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PAPERS ON THE

CONSERVATION OF WATER RESOURCES

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PAPERS ON THE CONSERVATION OF WATER RESOURCES.

INTRODUCTION.

This volume is a reprint of selected papers on the conservation of water resources, written by members of the United States Geological Survey in response to executive order, for the report of the National Conservation Commission (S. Doc. 676, 60th Cong., 2d sess.). Nearly all the information from which the papers are compiled had previously been collected by the Survey in the performance of its regular duties. The remainder has been taken from the records of other federal bureaus. The papers, therefore, constitute a summation of certain official work which has been in progress for more than twenty years and whose results eventually must have been published in the regular series of water-supply papers had they not been diverted to become a part of the larger work on conservation. The printing of the conservation report has furnished an opportunity to present these reprints in convenient form and, as the demand for the larger report will greatly exceed the edition authorized, this segregation of the papers relating to water will prove useful.

DISTRIBUTION OF RAINFALL.

By Henry Gannett.

The ultimate source of our water supply is rainfall, the chief source of which is evaporation from the Pacific Ocean, while secondary sources are the Gulf of Mexico and the Atlantic Ocean. Brought from the Pacific by the westerly winds of the north temperate zone, the moisture in the air is carried eastwardly nearly across the continent in diminishing quantities, varying at different times of the year. The supply in the atmosphere is reenforced in the Mississippi Valley from the Gulf of Mexico, whence it is drawn inland by southerly and southwesterly winds; and again east of the Appalachian Mountains it is reenforced from the Atlantic Ocean, from which it is drawn by easterly winds accompanying cyclonic disturbances.

The areal distribution of the rainfall is in general terms as follows: The precipitation is very heavy upon the north Pacific coast, where at several points in the States of Washington and Oregon it exceeds 100 inches annually, but diminishes southward so that at San Diego, Cal., the rainfall is very light and desert conditions prevail. Inland, back of the Coast Ranges, the northern part of the great depression separating these mountains from the Cascades and the Sierra Nevada is well watered. The amount of rainfall diminishes southward, so that in the southern part of the depression, which is occupied by the San Joaquin Valley, precipitation is scanty and arid conditions exist. The high mountains of the Cascade Range and of the Sierra Nevada are copiously watered, but east of them, in the valleys and low plateaus and on the great plains as far east as the one hundredth meridian, the rainfall is very light. The mountains of this (the Rocky Mountain) region, however, enjoy a more copious rainfall than the valleys, the amount differing with the altitude and latitude, the more northerly and higher ranges receiving the greater amount.

Continuing eastward, the small supply of moisture still remaining from that brought from the Pacific Ocean is augmented by a generous contribution from the Gulf of Mexico, and the rainfall increases. Upon much of the Gulf coast it exceeds 60 inches annually, but it diminishes northward, until in the neighborhood of the

Great Lakes the precipitation does not exceed 30 inches yearly. The Appalachian Mountains are abundantly watered, and the Atlantic plain receives everywhere a sufficiency for agricultural purposes, derived largely from the Atlantic Ocean.

