the elementary principle in all forestry and in all use of the land, that each part of the soil must be put to the use in which it will contribute most to the National welfare, makes this phase of the question peculiarly difficult to discuss.

As well might it be said that it would be an excellent thing to devote the west side of Fifth Avenue to the growth of lima beans, because their transportation from that place to the consumer in New York City would be so much more convenient and so much cheaper than if they were grown on Long Island. But the west side of Fifth

Mr. Pinchot. Avenue has a greater value for another purpose; and the soil on which Colonel Chittenden recommends that trees shall be grown has a vastly greater value for agriculture than it could ever have for forestry.

The suggestion that trees be planted for the supply of the next thirty or forty years, instead of protecting and guarding the present forests, is the revamping of an idea which was prevalent in the earlier stages of forest agitation in this country. Those who have given attention to the matter have come to see that forest plantations can never take the place of protection of the natural forest and of its natural reproduction.

When Colonel Chittenden objects to the use of the term wasted in speaking of timber lands which pass into the hands of private lumber companies, he fails to remember this vitally important fact, which is another of the fundamental conceptions of forestry, namely, that, when the Government cuts timber from the National Forests, it does so with the distinct and avowed purpose that the land shall go on producing timber. When a great lumber company cuts timber, it proceeds, almost without exception, with the idea that the land shall cease to produce timber. In other words, if the great lumber companies are not wasting timber, because the timber comes into the market, they are wasting forests, which is the essential thing. Less than 1% of the privately owned forests in the United States are being conservatively handled.

A word in summing up: If the speaker's points are well taken and have been made plain, Colonel Chittenden's fundamental conception as to the forest floor and its influence is mistaken. His idea that records in the United States do not show an increase in the frequency of floods and low waters is mistaken. His idea that the critical point to be considered is flood heights, and not flood frequencies, is mistaken. And his conception of forestry, of the functions and management of the forest, beyond its relations to water supply, is so fundamentally mistaken that the speaker might discuss it at far greater length without exhausting the mistakes.

Mr. Chittenden.

H. M. CHITTENDEN, M. AM. SOC. C. E. (by letter).—Owing to the wide range which this discussion has taken, it will manifestly be impossible to review it in detail without making the closing argument much longer than the original paper. The most that the writer will attempt will be to go over his seven fundamental forestry propositions, noting how each has fared, and then consider a few of the more important features of the several contributions.

PROPOSITION 1.

"The bed of humus and débris that develops under forest cover retains precipitation during the summer season, or moderately dry

periods at any time of the year, more effectively than do the soil and crops of deforested areas similarly situated. It acts as a reservoir, moderating the run-off from showers and mitigating the severity of freshets, and promotes uniformity of flow at such periods." Mr. Chittenden.

From the further study which the writer has made since the appearance of the paper, and from the various arguments that have been presented by those discussing it, he is more than ever convinced that the above statement errs on the side of liberality to the conventional forestry theory. So accustomed have we become to the idea that the forest bed possesses a vastly greater absorptive capacity for rain water than does the soil in the open country that we rarely stop to verify these impressions by reference to the facts. Plowing and tilling are great agencies in promoting the porosity and absorptive power of the upper layer of the soil. Quite as important is the constant putting forth of plant roots and their annual or periodic decay as crops are harvested or changed. To a great extent do these processes of cultivation open up interstices in the soil that did not exist before, and thus increase its absorptive capacity. Mr. Pinchot has cited an example of this in the cultivation of treeless tracts in the Red River Valley. There may also be cited the example of the Minnesota River watershed and that of Devil's Lake, in North Dakota, where a portion of the water which once flowed rapidly away into the streams is now absorbed in the soil and either given out in the growing crops or conveyed to the streams later through underground seepage.

In the forest, on the other hand, the soil is not soft, as we are commonly led to suppose, unless it be in wet or swampy situations. Under the thin covering of deciduous trees, particularly in the hilly districts of New England and the Middle States, the soil is clean and sharp, unmixed with mould, hard and firm. The writer has verified this fact hundreds of times in actual work. In the evergreen forests of the Rocky Mountains the thin covering of needles has almost no retentive capacity. The ground is often distinctly visible and the shoes of horses passing over it cut into the clean dirt. In the figures shown on Plate XXXVII the forest soil has nothing like the retentive capacity of the soil shown in the open country picture. In the one case it is hard and compact, the covering very thin; in the other, mountain grasses and other plants are growing, the soil is loose and much worked up by burrowing animals, and yields readily to pressure. As between these two typical areas, the open country soil, although never cultivated, has the greater absorptive or retentive capacity.

Particular stress is here laid upon this fact of the naturally compact condition of a forest soil, because of the prevalent opinion to the contrary. Mr. Leighton says that the forest mulch keeps the ground "in a condition that is always equivalent to that of a newly plowed field. No one who has ever scratched away the mulch cover in a

Mr. Chittenden. forest can deny this." The writer has personally supervised, or has otherwise observed, this scratching away on many hundreds of acres of ground in widely differing classes of forest, and he does deny it most emphatically. Once the rubbish is cleared away, a plow is just as necessary for loosening the soil as in the open country—more so than in land under active cultivation. So far as a rational comparison can be made, taking the country over, the writer would say that, in point of absorptive power, cultivated land ranks first, forest soil second, and old, well-trodden pasture or unbroken prairie soil third.

Theorists expatiate upon the effects of tree roots in opening up the soil and rocks and keeping them porous,* often specifying both soil and rock in the same connection, as if the action of roots upon the two were not exactly opposite. A spike driven into the ground compacts it; into a rock, splits it. The roots of trees do not hang loose in the ground, like a sword in its scabbard. The bond is exceedingly close, and is so developed by the very necessity of keeping the tree from falling.

One feature of the forest soil which restricts its absorptive power is the presence of the trees themselves, and this effect increases in proportion to the density of the timber. An acre of typical Washington forest recently measured showed that 4.3% of the area at ground level was covered by the solid wood of trees of more than 10 in. in diameter. If the trees of smaller growth had been included, the covering would doubtless have amounted to 5 per cent. But this represents only a minor part of the area actually excluded from absorption of rainfall. The large roots of trees spread very rapidly from the surface of the ground down. The earth around these roots and beneath the stump becomes densely packed through the weight of the tree and the stress produced by the wind, which develops a tight bond between roots and earth and ensures the stability of the tree. Those who have had experience in grubbing out stumps realize how close this bond is. It is a matter of common observation that the stumps of trees up-turned by the wind carry with them the solid mass of earth among the roots, and that this is so compact and hard that it often resists for years the action of the elements. This compacted soil is almost as impervious to water as the puddle wall of an earthen dam. Its area is from two to four times the stump area at ground level, and it is a fair assumption that in forests of average density 10% of the soil is thereby rendered not available for absorbing rain water. In very dense forests of large trees this percentage is undoubtedly greater. If these covered areas, of which one never thinks in looking at a forest, were spread out in the form of a concrete pavement they would make an impression. They evidently amount to as much as the ground covering

* "The deep penetrating roots also open passages through which water readily passes into the great reservoir of ground water." Pinchot.

in country towns of 10 000 to 20 000 inhabitants, and are as completely excluded from absorptive activity as is the ground under a city pavement.

Mr. Chittenden.

On the whole, it may be considered entirely probable that, acre for acre of ground otherwise similarly conditioned, the cleared land, particularly if under cultivation, will hold and transmit to the ground below more water than will the average forest. What makes the run-off in the open country more rapid generally than in the forest is drainage (including in that term roads and their ditches, regular drainage trenches, tiling, furrows of cultivated fields, etc.), and the roofs and pavements of towns; and it is due to these features, mainly, that the writer's first proposition has a limited application. Omit these features, and the reverse would more than likely be true.

The criticism, by Messrs. Swain, Pinchot, and Leighton, of the writer's "ideal illustration" in the beginning of the paper, because of his use of the words "practically impervious" is, to say the least, captious, and comes with particularly bad grace from Mr. Pinchot who himself has made public use of identically the same kind of illustration. Surely his "photograph of a denuded hillside" from which water sprinkled thereon "disappeared instantly" was practically impervious. In fact, one can rarely make a model which will represent natural conditions accurately, and the best that can ordinarily be done is to take an ideal case, and then note its departure from such conditions. This is what the writer did. No sooner had he stated his illustration than he hastened to explain that it was "never fully exemplified in the cleared land and the forest;" and that there was always an absorptive capacity in soil without any covering; but, that the principle of the illustration applied perfectly, viz., that there were times when the greater retentive capacity of the forest was so far exhausted that it was powerless to act further, and there were other times when it was great enough to absorb all the precipitation that came to it.

The writer, however, might, with perfect correctness, stand upon the literal application of his illustration, if he chose to do so. He was illustrating the difference in absorptive or retentive capacity of the forest and the open country. It would have been entirely proper to have eliminated those features common to both, such as slope and the capacity of the subjacent soil to take up moisture from above, and thus consider the ground in both cases as impervious. It would simply have been subtracting the same quantity from both members of the equation, and would not have affected in the least the principle involved.

Upon the basis of this distorted construction of the writer's words, extreme conclusions have been drawn. These are perhaps sufficiently indicated by Mr. Leighton's statement that the writer "denies that there is a pervious soil under the forest"; and again that he "denies the existence of ground storage." No word can be found in the entire

Mr. Chittenden. paper to justify either of these statements. Nothing of the sort was in the writer's mind at all. In another place in his paper, speaking of natural reservoirs, he states that "the ground is the most important of these, absorbing on the average probably one-third of the total rainfall." But in discussing the causes of floods he relegated ground storage to the background, for the excellent reason that it plays a very minor part in such occurrences. The great bulk of the water that makes floods is what some one has well called "fugitive" water—that which escapes into the streams over the surface of the ground. Time is the controlling element in the quantity of water that percolates into the earth. A given soil will permit a given quantity to pass through it in a given time, and if Noah's flood were to pass over the surface this percolation would not be any faster. Moreover, what does soak into the ground may be a long time in returning to the surface through springs, and any such portion of a storm plays almost no part in the flood which the storm produces. Whatever part ground-water plays in a great flood (and it is always a minor part) it is generally from precipitation long prior to that which produced the flood, and it cannot therefore be well considered when tracing the relation between a given storm and the resulting flood.

Another point in which some of the writer's critics have found a stumbling block is this: that even though the forest bed be filled to saturation, still the mechanical obstructions to run-off, the crooked and indirect channels, would retard flow more than in the open. But in all the writer's reasoning upon this subject, the superior "retentive capacity" of the forest as compared with that of the open country has included all these retarding causes in the one that are in excess of those of the other; and whenever he has spoken of the forest bed being saturated he has meant that whatever difference may have existed at the beginning of a storm has been obliterated so that the water reaches the streams as rapidly from one class of surface as the other, provided they are otherwise similarly conditioned.

Mr. Leighton makes the following remark in regard to the forest bed: "The common understanding is that the forest mulch is not the storage agent in any except a merely nominal sense." It seems impossible that Mr. Leighton can mean this literally, as otherwise he would sacrifice the position of both himself and Mr. Pinchot, that the forest bed does hold the water of precipitation and give it an opportunity to soak into the ground. Indeed, Mr. Leighton not only contradicts the universally accepted view of forestry advocates, but even his own opinion, as expressed on former occasions. On page 7 of Forest Circular 143, issued November 7th, 1908, is the following from himself and Mr. Horton:

"The Southern Appalachian forests act as a great storage reservoir, and this is done largely through the medium of its humus, the litter

of decomposing vegetable matter which forms the forest floor * * * Mr. Chittenden.
[citation of foreign authorities] * * The function of the forest
and of the humus beneath as a storage reservoir is of high importance."

To the same end is the following, from the report of the Secretary of Agriculture, on the Southern Appalachian and White Mountain Watersheds, submitted to Congress December 11th, 1907 (pp. 16-17):

"There is but one natural factor which tends to equalize the flow of the Southern Appalachian streams—the forest. In one continuous mantle, covering ridges, slopes, and coves, it has for untold ages been nature's sole reliance for the proper distribution of rainfall. If storm and deluge came, the downpour fell upon a foot-deep layer of humus, which readily received many times its own weight of water before it allowed any to escape. When filled, it passed on the excess to a soil made porous by myriads of penetrating roots and countless tons of vegetable mold. If drought came, it found the humus and soil filled as a reservoir with water for the steady supply of springs and streams through weeks or months of rainless weather. * * * It was as efficient as would have been a system of lakes. It had power to hold back the water on a steep mountain side almost as though the ground were level."

Read this twice, for it is not only an authoritative announcement that the humus is a reservoir, but it shows that the free play of the imagination has its place even in the most serious public document.

Of course there can be no dispute over the fact that the forest bed, wherever it exists, has a storage capacity, and why Mr. Leighton now says it has not, is a mystery. If he had said that such capacity is greatly over-rated in the popular estimation, he would have been entirely correct, but that it does exist to some extent is not to be questioned, and in certain situations it is quite large. The point of essential importance is that it gives up that storage along lines of least resistance, whether those be by percolation into the ground, by run-off from its surface, or by evaporation into the air. In proportion as the soil itself is porous and the surface slope small, the quantity absorbed into the soil will be greater. And, conversely, as the soil is compact and impervious and the slope steep, the quantity that runs off will be increased. In times of prolonged drought, it may absorb the whole of such fugitive showers as come along, and give them up in evaporation. But it must be carefully borne in mind that in any storm capable of producing a flood, this storage capacity becomes completely exhausted before the storm has progressed far, and thereafter it has no appreciable power to modify the flood. It would probably be a liberal estimate to say that, in our eastern deciduous forests, $\frac{1}{2}$ in. of rain in a continuous shower would exhaust the storage capacity of a fairly dried-out forest bed; $\frac{1}{4}$ in. in the Rocky Mountain forests, and from 1 to 2 in. in those of the Pacific Coast.*

* This subject should not be confounded with that of the storage capacity of the ground itself below the immediate surface. This is exceedingly variable, depending upon its geologic structure.

Mr. Chittenden.

PROPOSITION 2.

"The above action fails altogether in periods of prolonged and heavy precipitation, which alone produce great general floods. At such times the forest bed becomes thoroughly saturated, and water falling upon it flows off as readily as from the bare soil. Moreover, the forest storage, not being under control, flows out in swollen streams, and may, and often does, bring the accumulated waters of a series of storms in one part of the water-shed upon those of another which may occur several days later; so that, not only does the forest at such times exert no restraining effect upon floods, but, by virtue of its uncontrolled reservoir action, may actually intensify them."

The broad truth contained in this proposition—that floods have not increased with the settlement of the country—is accepted by all participating in this discussion. *Engineering News*, in its criticism of the paper, says:

"We believe that most engineers who give careful study to the question will find themselves forced to accept fully Colonel Chittenden's most important conclusion given under (2) above, viz.: That forests do not prevent floods." And again—"With his main conclusion—that forests have little influence on stream flow compared with what is generally believed—we have already expressed our accord."

Conservation (formerly *Forestry and Irrigation*), the pages of which have always overflowed with the doctrine that forests do prevent, or at least diminish, floods, refers editorially* to "the well-known fact that flood heights do not sensibly increase with deforestation." How many of the readers of this excellent magazine have ever gathered any such impression from its pages heretofore? And finally, Mr. Leighton says that "no well-informed person now believes that flood heights increase with deforestation." The word "now" is significant. The statement itself may be correct; it certainly should be; but it is the very reverse of the teaching so vigorously put forth during the past two years in the interests of forestry.† And some "well-informed persons" apparently cling to the old theory still, if one may judge from the astounding statement by Dr. McGee in the December issue of *Conservation*, that "In a state of nature * * * most streams flow fairly clear and in fairly uniform volume throughout the year."

* November, 1908.

† Mr. Leighton, of course, will be willing that the writer should cite his testimony before the Committee of Agriculture, January 30th, 1908, wherein he not only held that floods are now higher and of longer duration than they used to be, but explained why this must necessarily be so. His remarks are an excellent example of what one can prove if he only makes the right assumptions. Answering a question by Mr. Hawley, Mr. Leighton said in part, comparing the past and present:

"You cannot push through a channel more than a certain amount of water at a certain stage. In the former conditions we will assume that half of the water was taken into the ground and half ran off directly. That half that ran off created a high flood and at the same time it was of shorter duration because the water was not there to continue it. Now, we will assume that it all runs off, but it has got to go through the same channel, between the same banks, and therefore it cannot get through so quickly, and therefore the flood will be higher and at the same time longer continued."

It may be added that Mr. Hawley was so unreasonable as to suggest that "The floods at the time of George Washington spread all over that country."

In short, it is true, as every one knows, that the almost universal belief among our people to-day, developed in large part through the agency of supposedly well-informed persons, is that forests do diminish flood heights, and the statement that they do not, comes to most people as a distinct surprise, and their first impulse is emphatically to dispute it. Mr. Chittenden.

The position now taken in this matter by Messrs. Swain, Pinchot, and Leighton* involves a complete change of base, so far as the writer's study of current literature, both official and non-official, upon this subject goes. Extreme high waters, it is now held, are not the important matter at all, but the average high waters of a period of years; and for this purpose a period of ten years has been found by the Geological Survey to be long enough. It is difficult to understand just what this means. Mr. Leighton says that by his method the floods are "smoothed out and compensated and afford a less involved idea"; and that "extreme conditions are mere sports, due to unusual occurrences, and it is as illogical to consider them as representative of general tendencies, as it would be to accept the physiological and anatomical freaks in a museum as representative of the human race." The same rule applies also to low waters.

This is very ingenious, and may be entirely satisfactory to Mr. Leighton, but the writer would like to ask him if the idea would ever have found birth had river records been different than they are in the matter of high floods. Does any one doubt that, if the figures in Table 1 of the paper had shown a progressive increase of flood heights with the progress of deforestation, they would have been blazoned from one end of the country to the other as evidence of the baneful effects of deforestation? Now that they show no such tendency, but the reverse, if anything, this feature is pronounced to be quite a subordinate matter, and the main point is said to be the frequency of floods of ordinary height. It is not the great floods that come occasionally, but the lesser floods that come often, that should be considered as of first importance. Mr. Leighton takes periods of years, obtains the means of the floods, smooths or flattens out the irregularities, pronounces these results to be the real criteria, and, by comparing similar periods in states of progressive deforestation, arrives at the conclusion that these smoothed-out results increase as the forests disappear. The great floods which have always come, no matter what the state of the forests, he curtly dismisses as "sports" or "freaks," not subject to intelligent rule and not to be considered as affecting the merits of the question.

Accepting Mr. Leighton's tables as entirely correct (the writer has had no time to verify them) and accepting for the moment the correctness of his conclusion, that the results shown are due to deforesta-

* The writer frequently uses these three names conjointly because their discussions run so closely parallel as to amount practically to identical, or at least supplementary, statements.

Mr. Chittenden.

tion, let the practical aspect of the matter be examined. Will engineers of the country admit that, in the problems of high and low water on our navigable rivers, the extremes are of minor importance, and the average, smoothed-out, floods are the controlling factor? Let us suppose that Mr. Leighton is presenting his views to a committee of land holders in the Lower Mississippi Valley, who want his advice as to the best method of protecting their lands from overflow. Mr. Leighton compares his two smoothed-out periods and shows that if the forestry conditions of the first period can be restored there will be a certain lowering of average flood heights and a diminution of their frequency. If his arguments have any meaning, it must be that if local flood relief measures which will meet these average conditions be supplemented by forest development which will make the conditions permanent, the problem can be satisfactorily solved.

The plan appears simple, but now some one in the committee who has looked up the records inquires if the very highest floods that the river has ever seen did not occur before the forests were cut off at all, and if those high floods were not on the whole as frequent then as they have been in recent years. Mr. Leighton admits that such is the case, but explains, with ill-concealed contempt, that such occurrences are quite out of the regular order of things, and can be considered only as "sports," "freaks" of Nature, which "it is as illogical to consider * * * as representative of general tendencies, as it would be to accept the physiological and anatomical freaks in a museum as representative of the human race." Silenced for a moment by the stunning effect of this reply, the questioner presently ventures to ask what is going to happen to the levees and the property behind them when these freaks do come. This is a poser to Mr. Leighton, and while he is hunting up a satisfactory reply another member of the committee asks how long it will take to reforest the water-shed so as to produce the results that are promised. He is informed that it can be scarcely less than from 50 to 75 years. What will happen in the meantime? Again Mr. Leighton hunts for an answer. What will the reforestation cost? Unknown, but certainly many millions of dollars. Is it a sure thing that agricultural land enough can be given up to provide the necessary forests? In other words, is the proposed reforestation a possibility? That is a point not yet determined, but very doubtful.

By this time those who have listened to the conversation have made up their minds, and they suggest to Mr. Leighton that if he will take the money necessary for reforestation, add it to the funds for local works, get busy and strengthen the levees so that they will keep out the "sports," they will not ask anything of him on account of the "smoothed-out" floods. If the great floods are taken care of, they will not worry much about the smaller ones.

In like manner we may imagine a similar conference with the navigation interests of the Ohio and Mississippi. Is there any doubt that,

in spite of all his tables and plausible arguments, the upshot would be that, if the "sports" or "freaks" (the extreme low waters) are taken care of, navigation will accept the inconveniences that may come from any possible increase in frequency of lesser low waters? Mr. Chittenden.

At the risk of repetition, the writer will notice also Professor Swain's remarks in this connection. He says: "A few great, but not extreme, floods may do more damage than one extreme flood, and may necessitate more expenditure for dredging and other purposes." Professor Swain is a teacher in one of the leading technical schools of the world. Undoubtedly, he inculcates the habit of clear statement and the avoidance of loose generalities in speech on the part of his pupils. But he has violated the most elementary principles upon this subject in the proposition quoted above. What is an extreme flood, and what a great flood? Has he any clear distinction in his own mind? And are causes that operate to produce an extreme flood any different from those in a great flood? The only possible construction to place upon the above statement is that forests produce a beneficial effect upon floods up to a certain limit, and after that the reverse effect. Professor Swain can hardly wish to stand sponsor for any such theory as that.

Again, what would be the practical bearing of the theory, if it were true? In carrying out works of flood protection, if the conditions of the extreme flood are met, all others are included; but if only some lesser floods is considered, then the great floods remain uncontrolled. Now it is of course true that a sufficient number of smaller floods may do as much damage as one very great flood; but, as a general rule, the damage wrought by floods increases very rapidly with their height, and if Professor Swain places a wide limit between his extreme and his great floods it is doubtful if all the latter, on any river that may be considered, cause the amount of damage that the former do. But manifestly the subject, as stated by Professor Swain, is altogether too indefinite to base an opinion upon, one way or the other.