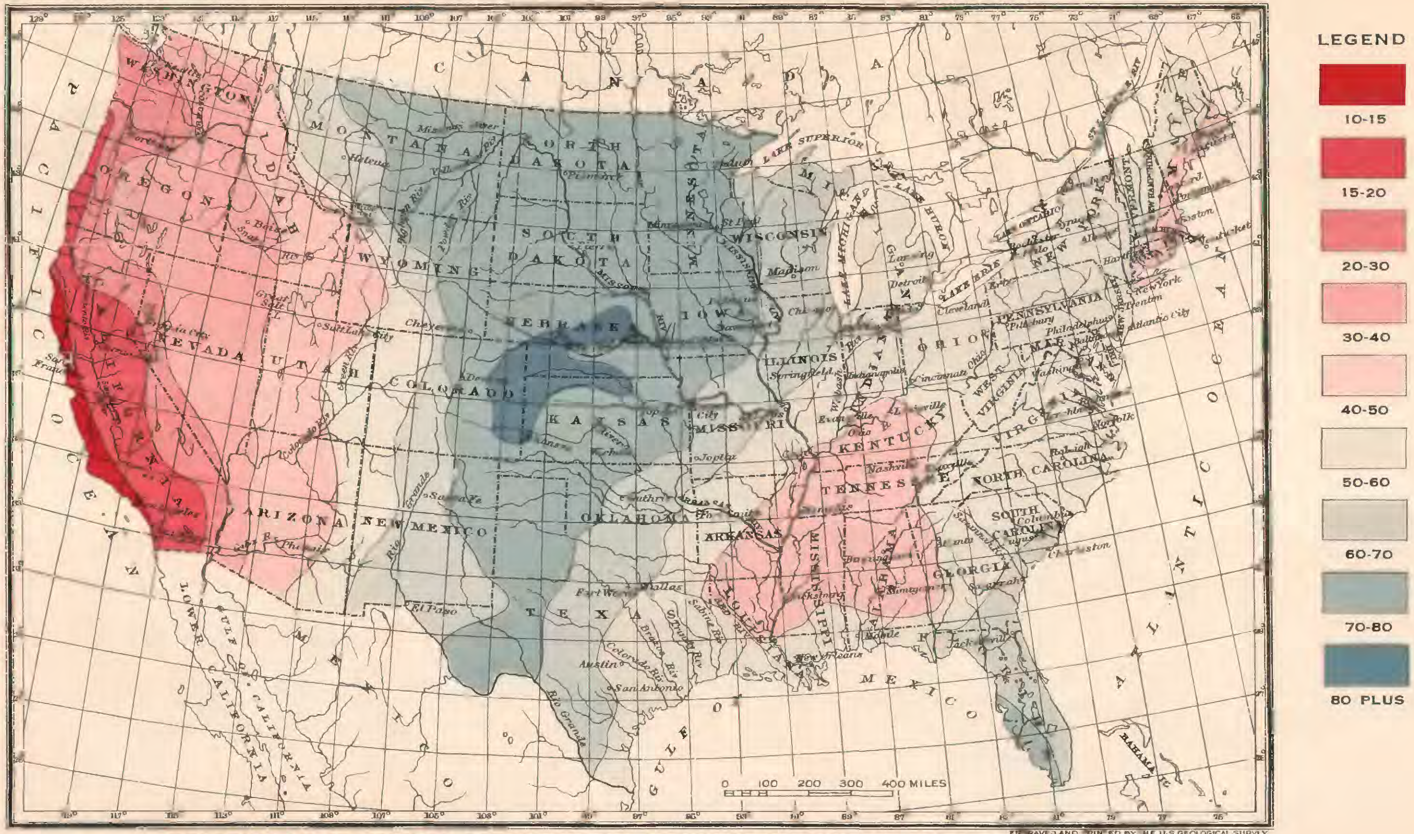
The causes of these great differences in amounts of precipitation in the various parts of the country are simply explained. All air holds a certain amount of moisture, ranging from the amount sufficient to saturate it to a very small proportion of that quantity. The point of saturation is much higher in warm air than in cold air; i. e., warm air can hold a much larger quantity of moisture than can cold air. Whenever air is cooled below the point of saturation, rain falls, and it can only fall when thus chilled. There are several ways in which air currents may be cooled; the current may be forced upward, as when it climbs the slope of a mountain range; it may be cooled by intermingling with colder air currents; and again, by coming in contact with a cold land.

The sea receives heat slowly and parts with it slowly; the land, on the contrary, is rapidly heated and parts with its heat as quickly. It results from these conditions that the ocean has a fairly uniform temperature the year around, while the land is much colder in winter than in summer.

Now, let us apply these principles to the United States. The prevailing winds in the Temperate Zone are from the west. These winds come off the Pacific laden with moisture and having the temperature of the ocean. If they encounter land having a lower temperature they are chilled below the point of saturation and some of the moisture is deposited in the form of rain or snow. If, on the other hand, the land is warmer than the air, the currents pass over it without any reduction in temperature and with little or no loss of moisture.

During the winter the north Pacific coast is colder than the sea, and hence the copious precipitation which it enjoys at that season of the year. In the summer the conditions are reversed, and the air currents, although containing at least as much moisture as in cold weather, pass over the land with comparatively little loss from precipitation. Southward, down the coast, the land is progressively warmer in winter, and consequently receives less rain, while in southern California there is little rain even in winter, except upon the mountains. Although the atmosphere at Los Angeles contains more moisture than does that at Washington, D. C., rain seldom falls in the former locality, as there is nothing to cool the air currents.

Thus it is that the Pacific coast has well-defined wet and dry seasons corresponding to winter and summer in other parts of the country. In winter the country drains the air currents of their moisture and they pass eastward as dry winds, while in summer these currents carry most of their moisture over the mountains and precipitate it upon the Rocky Mountains farther to the east and upon



PERCENTAGE OF ANNUAL PRECIPITATION RECEIVED IN THE SIX WARMER MONTHS, APRIL TO SEPTEMBER, INCLUSIVE the great plains. Hence, it is that in these two regions the greater part of the year's rainfall occurs in the warmer half of the year.

Going eastward into the Mississippi Valley the moist air currents, drawn northward from the Gulf of Mexico by southerly winds, are carried progressively into more northerly and colder climates, and part of their moisture is deposited in a similar manner.

The Weather Bureau has furnished the Commission with data upon precipitation from about 4,000 stations within the limits of the United States proper. These data consist of records of the normal yearly and monthly rainfall, and the study which has been made of them is very illuminating.

In preparing the rainfall map (Pl. I), the data from all these stations were platted upon a large-scale map of the United States, and in the plains and level country generally isohyetal lines were sketched at intervals of 10 inches of rainfall in accordance with these data. In the mountain regions, however, but little weight was given to the rainfall data, inasmuch as the stations are generally situated in the canyons rather than on the ridges, and hence do not represent well the rainfall of the region, but in such country consideration was given to the relief of the land, its mountains, etc., and to the character of its vegetation; it is known, for instance, that the lower limit of yellow pine timber is not far from the isohyetal line of 20 inches. The areas between these isohyetal lines were measured by planimeter, and the average rainfall of each such area was assumed to be the mean of the two isohyetal lines limiting it. The areas were then multiplied by their average rainfall, the products summed up, and the total divided by the total area of the country. In this way the figure, 29.4 inches, was obtained as the mean average rainfall of the United States.

Another use has been made of these data. The percentage of the annual rainfall which was received during the six warmer months was computed for each station, and the results platted (Pl. II), thus showing the preponderance of summer or winter rainfall throughout the country. Over most of the area the greater part of the rain occurs in the warmer season, but upon the Pacific coast and in the Rocky Mountains as far east as western Montana, eastern Idaho, eastern Utah, and Arizona the bulk of the precipitation comes in the colder season. The highest proportion, three-fourths to four-fifths of that of the year, is on or near the Pacific coast, and the proportion diminishes eastward. Again, in an area adjacent to the Gulf of Mexico, winter rainfall preponderates slightly. The highest proportional summer rainfall is on the plains east of the Rocky Mountains, where it ranges from three-fourths to four-fifths of that of the year. In the Mississippi Valley and on the Atlantic plain the proportion which falls in the warmer season is but little more than half of the annual precipitation.

FLOODS.

By M. O. Leighton.

INCREASE.

A broad and comprehensive review of river-discharge records in the United States indicates unmistakably that floods are increasing. It is true that the opposite tendency may be shown on some rivers, while the records on others may indicate little or no change; but, taken as a whole, the rivers that reveal more intense flood tendencies so thoroughly dominate the situation that the conclusion above expressed must be inevitable.