Mr. Leighton and Professor Swain will inevitably find, when it comes to a practical application, that they cannot get very far away from the writer's statement that "it is the extreme of flow * * * that controls the cost of river regulation. It is the floods and low waters that measure the cost. Any scheme of control that is not based upon these is worthless."

The writer now withdraws his momentary acceptance of Mr. Leighton's theory, and challenges his statement that his tables prove "beyond controversy the increase in floods due to deforestation." His theory was first given prominent publicity by Dr. W J McGee in a speech before the Ohio Valley Improvement Association, in Louisville, in October, 1908, in which he presented a table, reproduced here as Table 18. The last two columns have been added to show the stages used by Dr. McGee to denote his floods and the danger line stages that are usually considered as defining real floods:

TABLE 18.

River.	First and second period of record.	Mean precipitation, in inches.	Number of floods.	Total days.	Average days.	Flood stage considered in feet.	Danger line stage, in feet.
Ohio, at Wheeling, W. Va.....	{ 1882-1894 = 13 years. 1895-1907 = 13 "	38.66 38.08	46 59	143 186	11.00 14.40	22	36
Monongahela, at Lock No. 4, Pa.....	{ 1886-1896 = 11 " 1897-1907 = 11 "	39.76 39.27	30 52	55 100	5.00 9.09	20	28
Cumberland, at Burnside, Ky.....	{ 1890-1898 = 9 " 1899-1907 = 9 "	46.27 41.42	32 48	89 102	9.90 11.38	25	50
Allegheny, at Freeport, Pa.	{ 1874-1880 = 17 " 1891-1907 = 17 "	40.13 35.23	39 53	92 131	5.41 7.70	16	20
Tennessee, at Chattanooga, Tenn....	{ 1875-1880 = 17 " 1891-1907 = 17 "	52.10 45.01	32 33	164 148	9.65 8.41	24	33
Muskingum, at Zanesville, Ohio.....	{ 1887-1897 = 10 " 1898-1907 = 10 "	36.87 35.17	17 41	78 171	7.30 17.10	15	25

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Table 18 makes a very good *prima facie* case. The periods considered on the various streams range from 18 to 34 years, divided into two equal portions, and the mean annual precipitation, number of floods, and average duration of floods, for each, are given. In every case the precipitation in the second period is less than in the first, the deficiency ranging from about 1 to about 16 per cent. In every case the number of floods is greater in the second period, the excess ranging from 3% on the Tennessee to 140% on the Muskingum. In every case but one the average duration of the floods is greater in the second period, the excess ranging from about 15% on the Cumberland to 134% on the Muskingum. Presumably deforestation had been in progress in every case, and the inference of cause and effect was irresistible. *Post hoc ergo propter hoc*. It was indeed an alluring bait, and Mr. Leighton and his associates jumped clear out of the water to grab it; but the writer is much mistaken if they found anything more than an ugly hook from which they would now be glad enough to shake themselves free.

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While admitting the correctness of Dr. McGee's and Mr. Leighton's tables, a prudent investigator would still be very wary about admitting the conclusions which they have drawn from them. There are several things quite near the surface that do not look well. One of these is the brevity of the periods considered and the fact that they do not commence until deforestation is already far advanced. Ten-year periods may satisfy Mr. Leighton, but it will generally be considered that a period reaching back to the time when forests were much more prevalent would be better. Another disturbing feature is the fact that almost no change in forest areas has taken place on some of these water-sheds during the period considered. On the Muskingum, where the changes in flood conditions have been most marked, there has been practically no change in the quantity of woodland. On the Connecticut there has been something of an increase. On the Allegheny and Monongahela the changes amounted to practically nothing on the first stream and 11% of the total area on the second, or 5.5% from any point in the first period to the corresponding point in the second. Manifestly, no possible conclusions, either one way or the other, can be based on such insignificant changes as these. The writer has not the data for the changes in the forest areas on the other water-sheds, but assumes that they are greater than on those just considered.

Another suspicious circumstance is the fact that on the Muskingum, where there were no changes to speak of in woodland areas, and where the mean rainfall for the two periods was practically the same, the increase in floods is by far the greatest; while on the Tennessee, where the difference in rainfall and the change in forest areas are much greater, the difference in flood conditions is least.

Still another, and very important, consideration, which has involved

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our forestry friends in a serious tangle, is the fact that the duration of floods in the second period is in nearly all cases longer than in the first. If there is any truth at all in the forestry theory, the removal of the forests ought to heighten and shorten the floods; but these tables indicate that it lengthens them! In fact, Mr. Pinchot states that certain rivers in the South, as a result of deforestation, "disclose a marked increase of floods and flood duration"; though, immediately after, in the same paragraph, he returns to the conventional theory that deforestation leads to "sudden, violent floods of short duration."

Discrepancies and contradictions like the foregoing would, as already stated, lead a prudent investigator to pause and inquire. He could not help seeing that there must be some other explanation. Might it not be in the distribution of the rainfall? and might not his very method of toning down and smoothing out the records mask the particular fact that it was necessary for him to know? Such indeed is precisely what has happened. Although the labor of searching out these individual floods and the attendant rainfall was so great that the writer had no time to undertake it, he has fortunately seen a most careful recent study covering a portion of the streams embraced in Mr. Leighton's tables and worked out on truly rational lines. This consists of three tables (Tables 19, 20, and 21) showing rainfall and freshets by months for periods of twenty years for the Ohio at Pittsburgh, the Allegheny at Freeport, and the Monongahela at Lock No. 4. These tables were prepared in the United States Engineer Office at Pittsburgh, and, at the request of the writer, their use in this connection is permitted. They constitute the most comprehensive study of this question, on so extensive a scale, that has come to the writer's notice. Particular attention is invited to them, for they afford a complete explanation of the many discrepancies above pointed out in the study by annual means. The following extract is from the notes accompanying these tables:

"These monthly comparisons are obviously more significant than annual ones, and in general they explain the apparent discrepancies shown by the latter. On the other hand the monthly records also exhibit some discrepancies that can be readily explained by a more detailed examination of such months. In each case they cover a period of twenty years and are summarized for the first and second ten-years. They all give similar results, showing a greater number of freshets for the second period even with a less rainfall. These accordant results are somewhat disturbed, however, when we observe the annual totals. Here we notice but little consistency in the relation between rainfall and number of freshets. On the other hand, this lack of consistency usually finds a ready explanation in the distribution of the rainfall among the different months, and moreover the greater frequency of freshets in the second period is at once seen to result from the very marked increase in rainfall for this period during the month of March, which is one of the greatest flood-producing months. Great

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TABLE 19.—RAINFALL ON THE OHIO RIVER WATER-SHED ABOVE PITTSBURG, PA.
 Monthly averages, in inches, from nine stations. Small figures give number of freshets at Pittsburg,
 15-ft. stage.

Year.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean Annual.
1889	2.81	2.08 ₁	1.91	4.50 ₁	4.08	5.19 ₁	5.51	2.64	3.64	3.13	5.31	3.41	42.99 ₂
1890	4.79 ₂	5.13 ₂	4.93 ₂	4.89 ₂	7.52 ₂	4.02	2.96	6.09	5.86 ₁	6.46 ₂	2.86	4.16	59.18 ₃
1	3.20 ₂	6.25 ₂	4.12	3.03 ₁	3.11	5.64	7.30	4.72	2.56 ₁	2.50 ₂	3.70	4.20 ₁	50.30 ₄
2	3.36 ₁	2.87	3.14	3.40	5.85	4.86 ₁	4.04	2.92	2.33	1.09	3.66	3.39	39.96 ₅
3	2.61	5.97 ₄	1.79 ₁	5.48 ₁	5.15 ₁	4.19	3.61	3.18	2.00	3.63	2.13	3.43	43.23 ₆
4	2.90	3.30 ₁	2.18	3.84	6.21 ₁	2.46	2.35	1.27	5.01	2.30	2.60	4.33	38.39 ₇
1895	4.08 ₂	1.27	2.81	3.40 ₂	2.14	3.24	3.68	3.17	1.85	0.95	3.24	3.02	32.86 ₈
6	1.61	3.09	3.78 ₁	2.39	3.38	5.03	10.04 ₂	3.18 ₁	4.89	2.86	3.06	1.82	45.13 ₉
7	2.23	4.04	4.08 ₁	4.01	3.51	3.40	5.64	2.96 ₁	1.96	0.31	6.10	4.11	42.30 ₂
8	5.54 ₂	2.13	6.22 ₁	2.53	4.37	3.73	3.01	6.75	2.23	4.61 ₁	3.22 ₁	6.44 ₂	46.98 ₃
9	3.54 ₂	3.33 ₁	5.23 ₂	2.24	5.29 ₁	4.01	4.78	2.76	3.05	1.22 ₁	2.91	3.62	42.95 ₄
1900	2.65 ₁	3.89 ₁	3.44 ₂	1.42	2.15	4.69	5.15	2.32	1.36	2.73	5.08 ₁	1.99	37.37 ₅
1	2.64	1.16	4.09 ₂	6.30 ₂	3.40 ₁	4.30	3.58	5.30	3.24	0.69	3.02	4.94	44.86 ₆
2	2.69 ₁	2.05	3.92 ₂	3.72 ₁	3.21	5.28	6.38 ₂	2.15	2.63	3.50	1.90	5.73 ₂	43.48 ₇
3	3.52 ₁	4.42 ₂	4.47 ₂	4.09 ₁	2.96	3.76	4.79	4.55	1.72	3.19	2.91	2.16	43.84 ₇
4	3.19 ₁	2.91 ₁	5.48 ₂	4.09 ₁	3.84	3.76	4.66	3.08	2.18	1.32	0.61	3.09	38.80 ₈
1905	3.36	2.13	4.52 ₂	3.32	3.66	5.91	6.37	4.19	2.91	4.65	3.16	3.76 ₂	48.44 ₄
6	3.20 ₁	1.31	4.56 ₁	3.31 ₁	2.99	4.61	4.27	5.48	3.18	3.30	1.71	4.97 ₂	42.84 ₅
7	7.02 ₁	2.09	6.06 ₁	3.19	3.66	4.82	5.85	3.46	4.53	2.95	2.91	3.45	49.99 ₄
8	2.95 ₁	4.49 ₁	6.68 ₄	4.48	6.59 ₂	3.12	4.75	2.36	1.00	0.60	0.97	3.22	41.19 ₅
First ten years.	33.14 ₆	36.08 ₁₂	34.91 ₉	37.47 ₇	45.32 ₂	41.65 ₂	48.14 ₂	36.88 ₁	32.39 ₁	28.06 ₃	35.42 ₁	33.57 ₃	44.198 ₃₄
Second ten years.	34.76 ₁₁	27.78 ₅	48.48 ₂₆	35.70 ₂	39.74 ₄	46.23 ₀	41.08 ₂	36.10 ₀	26.72 ₀	25.05 ₀	25.18 ₁	36.95 ₅	43.376 ₅

TABLE 20.—MEANS OF MONTHLY RAINFALL AT WARREN, CLARION (OR FRANKLIN),
JOHNSTOWN AND FREEPORT.

ALLEGHENY RIVER.

Small figures give number of freshets at Freeport, 16-ft. stage.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean Annual.
1889	3.18	2.12	1.97	5.29	4.04	5.66	6.62	3.36	3.39	3.42	4.46	4.08	48.14 _o
1890	4.97 ₁	4.77	4.68	5.00 ₁	7.70 ₂	3.41	2.48	6.06	6.62 ₁	6.28	2.63	3.89	58.49 ₂
1	2.94	5.86 ₂	3.96	2.60	1.96	6.00	8.16	3.99	2.45 ₁	2.66	3.98	4.14	48.66 ₂
2	3.61	3.26	3.08 ₁	2.40	6.80	5.62 ₂	3.50	2.79	2.71	1.32	3.92	2.24	41.50 ₁
3	2.98	7.37 ₂	5.65 ₁	5.62	5.65 ₁	4.31	3.44	4.00	2.11	3.55	2.37	4.48 ₁	48.31 ₂
4	3.34	8.14	2.06	3.44	7.14 ₁	2.58	2.02	0.78	6.36	2.72	2.57	3.76	40.50 ₁
1885	4.30 ₁	1.34	2.17	3.08 ₂	2.46	3.66	3.43	3.69	2.96	1.05	3.79	3.21	35.04 ₂
6	1.31	3.18	3.85 ₁	2.38	3.14	4.53	7.40	3.66	5.26	2.62	3.11	1.81	42.28 ₁
7	2.29	2.77	4.48 ₂	3.67	3.80	3.18	6.48	3.37	2.12	0.35	6.15	3.34	41.88 ₂
8	5.19 ₂	2.06 ₁	5.38 ₁	2.10	4.74	4.36	3.06	7.07	2.10	5.12	2.69	2.65	47.40 ₁
9	2.91 ₁	3.44	4.94 ₁	2.43	5.08	3.16	4.25	2.99	3.36	1.53	2.60	4.32	42.20 ₁
1900	3.09 ₁	4.07 ₁	3.16 ₁	1.86	2.17	4.34	5.74	3.12	1.79	2.75	5.28 ₁	1.92	38.79 ₂
1	2.37	1.23	4.37 ₁	6.79 ₂	5.48	4.90	7.60 ₁	6.98	3.59	0.82	3.50	5.61	47.96 ₂
2	1.82	2.14	3.69 ₂	3.61 ₁	3.39	5.97	3.60 ₁	1.96	3.95	3.67	1.56	5.01	44.87 ₄
3	3.69	4.08 ₂	4.60 ₂	3.35	2.59	5.72	6.10	3.75	1.88	3.45	3.18	2.85	45.66 ₄
4	3.49 ₁	3.18 ₁	6.00 ₂	4.79 ₁	4.57	3.65	6.46	3.75	2.49	2.17	0.92	2.80	44.24 ₆
1905	3.44 ₁	1.95	4.06 ₂	3.39	3.36	6.06	8.39	4.14	3.61	4.74	3.39	4.18 ₁	50.70 ₁
6	2.75 ₁	0.97	4.21 ₁	2.60 ₁	2.90	3.97	4.32	6.02	3.34	3.27	1.63	4.44	40.92 ₂
7	5.98 ₁	1.55	5.24 ₂	3.28 ₁	3.40	4.67	3.57	2.74	4.99	8.27	2.83	3.48	44.98 ₂
8	3.24	4.84 ₁	6.58 ₄	3.90	6.55	3.35	4.54	2.12	0.67	0.50	1.14	3.37	41.00 ₅
First ten years.	34.00 ₄	35.87 ₆	34.06 ₆	36.44 ₃	47.43 ₄	43.56 ₂	46.58 ₆	38.71 ₀	37.18 ₁	29.09 ₀	36.67 ₀	33.60 ₁	45.218 ₂₈
Second ten years.	33.70 ₄	27.19 ₆	46.84 ₂₀	34.45 ₅	40.09 ₀	45.81 ₀	53.78 ₁	39.92 ₀	30.54 ₀	26.57 ₀	27.03 ₁	36.42 ₂	44.134 ₂₈

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TABLE 21.—MEANS OF MONTHLY RAINFALL AT WESTON, W. VA., ROWLESBURG, W. VA., AND LOCK NO. 4.
Small figures give number of freshets at Lock No. 4, 20-ft. stage.
MONONGAHELA RIVER.

Year.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean Annual.
1889	2.77	1.85 ₁	1.68	4.16 ₁	3.22	4.98 ₁	4.85	1.72	4.01	3.06	6.83 ₁	2.64	41.77 ₄
1890	4.80 ₁	5.44 ₃	4.96 ₁	4.71	8.32	5.26	8.87	6.92	5.38	6.43 ₂	2.31	4.07	62.47 ₇
1	3.34 ₁	6.25 ₃	4.60	4.24	4.41	5.04	6.24	6.09	2.57	2.87	3.82	4.75	53.72 ₅
2	3.13 ₁	2.67	3.52	4.44 ₁	5.55	3.62	3.77	3.47	2.35	1.05	4.05	2.84	40.46 ₂
3	2.29 ₁	4.60	1.21	5.31	4.22	4.92	3.67	2.16	1.76	3.82	2.00	2.59	39.55 ₁
4	2.52 ₁	3.54	2.21	4.07	5.64	2.76	3.00	2.19	3.36	2.31	2.31	5.02	39.43 ₁
1895	4.16 ₂	1.29	3.61 ₁	4.29	1.84	2.65	3.71	1.92	0.99	0.86	2.91	2.86	31.09 ₃
6	2.12	1.93	3.47 ₁	1.89	3.30	5.88	13.21 ₂	2.47	4.08	3.50	2.31	1.92	46.53 ₃
7	2.03	5.03 ₁	3.50 ₁	3.56	3.11 ₁	4.21	4.09	3.06	1.65	0.28	6.45	5.28 ₁	42.27 ₃
8	6.39 ₃	2.33 ₁	7.47 ₂	3.31 ₁	4.02	3.01	2.57	6.72 ₁	2.81	3.96 ₁	2.81	2.70	48.10 ₉
9	4.13 ₁	3.43 ₁	6.07 ₂	1.31	5.27	5.24	5.42	2.57	3.34	0.69	3.26	3.24	44.97 ₄
1900	2.50	3.85	4.00 ₁	1.49	2.43	5.24	3.91	3.23	0.87	2.77	4.76 ₁	1.69	36.84 ₂
1	2.33	1.04	3.77	7.12 ₂	4.87 ₁	4.22	3.34	3.88	3.04	0.53	2.84	6.28 ₂	43.26 ₅
2	3.78 ₁	2.33 ₁	4.30 ₂	3.76 ₁	2.86	4.59	6.17	2.58	2.47	4.23	2.71	6.40 ₂	46.29 ₂
3	3.37 ₁	5.82 ₂	3.85 ₁	3.86	3.81	6.47	4.55	2.03	2.83	3.13	2.64	2.50 ₂	46.88 ₆
4	3.11 ₁	2.96	5.35 ₁	3.66	2.32	3.94	3.67	2.09	2.05	1.64	0.45	3.30	35.32 ₂
1905	3.53 ₁	2.59	5.47 ₂	3.57	4.32	5.22	6.28	4.07	2.44	5.01	3.12	3.80 ₁	49.43 ₄
6	5.89 ₁	1.89	5.19 ₂	4.49 ₁	3.25	5.72	4.38	4.56	2.95	3.14	2.06 ₁	5.71 ₅	49.29 ₇
7	7.99 ₂	2.79 ₁	6.90 ₂	3.31 ₁	4.50	5.16 ₁	9.40 ₁	4.66	4.77	3.18	3.34	3.68	59.73 ₇
8	2.33 ₁	4.77 ₁	7.31 ₃	4.42	7.56 ₂	3.46	4.10	2.42	1.01	0.78	0.86	3.49	43.13 ₇
First ten years.	33.55 ₅	34.93 ₃	36.23 ₃	39.98 ₂	43.63 ₁	42.33 ₁	48.98 ₂	36.74 ₁	28.91 ₀	27.64 ₃	36.80 ₁	34.67 ₁	44.439 _{av}
Second ten years.	39.56 ₅	31.57 ₆	53.21 ₁₇	37.71 ₄	41.88 ₃	49.26 ₁	51.28 ₁	32.39 ₀	25.47 ₀	25.10 ₀	26.04 ₂	40.15 ₇	45.507 ₀₀

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variations will be observed in the rainfall for the same month, as well as from month to month for the same year, though the mean monthly averages do not differ so widely. The comparative absence of freshets in the summer illustrates the influence of temperature. It is clearly not due to less rainfall in that season, since the average precipitation then is greater than during the flood months. * * *

"It will be found by a careful examination of these tables that usually the occurrence of the freshets is sufficiently explained by the monthly rainfall. Now and then discrepancies appear, especially during the flood months, as when a freshet accompanies an unusually small rainfall, or fails to accompany a comparatively large rainfall. In such cases an examination of the hydrograph usually shows that the small rainfall was concentrated in a few days, while the large one was distributed through the month and sometimes accompanied by several freshets that failed to reach the stage under consideration. It is believed that these considerations, making freshets entirely dependent on rainfall and temperature, fully meet the arguments of those who attribute their increase to deforestation."

Several interesting facts are disclosed in these tables. Note that practically the whole excess in number of floods in the second period occurred in the month of March and that it is all accounted for by excess of rainfall for that month. The effect of temperature has been pointed out. This, of course, acts not only through direct evaporation while a storm is going on, but through the greater absorptive capacity of the soil at such seasons, due to its drying out more rapidly when it is not raining, and to the heavy draft for the growing crops and trees. It takes a heavier rain at such times to produce a given result in stream flow than in the cold seasons of the year. Again, after a period of high rainfall, the precipitation for a month may produce a greater flood than the same precipitation after a period of light rainfall, other conditions being the same. A more minute study, going into the details of each storm, would be required to explain all discrepancies; but these monthly records go a great way in that direction and indicate the proper lines along which a study should be developed. The writer regrets that because of lack of time he could not carry this study to other water-sheds, but until it is so applied to every case, any pretense that changed flood conditions on such water-sheds are due to changes in forest areas is entirely without warrant. There is nothing in our existing state of knowledge to indicate that these records may not be completely reversed in the next ten years.

It is submitted that the above exhibit effectually punctures the iridescent bubble which Messrs. Swain, Pinchot, McGee, and Leighton have set afloat in this discussion. Their vaunted criterion of a ten-year period is a pleasing pipe dream and nothing more. Their smoothing-out process is a smothering process. It suppresses the very facts that the engineer most needs to know. It substitutes a sham for the real thing. It is fundamentally unscientific.

Both Professor Swain and Mr. Leighton have misunderstood the writer's argument in regard to the effect of forest storage in promoting tributary combination, though each has criticized it from a different point of view. As they have understood it, the writer entirely agrees with both. The sketch illustrations given by Professor Swain are doubtless true for the conditions as he states them, and he could multiply such illustrations indefinitely and find conditions in Nature that would fit them all. The trouble with this method of reasoning is that it proves nothing because it proves everything. Any one who embarks upon this sea of confusion will "find no end, in wandering mazes lost," and will soon throw up his hands in despair. Fully understanding the impossibility of coming at any definite result in this way, the writer did not go into it in his paper, but stood upon the indisputable fact, as shown by the records, that rainfall and floods and low waters are essentially the same now as they were before the forests were cut off.