It will be well to consider at the outset just what index may be used to determine the trend of flood tendencies. It is common in inquiries of this character to select and compare the highest stages attained in the several years of record, and because, perchance, higher floods may be shown in early years, many really competent persons have believed themselves forced to the conclusion that there is no increase in flood tendency. The actual height attained by the maximum flood each year is, however, a matter of small consequence in such considerations. A little reflection will show how this must be true. The precipitation, which is the ultimate cause of floods, takes three courses, only two of which are really important in the present discussion, namely, the course along the surface of the ground directly into watercourses, and that into the ground by percolation, with subsequent discharge into the rivers by seepage. In general terms it may be stated that the water which causes floods is that proportion of the precipitation which the earth does not absorb and which, therefore, must flow along the earth's surface. Now it is apparent that when precipitation becomes so intense and long continued that it practically saturates the ground the rain that falls thereafter must take the direct route and floods must necessarily arise. Therefore the height of great floods is fixed primarily by the intensity of precipitation and, as the amount of rain varies from year to year, now bountiful and again scanty in what seem to be fairly uniform cycles of years, the observation of an especially high flood during an early year compared with that of a much lower one during a recent year can give no index to flood tendency in any river. The real index is of more fundamental origin than the mere occurrence of high floods.

When the question "Are floods increasing?" is asked, the considerations involved are not those of height but those of duration and frequency. In other words, the question means, Are floods of more frequent occurrence and are there more days of flood than formerly?

Reverting for the moment to the discussion in the foregoing paragraphs, it is plain that floods will occur more frequently in response to a given rate of precipitation, if there are in the drainage area influences that either inhibit or prevent the ready absorption of the rain by the ground, than they would if absorption were ideal. Such ideal condition assures complete absorption of all precipitation. A rain of a given depth in a unit's time—say 2 inches in one day—would surely produce a flood in a drainage area which was nonabsorbent. On the other hand, the same amount of rain would not change the river stage if the conditions enhancing absorption on the drainage area were ideal. Between these two extremes there are wide and varying conditions which tend to increase or to diminish the resultant floods from a given rainfall. In other words, the question "Are floods increasing?" means, essentially, Are the conditions of the surface of the ground in the river basins so changing that they render the ground less absorbent? If this be the case, it is clear that a much larger proportion of the precipitation would run directly off into the rivers than that which was so conducted at an earlier period.

There are five classes of agencies or conditions affecting the flow of streams. The first is climate, under which are comprised rainfall, evaporation, temperature, wind, and humidity. Although these are exceedingly variable from day to day and from season to season, the observations that have been recorded indicate that a period of years embraces all conditions, so that the mean of them may be considered fairly constant. There is very little evidence, except in special areas, that reveals any progressive and permanent change in climatic conditions. The second agency is topography, and the third geology, both of which may, for present purposes, be considered absolutely stable. The fourth is surface vegetation, which includes forest cover and cultivated land. This is subject to progressive change, according to the demands, conveniences, and usages of society. The fifth consists of artificial agencies, such as storage, reservoirs, and drainage, which produce rapid and marked effects on river discharge.

Therefore, the consideration of river discharge and especially of floods involves the appraisal of the effects of climate, vegetation, and artificial agencies. The other two agencies, being constant, may be left out of consideration. It is necessary to take account of these conditions in connection with all studies of progressive flood trend. This emphasizes the futility of many studies that have heretofore been made, in which not only have the extreme flood heights been the basis of determination, but there has been a total lack of consideration of climatic conditions, especially that of rainfall. A river, for example, may show a progressive decrease in flood frequency during a period of years. If that were taken alone it would indicate a decreasing flood trend; whereas, if the rainfall be compared progressively in the same manner, it might readily be shown that the flood trend was increasing rather than diminishing, because the precipitation was decreasing faster than the flood frequency.