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In like manner, Mr. Leighton's point that any draft upon the storage in the forest bed leaves room for that much more is, of course, entirely correct, and the writer has nowhere said anything to the contrary. What the writer did say in elucidating this subject was:

"When a period of heavy storms occurs, spreading over a great area, continually increasing in intensity, the forests, by retaining some portion of the earlier showers and paying them out afterward, do produce a general high condition of the river which may greatly aggravate a sudden flood from some portion of the water-shed."*

This may be made clear, if there is really any doubt as to its meaning, by comparing it to a similar phenomenon with which all are familiar. Take the case of ground storage, acting through a longer period. After a long wet spell the superficial springs and underground sources become replenished, the small streams swollen, and the trunk stream assumes a high stage. Manifestly, this condition is less favorable for the reception of a heavy flood from any portion of the watershed than if the river were low. In like manner, to the extent to which it is effective, forest storage operates in the same way. If the writer were to re-write the sentence above quoted, he would omit the word "greatly," because the more he considers it the less weight is he inclined to give to the forest bed as an agency for holding water. In fact, he did indicate this feeling to some extent in a later sentence in which he said:

"It is not contended that this increase is ever very great, but it is contended that forests never diminish great floods and that they probably do increase them somewhat."

* The phrase "some portion of the water-shed" is used because it rarely, if ever, happens that, in a great river like the Ohio, the downpour that brings the crisis of the flood covers all, or even the larger part, of the water-shed.

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In reviewing the wording of Proposition 2, the writer can see that, taken by itself, it may justify the interpretation of Professor Swain, but not if read in connection with the explanation in the text. It would convey the writer's meaning more clearly if the words "may, and often does, bring the accumulated waters of a series of storms in one part of the water-shed upon those of another which may occur several days later," were changed to read "may, and often does, produce an increase of stage in a river, which may aggravate a later flood coming from some portion of the water-shed."

PROPOSITION 3.

"In periods of extreme summer heat forests operate to diminish the run-off, because they absorb almost completely and give off in evaporation ordinary showers which, in the open country, produce a considerable temporary increase in the streams; and therefore, while small springs and rivulets may dry up more than formerly, this is not true of the larger rivers."

The writer has already called Mr. Leighton to account for misstating his position in regard to ground storage. He nowhere ignores its existence. Neither has he anywhere said what Mr. Le Baron implies he has said, that "if there were no springs, rivulets, or brooks," there would still be rivers. What he did say is: "The difference between the former low-water flow of a spring or rivulet and what it is now is relatively an insignificant quantity." He was dealing with relative, not absolute, quantities. Formerly streams were lower in autumn than in spring; the same is true now. The current theory is that they fall lower now than they once did. The writer simply said that, whatever may be the difference between the former time and now, it cuts very little figure in comparison with the total flow that makes up a river. And he will now add that he is more convinced than ever that the difference itself is very greatly exaggerated in the public mind.

Springs are, of course, an exceedingly important factor in stream flow, possibly more important than the surface run-off. In time of flood the surface run-off is far the greater. In times of low water the spring supply is generally, though not always, the greater. In considering the function of springs in the low-water flow of streams, it is necessary to take into account their origin and character. For this purpose they may be classified as deep and shallow springs—that is, those that come from deep subterranean sources and those that emerge in the near vicinity of their supply. The true spring—the spring of real economic importance—comes from deep and distant sources. Its course before emergence may lie for great distances between impervious strata, where it is entirely cut off from external influences. Springs of this class are generally permanent, respond slowly to precipitation, and vary but little throughout the year. Every country

abounds in them. In 1898 the writer investigated with great care a number of these springs in the vicinity of Huntsville, Ala., and could find no evidence that they are smaller now than formerly, though in one case his evidence extended to the period before the Civil War. Important towns in various parts of the world rely upon such sources of supply. It is these springs that yield the bulk of the low-water flow of streams, so far as this comes from the ground, and it is not likely that their present volume is much less than before the forests were cut off.

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Springs of the other class come from shallow sources, the water reappearing in the near vicinity of where it soaks into the ground. Such springs are very copious in wet weather, and their aggregate volume probably exceeds that of the other class. But they are much less permanent, responding quickly to surface conditions and drying up much more completely than the deeper springs. It is within the knowledge of everyone who has rambled much through the country, either forest or open, that all such springs diminish greatly in dry weather and often disappear altogether. So far as springs have suffered at all from deforestation, it is this class which has suffered most. But it is wholly a mistake to assume that such springs did not generally dry up when forests covered the country; and the actual deficiency since the woods have been cleared away is probably much less than popularly supposed. The writer has observed these springs and the small streams in different kinds of forest, and knows, from experience in the handling and use of such sources of supply, that they are extremely variable with seasons and with precipitation conditions.

At this point it is worth while to consider the evidence relating to this matter of the drying up of springs, wells, and little streams. It is for the most part hearsay evidence only, and of the most unreliable character. While the forest remains around a spring, the latter is ordinarily not closely observed. When the land is cleared, the spring is generally brought into use. In the case of many small springs which the writer has observed, the demand upon them has greatly increased with the development of the country, and their capacity has become deficient. Under such circumstances the user is likely to say that the supply is growing less. In scarcely any case of the flow of a small spring is there a reliable record extending over a considerable time.

In the case of wells of considerable age, the evidence is more definite that the water in them stands lower than it did when they were built; also, that new wells have to be dug deeper than formerly; and this is said to be due to the removal of the forests. Again, "after this, therefore on account of this" is the only reason for connecting the two facts as effect and cause. There is only one thing that we know with cer-

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In a well in Prospect Park, Brooklyn, a continuous draft of less than $\frac{3}{4}$ cu. ft. per sec. caused the water level to fall nearly 6 ft. in ten years. During this time there was no change in forest cover. In some places this effect of wells has been traced several miles. Is it not altogether likely that if all wells could be closed for a period of, say five years, most of the lowering of water level attributed to forest removal would disappear?

The commonly cited example of defunct mill-powers is another case of defective evidence. Let any one trace the history of an abandoned mill built in the early days on any of our small streams, and search out the actual cause of its abandonment, and the chances are that, in nine cases out of ten, he will find that it was for business, not physical, reasons. In some cases deforestation has ruined saw-mills, not by cutting off the water supply, but by cutting off the timber supply. But the great cause of the abandonment of little mill-powers has been the development of steam, by which all the work formerly done by the little mill has been done much more effectively and cheaply. Rightly understood, the old abandoned mill-powers are evidences, not of the diminishing flow of our streams, but of failure in the battle with steam. The improved weapons of water-power—the turbine, the impulse wheel, and electricity—and the growing cost of steam are now turning the tide of conflict the other way.

The evidence of the oldest inhabitant, so often cited, is never reliable. The writer has himself tried the plan of collecting opinions of individuals as to the drying up of springs, etc. There is always a strong affirmative majority, but there is also a minority large enough to upset confidence, particularly when it is found that such minority generally embraces the closest observers. An example may be seen in the recent widely-quoted report of the Pennsylvania Flood Commission, in which a summary was given of replies received to certain questions as to the effect of deforestation upon the flow of the Susquehanna River. In one set of replies there was a large minority that

thought no effect was traceable; in another set of replies this minority was much smaller; but in neither case was the vote by any means unanimous. The drawing of hard-and-fast conclusions upon evidence of this sort is open to the same criticism as was the verdict of a jury who acquitted a man of theft because six witnesses swore that they did not see him commit the theft, and only four that they did see him commit it. The simple fact is that our evidence in all these matters is not clear, and that the tendency has been to ignore or set aside many good and valid explanations of existing phenomena and attribute them to one cause alone—the cutting off of the forests.

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Coming back to his argument, the writer holds that the strong and permanent springs, which form the real sources of our low-water supply, have not changed appreciably with the development of the country; that the superficial springs possibly dry up more than formerly, but that the difference between their former and present condition is much exaggerated; and that in most cases the diminished flow of little streams is due to the increased use of the water more than to the clearing of the land. To offset this diminished flow where it exists there are several influences brought into effect by the settlement of the country. In towns, a portion of the water supply drawn from wells or springs, or stored in reservoirs during high water, finds its way back into the streams as sewage. In some towns cistern storage is sufficient to absorb a large part of the rain that falls on roofs, and a portion of this finds its way back into the streams in low water. But the principal compensating effect is the run-off from summer showers, to which the writer refers in his paper. In the low-water season the difference between the forest and the open country in the matter of restraining run-off is at a maximum. The forest prevents practically all such showers from reaching the streams, whereas the effect of roads, ditches, and pavements in the open country is to deliver some portion into the streams. Every one has witnessed this difference at such seasons, and its effect is at times considerable. Putting all these causes together, it is clearly not a proven fact that the aggregate flow of small streams in the open country during periods of low water is less than it was under forest conditions. It may be more irregular. It may fall lower, but at the same time it may rise higher and the aggregate result may be very doubtful.

Mr. Leighton repeats the old dictum, which is just now enjoying a revived popularity, that a "stream is a stream from its mouth to its source," meaning thereby that no really comprehensive method of dealing with the lower course of a river is possible which does not take into account the extreme head-waters as well. This used to be a favorite doctrine with the writer, and, to a limited extent, is so still; but he has long since learned that the only real resemblance between a great river and any one of its innumerable sources is the fact that both

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are carrying water on its way from the uplands to the sea; and he believes the truer doctrine is, in the words of Colonel Roberts: "A river is a river, and a creek is a creek." Let any one reflect but a moment upon the many and radical differences between these two classes of streams, and he will see that their practical relationship is often more fanciful than real. Only one feature of difference will be noted here, and that is the reservoir function of the trunk stream. A river is made up of tens of thousands of little tributaries. These are separate sources, often acted upon by separate causes—some experiencing freshets, while others are entirely undisturbed, and all changing in their flow more or less independently of one another. The river knows nothing of these irregularities. The freshet of a remote tributary causes scarcely a ripple on its surface. The river is a reservoir. It is uniform in a sense that little tributaries never are. It responds only to general causes that affect a great number of tributaries alike, and most readers of this paper will have no difficulty in understanding what is meant by uniformity of flow in a river, as distinguished from any one of its numberless sources. It is therefore in the great river, where the infinitely variable elements of its supply are integrated into one definite result which can be observed and measured, that we should go to see whether the flow of our streams is smaller in volume than it used to be. Resorting to this tribunal, we find nothing to justify the popular theory. Whatever may be happening to the springs and wells and little streams, as much water gets into the great rivers in low stages as used to, and apparently more. The low-water flow of the Monongahela at Pittsburg for 1908, about 200 cu. ft. per sec., was certainly as great as in certain other extreme low waters, and if it could be corrected for losses for industrial uses that have come into existence in the past fifty years, its discharge at the height of this extraordinary drought would be found to be materially larger than in the great drought years of 1838 and 1856.

In fact, it is growing evident, as this matter is looked into more carefully, that the forest, in more ways than one, is a voracious consumer of water during periods of drought, and that it is not at all the source of low-water supply that it has been held to be.

PROPOSITION 4.

"The effect of forests upon the run-off resulting from snow-melting is to concentrate it into brief periods and thereby increase the severity of freshets. This results (a) from the prevention of the formation of drifts, and (b) from the prevention of snow-melting by sun action in the spring, and the retention of the snow blanket until the arrival of hot weather."

As to the soundness of this proposition, the writer is quite content to rest his case upon the judgment of those who will carefully read

his argument, supplemented by the statements of Messrs. Leffingwell, Strong, and Johnston, and even of Colonel Pickett himself. He would also cite the article from *Science* which is included in the Appendix. The proposition has come to many as a surprise, and their first impulse has been to deny it, and this impulse has led to the only efforts of consequence, and these very feeble ones, to controvert the writer's argument.

Mr. Leighton says that drifts form in forests. Occasionally; but such drifts may generally be accounted for by the topography. A sharp ridge, for instance, by forming an eddy in the air, causes the snow to collect more deeply behind it. Such instances are in direct line with the writer's theory. The only situation where the trees themselves form drifts is on the edge of the timber, where the wind blows into it from the open. In such cases drifts will accumulate for a hundred yards or so under cover, depending on the density of the timber.

But Mr. Leighton is wholly wrong in asserting that but a small part of the snow in the open gathers into drifts. Omitting the very early and very late snows, which are generally wet and accompanied by less wind, the vast bulk of the mountain snows falls under the influence of the wind. This snow is dry and floury, and yields to the slightest breeze. In the open country it is nearly all thrown into drifts of greater or less magnitude.

The writer craves the pardon of the Society for referring so much to his personal experience, but the position taken by certain participants in this discussion, in holding that there is no essential difference between the forest and open in the way in which snow collects on the ground, seems so extraordinary that he is inclined to specify more particularly the sources of his own knowledge. For many years his work brought him frequently in the heavy forest during the worst storms of winter, while in the spring he was almost constantly in the woods in connection with the making of maple sugar, from the very earliest melting until the leaves were out on the trees. This was in a dense, primeval, deciduous forest, and in a country of very heavy snowfall. He states most positively that in such a forest the snow never drifts to any great extent unless there are sharp hills, or openings, or other similar disturbing elements, and that then it does not drift as in the open country. In the region here considered, drifting in the open was the rule everywhere after cold weather really set in, and was a source of great inconvenience to travel wherever there were fences along the roadside. Nothing was more common than to see roads staked out through these drifts, or the highway abandoned altogether, and travel taken to the open fields. No such trouble was ever experienced where roads lay through extensive forests. These open country drifts often lasted until the land around them was dry and dusty and the forest bed well dried out.

So in the mountain forests; there is a long belt of open country,

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from 5 to 10 miles wide, extending along the northern border of the Yellowstone Park, and constituting the greater portion of the grazing ground for game. A road extends east and west for 50 miles through this section, and 4 miles of it are in a heavy forest. The drifts form so heavily in the open section that in many places it is impossible to maintain travel except by leaving the road and going around the drifts. This trouble is never experienced in the forest.

Fig. 1, Plate XXXVII, accurately depicts the condition of the snow in a dense forest. Someone has hinted that this is a fresh snow-fall. A glance at the left of the picture, where the ground at the foot of the trees is entirely bare from sun melting, would have saved the necessity of that suggestion. The writer took this picture himself, and at the date on which it was taken the snow all over this country lay in a solid, nearly uniform blanket, fully 4 ft. thick. Within ten days it was nearly all gone. The two pictures in Plate XXXVII will bear study. They tell the whole story, and the writer can only say, of those who belittle the difference between forest and open country in the matter of snow distribution, that they are not familiar with the subject. Surely Mr. Pinchot has never "entered into the treasures of the snow" in his study of our western water supply, or he would not speak lightly of the great reservoirs formed by the drifts of our mountains. They do more to equalize and prolong the flow of such streams than any other cause, except, possibly, the deep subterranean springs.

Mr. Leighton is also in error in what he says about the melting of snow from underneath. This does not take place to any appreciable extent in the Rocky Mountains. The heavy snows—the real accumulation of winter—come in February and March. Long before this the ground under the thin covering of the earlier snows is frozen solid to a considerable depth. It does not thaw out during the winter enough to cause any appreciable melting of the layer of snow above it. Even such melting as does occur soaks into the snow rather than into the ground, for the snow is the better sponge. The writer has examined this matter too many times to admit of any question upon it. The sub-surface melting is practically a negligible quantity, and the winter's supply of snow, except such as escapes in evaporation, gradually compacts until it reaches a stage of saturation at the time when the genuine warmth of summer arrives.

This condition also prevails, though to a less degree, in the eastern deciduous forest, as confirmed by Messrs. Le Baron and Snow. The difference in temperature between the forest and open country is not great, and while the ground is more protected in the woods than under the thin covering of the open, it is not as well protected as under the open country drifts. But there is one feature of these forests that effectually hinders the assumed soaking into the ground from sub-surface melting, and that is the flattened out layer of leaves to which

Mr. Snow has called attention. Anyone who has observed the condition of the forest bed under deciduous trees just after the snow has disappeared will understand this. Those leaves virtually form an oil-cloth separator between the snow and the ground, and whatever melting there may be from beneath is drawn up into the open sponge above rather than through the leaves into the ground beneath. This fact should be borne in mind by those who lay so much stress upon the frozen condition of the ground on our eastern water-sheds when the floods of winter and early spring take place. This condition in the open country is partially, and possibly fully, offset by that of the forest bed above described, particularly when the bed of leaves is itself sealed up by frost.

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The curves (Fig. 1), to which Mr. Leighton refers so slightly, will stand as a rational expression of a scientific truth which will be fully recognized as this subject comes to be better understood. The time scale has more immediate application to the great central Rocky Mountain region about the sources of the Yellowstone. The vertical scale is, of course, only a most general expression. As shown in the figure, it represents the writer's estimate of an extreme case, like the flood of 1899. In average years the two crests are much closer together. The great saving factors in these mountain floods are difference of altitude and changes of weather. The lower altitudes yield up their waters first, and these are safely carried away before those from the higher altitudes come down. The melting at the same altitudes is often interrupted by a sudden drop in temperature. On more than one occasion has the writer taken measures to patrol the roads in the Yellowstone when conditions seemed to make a flood imminent, but has been spared any trouble by a sudden change of weather which stopped melting, tightened up the little streams and allowed the accumulated waters to run away. This, in fact, is the general rule; but every five or six years a season will come in which warm weather and rains continue for several days without interruption, and it is then that disasters follow.

The writer will note here a common, but very erroneous, impression to the effect that delay of forest melting is a benefit to irrigation. This point has been urged by Colonel Pickett and by the Editor of *Engineering News*. Far from being a benefit, this delay, by concentrating and intensifying the run-off, is a positive injury by the damage it causes to irrigation works. The water comes in such volume that it cannot be used, and all the excess which constitutes the flood is absolutely lost to irrigation. Storage reservoirs alone can save it. Particular attention is invited to the fallacy of popular thought in this matter, because it has a bearing upon the main question here considered.

Professor Swain takes exception to the writer's statement that the

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forests of the Pacific Coast intensify floods, and asks, "Would it not be more correct to say that * * * even in densely forested areas there may be tremendous floods?" No, that would not define the situation, at all. The fact is that we have here, as stated in the paper, "the densest forests in the world, the deepest beds of humus, and the most perfect reservoir effect so long as it is in action." In building a road into the Mount Rainier National Park, the writer found that the clearing away of the débris which covers the soil was in many places the heaviest item of the work. It is often 2 and 3 ft. thick. If there is anything in the forestry theory, we should find it more fully exemplified here than anywhere else. Yet the contrary is the case, and the writer believes it to be strictly a true statement that freshets are more sudden and violent, and caused by smaller rains, than in the cultivated sections of our Eastern States. It was a great surprise to him to learn this fact; but the explanation now seems to him very obvious. The snow and the subsequent warm rains have the effect of bringing two storms together. The forests enhance this effect by distributing the snow so that a vastly greater area is exposed to the melting influences than would otherwise be the case.

To show how strikingly true this is, the records of the flood of November, 1906, on Cedar River are given in Table 22. This is an important stream, though a small one, for it furnishes the water supply for the City of Seattle, and its water-shed is to be thoroughly protected and its records carefully kept. Table 22 gives the record for November 12th to 18th, 1906:

TABLE 22.

Date.	Temperature.	RAINFALL.		Discharge of Cedar River.
		Inches.	Cubic feet per second.	
Nov. 12th.....	50°	1.84	5 027	1 430
" 13th.....	56°	2.12	7 992	3 028
" 14th.....	60°	1.15	4 835	7 610
" 15th.....	55°	2.26	8 488	10 800
" 16th.....	44°	0.07	254	6 930
" 17th.....	44°	0.07	254	8 610
" 18th.....	50°	0.00	0	2 380

The area of the water-shed is 143 sq. miles, and the maximum flow in this flood was therefore about 75 cu. ft. per sec. per sq. mile. The distance to the gauging station from the center of the water-shed is about 12 miles, and it is probable that the run-off, as measured, all originated within the previous 24 hours. Comparing the rainfall of the four days, 12th to 15th, with the run-off for the four days, 13th to 16th, it appears that the run-off exceeded the rainfall by 632 cu. ft. per sec., or about 220 000 000 cu. ft. for the four days. The discharge

CEDAR LAKE, ON CEDAR RIVER WATER-SHED.

of the river just before the storm began was about 1 000 cu. ft. per sec. Mr. Chittenden.

It should be said that the figures for rainfall are made up from two stations, the only ones available, viz., Cedar Lake, west of the center of the water-shed, and Lester, just south of the eastern portion. Both these stations are in valleys, and probably do not represent accurately what took place in the hills. But the explanation of so large a freshet compared with the rainfall is in any event obvious. The month had been very rainy and the storage capacity of the water-shed was exhausted. There was a considerable quantity of snow in the hills, both on the ground and on the trees. The temperature was high, and the water from the snow came down with that from the rain; so that, in spite of the heavy layer of humus over-spreading the whole water-shed, and in spite of the presence of a considerable lake which has a moderating effect on freshets, the discharge rose and fell quite as rapidly in response to precipitation as on an eastern stream in the hilly country where the forests have been cleared away. Plate XLVI is a view of the water-shed.

Cedar River is the stream which Mr. Pinchot, in the January, 1908, number of the *Annals of the American Academy of Political and Social Science* (devoted to the subject of American Waterways), has compared with Owen Creek, Arizona. Both streams are given as having a water-shed of about 173 sq. miles; that of Owen Creek is barren and treeless, with much rock exposed, and the water flows off as from a roof. Little rain falls, and there is no record of the precipitation that caused the heavy freshet of 1896 which Mr. Pinchot cites; but, from all experience in that country, the storm was evidently in the nature of a cloudburst. There was a record of only about 15 in. of rainfall for the year at the nearest Weather Bureau station. The freshet cited was estimated at 9 000 cu. ft. per sec., or a little over 50 cu. ft. per sec. per sq. mile.

The data given for Cedar River in the flood of 1897 were as follows: Rainfall, 93 in. for the year, estimated at 150 in. in the mountains; maximum flood flow, 3 601 cu. ft. per sec., or 21 cu. ft. per sec. per sq. mile.

Of course any such comparison, as illustrating the effect of deforestation, is wholly inapplicable. It would even be as fair a comparison to take the City of Seattle, with its roofs and pavements. A legitimate method would be to compare a forested area with a deforested area in the same kind of country. The comparison as given omits all reference to distribution of rainfall, yet in Phoenix, in 1896, rain fell on only 51 days while in Seattle and vicinity it falls on the average 160 days in a year. Moreover, the flood flow of Cedar River, as stated, is evidently wholly in error, for the flood of 1897 is locally considered to have been greater than that of 1906 when it reached 10 800 cu. ft. per sec., or 75 cu. ft. per sec. per sq. mile. The area of

Mr. Chittenden. the Cedar River water-shed is overstated by 20%, and no mention of the lake is made. It appears, however, that, notwithstanding the unfitness of the parallel, and the defective data for Cedar River, the illustration stands decidedly against the argument which it was intended to enforce.

A recent freshet in the Skagit River, in which snow played very little part, and in which the rainfall was by no means excessive, still further confirms the view that the moderating effect of these forests on floods is much less than is popularly supposed. The rainfall at Sedro Wooley (the only station on the water-shed), which, for a week prior to November 16th, 1908, had been nothing, was 0.46 in. on the 16th, 1.11 in. on the 17th, 0.01 in. on the 18th, and 0.26 in. on the 19th. The corresponding gauge readings were 37, 48, 52 and 47.6 ft.—a total rise of 15 ft., the river reaching bank-full stage. The rainfall was doubtless heavier in the mountains, though records at three points outside the water-shed do not indicate that it was so. Mr. H. L. Devine, weather observer at Sedro, and for nineteen years a resident of that place, stated that the absence of snow alone prevented a most disastrous flood. The writer cannot account for the fact that such a rainfall could produce such a result in such a country, except upon the supposition that previous rains had left the forest bed well soaked, and also that, through long periods of time, the water had developed little channels under the débris through which it flowed away much more easily than would seem possible from superficial appearances. The Skagit River at Sedro has a rapid fall, and a 15-ft. rise in gauge height means a great increase in discharge.

How well the inhabitants of this region understand the danger involved in heavy snowfalls in the lower altitudes is well shown by what is transpiring at this writing. A week of frequently recurring heavy snow storms with light wind had loaded the trees and brushwood heavily with snow. (Plate XLVII.) This was followed by rain and warm winds, though very fortunately with intermittent cold snaps. But the farmers, understanding fully what would happen if the warm spell should be prolonged, immediately began strengthening the weak places in the river dikes and otherwise preparing themselves for a probable flood.

Proposition 4 is hardly comprehensive enough to cover the entire subject of snow-melting as treated in this paper, because it applies specifically to the Rocky Mountain region. A more complete summary of the general influence of forests upon the run-off from snow-melting is given in the following statement:

Snow has the effect of postponing the run-off from precipitation to a period subsequent to that in which the precipitation occurred. If the melting is accompanied by rain, the result is to add the run-off of two or more storms together.

SNOW ON EVERGREEN TREES.

The forest increases the intensity of the run-off from snow-melting primarily by its effect upon the distribution of the snow, whereby the area exposed to the melting influences is increased over what it is in the open country where the snow is largely thrown into drifts. Mr. Chittenden.

The forest, by virtue of its shade, delays melting from the direct action of the sun, and tends to hold the snow until warm-weather conditions arrive, when the snow melts with great rapidity. This applies more particularly to the central Rocky Mountain region, where the forests are evergreen, and where the sun shines a great deal. It has a smaller application to the eastern deciduous forests, where there is less shade and less clear weather. Smaller still is its application on the Northwest Coast, on account of the lack of sunshine in the season of melting.

In the eastern forests, the flattened-out, and often frozen, layer of leaves from deciduous trees in a measure offsets the more general freezing of the ground in the open country in the matter of shedding the water from heavy rains and melting snow.

On the Pacific Coast, the wet condition of the snow and its tendency to cling to trees and underbrush give the warm ocean winds, common in that region, great effect in melting, and this circumstance adds materially to the intensity of the resulting freshets.

As a general rule, therefore, in all situations, the effect of forests upon the run-off from snow-melting is to intensify it.

After the above writing had been completed and forwarded for publication, a letter appeared in *Engineering News* for January 28th, by Jeremiah Ahern, M. Am. Soc. C. E., District Engineer, U. S. Reclamation Service, strongly confirming the writer's theory in regard to snow-melting in the mountains. He says that such snows always melt in the following order:

"(1) Snow on the unforested areas not collected in drifts.

"(2) Snow on the forest areas.

"(3) And last, snow in drifts scattered over the unforested areas."

He quotes the late Major John W. Powell as follows:

"When the mountain declivities are grassy slopes, the snows of winter drift behind ledges and cliffs and into great banks among the rocks, and they fill ravines and canyons, and are thus stored in compact bodies until they are melted by the summer suns and rains. But when forests stand on the slopes the snows are spread in comparatively thin sheets, and great surfaces of evaporation are presented to the sun and the wind. For all these reasons the forests of the upper regions are not advantageous to the people of the valleys, who depend on the streams for the fertilization of the farms."

PROPOSITION 5.

"Soil erosion does not result from forest cutting in itself, but from cultivation, using that term in a broad sense. The question of preventing such erosion or soil wash is altogether one of dispensing with cultivation

Mr. Chittenden. or properly controlling it. The natural growth which always follows the destruction of a forest is fully as effective in preventing erosion, and even in retaining run-off, as the natural forest."

This proposition, like the one preceding, has been received with more or less protest, and exclamations of "impossible;" but a calm review of the discussion will disclose a complete failure to shake its essential correctness. Mr. Leighton characteristically tosses it aside with a promise that if the writer will accompany him to certain regions he will convince him; but the writer ventures to predict that, if the suggested visit were made, he would find, in practically every instance which might be pointed out, that the erosion was initiated by attempts to reduce the land to cultivation. In fact there is nothing about a tree 3 in. above the ground that has any influence on erosion. The only feature connected with the removal of timber, *per se*, that can induce erosion is the log roads developed in hauling it out. These, of course, may start washing which may develop into large gullies. But the primary cause of erosion is injudicious efforts at cultivation, and in no place is the fault more in evidence than in the region to which Mr. Leighton refers. A recent writer incidentally refers to this matter in the following language:

"Of all the crimes of poor tillage which have aroused the workers toward conservation; of all the reckless clearing of timber, burning of soil, washing away and eroding of fields; all the process of robbing the land of its fertility by endless succession of the same crops, the worst examples are to be found among these mountains."

The writer lays particular stress upon this point because the problem of erosion is a problem in cultivation. There must always be a large percentage of cleared land in all parts of the country to sustain the population. The problem is to handle this cultivation in such a way as to reduce soil wash to a minimum. Coupled with the associated problems of crop rotation, fertilization, etc., it is easily the most important conservation problem before the people to-day, out-ranking forestry, or water-power, or navigation. In the great majority of situations, nearly all classes of cultivation can be managed so as to prevent excessive erosion. In all but a very few, grass cover is an effective agent; as much so as the forest itself. But there are some soils which are so unstable that the scratch of a hoe leads to erosion, and undoubtedly such should be reserved for that class of vegetation which never requires extensive breaking of the soil, viz., the rearing of forests. This is a very different thing from the wholesale and sweeping assertions that tree cutting naturally and inevitably leads to erosion.

Mr. Le Baron raises the point that cultivation is a concomitant of deforestation, and that therefore the writer's distinction is not a valid one. But his statement is not correct, either as to fact or conclusion. Let him look out of a car window on any railroad in

the eastern section of our country and see the woodland in all directions. In much of this the virgin timber has all been cut away. Let him visit the vast pine-stripped areas of Michigan and Minnesota and the Southern States, and in fact examine the country in almost any direction, and he will see that the original cutting down of much of our timber has not been followed even proximately by cultivation. It is true that the extirpation of the forest is necessary to cultivation, but the erosion, where there is any, begins with and is caused by the cultivation. Mr. Pinchot says, in the same vein: "Whether one destroys the forest to cultivate the soil, or cultivates the soil after the forest is destroyed, makes no difference." As logically might he say that if the ground were cleared of trees for the building of a dam, the clearing would be the cause of water collecting in the reservoir.

The point is often made that the trees break the violence of storms so that they do not strike the ground direct. This argument is altogether trivial and inconsequential. Wind-driven rain does not affect the soil of fields covered with grass, grain or other crops, much as it may "lodge" and play havoc with the crop itself. Most precipitation falls in winds of moderate power. Snow falling, no matter how fierce the wind, never produces erosion. Finally, the point is quite irrelevant, because it is impossible to have tree cover for our towns, cultivated fields, and pasture land, anyway, and there is of course no objection to its presence on the remainder of the land.

The writer notes two instances in which officials of the Forestry Bureau and Geological Survey have confirmed the views expressed in his paper upon this subject. In a paper by Mr. W. W. Ashe, Forest Assistant, published in the preliminary report of the present Inland Waterways Commission, he says that, of the sediment borne along by our rivers, "agricultural lands contribute only a relatively insignificant part." This is very different from the thousand million tons of soil from our fields, worth a dollar a ton, which we have read of so much during the past two years.

In a recent well-prepared article* by Mr. Herman Stabler, Assistant Engineer, U. S. Geological Survey, it was shown that the soil erosion above the proposed reservoirs on the Ohio water-shed under present conditions would fill up these reservoirs, if built, at an average rate of only 10% in 835 years, or 50% in 4 000 years. For the Monongahela, the period for 10% filling is 1 260 years; and for the Allegheny, 2 410 years; yet the water-shed of the first of these streams is over 50% deforested and that of the other over 60 per cent. These figures have a very important bearing upon the question here considered. They completely refute the claim so strenuously put forth that deforestation at the sources of these streams is producing ruinous erosion, and that the preservation and extension of the forested areas is absolutely

* *Engineering News*, December 10th, 1908.

Mr. Chittenden. necessary as an adjunct to reservoir construction. Secretary Wilson's report, already quoted, says: "No matter what its purpose or design, any reservoir system developed in the Southern Appalachians is foredoomed to failure unless the watersheds that feed it are kept under forest;" and Mr. Leighton—"the reservoirs will not be worth a minute's time nor a cent of money unless the forests are retained." Yet it seems that on the Cumberland and Tennessee, with deforestation already far advanced, it will take about 700 years to fill the reservoirs 10%, and of course only a small portion of this can be traced to deforestation.

The silt measurements of these streams also confirm, though from another point of view, the writer's conclusions, from observation and study of the rivers themselves, that our navigable streams are not shoaling appreciably more than formerly.

At this point reference may properly be made to an argument advanced by two or three parties to this discussion, that soil cover is necessary over rocks because of its aid in disintegrating them, and also that trees are important in such places for the same reason and for the added reason that, by splitting up the rocks, they facilitate the ingress of water and its storage in the ground. In arguments of this kind one clearly traces the mental habit of the geologist whose very calling directs his study to the rocks of the earth and leads him to magnify both the extent and importance of those localities where rock is near the surface. Whatever force there may be in the argument itself is neutralized by its very limited application. Forest roots do not penetrate to the underlying rock, except to a very small extent, even in mountainous countries. In clearing the routes for at least a hundred miles of road in dense forest in the heart of the Rocky Mountains the writer does not believe that 5% of the trees removed penetrated to rock. Taking the whole country over, it cannot be that even one-tenth of 1% of the trees have any influence on the underlying rock. And so it is of soil covering; the areas where rock *in situ* lies within reach of the plow, or even within 2 ft. of the surface are very limited, and play an insignificant part in the general economy of the soil.

PROPOSITION 6.

"As a general proposition, climate, and particularly precipitation, have not been appreciably modified by the progress of settlement and the consequent clearing of land, and there is no sufficient reason, theoretically, why such a result should ensue."

The correctness of this proposition seems to be generally conceded by those who have carefully studied the question. For every rainfall record that forms an apparent exception, one can be found to offset it. Both in this country and in Europe long-time records of precipitation show little change, and certainly none in the direction of

decrease. Simply as an illustration of this general truth, two of the longest records which the writer has been able to find in our own country are given in Table 23. In deference to Mr. Leighton's penchant for 10-year periods, the means for each decade are also given, though in a few cases they are based upon partial records.

TABLE 23.—RECORDS OF RAINFALL AT PHILADELPHIA, PA., AND MARIETTA, OHIO.

Year.	Phila- delphia	Marietta.	Year.	Phila- delphia.	Marietta.	Year.	Phila- delphia.	Marietta.
1811	34.97	.....	1844	40.17	36.64	1876	47.39	48.19
1812	39.30	.....	1845	40.02	33.90	1877	37.26	34.76
1813	35.63	.....	1846	44.39	46.27	1878	34.53	37.53
1814	43.14	.....	1847	45.09	52.30	1879	36.75	30.50
1815	34.67	.....	1848	35.00	43.18	1880	33.58	46.36
1816	27.95	.....	1849	42.09	42.89			
1817	36.01	.....	1850	54.54	52.36	Mean	42.69	35.99
1818	30.18	50.92	Mean	45.22	43.42	1881	30.21	36.78
1819	23.35	36.30	1851	35.50	34.94	1882	45.58	59.96
1820	39.61	39.11	1852	45.75	46.50	1883	39.17	43.62
Mean	34.48	42.11	1853	40.66	37.04	1884	39.34	38.54
1821	32.18	43.32	1854	40.18	38.80	1885	33.53	41.68
1822	29.86	43.38	1855	44.09	45.76	1886	37.24	42.14
1823	41.85	.....	1856	33.93	32.46	1887	42.17	37.32
1824	38.74	.....	1857	48.29	40.64	1888	44.06	56.28
1825	29.57	.....	1858	39.85	61.84	1889	50.60	40.95
1826	36.15	.....	1859	58.12	48.55	1890	34.02	60.99
1827	38.50	.....	1860	44.09	39.48	Mean	39.59	46.33
1828	37.97	49.50	Mean	43.05	42.60	1891	38.19	40.76
1829	41.85	39.52	1861	46.34	46.42	1892	34.78	34.83
1830	45.07	37.26	1862	45.01	42.71	1893	37.65	39.94
Mean	37.17	42.60	1863	49.19	37.07	1894	40.34	30.08
1831	44.94	53.54	1864	46.00	40.94	1895	31.01	26.61
1832	39.87	43.33	1865	50.26	48.84	1896	32.15	.....
1833	48.55	40.37	1866	45.26	47.27	1897	42.04	41.41
1834	34.24	34.66	1867	61.19	46.71	1898	49.23	48.07
1835	39.30	42.46	1868	51.40	50.06	1899	39.96	43.73
1836	42.66	36.75	1869	48.86	42.86	1900	40.91	38.43
1837	39.04	43.86	1870	44.11	40.18	Mean	38.63	38.20
1838	45.24	35.48	Mean	49.37	44.31	1901	45.54	37.62
1839	43.74	33.32	1871	47.32	29.02	1902	49.76	.....
1840	47.40	39.09	1872	43.36	.....	1903	41.50	41.96
Mean	42.50	40.79	1873	55.28	47.98	1904	39.76	26.01
1841	55.50	42.82	1874	46.25	39.57	1905	41.61	46.38
1842	48.54	42.07	1875	40.22	46.04	1906	51.87	40.63
1843	46.91	41.76				1907	.....	53.14
						Mean	45.01	40.96

Means for whole period — Philadelphia, 41.63; Marietta, 42.34.

Mr. George P. Marsh, in "The Earth as Modified by Human Action," presents the strongest possible arguments for the conventional forest theory—in fact, his zeal in this cause often leads him into extravagances that rival those of the present day; but upon this particular subject he is compelled to say:

"I am unable to refer to a single instance where the records of the rain gauge, for a considerable period before and after the felling or planting of extensive woods, can be appealed to in support of either side of the question. The scientific reputation of many writers who

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have maintained that precipitation has been diminished in particular localities by the destruction of forests; or augmented by planting them, has led the public to suppose that their assertions rested upon sufficient proof. I cannot affirm that in none of those cases did such proof exist, but I am not aware that it has ever been produced."

Perfectly applicable is this statement to the common theories of the present day.

It is also claimed that precipitation is more irregular, but here again evidence is lacking, and, such as there is, is conflicting. There is nothing of sufficient duration or accuracy to enable one to draw positive conclusions, except that whatever changes may have resulted are of very small magnitude. The distribution of rainfall throughout the year is very irregular, and upon this fact Mr. Leighton and others have built up their theory of increased flood frequencies following deforestation. It might possibly be claimed that this irregularity itself is due to deforestation, but this is negated by the fact that the greatest irregularity in the numerous records cited by Dr. McGee and Mr. Leighton occurred on those water-sheds where there had been the least change in those years in forest areas.

The claim often advanced, that broad general changes in climate have resulted from changes wrought by Man on the surface of the earth in particular localities, is likewise without substantial foundation. The writer believes that a careful study of the question, with the same rules of evidence that would be applied to any other subject, will convince any one of the substantial correctness of the following statement by Professor Cleveland Abbé, of the U. S. Weather Bureau, in his article on climate in the International Encyclopedia:

"There is no well-authenticated case of an appreciable change of climate within the past two thousand years. The researches of Eginitis on the climate of Greece seem to establish this principle beyond doubt. Neither is it possible that any change on the surface of the earth due to man—such as deforestation, reforestation, agriculture, canals, railroads, or telegraph lines—can have had anything more than the slightest local effect, if any, on climatic phenomena that depend upon the action of the whole atmosphere."

One of the most common of popular fallacies is this belief in change of climate. In every community probably the majority of people believe that material changes have occurred within a generation. Most of us can remember when it was generally thought that the climate of Western Nebraska and Kansas was changing, and rain was becoming more frequent as a result of settlement and cultivation. A succession of more than average wet years was responsible for this belief, and many settlers moved to that country on the strength of it. But after a while normal conditions returned—perhaps the pendulum swung the other way—and many a settler was forced to leave the country. These facts are matters of official record.

It would be, indeed, a most welcome fact, if it were true, that, by introducing cultivation into the arid regions, rainfall could be increased; but it would be less welcome if it had to be accompanied by another fact, that the settlement of the humid regions reduced precipitation.

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Mr. Leighton takes exception to the writer's statement that seasons of drought are more to be dreaded than seasons of flood. He states that the flood damages for the year 1907 amounted to \$260 000 000. He does not say whether this means direct damages, or whether it is made up in part of indirect or inferential losses, such as interference with transportation, temporary depreciation of real estate, and the like. The figure looks pretty large for direct damages alone. Nothing is said, either, as to the great compensating effect of fertilization of bottom land due to general overflow. It is well known that the effects of such overflows in increased yield of crops are noticeable for several years after their occurrence. Their aggregate value is undoubtedly large, and constitutes a material offset against direct damages. In many parts of the world these overflows are a regular reliance, and one of the evil results of the levee system, wherever used, is that it cuts off this means of periodic renewal of the soil. But taking the above figures as representing actual and uncompensated loss for this one year (they certainly do not represent the average annual loss), let them be compared with the effects of the shrinkage of crops through drought. The value of the agricultural products of the United States for the year 1908 was more than \$7 750 000 000. A shrinkage of a trifle more than 3% would equal the above flood loss, and it is well known that a not excessive drought will cause a shrinkage far in excess of this amount. Famines, the world over, and throughout recorded history, have generally resulted from widespread deficiency of rain, particularly where such deficiency has extended through several years.

The constantly increasing losses from floods, with the settlement and development of the country, are often cited as evidence that floods are increasing. But the fallacy of such reasoning is strikingly illustrated by a single example. In 1844 occurred the greatest flood on record in the Missouri and Kaw Rivers at their confluence. The damage was insignificant, because there was little property there. The next greatest flood was in 1903, and the damage approximated \$30 000 000. Kansas City had been built in the path of the flood. Care should be taken, in comparisons of this sort, not to ascribe to increasing flood heights or frequencies losses which are due to Man's operations in placing property in the way of floods.

Messrs. Pinchot and Willis have referred to the cooler status of the forests as inducing precipitation, Professor Willis citing the evidence of aeronauts that the air is cooler over forests than in the open. But the inconclusive character of evidence like this is apparent at a

Mr. Chittenden. glance. It applies only to hot weather and to the air near the surface of the ground. It is certainly not true of the fall, winter, and spring seasons, when most of the rain and all the snow falls. It is probably not true even of summer storms of considerable duration. Whatever influence there is of this kind is small even in summer showers. The example, cited by a recent writer in *Engineering News*, of showers soaking the forests but leaving the clearings untouched—like Gideon's fleece, saturated with dew while it is "dry upon all the earth beside"—requires something more than a bald statement to substantiate it. If there is any such tendency it may be questioned if it is not more than offset by the greater absorptive power of the forest than that of the open country at such times.

It should be carefully borne in mind, in any discussion of this subject, that floods and low waters result primarily from the quantity and distribution of precipitation. It is rarely necessary to go beyond this simple fact for an explanation; but apparently because climate is still one of those natural phenomena over which Man has acquired no control, the tendency is to ignore it and attribute to other causes results for which it is alone responsible. The greatest discovery or advance in scientific knowledge, so far as the practical welfare of Mankind is concerned, that the world is likely ever to see (if it should see this) will be of some means of controlling the weather, and particularly precipitation. Many experiments have been made in this direction, but so far without appreciable success.*

PROPOSITION 7.

"The percentage of annual run-off to rainfall has been slightly increased by 'deforestation and cultivation.'"

The writer submits this proposition simply as an expression of his own opinion, without many confirmatory data. The 20-year record of the Connecticut at Holyoke,† by Clemens Herschel, M. Am. Soc. C. E., seems to confirm it on that stream, though the period is short. The low-water discharge of the Ohio seems to be as great and possibly greater than formerly, particularly if there be included the very large consumption for human use which would otherwise get into that stream. The writer does not believe that there is any large increase in the percentage of run-off over that of former times, but he believes, in any event, that it has not diminished.

* Though admittedly irrelevant, the interesting character of the following item justifies its insertion here, as another example of the old saying that "There is nothing new under the sun." Everyone is familiar with the superstition (possibly it deserves a better name) that great battles produce rain. The vibrating effect upon the atmosphere of the multitudinous detonations of artillery is generally ascribed as the cause. Read this from Plutarch, who flourished 45-125 A.D.

† It is an observation also, that extraordinary rains pretty generally fall after great battles; whether it be that some divine power thus washes and cleanses the polluted earth with showers from above, or that moisture and heavy evaporation, steaming forth from the blood and corruption, thickens the air, which naturally is subject to alterations from the smallest causes."

† *Transactions, Am. Soc. C. E.*, Vol. LVIII, p. 31.

Having reviewed the seven fundamental conclusions deduced from his original argument, the writer will ask the attention of those who have considered his views "extreme" to the conservatism which has marked every stage of his reasoning. More than once he has called attention to the unwisdom of building positive theories upon any one of the multitudinous details of this subject, in which definite data are still so lacking; and the general result of his argument was summed up in the following sentence, which he would here print in italics if the rules of the Society would permit: "The difference between past and present conditions is not great." The forest with its bed of humus is replaced by the cultivated field which quite equals it in absorptive power. The influence of forest growth upon evaporation is offset by that of growing crops. The greater parching effect of the direct rays of the sun upon the surface of the ground in the open country is relieved to some extent by the deposition of dew. If the forests are cooler in summer and possibly induce greater precipitation, they are warmer at other seasons and possibly have the contrary effect. And so, when we go to the great rivers to gather up the net result of these manifold influences, we find things very much as they used to be. It should be a matter of profound satisfaction that this is so. It is a pleasing picture to turn to after the saturnalia of horrors—"waste," "desolation" and "ruin"—to which we have been treated during the past two years by the forestry propaganda.