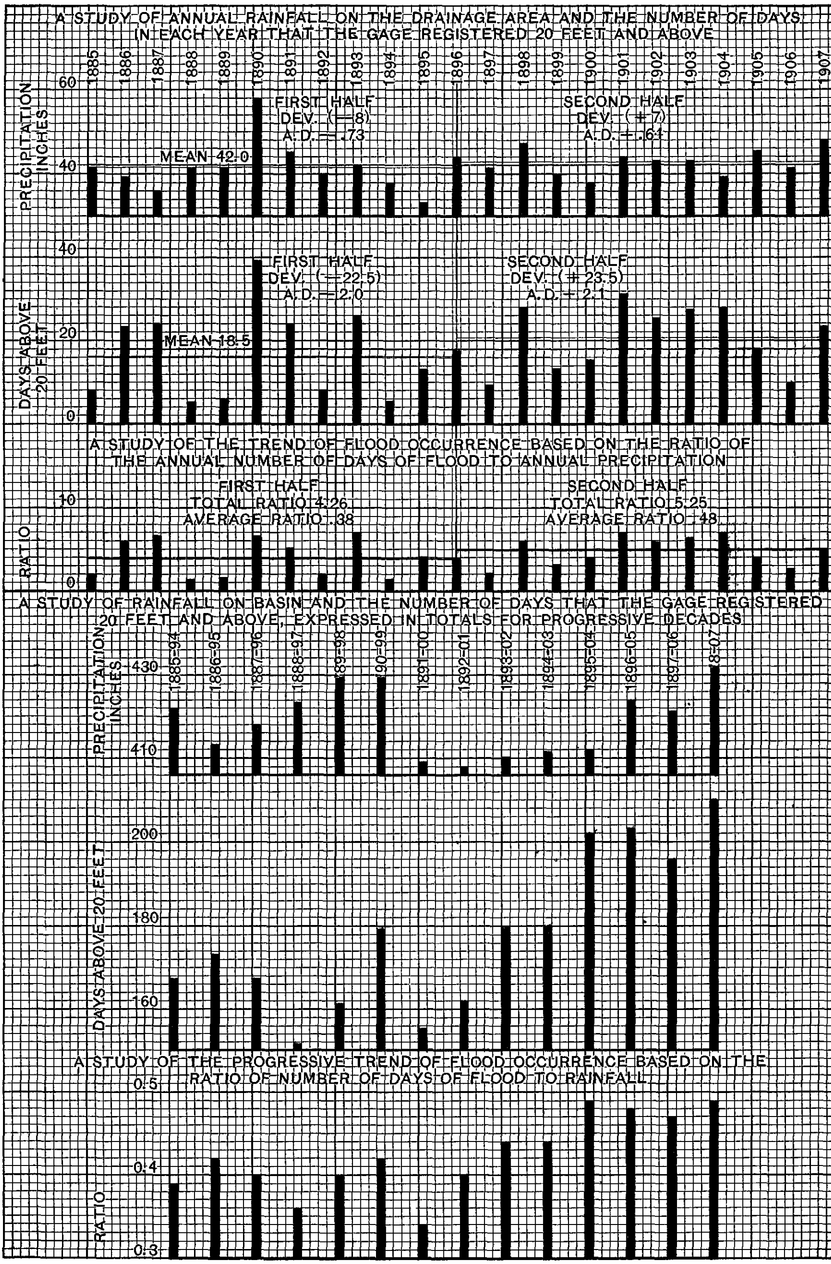
The above considerations have been kept in mind in the study of flood frequency here presented. The accompanying diagrams (pp. 13 to 20) are the result of appropriate studies made of flood occurrence on rivers on which gages have been maintained for a long period, the longest, in fact, of which there are available and useful records in this country. Examination shows conclusively the increasing trend of flood occurrence and the cause thereof comes now properly into question.

As already stated, the rainfall, which is by far the most important of the climatic conditions, has been accounted for in these diagrams, and we have, therefore, remaining only the condition of the ground surfaces in the drainage areas and artificial agencies. For each of these rivers artificial agencies may be eliminated. Our general knowledge of conditions on the drainage areas gives assurance that there has been no reservoir installation of extent sufficient to modify in the slightest degree the normal conditions of flood discharge. This is also true with respect to artificial drainage.