This paper had "particular reference to navigable rivers," and its general conclusions must be read with reference to our large streams. The writer holds that there is nothing in forestry that can lessen in any material degree the cost of works necessary for flood protection and navigation improvement. An important point in the paper, which has been passed over in silence by its critics, is that, even if the claims of forestry advocates in this connection were true, they would still offer no hope because they cannot be generally applied. It will never be possible to increase our present woodland area. The requirements of cultivation and occupancy will rather cause it to be reduced. There may be a shifting of wooded areas, a clearing-off of present woodland and a planting of new, but the grand total cannot be increased. Not only, therefore, are forestry advocates filling the public mind with erroneous theories on this subject, but they would be unable to apply those theories even if they were correct. They would doubtless reply to this, however, by saying that it is not expected to restore original conditions to any marked degree, but only to prevent a further departure from them.

The attitude assumed by some of the writer's critics is that he is hostile to forestry expansion and development. No candid reader of his paper can come to any such conclusion. The writer has made it very plain that he is not only friendly to the cause of forestry, but is

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Mr. Chittenden. a thorough believer in its great importance. He has not said a word against the interests of legitimate forestry, but he has attacked a spurious forestry which in these later days is trying to substitute a shadow for a reality and make the shadow the main issue. Deeply significant is the statement by Mr. Todd that:

"There seems to be a great popular belief, even among some residents of the Lower Mississippi Valley, that deforestation is largely responsible for most of the recent great floods."

Suppose that this popular belief, which finds its source in the scientific bureaux at Washington, were to be carried to its logical conclusion, and the people of the valley were to spend money provided for flood protection in pursuing the will-o'-the-wisp of reforestation. Could the teaching that would lead to such a result, and jeopardize life and property for a chimera, be considered scarcely less than criminal? Happily, the sober counsel of the engineer will always stand in the way of any such foolhardy project as this; and although there is every reason to believe that, if the suggested bond issue of \$500 000 000 for improving our navigable waterways were made, a large slice would be asked for, for forestry purposes, it is not to be believed that the better judgment of the country will ever sanction it.

The writer insists that forestry should stand on its own bottom, and not bolster itself up by the aid of interests with which it has no connection. The preservation of timber for this and future generations, the maintaining of woodland for the pleasure of the people, for their protection against storms, and in many places as the most available preventive of soil erosion and the drifting of sand—these are the true purposes of forestry, and to the promotion of these ends its propaganda should in the main be confined.

In the further matter of public policy, involved in the location of our national forests, the writer willingly defers to Mr. Pinchot's more extended study, but he nevertheless desires that Mr. Pinchot's statement, that only existing virgin forests are adapted for future reserves, be clearly understood. Possibly the writer has been unduly influenced, through his experience in mountain forests, by the great drawback involved in the inaccessibility of such regions. Hundreds of times he has heard visitors to the Yellowstone, in riding through those extensive fields of down timber, remark in substance, "What a pity it is that all this timber cannot be near New York or Boston, where it could be used;" and anyone who has seen how every scrap of wood is gathered up in foreign countries and turned to use, and how eventually the same will be true of this country, cannot but realize the importance of having our forests convenient to the homes of the people. And when he considers the greatly increased cost of lumber from getting it out of inaccessible places, and the further cost of transporting it over great distances, he realizes still more fully the same necessity.

A tree conveniently located for access and use is worth two, or five, or ten, in the mountains. Add to the advantages from the above points of view those of the enjoyment of the people from access to the forests, the value of forests as wind-breaks and shelters, their greater immunity from fire if in detached areas than in continuous areas, and there may seem to be after all some merit in the writer's idea of a wide distribution. Some have construed the writer's words on this subject to mean that he would devote good agricultural land to this purpose. He expressed no such thought. In almost every locality there are lands of little agricultural value that could be devoted to this purpose without unduly restricting areas of cultivation.

The writer can hardly believe, and is quite certain that the country at large does not believe, that good results cannot be obtained in the development of forests upon our cut-over lands throughout the country. Mr. Pinchot says that a forest plantation can never take the place of the natural forest. Very true, but the forest primeval is gone forever, or soon will be. Even such as are retained will no longer be "primeval" after a period of cutting. It will be necessary here, as in Europe, to rear up new forests, and this in fact is constantly urged in current forestry literature. If this is the revamping of an old idea, let it continue to be revamped until it becomes the main idea. It need not be imagined that the people of the country will consent to be taxed for the purchase and maintenance of forests in the eastern mountains, and stop there. If forests are necessary and if general taxation is to maintain them, their benefits must be brought home to all the people as nearly as possible. It seems to the writer very desirable that this subject be thoroughly considered and a general policy adopted by Congress before it launches out upon some partial or local measure.*

Concerning the second section of the paper—the function of reservoirs in the control of stream flow—very little has been brought out in the discussion that requires attention. By what reasoning a few of his critics have concluded that the writer is opposed to the general idea of water storage on a large scale, it is impossible to conceive. No word in the paper justifies such an inference. In fact this particular subject has always been a professional hobby of the writer's, and no one appreciates more fully than he its possibilities and the importance of locating and constructing such reservoirs as rapidly as conditions will justify. The example of the State of New York in taking up the matter with a view of storing its waters and rendering them available for power is one that should be followed by other States and by the Government, in their respective spheres.

*The writer is glad to note a desire on the part of Congress to enter upon this work on broad lines without restricting it to any particular section of the country. The Weeks bill, favorably reported on January 28th, is a step in the right direction. It is to be hoped that this, or some equally comprehensive measure, will become a law.

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The writer's criticism was directed solely against the visionary aspects of the case and the bold effort that was being made to sidetrack important practical projects in the interest of a stupendous and uncertain scheme. An estimate of \$125 000 000, held out in dazzling figures before the people, is now withdrawn in favor of the writer's estimate of \$500 000 000. This is exactly the amount of the bond issue now being urged to bring all the waterways of the country into prime condition. If this reservoir system were to be built, where would the remainder of the country come in?

The time is now at hand when some of these reservoirs should be built; the low-water conditions of 1908 demonstrate this necessity. The time may come when they will all be built, but it will only be when their utility has been demonstrated on other grounds than flood protection and navigation. If ever built, they will unquestionably be of value to both those interests, but they cannot be justified on their account alone.

Arthur P. Davis, M. Am. Soc. C. E., Chief Engineer, U. S. Reclamation Service,* calls attention to the great value of the reservoirs being built for irrigation in controlling floods on the streams below them. Mr. Davis' views throughout are characterized by a clear comprehension of the possibilities and limitations of reservoirs in promoting one purpose though built for another. His anticipations will doubtless be fully realized.

The writer is glad to note in a recent issue of one of the technical journals that steps are being taken to determine a more definite estimate of the value of our natural water-powers. It is indeed important that this be done. Whatever may have been Mr. Leighton's intention in regard to the \$20 value, as used in his numerous writings upon the subject, the understanding which the average reader has gathered is that undeveloped powers (that is, minus power-plant installation) would be worth at least \$20 to the Government.

Having considered the more general aspects of the discussion, the writer will now take up a few of the special points brought out by the several contributors. He will take these up seriatim as presented, and not attempt to reduce them to classification. In large part the adverse criticisms of his paper are based upon a misunderstanding of what the writer said. The first reading has aroused a feeling of opposition among those who have always thought the other way. Instead of weighing his arguments, they have frequently replied either by flat contradiction or the citation of exceptions, forgetting that an exception does not ordinarily invalidate a rule. There will be no attempt to notice all these criticisms, and the reader will simply be asked to compare them with the text to which they relate.

* *The Engineering Record*, November 18th, 1908, p. 558.

The opening sentence in Mr. Collingwood's criticism has a significance which the writer probably did not intend. His reference to "conclusions" as "firmly established" indicates that he is under the impression that the current forestry theories are so established. A similar suggestion is made in a recent State paper in which the writer's views are characterized as being "contrary to the experience of mankind" and "opposed to all the recent work of the scientific bureaus of the Government." Professor Swain, in an elaborate paper prepared at the request of Governor Guild of Massachusetts to controvert the writer's arguments, expresses the same opinion. What are the facts upon this point? Mr. Chittenden.

Forestry has been a living issue in France for nearly a century. Between 1850 and 1870 the subject was much discussed *pro et con*, forestry advocates being very pronounced in their views that forests exercise a marked regulative effect upon streams, and many prominent engineers taking exactly the opposite view. In 1857 M. F. Vallée published a paper upon this subject which was translated in 1873* by Captain Charles J. Allen, Corps of Engineers, U. S. A., and printed under the auspices of the Engineer Department of the Army. M. Vallée goes into the subject exhaustively, traversing the entire argument that forests have a beneficial effect upon either high or low water. He cites many interesting examples, relating to floods, springs, low waters, etc. Professor Swain refers slightly to this paper, saying that it had no effect on public opinion at the time. Be that as it may, M. Vallée was not alone in his views by any means, and an event occurred at about that time which shows that his views were adopted practically, whatever may have been the opinions of doctrinaires.

After the great flood of 1856 in France, elaborate studies were made of the flood problems of several of the rivers, as related in the writer's paper. The subject of reforestation, as a means of reducing flood heights, was considered for both the Rhône and the Loire and rejected as impracticable. The comments upon the sources of popular opinion on the subject, its lack of foundation, the fact that the great floods cannot be modified by this or that change which Man may make on the surface of the earth, are all pointed out very effectively. This is probably the first example in which reforestation has been urged as a practical means of regulating the flow of great rivers, and it was rejected summarily. The example so set has been followed ever since.

About this same time appeared an elaborate work by M. Champion, giving a history of the floods of French rivers since the sixth century. It showed that floods had been diminishing, so far as there was any change, this tendency in the case of the Seine being very pronounced. Thus the gauge at La Tournelle Bridge, Paris, showed the following mean heights for five half-centuries from the year 1600: 8.39, 8.03, 7.72, 6.83 and 6.47 meters.

* In the paper the writer erroneously gave the date of publication as 1873.

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In 1864 appeared Marsh's book "Man and Nature," which was revised in 1884 under the title, "The Earth as Modified by Human Action." This work set forth the ultra-forest theory so closely on the lines that we are now familiar with, that the writer has appended to this discussion a brief extract, on account of its historic value.

In 1873 appeared a treatise by Sir Gustav Wex, presented to the Austrian Society of Engineers and Architects, "On the Decrease of Water in Springs, Creeks, and Rivers Contemporaneously with an Increase in Height of Floods in Cultivated Countries." This work set forth in elaborate form the conventional forest theory. But its propositions were disputed to such an extent by "engineers and hydraulic experts" that Wex issued another and more elaborate treatise in 1879. Its reception, however, was no more favorable than that of his first work.

In our own country, in 1885, Colonel Thomas P. Roberts presented an elaborate paper before the American Forestry Congress, based upon river records, showing that the commonly accepted theories had no foundation in fact. This paper is historically important, not only as an isolated example of courage in opposing an almost universal popular opinion, but because it was the first to call attention to the compensating effect of summer showers in the open country in offsetting any possible deficiency in the flow of springs as compared with that of the forest during periods of drought. A brief extract from this paper is given in the Appendix.

In 1896 appeared the article by Mr. R. L. Fulton in *Science* which the writer has referred to in his paper. It is probably the first publication that sets forth, substantially in accordance with the facts, the action of mountain forests upon the run-off from snow-melting. Owing to its intrinsic and historic value, the main portion of this article is given in the Appendix.

M. Lauda's report upon the great Danube floods of 1897 and 1899 is referred to in the writer's paper. A lengthy abstract from the report was translated by the writer.* A perusal of this abstract will show how little value that eminent authority places upon forests as regulators of stream flow.

At the 10th International Congress of Navigation, held at Milan in 1905, this very subject was one of the questions considered. Five countries—Russia, Germany, France, Austria, and Italy—were represented in the discussion, and the consensus of opinion was that, important as forests might be from other points of view, they had no appreciable effect upon the regimen of great rivers. It was held, however, that forests are an important means of preventing erosion on mountain slopes.

To all these authorities should be added the important negative

* *Engineering News*, October 29th, 1908.

evidence that there seems to be no instance on record in this or any other country where a scheme for the improvement or regulation of a navigable stream has embraced as an essential feature the reforestation of any part of its water-shed. Mr. Chittenden.

Such is a brief summary of the evidence concerning the "experience of mankind" on this particular subject. The "firmly established" conclusions are no conclusions at all. On the one hand are the forestry advocates in this and other countries claiming that the welfare of our rivers depends upon the preservation of our forests; on the other is the practical engineer who holds that our rivers cannot be regulated by any such means. If Mr. Collingwood had said that these views are firmly established in popular thought he would have been entirely correct; but that is not a sufficient reason for believing them to be true. Whether a popular belief is correct or not depends upon how it originated. Since the appearance of this paper many have said or written to the writer that they had never even thought that there were two sides to the question; that they had accepted unquestioningly the current theories, as put forth by writers and lecturers, without investigating at all. Manifestly, such a belief is worth as much as the source from which it is derived and no more. Remember that "truth does not depend upon the number of its adherents." Authority cannot change the laws of Nature, nor can the most implicit belief in the influence of forests upon stream flow make that influence a fact where it does not exist.

As to the work of the scientific bureaus, upon this particular subject, it is extremely difficult to determine precisely what it is or what their views are. It is an excellent example in which "doctors disagree." At one time it is held that forests diminish floods, and at another that no "well-informed" person entertains such a view. It was announced not long ago that the forest bed is a great reservoir; now, that it is held to be such in only a "nominal sense." Deforestation is said, in one breath, to increase the height and shorten the duration of freshets, and, in the next, to increase both height and duration. One authority declares that the lower layers of the soil are always drier in the forest than in the open, while others strenuously insist that the contrary is the case. A little while ago the country was told that a thousand tons of soil are yearly washing from our agricultural lands into the sea, while just recently it is stated that only an insignificant portion comes from that source. In a formal public document it is stated that deforestation of the Appalachian slopes would speedily destroy any reservoir that might be built in that region; and in an equally formal professional paper it is shown that, even where deforestation already covers 50 and 60% of the land, it would take from 10 000 to 20 000 years to fill the proposed reservoirs with sediment. Some authorities hold that rainfall and climate are changing for the

Mr. Chittenden. worse through deforestation; others, equally high, hold that the history of the past, as well as modern records, affords no warrant for any such claim.

It would, of course, be entirely unjust to ascribe this discord to any deficiency of qualifications, knowledge, or industry on the part of our scientific bureaus; no one acquainted with their work would admit that. It is forced upon them by the exigencies of a "cause." Of late, the prominent feature of this cause has been the White Mountain-Appalachian project. Every argument that could be devised to influence public opinion in favor of this project has been used; and a practical necessity has forced the stream-flow function of forests in this connection prominently to the front. Legal authorities have held that this forest reserve could not be created as a timber reserve, pure and simple, because, forsooth, an instrument written a century and a quarter ago says it cannot be done unless such reserve will also promote the navigability of the rivers that flow from it. Thus a feature of the forestry propaganda, which is a wholly subordinate one, is made the chief stone of the corner. Inasmuch as the very foundations upon which it is sought to lay it are to a very great extent fictitious and non-existent, it is no wonder that discord and confusion have resulted in trying to build upon them; and the Engineering Profession, at least, will probably feel that the "recent work" of the scientific bureaus upon this particular subject is not exactly a safe guide.

Mr. Collingwood, with the perfect simplicity of the typical forestry enthusiast, after citing certain changes in the Chemung River, asks: "If the cutting of the timber did not do it, what was it?" Again, "after this, therefore on account of this." Has Mr. Collingwood ever inquired whether there might not be some other cause? Has he examined into the nature of Man's operations along that river, the effects of cultivation, etc.? He admits that he has no data of value as to the earlier condition of the stream, but only as to its later condition. Is it not a fact that much of the havoc he mentions was wrought by a single flood, that of 1889, the year of the Johnstown flood, when 8 in. of rain fell in 3 days in the hills around Elmira? According to his own statement, the rafting of logs, which naturally marks the active inroad into the virgin timber, ceased nearly 60 years ago, and only the cutting of hardwood has progressed since. Yet the great changes which he notes have taken place within 20 years. Does Mr. Collingwood consider evidence of this kind very convincing?

The writer is quite willing to accept what Mr. Le Baron says of the precipitation in tropical countries; but it manifestly does not apply to our northern climate, which alone is considered in this paper.

Mr. Le Baron refers to possible development of forests on irri-

gated lands as opposed to the writer's statement that the aggregate forest area of our country cannot be increased. As soon as Mr. Le Baron demonstrates the practicability of a large development of genuine forest in the arid regions the writer will modify his statement proportionately. As a general rule, lands under irrigation are devoted to intensive farming, and are too valuable to be converted into forest; though Mr. Johnston intimates the practicability of forest extension by this means.

Mr. Le Baron is very much astray in his inference regarding the saving of cost of installation of water-powers by the use of Government dams. In the first place, this would not apply to the great majority of water-power developments, if such developments are to be made on a really extensive scale. In the second place, the sites of locks and dams are not favorable on account of the low head and the great relative fluctuation. Compared with the power attainable, the installation is necessarily much more costly than where the same power-house and machinery would yield several times more power.

The writer notes the interesting point brought out by Mr. Todd in regard to the percentage of run-off as affected by slope. That a greater percentage of rainfall runs off from flat than from steep slopes is at first not easy to admit, but where the soil is swampy and ground storage is not available, it is quite probable that this is true. The example is another proof of the necessity of care in making generalizations upon so uncertain and variable a subject.

When Professor Swain says that "the author seems to be attempting to convince us that, not only forests, but reservoirs, increase the violence of freshets," he says something that has no substantial warrant anywhere in the paper. The whole tenor of the argument is that the difference between the past and present is not great, although the records show that we actually had greater floods before the forests were cut than we now have. Only in the effect of forests on snow-melting, as described by the writer, can Professor Swain find any support for his remark, and only in rare combinations do reservoirs operate to increase freshets.

Professor Swain does not understand the writer's reference to the suggested reservoir system for the River Rhône in France. If he will examine page 39, *et seq.*, House Document No. 141, 55th Congress, 2d Session, or the French reports upon this subject, he will find the matter fully explained. With characteristic detail, the French engineers worked out a system of reservoirs for that stream which was ample to protect the valleys of the tributaries and the upper courses of the main stream; but they found, on applying it to a great flood

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like that of 1856, that it would produce a greater overflow than actually occurred in the lower stretches of the valley. This was due to the more extensive combination of tributary flow from prolonging the runoff of the various affluents.

Professor Swain says, in reference to the writer's statement that a greater forest area in Western Montana would have aggravated the flood of 1908, that this "is a mere statement of the author's opinion, entirely without proof, and undoubtedly incapable of a proof." It is not a matter of opinion at all, but a clear, logical deduction, as capable of proof as any proposition in mathematics. The facts are that there were extensive forest tracts in the region affected by this flood. These forests held the snow, and there was a large mass of it on the ground when the heavy rains came. The melting of these snows added materially to the flood. If Professor Swain doubts these facts, he can corroborate them by reference to the Weather Bureau records. It is also a fact, which he can readily verify, that in the neighborhood of these forests there are extensive tracts of non-wooded lands similarly conditioned as to topography and altitude to the forested lands. Now if these tracts had also been covered with forests, the ground within them would have been covered with snow, as the ground in the existing forests was; that snow would have melted as the snow actually there did; and in the same way would have added its quota to the flood. *Q. E. D.*

Professor Swain has cited Professor Carpenter on the subject of snow-melting. The writer has often drawn upon the ample fund of information which Professor Carpenter has accumulated, and has conferred with him on more than one occasion. It is a pleasure to bear testimony to the value of his opinions upon any subject. It is possible, however, that he may not have studied closely the phase of this question presented by the writer. In any event, the citations given by Professor Swain are not sufficient to carry conviction. There are several important questions that need to be answered in that connection. The diurnal fluctuation of the streams due to snow-melting is precisely the matter upon which the writer has laid stress in his paper. The great safety device of Nature in letting down the snows in these mountains is the sun and the open country drifts. It is as if a care-taker of some great reservoir hoisted the gates for an hour or so each day, letting out a quantity of water and not closing them again until it had flowed away. The diurnal rise and fall may be a source of some inconvenience at head-gates, but this is really a trivial matter after all, and a hundred miles down the stream largely disappears. The writer doubts whether Professor Carpenter ever saw a real flood from this cause; but he has seen many a flood which has come down when the forests gave up their snow. Why has not this fact made an impression? And has he not often seen drifts in the open

country of his mountains long after every vestige had disappeared from the forests? Is it not true that these drifts and those higher up are a valuable resource long after the forest snows are gone? Mr. Chittenden.

Mr. Willis states that the forest prevents from 20 to 40% of the rain from reaching the ground, depending upon conditions. The range is far wider than this. In the heat of summer, and with light showers, forests often hold back nearly 100% of precipitation; but when it comes to cold, heavy rains, from 1 to 3 in. in a day, and in deciduous forests where, for large portions of the year, there are no leaves on the trees, will any one venture to say that the forests prevent even 1% of the rain from reaching the ground? Yet it is with these very extremes, as the writer has pointed out with emphasis, that our practical problems in river control are concerned.

The writer would request those interested in this discussion to read carefully the quotation given from Ernst Ebermayer early in Mr. Willis' discussion. It is a plain case of being unwilling to swallow one's own doctrine. If that quotation means anything, it means that the forest prevents rain-water from penetrating the ground as readily as in the open country. But, "the forest on the mountain differs very decidedly from that on the plain in regard to water control," and "a factor is introduced through which wooded mountain slopes receive a much larger amount of water than bare unwooded water-sheds." What is the factor? What is the difference between mountain and plains forests in regard to water control? The writer maintains that, so far as there is any difference, it is all in favor of the plains forests. For the same forest bed, the retentive capacity diminishes as the slope increases. Anyone can verify this fact by experiment. Far from the mountain forest being more effective in resisting run-off, the exact opposite is the truth. This example affords a pointed illustration of the straits to which forestry advocates are often put in trying to square the direct and necessary consequences of their reasoning with a conventional theory which they are reluctant to oppose.

In the following sentence Mr. Willis repeats that singular inconsistency which can arise only from trying to fit facts to a preconceived theory:

"So retentive is the humus that, while it serves as a sponge to prevent run-off and transmit water to the ground reservoir, it does not give up much to storage, and yields its water-content only slowly, to the moderate influences of evaporation in the shade."

The direct inference from this is that the water stored in the forest bed will yield itself up to soak into the ground, but not to run off the surface of the ground. The water will follow the line of least resistance wherever that may be. Under certain conditions more will

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Mr. Willis should take this sentence and go out into the woods in a long, flood-producing rain, and see what will become of it; and then go into the forest in the height of a severe drought and see how it will apply to a chance shower that may come along.

The writer will not consider Mr. Willis' remarks regarding the action of forests upon snow-melting further than to cite his real conclusion, which coincides exactly with that of the text:

"Later in the season, the forested parts of such regions sometimes occasion severe floods in consequence of a large body of snow lingering until the warm winds strike it. This effect is undoubtedly unfortunate, but the question may well be asked whether it were better to have the June flood on top of that of April, rather than divided, as they are likely to be in consequence of the presence of the forest."

Concerning this last point, the writer has indicated in the curves of Fig. 1 how much he thinks absence of the forests would advance the crest of the flood. It would probably never amount to more than two or three weeks. There would be no danger of its coming on top of the April rise.

Messrs. Willis and Pinchot both raise the point that second-growth timber, filled, as it generally is, with underbrush of various sorts, is not as effective upon water storage as the virgin forest bed. While the writer does not wish to obtrude his opinions against such eminent authority, he can only say that, from quite extensive observations in a direct practical way, he believes the opposite to be the truth, and he can see no reason, even theoretically, why his view is not correct. Let any one go out into a genuine tract of second-growth timber, compare the tufted ground with that of the forest, observe the effect of showers, and he will find very little to support the above theory. In regard to erosion, there is no question whatever but that the soil under such growths is as well protected, and often better than under the virgin forest.

The following quotation is given from Mr. Willis' reference to the investigation of Professor Glenn, of Nashville, simply to fix the attention of engineers upon the character of the evidence being introduced in this discussion:

"Forty-six creeks and small rivers, the water-sheds of which may be described as timbered rather than cleared, are known, according to observation and local repute, to rise gradually in times of flood, to continue high for several days, and to subside slowly. They carry but little sediment, and they maintain a good volume of water during dry seasons.

"Thirty-eight creeks and small rivers in the same water-sheds, having slopes which may be described as cleared rather than tim-

bered, are known, according to observation and local repute, to rise rapidly in times of flood to extreme flood height, to carry excessive quantities of mud, sand, and gravel, and to fall quickly. In dry seasons they are very low, and the range from lowest to highest stages has increased, and has inflicted much damage in very recent years."

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Note the complete absence of data which would ordinarily be considered necessary to base a conclusion upon—nothing as to relative areas of cleared and wooded land; nothing as to character and extent of cultivation; nothing as to slopes and character of water-shed, and the location of permanent springs; no records of rainfall and none of stream flow; no past records of any kind to compare with the present; nothing but "observation and local repute." The writer will not comment upon this matter further than to animadvert, perhaps rather severely, upon the unscientific character of methods like these, which are so largely resorted to in promoting the cause of forestry. The scientist who permits his researches to become enlisted in the advocacy of a "cause" is treading upon dangerous ground. The moment he departs from the narrow path of declaring the truth, no matter where it strikes, that moment he ceases to be a scientist and becomes a partisan. Less culpable is the use of loose and inaccurate data in one whose business is promotion rather than scientific research; but even with him common sense should be given some authority. Recently the whole country was startled by the news that a distinguished official of the State of New York had found a place near the source of the Hudson River where the water of that stream was only 2 in. deep! This was the only fact stated; nothing of where the shallow part was found, nor whether it was upon some broad gravel bar where the stream spread out in a thin sheet, nor whether the figure was a measurement or a guess. Only one other thing was certain, and that was that the destruction of forests was the cause of the low water, although this was after one of the most prolonged droughts that the country had ever seen. Lewis and Clark record that after their long journey of many months and several thousand miles up the Missouri River they at last came to a point where the stream was so small that a man could bestride it. Their report contains no hint that this was due to a lack of forests.

The official above referred to also declared that New York City's new water supply would be ruined if certain forests in the Catskills were cut off. While it may be undesirable to permit those forests to be cut, it would be utterly impossible to prove that, if they were cut and replaced by a good turf with grass or shrubbery, the supply from the water-shed would suffer in the smallest degree, either in quantity or quality. Yet this alarmist report was taken up by the press quite seriously, and spread all over the country.

In reference to Mr. Willis' closing remarks concerning erosion

Mr. Chittenden. as a result of forest cutting, the writer maintains that these effects are generally confounded with those of cultivation, and evils are charged to the removal of trees for which it is in no wise responsible. He will endeavor to show later that the case of China is no exception.

Dr. Smith makes what seems to the writer an essentially sound statement of the function of the forest mulch when he says that it "acts as a temporary reservoir of limited capacity, but it contributes its stored waters downward as well as outward." This is the writer's position exactly, although he may differ from Dr. Smith as to the relative quantities that go outward and downward under varying conditions. The writer, however, dissents in the general case from the further view that cultivated land does not store and transmit precipitation to the ground as effectively as does a forest soil otherwise similarly conditioned.

Dr. Smith's reference to his observations on Table Mountain should be read in the light of his frequent encounter of drifts. It is precisely that formation, whether in or out of the forest, that prolongs runoff far into the summer. To make his experience applicable to the writer's argument, he should have mentioned what he found in those areas of the forest, by far the greater portion, where drifts did not take place. Mr. Collingwood's remark: "In the woods * * * near Elmira, N. Y., the drifts remained unmelted long after every bit of snow had disappeared from the cultivated portions of the valley," is subject to the same criticism.

Dr. Smith and Mr. Willis both take exception to the writer's citation of White River, Washington, as an example of a torrential stream coming from a perfectly protected water-shed. Both attribute its character in this respect to the glacier at its head, Mr. Willis deploring the writer's "unfortunate" lack of acquaintance "with the real character of the river." Concerning this last matter, it may be said that after the great flood of 1906 the writer was engaged by King and Pierce Counties, Washington, to investigate the flood problem of the Cedar, Green, White, and Puyallup Rivers, and made a special study of the situation on White River. He states most positively that the glaciers are an entirely negligible quantity in producing the floods of that stream.

In the first place, at the season of the year considered, precipitation on the glacier is almost exclusively snow, a part of the accumulation that goes on every winter. It is not believed that there is any large amount of surface melting at that season, and what there is tends more to compact the body of snow beneath it than to run off into the streams. It is in midsummer that the flow from the glaciers is greatly accentuated. It is then that it bears the milky appearance from

which this stream is said to derive its name; but its character as a "bad" river comes not at all from this regular annual glacier run-off, but from the great freshets that originate almost entirely below the glaciers.

In the second place, the glacial area on the White River watershed is barely 2% of the total area. Even if it contributed its full quota, based upon areas, and it could do no more, its influence would still be quite insignificant. The same consideration is equally true of the Skagit River, in which the proportion of glacial area must be even smaller.

Finally, the simple fact is that there was no apparent difference in the run-off of those water-sheds in the flood of 1906. While the much steeper slope of the White gave its flow a more torrential character, there was nothing to indicate that the yield per square mile from the water-shed was greater than from the Green. The overflow of Green River was extreme, and the destruction wrought was great. Even the Cedar River, a small stream, was quite as destructive as the White in proportion to its area of water-shed, washing away railroads and doing other extensive damage.

As to the statement that the floods of White River get out of the way before those of the Green and Cedar come down, it is wholly erroneous in any general flood. Possibly a storm might affect the White River water-shed in some case in advance of the others, and this, with the steeper slope of that stream, might bring its waters down somewhat in advance, but this was certainly not the case in the flood of 1906, and in all the writer's investigations he never before heard the idea suggested. The water-sheds of all these streams are within 24 hours (by river flow) of the lower valley, and this fact itself makes it impossible that the floods of one should escape those of the others, except in a very slight degree.

The writer would invite particular attention to Mr. Kuichling's statement of the difficulties of treating these subjects with scientific precision, on account of the lack of data, and of the necessity of acquiring "a much larger volume of accurate observations" before these questions can be definitely settled.

Mr. Labelle, in the same vein, touches upon an important matter when, in reference to the studies of the Forestry Service now in progress for determining the various relations of forests to rainfall and run-off, he says "The Engineering Profession can never have full confidence in the results of work of this kind done by the Forestry Service alone." The reason for this is that that service has a "cause" to promote, and it is human nature to bend everything toward the side of such a cause. The writer has found in his studies that in nine

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Mr. Chittenden. cases out of ten he can write out beforehand the answers which a forestry enthusiast will make to a given set of questions pertaining to the influence of forests on stream flow, and in some of his researches into foreign conditions he had to reiterate his request that his inquiries be referred, not to the forestry organizations, but to hydraulic engineers familiar with practical river problems. If the Government is wise, and wishes the results of any investigation that it may make of this question to command the confidence of the trained thought of the country, it will place it in the hands of a body of which a majority at least belongs to the Engineering Profession and are not directly or indirectly so connected with the forestry service as to be biased in their deductions. The engineer has no cause to promote. His business is to direct the powers and resources of Nature to the benefit of Mankind. He has no "preconceived ideas" that are likely to interfere with his findings. If the planting of forests can be made of practical value in regulating our rivers, he will welcome that fact; if not, he will not hesitate to say so. Therefore any comprehensive study of this question should be placed in the hands of the Engineering Profession if its results are to command the confidence of that Profession.

The references to China, by Messrs. Labelle and Willis, suggest a feature of this subject which the writer is inclined to develop somewhat. Although perfectly cognizant of the part which historic allusions to Syria, Spain, China, and other countries have been made to serve in this forestry propaganda, the whole argument seemed so entirely unworthy of serious weight that he made no reference to it in his paper. It has, however, been prominently brought to the front of late, and even carried into this discussion, and it is, perhaps, just as well to give it brief consideration here.

The following, from *Conservation (Forestry and Irrigation)*, is a typical statement of the case:

"Before the forests of Lebanon were destroyed, Palestine supported in affluence ten millions of people. The mountains have long been denuded. Forbidding slopes, barren and ugly, rear their weird forms sharply above the dismal and desolate valleys. Scarcely four hundred thousand remain in all the region, and most of those are in wretched, hopeless poverty. Syria, once maintaining a multitude of prosperous towns and cities * * * is at present a scene of irreparable ruin. The destruction of Syrian forests, begun 2650 B. C. [note the minuteness of this historic detail], followed by the disappearance of her soil and the decay of her industries, would alone have produced this result."

Where is there even a shred of evidence to support any such sweeping statement as this? Anyone who has ever read the Bible knows that it abounds in proof that the general climate of Syria and contiguous countries was essentially the same 4000 years ago that it is

to-day. When the children of Israel left Egypt and traveled around the Arabian peninsula on their way to the Promised Land, they nowhere lost their way in a primeval forest. They were in a "desert" or "wilderness" (synonymous terms in the Bible) most of the way. References to the "desert" everywhere abound in the Bible. As soon as one was a stone's throw away from the towns or cultivated tracts he was in a desert or the wilderness. The folk-lore of the Scripture makes repeated references to trees growing by watercourses, which have no meaning to a person familiar only with a country where rain falls abundantly and trees grow everywhere, but are full of meaning to him who has lived in an arid country where trees grow only along watercourses.*

The celebrated Forest of Lebanon was not in Palestine, but occupied the valley of the Leontes River and the neighboring mountains to the north; a tract possibly 100 miles long by 20 wide. Its area did not exceed 2% of the area of Syria. Its influence upon the climate of that country was and is due almost entirely to its mountainous character. The famous cedars grew in groves, not densely continuous, and covered only a portion of its area. That the removal of those forests has not by any means ruined the country, even where they once used to thrive, is evidenced by the fact that agriculture on a considerable scale flourishes there, the streams are fed by perennial snows, and the region maintains a population estimated at from 260 000 to 400 000.†

Professor Albrecht Socin, of the University of Tübingen, a very learned authority upon these subjects, says:

"Palestine is a country of strong contrasts. Of course it was the same in antiquity; climate, rainfall, fertility, and productiveness cannot have seriously altered. Even if we suppose that there was a somewhat richer clothing of wood and trees in the central districts of the country, yet on the whole the general appearance must have been much the same as at present. To the stranger from the steppes arriving at a favorable season of the year, Palestine may still give the impression of a land flowing with milk and honey. The number of cisterns and reservoirs is proof enough that it was not better supplied with water in ancient times."

The same authority says, of the ancient population of Palestine:

"The number, two and one-half to three millions, may indeed be taken as the maximum; the population can hardly ever have been more than four times its present strength, which is estimated at about 650 000 souls."

* For example, Jeremiah xvii, 8: "For he shall be as a tree planted by the waters, and that spreadeth out her roots by the river, and shall not see when heat cometh, but her leaf shall be green," etc.

† Objects that loom big through the vistas of time often dwindle to pigmy proportions when seen from near by. The draft upon the Forests of Lebanon for the building of Solomon's Temple, an event of such vast moment in its day, and employing an army of men large enough, apparently, to sweep the whole country free of trees, did not amount to more lumber than a well-equipped modern saw-mill would cut out in a single day.

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Another authority says: "Under good government and with thorough cultivation, several times the number [of the present inhabitants] could be easily supported;" and Professor Socin says of Mesopotamia, that now abandoned home of former millions, that a restoration of the ancient canals would restore the former productivity of that region.

It is not too much to say that, from any point of view, it is doing violence to common sense to attribute to the removal of forests (where they have been removed) the conditions now prevailing in those countries. Those conditions are due to the character of the inhabitants and to a demoralizing and despotic government, which suppresses true liberty of trade and industry, and makes even human life unsafe. Such a people and such institutions would make a desert of Eden in any part of the world. Sweep away the inhabitants and their government and replace them with the free institutions and virile life of the Anglo-Saxon or German people, and the face of Nature will undergo an immediate change whether a tree is planted or not.

So, likewise, the claim that the present climatic and physical conditions of Spain and Northern Africa are due to the removal of forests that once existed there cannot be supported by evidence that would be considered satisfactory upon any other subject. We know little if anything of a definite character concerning the extent of the forests alleged to have flourished there. We know nothing of the rainfall and stream flow, as they were before the period of the supposed removal of those forests. If there is a difference, we do not know that it is even remotely traceable to the removal of forests. All we know is that conditions of stream flow in some districts are not such as might be desired, and that forests are not as extensive as might be desired; but there is absolutely no warrant for connecting these conditions in the relation of effect and cause.

The Nile has apparently not changed its characteristics in the long period of recorded history in that valley, and certainly not from any traceable relation to a removal of forests on its water-shed. Among the replies received in response to a circular letter of August 27th, 1908, by the Forestry Bureau, inviting answers to certain questions in regard to the effect of deforestation upon stream flow, Mr. Oscar T. Crosby, formerly an officer of the Army, submitted the results of his quite extensive observations upon the Blue Nile in Abyssinia. Judging from the presence of a few flourishing groves, and the fact that the plateau would evidently support trees, he assumed that forests probably existed there prior to the occupancy of the plateau by Man, and that they had since been removed for his convenience and use. But as to the effect of their absence upon the flow of the river he thought it quite negative, and summed up his conclusions as follows:

"First. The Blue Nile presents a case in which deforestation of the drainage area has taken place, followed by a covering of the soil

with various prairie grasses and to some small extent with agricultural crops. Mr. Chittenden.

"Second. In spite of such deforestation, and in spite of a strongly marked seasonal rainfall, and in spite of the narrow bed in which the river flows, there is no indication of a more strongly marked fluctuation in the flow of the river than was the case before deforestation.

"Third. The said variation in flow is not greater than that met with in streams whose drainage areas are still fairly well covered with native growths or with luxuriant agricultural crops."

But the *pièce de résistance* in this class of argument is China. Now, China proves several things in regard to forestry, but the beneficial effect of forests upon stream flow is not one of them. Evidence that forests have prevailed to any great extent anywhere in China proper during the past 2 000 or 3 000 years is wholly fragmentary and illusory. In the most general terms possible, Marco Polo mentions that there were forests upon the hills in Shansi and Shensi in his time (13th century), but there is no reference to the extent or character of the timber. Anyone who will read the records of early overland journeys across the plains in this country will find equally strong references to woods, where nothing but the scanty covering of the Black Hills (as the name formerly applied to the mountains in Eastern Wyoming) and other similar tracts is meant. In fact, from the similarity of climate, it is reasonable to suppose that this was the character of the forest. Dense woods do not flourish in a dry climate, and the timber was probably similar to that which crowns the hills in the western portion of our own country. A recent traveler in China, and a practical observer, says of its hills:

"On the whole they remind one of the hills of New Mexico, Colorado, and Arizona, and, so far as one can now see, were never covered with trees and luxuriant vegetation. This is doubtless due in part, if not entirely, to the extreme aridity of the climate."

Marco Polo's reference would fit with our western forests better than with the luxuriant growth of humid climates, and some future historian of our own country would be just as much warranted in concluding, from early references to trees in the arid regions of the Far West, that that country was naturally richly wooded, as we are from Marco Polo's scanty allusions that China once supported heavy forests anywhere out of reach of the rainfalls that come in from the ocean.

But, whatever the character of the original forest growth of China, and whenever it was cut off, one thing stands out clear and indisputable, and that is that the character of her great rivers is essentially the same that it has ever been. This is notably true of the Hoang Ho, or Yellow River, which stands pre-eminent among the rivers of the globe as a stream of destructive floods. In physical characteristics, it is an exaggerated case of the Missouri River. Flowing from an arid or semi-arid region, its actual discharge per unit area of water-

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Now the habits of the Hoang Ho River have been the same from the very dawn of Chinese history. In the will of one of her great Emperors is the statement that it had been "from the remotest ages China's sorrow." Wex, in the treatise already alluded to, quotes at length from a voluminous Chinese work, in part translated into German in 1858, on the management of Chinese waterways, in which the diking of the Hoang Ho is traced back 2 500 years, B. C. The river has changed its outlet no fewer than eleven times in that period, and the evidence is conclusive that it has been essentially the same stream from the beginning. In the citation above referred to, no mention is made that its floods are worse than they used to be, or that they have been influenced by deforestation, if there has been any. Wex would not have omitted any such evidence if he had found it. He traces the growth of the levee system, by which the overflow of the Hoang Ho was kept under at least partial control. As a result:

"The extensive lowlands, which this water once covered entirely or turned into swamps, have been completely drained, cultivated, and planted with mulberry trees, cotton, sugar cane, rice, and all sorts of grain, and now indisputably belong to the most cultivated and fertile lands."

These agricultural developments were brought into existence without any reference to the forests on the water-shed of the Hoang Ho, and, if they are now undergoing an unfavorable change, it is not in any sense due to the absence of forests. That any such influence has changed or is changing the climate of Northern China is not for a moment to be admitted. That a course of civilization which has come

down through an era of 5 000 years, very unchangeable in its character, each generation doing essentially what its predecessors did, is now, within 50 or 100 years, changing the climate of its country and bringing the Mongol Desert nearer to its doors, is simply unbelievable. These results may be ensuing, but deforestation is not the cause.

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From the best evidence available, it does not appear that the magnitude of the floods of either the Hoang Ho or Yang Tse Kiang, measured in absolute quantities or per square mile of drainage basin, equal those of the Ohio. General James H. Wilson, who inspected the embankments of the Hoang Ho in 1885, considered that the control of that stream was entirely practicable, and that the present overflows are due largely to inefficiency in construction and negligence in maintenance of the levees.

The Hun Ho, which has been referred to as an example of deterioration due to deforestation, being navigable in Marco Polo's time but non-navigable now, is, according to Colonel Yule, the editor of Marco Polo's work, not the stream to which Polo referred at all. But whatever may be the stream to which he did refer, his references are so vague, and the character of navigation so uncertain, that definite conclusions cannot be based upon them. Moreover, if Man is the cause of channel deterioration in the streams of that country, assuming that such has taken place, it is, as the writer has pointed out in the case of our own country, cultivation (his subsequent operations on the soil) which is responsible, and not deforestation. In the Chinese order of life every vestige of vegetation is combed off the hills, and they are left barren and a prey to the elements. It is not trees alone, but grass, brush and growths of every description. The effect of the removal of whatever trees formerly stood there could be nothing to the subsequent denudation of the soil.

If one were to carry this illustration to its limit, he might enlarge upon what Mr. Labelle has pointed out, that the one fact which the case of China proves beyond peradventure is that a great civilization and a dense population can subsist with almost no reliance upon forests, for the Chinese make very little use of wood. Here is the oldest civilization in the world, the most homogeneous people, the densest population. It is not a race of invalids, either. General Wilson says of them as he saw them in 1885:

"After seeing the Chinese people under all conditions of life, and in many remote and widely separated parts of the empire, I am compelled to say that they seem to me to be remarkably sturdy, robust, and healthy, and to be especially free from consumption and all other forms of constitutional disease." And again, "the Chinese race is certainly strong and vigorous, and shows no sign whatever of decay."

Although a large part of China proper is too mountainous to be thickly inhabited, yet the average density of population per square

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Doubtless there are extensive areas in the Great Plain where it exceeds 1000. The population of Rhode Island is about 450, and of Belgium about 590 per sq. mile, these two areas representing, probably, the maximum densities of population in America and Europe.

Now look at the opposite picture. When Columbus crossed the Atlantic, the continent of North America from the ocean to and beyond the Mississippi was covered with the largest unbroken primeval forest then existing upon the globe. The country was inhabited, and the race found here had been here long enough for the forces of procreation and the restraints of environment to have found their equilibrium. There is no evidence that the population was increasing. While the estimates are uncertain, none of them give a population for the country as a whole exceeding one inhabitant to 7 to 10 sq. miles. This is what an all-forest country can support. The first thing our ancestors did on coming to these shores was to destroy the forests, and the greatest single work ever done on this continent has been the removal of the forest and the clearing of the land for cultivation. Its cost in money and labor has amounted to many billions of dollars.

Lest this illustration be construed as an argument against the usefulness of forests, Germany may be cited as a high type of progressive civilization, with a population of about 300 per sq. mile, and 25% of its area devoted to forest. Possibly that country presents the equilibrium between the forest and cultivated land that comes nearest an ideal condition. To us it seems that China might introduce wood into her economic life with advantage to her people, and that the planting of trees would be of great benefit. It would not simplify in the least degree the problem of her rivers, but if a portion of her territory could be devoted to forests, and if transportation facilities could be so developed that the product could be brought to the people, it would seem that their condition would be improved thereby.

The history of irrigation reveals the fact that in all the countries here considered irrigation was practiced in very ancient times. Remains of canals, aqueducts, etc., are indisputable proof of this fact, and therefore of the aridity of the climate where such measures were necessary. In our own country the remains of ancient ditches have been found in Arizona, yet no one would think of attributing their abandonment, nor the disappearance of the people who built and used them, to the destruction of forests. So likewise it is wholly unjustifiable to assume that the climate of these historic countries has changed, if at all, through any change that Man has wrought in the forests which are supposed to have existed there.

The instability of industrial and commercial conditions is a marked characteristic of human history, and quite as much so of the present as of the past. Cities grow up and play a great part in the

world's activities, and their foundations seem immovable. But a turn of the wheel—a political upheaval, a decisive battle, a change in commercial or industrial relations and even slow-moving forces indiscernible at the time—leads to their gradual decline and the transfer of their greatness to other localities. In but few instances do we know the actual causes of these changes, though doubtless diligent research would disclose them. Our forestry friends, unhappily, do not take kindly to this sort of research, but prefer the short-cut of attributing all such decadence to the removal of forests.

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The rivers of India and those of the comparatively new regions of Australia and South America furnish additional examples of the fact that the presence or absence of forests, *per se*, has little influence upon the character of the world's great rivers. Conditions that would improve these rivers, such as more copious rainfall, would also produce forests, and *vice versa*. The clearing of land in humid climates, like those of Central Europe, England, and the United States, has never produced a desert. Why, then, assume that desert conditions in the arid regions of the earth have been produced by this cause? Such an assumption is a reversal of cause and effect—a placing of "the cart before the horse." The cheerful readiness with which the genuine forestry enthusiast pursues this course, when common-sense considerations are all against it, is one of the singular phenomena connected with this subject.

While Colonel Pickett's observations of snow phenomena in the Rocky Mountains generally accord with the writer's, it is difficult to understand upon what basis he makes his deductions. Has he never stopped to ask why it is that the "June rise" is a forest flood? Has he ever seen such rise from the open country unless in some exceptional case? If forests moderate floods, why is it that the regular annual flood comes from the forests?

Colonel Pickett is clearly wrong in saying that crust forms more solidly in the forest than in the open. Just as dew and frost gather more abundantly in the open because of freer radiation, so the crusts on the drifts in the open are thicker than those in the forest. The Colonel further errs in saying that this crust always forms in the forest. It is just the opposite fact that causes the danger from forest snows. These snows are held until the genuine warm weather of summer comes. Then it invariably happens that there will come periods when the temperature does not fall below freezing at night and when rains continue for days at a time. These are the combinations that rush the waters headlong into the streams.

Colonel Pickett refers to his taking cattle to the high open country for grazing before snow has gone in the forest. But he omits to men-

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Colonel Pickett's reference to what he saw in the valley of Heart River, North Dakota, has a significance quite other than that which he has attached to it. These prairies are a living evidence of the efficiency of snow drifts in preventing floods. The deforested area of this watershed is very great, compared with the small extent of the forested areas at the sources, yet the "April rise," which marks the disappearance of the prairie snows and the break-up of the ice in the river, is nearly always inferior both in volume and duration to the "June rise." Why should this be so? Because the snow that falls in the open country of the water-shed is nearly all blown into sheltered corners, or behind clumps of brush, and, in these later years, fences. The early spring sun in that clear atmosphere carries off the thin covering outside the drifts, and when the warm weather comes that brings the "April rise" the snow surface left to act upon is an exceedingly small proportion of the entire area.

Colonel Pickett's supposed benefits of mountain forests to the floods of the Lower Mississippi seem to the writer wholly visionary. If he will take any "June rise" that he may select, differentiate the portion that comes from the forests, arrive at any estimate that he may consider fair of the difference in the volume of this rise due to any practicable change in forest areas, then trace this difference 3 000 miles to the mouth of the Ohio, he will have hard work to convince himself that it could amount to 10 000 cu. ft. per sec., a quantity that would be wholly lost in any great flood of the lower river. According to the writer's view, however, the difference produced by the reduction of forest area would be beneficial. The flood crest would come but very little earlier (see Fig. 1), and it would be lower. In fact, so far as the effect upon the run-off from snow-melting is concerned, one could look with complacency upon the entire removal of the mountain forests.

Colonel Pickett's suggestion that trees be planted along the upper limit of their present zone of growth is open to the criticism that the timber itself would be of no economic value because of its inaccessibility, and, so far as it might interfere with snow drifting in winter, it would be a positive detriment to stream-flow. The writer, however, has never gone to the length of suggesting a removal of our mountain forests in the arid regions, though the idea has been distinctly put forth by three contributors to this discussion. The writer assumes that the economic value of these forests for timber will outweigh their drawbacks in the distribution of snowfall. Then there is the uncertain effect upon precipitation, and until this relation is

thoroughly understood it would be unwise to remove the forests. In the region of the Yellowstone Park, however, of which 85% is covered with forest, the writer has long felt that a removal of say one-third of the present timber, selecting for this purpose the areas of undesirable lodge-pole pine, would promote every interest which that region serves. It would give wider pasturage for the game, it would give more frequent landscape views where now the tourist travels for hours at a time through monotonous forest, it would give a better distribution of snowfall and promote uniformity of stream flow, and it would be of great value in preventing the extensive range of forest fires.

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Concerning Mr. Leighton's entire argument, the writer cannot forbear observing that if he had devoted a small fraction of the mental energy in trying to understand what the writer actually said that he has in attempting to disprove what he did not say, the greater part of his contribution would have been unnecessary. Most of his arguments which the writer cares to consider, have already been noticed. A few remaining points will here be taken up.

Mr. Leighton's citation of Dr. McGee's opinions is simply a mass of misstatement which admits of no reply except a flat denial. Nowhere in his paper has the writer even remotely hinted that "there is no connection between rivers considered with respect to improvement and the sediment they carry"; or "that water is the object matter of the engineering art and sediment the object matter of scientific farming"; or that the sediment carried by a river is at one and the same time through and local freight. Until he knows more fully what Dr. McGee actually said, he will assume that Mr. Leighton has not quoted him correctly.

It is to be hoped, also, that Mr. Leighton misquotes when he says that Dr. McGee "testifies that the Missouri is still a clear river after passing the Montana Bad Lands." If Dr. McGee ever saw the Missouri River clear at any point below where it leaves the foot-hills of the mountains, he is the only person who ever saw it so, and the occasion was the only one on which it ever occurred. It was assuredly one of Mr. Leighton's "freaks." Below the point where the river emerges from the foot-hills and enters the alluvial bottoms it is never clear. The only time that it even approaches clearness is in the dead of winter, when the water-shed is locked in ice. In the winter of 1905 there was a prolonged period of very low temperature in the Upper Missouri Basin, the thermometer remaining well below zero most of the time for more than six weeks. The small streams all over the water-shed were frozen up tight. Curious to know to what extent the discharge of the river would shrink under these conditions, the writer caused

Mr. Chittenden. a measurement to be made at Sioux City. The result was 6 920 cu. ft. per sec., or about $\frac{1}{50}$ cu. ft. per sec. per sq. mile. The water, though much clearer than ever seen without the ice covering, was still so turbid that it could not properly be called transparent. An interesting feature was the appearance of the underside of the blocks of ice removed to admit the current meter. Glassy as is the ice formed on still-frozen water, it was nothing to the polished smoothness of the nether surfaces of these cakes resulting from the continual sand-papering by the fine sediment in the water.

Concerning the Upper Mississippi reservoir system, the writer reiterates his statement that he considers it of great public importance, and is an advocate of its extension; but that does not blind him to the fact that its value for industrial use far exceeds in importance, under present conditions, its value for either flood protection or navigation, or both.

Mr. Leighton's explanation of the flood of 1905 on the Upper Mississippi is quite unnecessary. The writer's point is very simple, viz., that a stream emerging from a natural lake never rises as high or falls as low in discharge as it would if the lake were not there. If, therefore, the lake be dammed up at its outlet, but cannot be allowed to rise beyond a certain elevation, and if that elevation is once reached, any subsequent storm finding the lake in that condition must be run out as fast as it comes in. If it is a heavy, flood-producing storm, it may and probably will cause a greater outflow than it would in the natural condition of lake and river. To that extent, it may enhance flood conditions in the valley below.

In like manner, the lengthy discussion of the writer's remarks about wave propagation down the Ohio River does not affect in the least the simple point involved, viz., that if a reservoir cuts off the peak of a flood wave on any stream, the resulting diminution of discharge at any point below will never be as great as at the reservoir, because of the flattening out and lengthening of a wave as it moves down stream. The writer thought that Mr. Leighton had calculated the full reservoir effect at all points below, and is still uninformed that he did not. If he did, his deductions were to some degree in error.

Mr. Pinchot's lengthy explanation of his illustration before the House Committee on Judiciary is quite irrelevant because it does not touch the point of the writer's criticism, viz., that he had used an illustration to explain to a responsible body of public men the beneficial influence of forests upon stream flow, and in so doing omitted to apply it to the conditions of flood and drought, the conditions of paramount importance, and confined it to medium conditions, mid-summer showers, so to speak. His illustration, therefore, was incomplete and misleading, and his explanation leaves the matter in no better shape than it was before.

Mr. Pinchot's remarks upon snow-melting are explainable only through lack of observation. Does he really mean to say that the forest temperature in fall, winter, or spring is lower than in the open? The reverse is generally the case. The more rapid melting in the open is due to the direct action of the sun upon the thin snows. This melting often takes place even when, in the shadow of a tree or rock, freezing is going on. It is not the warmth of the general atmosphere, but the direct action of the sun that melts snow in the open when it is not melting in the forest. Mr. Pinchot adds: "If the melting went on as fast in the forest as it does in the open, the discharge of the water would be greater, * * * and floods would thereby be intensified." This is precisely what happens when the forest melting begins. The forest snows then melt a great deal faster than in the open, and do materially intensify the floods. This is why our mountain floods in the spring, the "June rise," come from the forests. Again: "The only condition under which the melting, for like conditions, is anything like as fast as in the open is during a warm rain." Does a warm rain prevail in a cold atmosphere? And, when the rain stops, does it at once become cold? It is not the Chinook wind in the intra-mountain regions that does the melting of which the writer speaks. It is the natural warmth of summer. The forests hold the snows until genuine summer conditions arrive, with flowers blossoming wherever there is a bare foot of ground, and then yield up their water with a rush. Nearly always at such times, rains develop which accelerate the melting, and contribute their own water to the flood. The net result is to add together the precipitation of several storms.

Mr. Pinchot says that the drifts melt as fast as the shallow snows of the forest. As a matter of fact, this is not so. The heavy, solid drifts, like a mass of ice, melt much more slowly. But admitting for argument's sake that it were so, it is entirely foreign to the point which the writer brought out, viz., that the area exposed in the drift is but a small fraction of the area exposed in the forest for a like amount of snow. He would refer again to his illustration of a cubic yard of snow situated so that only 1 sq. ft. is exposed, and again so that 27 sq. ft. are exposed.

Mr. Pinchot questions the writer's assumption that, of an 18-in. snowfall, 12 in. might be stopped in the dense forests of the Pacific Coast before it reaches the ground. Very well. The writer will accept any proportion that Mr. Pinchot thinks more nearly correct. The principle involved does not depend upon absolute quantities; but, as a matter of fact, more than a foot of snow is often held by these forests, and anyone who has passed through the snow-shed district of the Southern Pacific Railroad in the Sierra Nevada in winter will not doubt that there is an average of a foot of snow on the trees. Mr. Pinchot's attention is invited to the photographs shown on Plate XLVII, taken while this writing was in progress, after a snowfall of

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Mr. Chittenden. about 8 in. The trees are possibly from 15 to 30 ft. high. When it is considered that in the native forest the trees are often 200 ft. high, and so thick that their tops everywhere interlace, and that there are trees of all heights and sizes, with dense undergrowth extending from the ground up to heights of 20 ft. or more, he will readily admit that the snow will find difficulty in reaching the ground, and that such extensive shelter will readily catch and hold temporarily, at least, a foot of snow.

But does Mr. Pinchot think it quite fair to pass from this simple illustration of a single storm to a general proposition of "two-thirds of the snow on the branches and one-third on the ground"? Does he really fancy that the writer believes that, of a winter snowfall in these mountains of, say 9 ft., 6 ft. remains on the trees?

To go into the elementary principles, the ability of snow to cling to any object depends very much upon its quantity, its condition, and the state of the wind. Snow in large flakes, and damp and sticky, such as is common in many of the storms of this region, will cling to almost anything, and the degree to which it will pile up on slender supports in the absence of wind is extraordinary. On the other hand, when the temperature is well below freezing and the snow is dry and fine it will slip from any inclined surface or through a mesh of underbrush as fine, dry sand slips through the fingers. If such snow falls, as is nearly always the case, under the influence of the wind, which shakes such movable objects as tree tops, almost all of it will sift through to the ground. Moreover, as to proportions on the trees and ground, a great deal depends upon quantity. A much larger percentage of a 2-in. snowfall will cling to the trees than of a 20-in. fall, other things being equal.

Both Mr. Pinchot and Mr. Leighton have apparently derived much comfort from the writer's comparison of the American River and Puta Creek water-sheds, in California, and both have referred to it as an "unfortunate" illustration. Let us see on which side of the question the misfortune of that illustration lies. The writer presents a map, Fig. 17, of the two water-sheds, prepared after he had read the report of Mr. Pinchot's remarks and before he had seen his map, Fig. 16. A careful comparison of these two maps is invited, with particular attention to the location of the gauging stations, the outline of the Sacramento flood plain, and the direction of the wind as shown on the writer's map. Mr. Pinchot places Guinda (71) on the Puta Creek water-shed, but, unless all the maps which the writer has consulted are wrong, it is on Cache Creek, quite outside the Puta Creek water-shed. The writer supposed that Calistoga (76) was within the water-shed, but it appears to be just outside, though practically on the border. There is a discrepancy in the position of Tamarack on the American River water-shed, but it is immaterial.

FIG. 17.

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The writer based his findings solely on data found in the paper by Messrs. Clapp, Murphy, and Martin.* He has since examined the Weather Bureau records, but finds nothing to modify these data, while they confirm the writer's views as to the course of the storms that produced those very heavy run-offs. As to the American River watershed, Mr. Pinchot's figures and the writer's practically agree, although Mr. Pinchot has added several stations outside the water-shed, not used by the writer. On the Puta Creek water-shed, of the eight stations† used by Mr. Pinchot—(76), (74), (17), (71), (77), (6), (78), and (72)—six—note carefully the number and location—are outside the water-shed, not including Calistoga. The use of so large an element from the outside would, in any case, be questionable; in the case under consideration, when the conditions are understood, it is indefensible. All these outside stations lie in the Sacramento flood plain except Guinda, which is a short distance in the hills. The storm conditions on this plain are entirely different from those in the valley of Puta Creek. That valley has always been noted for heavy rain-falls and enormous run-off. Messrs. Clapp, Murphy, and Martin say that "in the region about Clear Lake and Mount St. Helena, in the Lower Sacramento Basin, the precipitation is remarkably heavy, and occurs almost entirely as rain." The storms sweep in from the Pacific, break over the hills directly upon this valley, and drop the bulk of their burden in passing. The intensified character of these storms is thoroughly understood locally, and must be taken into account in any rational determination of their effects.

The storms in the Sacramento plain are entirely different. Sweeping up from the south, their precipitation is very much lighter than on the hills on either side. This is well shown in the records of this storm. Taking all the stations in the plain from Chico to Suisun, the maximum precipitation for the 10-day period is less than 6 in. in all but one or two instances. The use of these stations in any way in determining the precipitation on the Puta Creek water-shed is inexcusable, much less the assignment of 75% weight to them. A railroad engineer who would estimate in this way the flood flow of Puta Creek, in the absence of discharge measurements, and provide flood capacity on that basis under a bridge that he might be called upon to build, would be guilty of gross professional malpractice. The writer took the only records he had which directly covered the case, but he did not rely on them alone. At many of the stations, Messrs. Clapp, Murphy, and Martin gave 1904 flood readings, and there is a close correspondence running through all the records, between the 1904 and

* *Transactions, Am. Soc. C. E.*, Vol. LXI, p. 281.

† Mr. Pinchot does not specify the stations used in his determination, but he gives them in a letter to the writer as follows: Calistoga, Davisville, Dunnigan, Guinda, Helen Mine, Sacramento, Vacaville, and Woodland. The numbers on Fig. 17 are the designations used by Messrs. Clapp, Murphy, and Martin.

the 1907 floods. Applying this to the 1904 record at Middletown, Mr. Chittenden, which is well inside the water-shed, a precipitation of between 20 and 22 in. is indicated at that point. A similar use of the Mt. St. Helena record would have raised the figure.

In short, the writer went at the matter in what seemed to him a direct practical way. It was not a question of isohyetal lines at all, but of trying to find out what actually happened; and he believes that engineers will agree with him, on the basis of the data presented, that the precipitation on those two water-sheds for the period in question was about in the proportion of 20 in. on Puta Creek to 15 in. on American River. Mr. Labelle arrives at a similar result by taking the precipitation for a full month.

But the writer is not at all particular as to the exact figure. He is willing to take in the records of Cache Creek (but not under any circumstances those of the plain). Add in Lakeport and Guinda, and the record will still be about 18 in. Even if it were as small or somewhat smaller than that of the American River, it would not affect the principle involved. For some cause the Sierra water-shed, much larger in area, sent down a much greater percentage of run-off than did Puta Creek. The writer believes this was due in part to the distribution of snow on the Sierra slopes caused by the presence of the forests. In any event, the restraining effect of the forest totally failed to materialize.

And here the writer would like to ask why there should be so much stumbling in this matter. If momentary prejudice is dropped, and the question is looked at from a direct common-sense point of view, is not what happened the most natural thing in the world? Is it possible that the general result should have been other than what it was? Snow always has the effect of transferring the run-off from precipitation to a period subsequent to that on which the precipitation occurred. If the snow melts when additional precipitation is falling, the net result is to bring two storms together, and the run-off must necessarily be greater than that from either storm alone. So far as forests affect the distribution of the snow as to increase the rate of melting, so far they intensify the run-off.

The writer hopes that Messrs. Pinchot and Leighton will not waste any further sympathy upon him on account of this "unfortunate" illustration.

One more "unfortunate" of Mr. Pinchot's is found in Fig. 2, Plate XL, in regard to which it is insinuated that the writer selected a level tract of ground to illustrate the absence of erosion resulting from timber destruction. The writer would not notice this matter at all if it were not that it affords an opportunity to point out one of the chief sins of the forestry propaganda—the use of its photographs. As to the picture in question, it was taken several years ago by an artist from

Mr. Chittenden. St. Louis, whose fancy was captured by the wierd appearance of the dead standing timber. This, with several other pictures, was given to the writer, and it was the only one in his collection bearing upon the subject in hand when he came to write his paper. If he had had an opportunity to get others, he could have selected hundreds of places of all degrees of slope that would have illustrated his argument just as well. If Mr. Pinchot ever visits that region the writer would ask him to examine the steep slopes of Bunsen Peak and Terrace Mountain, burned over several years ago, and now grown up to grasses and underbrush where hundreds of deer graze during a large portion of every year; and also a steep hillside at Bluff Point, on the shore of Yellowstone Lake, where a former fire has been succeeded by a growth of jack pines so dense that it is impossible to take a horse through it. In fact, in all his travels of many hundreds of miles in burned-over districts in those mountains, the writer has never found any marked erosion resulting from such fires, and does not believe that there is any.

But the course which Mr. Pinchot has quite unjustly ascribed to the writer in this matter is one of constant regular practice by the forestry propaganda. Let anyone examine the photographs illustrating erosion in the Southern Appalachians and other places—bald, rocky knobs, seamed river bluffs, gorges, chasms, and ravines assumed to have resulted from deforestation—and see what exaggerated evidence they constitute. They bear no more resemblance to the normal aspect of cleared land than do the gullied precipices of the Bad Lands to the corn-clad hills of Iowa.

As to the writer's impression, which has so excited Mr. Pinchot's astonishment, that the forest under scientific management is kept free of *débris*, the writer will say that he has derived it from general reading, from the description of German and French forests, from conversation with those who have inspected those forests, from official publications of the Government,* and finally from correspondence with Mr. Pinchot's bureau itself. It is the writer's understanding that dead timber will not be allowed to accumulate in such forests, that tree tops are cut up for wood or else destroyed as a measure of fire protection, and that the ground will generally be kept clear of the litter that fills the ordinary forest. Possibly the writer's use of the word "rake" gave Mr. Pinchot the impression that he meant that the forest was carefully combed over with a garden rake as one clears up

* For example, in discussing the cause of forest fires, the Secretary of Agriculture says (Senate Document 91, 60th Congress, First Session, p. 29): "All kinds of waste materials left in the woods supply food for the flames, but the leaving of large, unlopped softwood tops on the ground adds enormously to the fury of a brushwood fire and greatly prolongs the length of time that a slash remains a menace to its own and surrounding areas."

And Senate Report 1596, 59th Congress, First Session, p. 7, says: "The dried branches and tops of felled trees also furnish ready material for the spread of the great forest fires which constitute the second agency contributing to the destruction of the forests."

The natural inference from this language is that it is desirable to avoid such accumulations of *débris*.

leaves from a lawn! He did not mean quite that, but simply that logs and tree tops and dried underbrush will no longer be allowed to accumulate. He would appeal to Mr. Pinchot himself if this is not a correct statement of the case. Mr. Chittenden.

In the forest primeval a large proportion of the mould that covers the ground comes directly from the decay of fallen timber. The accumulation from this source in the forests of the Pacific Coast is enormous. In the Yellowstone forests it is the main source, for the accumulation of leaves and the growth of a mould from the ground itself are very small. It would be interesting if Mr. Pinchot had stated positively whether it is a part of the forestry policy to allow this accumulation to go on. Certainly it is not the practice in foreign countries, judging from all descriptions that the writer has seen. Of course, in our new forest reserves of virgin timber, original conditions will continue for a long while, but they will gradually change as cutting goes on and fresh accumulations of débris are prevented.

From the broad standpoint of forest preservation, it would seem to be exceedingly unwise to let accumulations of dead timber and brush continue. It is the débris of the forest that makes fires so impossible to control, and the control or prevention of such fires is a matter of more vital moment than any beneficial effect of the débris upon the forest itself or upon stream flow can be.

In the light of Mr. Pinchot's definition of the word "waste," the writer's remarks upon that subject may indeed seem not quite to the point. This is another example of change of standpoint in reply to criticism. If waste means simply a loss of opportunity to continue an existing forest, then indeed there has been much waste, and there will be much more. And it is a kind of waste that the writer deploras as much as any one else. He would be very glad if every acre of our woodland, both primeval and cut-over, were under public control.

But this was not the matter to which the writer referred at all, and no one who has read the current literature upon this subject would gather any such idea from it. The constantly reiterated lament is that our forests have been and are being "wantonly" destroyed, "ruthlessly" wasted, "looted" for selfish purposes, and the like. It was to this feature alone that the writer's remarks were directed. Those who cry "waste" rarely consider what they are talking about, or the circumstances attending the alleged destruction. What is waste to-day was not waste at all forty years ago. When "logging bees" were common in New York or Pennsylvania, maple trees, for example, were often an encumbrance to the ground; to-day they are of great value for flooring, piano work, etc. When the pine forests of Michigan were entered, the price of timber was so low that only the best trees could be cut. Now everything that will make a 2 by 4 is utilized for boards, and all other parts of the tree are saved and worked up into

Mr. Chittenden. charcoal, wood alcohol, or other by-products. In many of our intramountain districts the timber that has been cut off served a more useful and necessary purpose at the time in that new country than it ever would again in a thousand years. We must consider the times and circumstances before we accuse our fathers of conspiracy against posterity in a profligate waste of our resources. It was not for them to save trees where their absence was far more valuable than their presence. It is for us, on the other hand, to save them now, for conditions are reversed; but in doing this, as a plain matter of duty to ourselves and justice to posterity, let us not be unjust to our fathers by denouncing them for doing the very things we would have done in their places, and would have done because they were the proper things to do.

The real waste, the lamentable loss, in our native forests has been that resulting from fire. It is difficult to fix the responsibility for this. Some of it has been unavoidable, much accidental, a great deal the result of carelessness, very little of it wanton or malicious. The first and foremost duty of forestry work to-day is to combat and control this agency of destruction.

Quite unnecessarily, Mr. Pinchot reads the writer a lecture to the effect "that each part of the soil must be put to the use in which it will contribute most to the national welfare." The whole tenor of the writer's paper is expressed in this sentence. The simple difference between the writer's point of view and that of his critic is that Mr. Pinchot holds that forests are of all-embracing and universal beneficence, while the writer holds that, like any other product of the soil, they have a strictly limited, though very important, sphere of influence. The writer also holds that their benefits will be greatly enhanced by having them as near as possible to the homes of the people.

The writer will close this review with a reference to the first paragraph in Mr. Pinchot's discussion. He says:

"In discussing the influence of forests on stream flow, it is unlikely that we will ever have a better statement, in certain respects, of the case against the forests than that which Colonel Chittenden has made."

Exception is taken to the word "against." If the writer had some project in hand which he considered of great public importance, and if a friend were to come to him and point out what seemed to be serious defects, while commending the project as a whole, it would scarcely be the part of fairness to charge that friend with hostility to the enterprise. It is precisely this intolerance of criticism which is one of the things most to be criticized in the forestry propaganda. It is noteworthy that no one ventures to utter a word in criticism of any feature of the propaganda without an apology and a careful explanation that he has nothing against the cause of forestry itself. The

writer is as firm a believer in, and as ardent a friend of, legitimate forestry as Mr. Pinchot himself. He has spoken against a spurious forestry only—a forestry which promises where it cannot make good. Fifteen years ago, he accepted without question the current theories, although then urged in a comparatively mild form. It was only by learning through practical experience the erroneous character of some of these theories that he was led to question the general claim in regard to the beneficial effects of forests upon stream flow, and to find upon investigation that it was indeed not well founded. For several years he has had it in mind to present a paper on the subject to this Society, but has desisted for the sole reason that he did not wish, even in appearance, to roll a stone in the pathway of the movement for the preservation of our forests. He should not have prepared the present paper but for the turn which things have taken in the past two years, in which conservatism has been thrown to the winds, the most exaggerated and erroneous notions have been seriously forced upon the public belief, and the drift was unmistakably in the direction of making forestry an adjunct of the improvement of our navigable rivers. In this situation he determined that at least one voice should be raised in protest—one plea made for sanity in dealing with this important subject. As stated at the close of his paper, this decision was taken solely upon his own initiative, and, right or wrong, he alone is responsible for it. If any one supposes that the work was undertaken as a mere holiday recreation, he is mistaken. It is easier to swim with the current than against it, particularly when that current is a veritable Niagara. Nothing but a sense of profound conviction could justify the writer's course, and two circumstances attending the reception of his paper have confirmed his estimate of its timeliness and importance. One is the commendatory references in this discussion and the numerous letters he has received from prominent engineers and others, showing a deep undercurrent of dissatisfaction with the extreme course which our forestry friends are pursuing. The other is the attitude of a few ultra-forestry advocates who have co-operated in this discussion to demolish the writer's argument. It is probably true that no paper has been presented to the Society during its existence that has been denounced in such unmeasured terms from beginning to end as has this paper by the small group of gentlemen referred to. They have found nothing but "fundamental" misconceptions and errors, "unfortunate" illustrations, "curious" doctrines, failure to grasp "elementary principles," "vitiated" reasoning, and finally mistakes so many that Mr. Pinchot plaintively remarks that he is unable to "exhaust" them. The literary form is indeed irreproachable, but a grave peril lurks in this very fact, for the unwary may thereby be "beguiled into acceptance of the author's precepts!" In the words of a gentleman who attended the Louisville Convention of the Ohio

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It is possible that these gentlemen are beginning to realize that they have slightly over-reached in this matter, and that their very strenuousness amounts to a confession of weakness. Be that as it may, the writer is content to accept the judgment of his professional brethren, in and out of this Society, upon the essential soundness of his seven forestry propositions and of his views of public policy connected therewith.

APPENDIX.

The following extracts from writings upon the subject of forests and stream flow are reproduced here because of their historic value in the literature of the subject. In every case they present early, if not original, enunciations of the principles which are now being brought into prominence through the medium of this discussion. Mr. Chittenden.

I.

The first extract is from "The Earth as Modified by Human Action," by Mr. G. P. Marsh, first published in 1864, and is reproduced because of its early date and because it is a perfect example of the mixture of wheat and chaff so conspicuous in the present forestry propaganda.

"General Consequences of the Destruction of the Forests.

"With the extirpation of the forest, all is changed. At one season the earth parts with its warmth by radiation to an open sky; receives, at another, an immoderate heat from the unobstructed rays of the sun. Hence the climate becomes excessive, and the soil is alternately parched by the fervors of summer, and seared by the rigors of winter. Bleak winds sweep unresisted over its surface, drift away the snow that sheltered it from the frost, and dry up its scanty moisture. The precipitation becomes as irregular as the temperature; the melting snows and vernal rains, no longer absorbed by a loose and bibulous vegetable mould, rush over the frozen surface, and pour down the valley seawards, instead of filling a retentive bed of absorbent earth, and storing up a supply of moisture to feed perennial springs. The soil is bared of its covering of leaves, broken and loosened by the plough, deprived of the fibrous rootlets which held it together, dried and pulverized by sun and wind, and at last taken up by new combinations. The face of the earth is no longer a sponge, but a dust heap, and the floods which the water of the sky pour over it hurry swiftly along its slopes, carrying in suspension vast quantities of earthy particles which increase the abrading power and mechanical force of the current, and, augmented by the sand and gravel of falling banks, fill the beds of the streams, divert them into new channels, and obstruct their outlets. The rivulets, wanting their former regularity of supply and deprived of the protecting shade of the woods, are heated, evaporated, and thus reduced in their summer currents, but swollen to raging torrents in autumn and in spring. From these causes there is a constant degradation of the uplands, and a consequent elevation of the beds of water courses and of lakes, by the deposition of the minerals and vegetable matter carried down by the waters. The channels of great rivers become unnavigable, their estuaries are choked up, and harbors which once sheltered large navies are shoaled by dangerous sand-bars. The earth, stripped of its vegetable glebe, grows less and less productive, and, consequently, less able to protect itself by weaving a new network of roots to bind its particles together, a new carpeting of turf to shield it from wind and sun and scouring rain. Gradually it becomes altogether barren. The washing of the soil from

Mr. Chittenden. the mountains leaves bare ridges of sterile rock, and the rich organic mould which covered them, now swept down into the dank low grounds, promotes a luxuriance of aquatic vegetation that breeds fever, and more insidious forms of mortal disease, by its decay, and thus the earth is rendered no longer fit for the habitation of man."

Oblivious to the humor of the situation, Marsh adds: "To the general truth of this sad picture there are many exceptions."

II.

The writer regards the following extract from an address by Colonel Thomas P. Roberts before the American Forestry Congress, in September, 1885, as well worth careful study. It is the first rational explanation that has come to his notice of the fact that the low-water flow of our rivers is not less than it used to be, in spite of the generally accepted fact that the little springs and rivulets dry up more than formerly. Colonel Roberts' life-long experience upon the Ohio River, and his inherited fund of information upon the subjects, through his father, the eminent hydraulic engineer, W. Milnor Roberts, whose career was also largely identified with that stream, give his opinion upon the matter, considered in the abstract, more than ordinary weight:

"A river of large drainage area is made up, to be sure, from a multitude of tributaries. Over an area of 20 000 square miles, which is the basin of the Ohio at Pittsburg, there are, even in the seasons of the most protracted droughts, almost daily thunder-storms, of limited area, perhaps, but each deluging in turn one or more of the minor tributary valleys and causing local freshets. No rainfall may be observed at any designated station for two or more weeks at a time; nevertheless the river represents the aggregate of their effect, its low-water discharge being in reality made up of numerous miniature freshets. In other words, I argue that the low-water discharge of the Ohio River is, to a very great extent, maintained by a circulating series of minor freshets.

"A dry-weather spring yielding two gallons of water per minute, making seventy-five barrels daily, would be accounted enough even for the maintenance of a large stock farm. The lowest stage of water ever known upon the upper Ohio was in 1838, when for several days the least discharge of the river was 552 000 gallons per minute, to maintain which it would require the united tribute of 276 000 such springs. For the average season of drought it would require more than 500 000 such springs, to maintain the low-water discharge of the Ohio River. On the other hand, it would require that only ninety-seven square miles of the entire territory of 20 000 square miles be daily visited with a storm yielding for discharge a little over half an inch of rainfall.

"These figures are presented merely to set forth very briefly how great rivers may maintain their low-water discharge. I am persuaded

that if absolutely no rains visited the Ohio valley for several weeks at a time during the summer, the river would literally dry up, for I have no faith that the perennial spring of the forests, supposing the region were a virgin forest, would support the loss due from evaporation in the long, wide, and shallow pools which exist in the main watercourse. Therefore it matters little if the "saw-mill" man's creek has been dried up by the denudation of forests; the river will preserve its constant average. Occasionally the saw-mill creek may burst its banks; rising possibly more suddenly and higher than before its banks were denuded; the river accepts it as just one of those 'ninety-seven square mile floods' due for one day."

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III.

The following article, so far as the writer is aware, is the first ever written in which the injurious effect of forests upon the run-off from snow-melting is set forth; it has reference only to the intramountain regions of the Far West. It is by Mr. R. L. Fulton, and was published in *Science*, April 10th, 1896.

"When American enterprise invaded with its iron cavalry the mountain regions of the West, many established theories were put to new tests, and not all sustained themselves. The relations of plant life to water supply, as found on the eastern half of the Continent, had led our fathers to believe that the destruction of forests would invariably and inevitably result in the depletion of adjacent streams and in all consequent evils. So potent is the thick shade which covers the ground in many parts of the Eastern States that no one imagined that conditions existed elsewhere that would produce entirely different results. The building of long lines of railroads [in the Far West] and the opening up of mines have led to the cutting off to the very ground of extensive tracts of timber, and the effect upon local streams has led observing people upon the spot to the conclusion that Nature has surer and wiser methods than she has been given credit for; that she has storage facilities among the mountain tops, capable of resisting the attacks of any human vandals, and that the fountains of her rivers will be preserved to send down precious floods throughout all future time, regardless of what man may say or man may do.

* * * * *

"Close observers, after long years of study, have been led to believe that if there is any difference in the flow of streams and the size of springs before and after the trees are cut from above them, the balance is in favor of the open country.

"That water which drops on shaded ground which is thickly overspread with spongy leaves and the air so near the dew point that it cannot absorb much more moisture should be held back, while that coming down on open ground should run off quickly, seems very natural, but in high mountain regions there are peculiar combinations which do much to modify the action of the law. The pine and fir are the only trees found growing at a high altitude in any abundance, and

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their thin needles do not make the heavy shade when on the tree, nor the thick mat when lying on the ground, that the broad leaves of the oak, beech and maple do. Instead of forming a spongy layer five or six inches thick, they are swept about by the wind and it is not unusual to see the ground bare under the trees and all the needles lodged somewhere in drifts. Even when they lie where they fall the coating is comparatively worthless so far as retaining moisture is concerned. On the other hand the foliage on this class of trees being as heavy in winter as in summer, the branches catch an immense amount of falling snow and hold it up in mid air for both sun and wind to work upon, and only those who have had experience of the absorbing power of the dry mountain air can form any idea of the loss from that source. Such as is melted falls upon that beneath, and breaking the surface sets in operation forces which are always ready to attack such substances. The theory that the shade protects the moisture laden soil means but little in such places. The law is doubtless in force with more or less strength wherever moisture falls and plants grow, but the class of trees that thrive here require a loose, sandy soil, and are often seen growing where there is no earth in sight at all clinging to the sides of the cliffs, so bare that the roots run along the surface entirely uncovered until they reach some crevice which they fill, and send tendrils down to draw sustenance from an unseen source. In such places the melting snow disappears quickly from the surface, and, except for their influence in keeping the soil light and porous so that the water can be absorbed readily instead of running off, it matters but little whether trees are there or not. No moisture remains upon the top of the ground long for shade to protect. It goes either into the air or else into the ground, and it is a well-known fact that a very large portion of water which finds its way down the steep sides of the Sierras disappears near its sources and is found again far below, either in springs, by means of artesian wells, or in the increased flow of the parent stream. Indeed, a number of very respectable rivers, not only in the mountains, but in some of the valleys, seem to owe their existence to such distant and hidden sources. If the trees have any direct power here it seems to be to draw from deep beneath the surface the moisture which has sunk into the earth and exhale gallons and gallons of it hourly. Any good-sized tree has been estimated to have a capacity of forty or fifty gallons every twenty-four hours, and a forest of such trees would effect very considerable results.

"I should like to offer the opinion of Captain J. B. Overton, of Virginia City, Nevada, just here. He has had control of the water supply of that city for many years, and also conducted large operations in the mountains in cutting timber, wood and lumber for the mines. His experience covers a quarter of a century and extends over several townships of land, from which his men cut the timber. He says:

"My experience proves to me that the cutting of the timber makes no difference in the amount of snow that falls, but that it drifts more and for that reason lasts about as late in the summer as it would before the removal of the shade. I do not think the streams get low any sooner or afford any less water. I am of the opinion that the trees absorb from the soil quite as much water as would be

evaporated by the action of the sun in the absence of shade. I know two small springs that ran for the whole year for ten years after the land was cut over, but, that since the thrifty growth of young pines have reached a height of from 15 to 25 feet and shade the ground as well, if not better, than the large trees did, have dried up about the last of August for five years past, and I can see no cause for it except that the trees are using the water. The supply of water used by my company in its operations has not decreased with the disappearance of the timber, and I do not find that the freshets are any more frequent or more violent than before the trees were cut off. The trees are coming up in a second growth much more numerous than they were before, and after sixty or seventy years about nine-tenths of them will die off and decay, leaving the timber about as it was when we first came to this country; then I think my springs will flow again. My observation teaches me that the amount of rainfall is not affected by denuding the mountain-side, but that the surface of the ground will therefore be drier, but that streams and the springs will be more diminished by the water used by the trees than by evaporation in their absence.'

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"Trees tend to dissipate the snows in the Springtime also, by breaking up the steady cold winds that come down from the north at that season, almost invariably. When the current is permitted to flow on in uninterrupted sweep it retains the chill, but let it strike a forest and wind in and out among the trees for a mile or two and there will be a decided change in the temperature. It will be much better prepared to absorb moisture and also to melt the snow banks in its changed form as it pursues its southern journey.

"But the strongest force at work to save our rivers is the drifting winds which heap up the snow in great banks, and in this the trees are a constant obstacle. There will be miniature drifts, it is true, but nothing to what they are when there is no obstruction. Outside the timber belt, where there is nothing to catch the snow as it falls and nothing to break the force of the wind, one of the most powerful and active agents in preserving the water supply of the country comes into play. By forming solid bodies of snow, the most effective means of saving water for summer is reached. Across the bleak summits and down the vast canyons the wind has a well-nigh irresistible force, and it not only gathers up the snow after it has ceased to come down, but it usually keeps at work all the time it is falling and carries it in whirling clouds until it strikes a cliff or a canyon set at just the right angle and there it deposits the whole load. As long as there is any material left outside to work upon this is kept up, and there is no knowing how deep some of the big drifts get to be in the course of a long winter. As the days get warmer, the surface thaws a little and moistens the cake down a few inches, but the cold nights found all the year round at such altitudes soon transform it into ice, making a crust upon which the heat of the sun and the absorbing power of the air find it difficult to make any impression. On open ground the process is aided by the packing power of the wind, and it is not an unusual thing to see a man on horseback traveling comfortably across snow-

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banks high enough to hide both the horse and rider many times over if they should chance to break through. It is this which has changed the opinion of four settlers out of five along the eastern base of the Sierra Nevadas, where the timber has been cut for the Comstock mines. Over half a billion dollars in treasure have been taken from that one lode, and it is said that for every ton of ore taken out the equivalent of a cord of wood has gone either in the shape of timber or of fuel. The whole mountain side for a distance of thirty miles has been cut over, covering the heads of such streams as Hunter's Creek, Galena, White's Canyon, Thomas Creek, Steamboat, and other small rivers, which have furnished water for irrigation since 1860 to the owners of probably twenty thousand acres of land in the valleys below. The consensus of opinion among this class of citizens, intelligent American farmers all of them, is that there is virtually no diminution in the supply of water that reaches them from the hills. James Mayberry had charge of two men who cut over twelve thousand acres in the early '70s. He is of the opinion that Hunter's Creek, with which he is most familiar, has a more certain flow and somewhat more water than before. John Wright has lived thirty years on Steamboat Creek. It was dry in 1864, when the timber was standing, but never has been since, and has furnished water for a constantly increasing settlement. Robert Jones lives on low land, and says he has had more crops killed by flooding in the ten years after the timber was cut than in the ten years before it was touched. G. R. Holcomb says the supply is equally certain if not more so and attributes it entirely to the drifting of the snows. Several made answer that the water melted earlier and ran off sooner and said anyone would know that, but failed to convince even themselves that they were lower than in former years.

"Hon. Ross Lewers, of this country, read a paper before the American Horticultural Society a few years ago in which he said: 'There are certain peculiar conditions that prevail in Nevada that I think worthy of notice. One of them is, that wherever the forest timber has been cut off, a new growth has sprung up much thicker, and none of the young trees will start until the old ones are gone. Another is, that the water supply from the mountains is greater and more permanent now than it was before the timber was cut off. The reason for this is, that the wind has a more unimpeded course, and as all the snow storms come from nearly the same point in the south, the snow is blown over the ledges on the north sides of the ridges where it is piled deep in drifts, and not being exposed directly to the sun's rays it melts very slowly and thus affords a more permanent supply. Spring floods are less frequent and for the same reason. I do not pretend to decide how much, if any, the presence of the trees induces precipitation. They may moisten the air, but the humidity is all taken out of the ground by the roots, and I observe that the undergrowth and grass is more luxuriant since the timber was cut off.'

"As I have laid much stress upon this matter of evaporation, which some may think hardly applies to snow, I will say that a considerable body has been known to disappear from our streets without making a particle of mud, leaving the ground dusty, showing that none of it melted, but that it all went directly into the air. And this

will occur any time when the thermometer does not go above thirty-two degrees within a short time after a storm. The importance of presenting as small a surface to the action of such an air as that is very apparent, and it is in storing up the snow in heaps and packing it away in deep pockets that the economy of nature is manifested. The center of the body will not melt at any time, and it requires a very warm day to get at the underside of the snowdrift. The grass will be growing all around it before the ground underneath it gets warmed up sufficiently to start a stream from it, but let a tree stick its head up through the crust and it [the snow] will go quickly. I have yet to see the first body of perpetual snow lying among the trees. It will hardly do to say that the timber lies below the line of perpetual snow, for there are many banks which only disappear entirely once in ten years or so (when there comes a long dry summer), which have trees growing higher up on the same mountain side.

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"In any case, I do not wish to be understood as favoring the destruction of the forests of this or any other country. I never cut down a tree in my life and never saw one fall without feeling that I had lost a friend. Whatever is proven, there will always be abundant reasons for preserving extensive tracts of woodland everywhere that trees will grow, and it is time the matter became one of public concern."

IV.

The following extract is given on account of its historic interest, and because it presents in exaggerated form the quixotism of the Ohio River reservoir project which the writer has criticized in his paper. It is from a book written by Colonel Charles Ellet, Jr., entitled "The Mississippi and Ohio Rivers;" published in 1853, pages 303 to 305.

"Réservoirs may eventually be made of sufficient capacity to hold *all* the annual excess, and make the daily flow almost entirely uniform. The banks of the Ohio and Mississippi, now broken by the current and lined with fallen trees, ready to be swept by the next freshet into the channel, there to form dangerous snags, may yet, in the course of a very few years, be cultivated and adorned down to the water's edge. In the opinion of the writer, the grass will hereafter grow luxuriantly along the caving banks; all material fluctuations of the waters will be prevented, and the level of the river surface will become nearly stationary. Grounds, which are now frequently inundated and valueless, will be tilled and subdued; the sandbars will be permanently covered, and, under a uniform regimen of the stream, will probably cease to be produced. The channels will become stationary. The wharves will be built as the wharves on tide water, with little, if any, reference to the fluctuations of the surface. The lower streets of all the river towns, no longer exposed to inundations, will acquire new value. The turbid waters will be arrested in the upper pools, and the Ohio first, and ultimately the Missouri and Mississippi, will be made to flow forever with a constant, deep, limpid stream. The ice will be swept off as it forms, and neither cold nor drought will longer be suffered injuriously to affect the navigation. The ocean steamers will

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"All this may be accomplished on the Ohio *for about the cost of three or four ships of the line*. The great and only difficulty is, so far to overcome the cold incredulity of the public as to obtain from Congress a sufficient appropriation for the completion of the first two reservoirs. This once effected, and a single practical demonstration made, it will perhaps be as difficult to convince the future engineer that a thing so clear and palpable could ever have been doubted, as it at first was to remove the doubts."

ERRATUM.

On page 509, ninth line from the bottom, insert the word "million" after the word "thousand," so that the sentence will read "A little while ago the country was told that a thousand million tons of soil are yearly washing from our agricultural lands into the sea," etc.