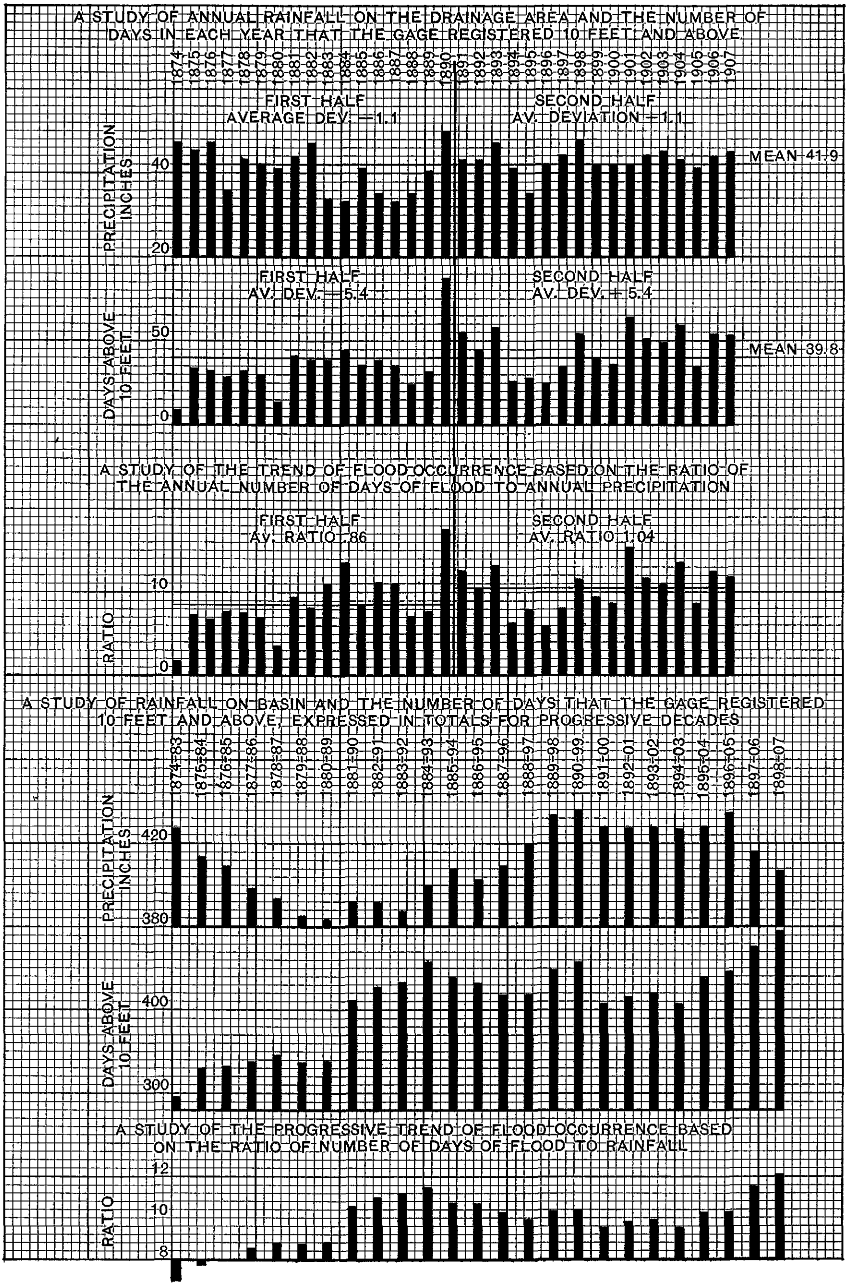
Therefore we come down to the condition of the land surface, or, as above expressed, conditions of vegetation. We are aware that on all of these drainage areas there has been progressive cutting of timber and building of roads. The latter improvements, however, have not been of sufficient extent to modify in any appreciable degree the discharge. A computation of the actual road areas, including the paved streets, etc., will show conclusively that, in comparison with the total area under consideration, they are insignificant. The conditions of cultivated fields undoubtedly have a marked influence in modifying the rate of river discharge, and it is certain that some of the effects in these areas are due to this cause. The cultivation of fields has, however, improved markedly in recent years. The farmer has learned to a considerable degree that it is more profitable for him to cultivate his inclined fields by contour or terrace cultivation, and a cursory view of the areas represented in the accompanying diagrams will show that to a very large extent improved methods of cultivation have been put into effect.

Altogether, when the physical conditions on the drainage areas are summed up, the one great change that has been produced in the vegetative conditions is the reduction of forest area. On some of these

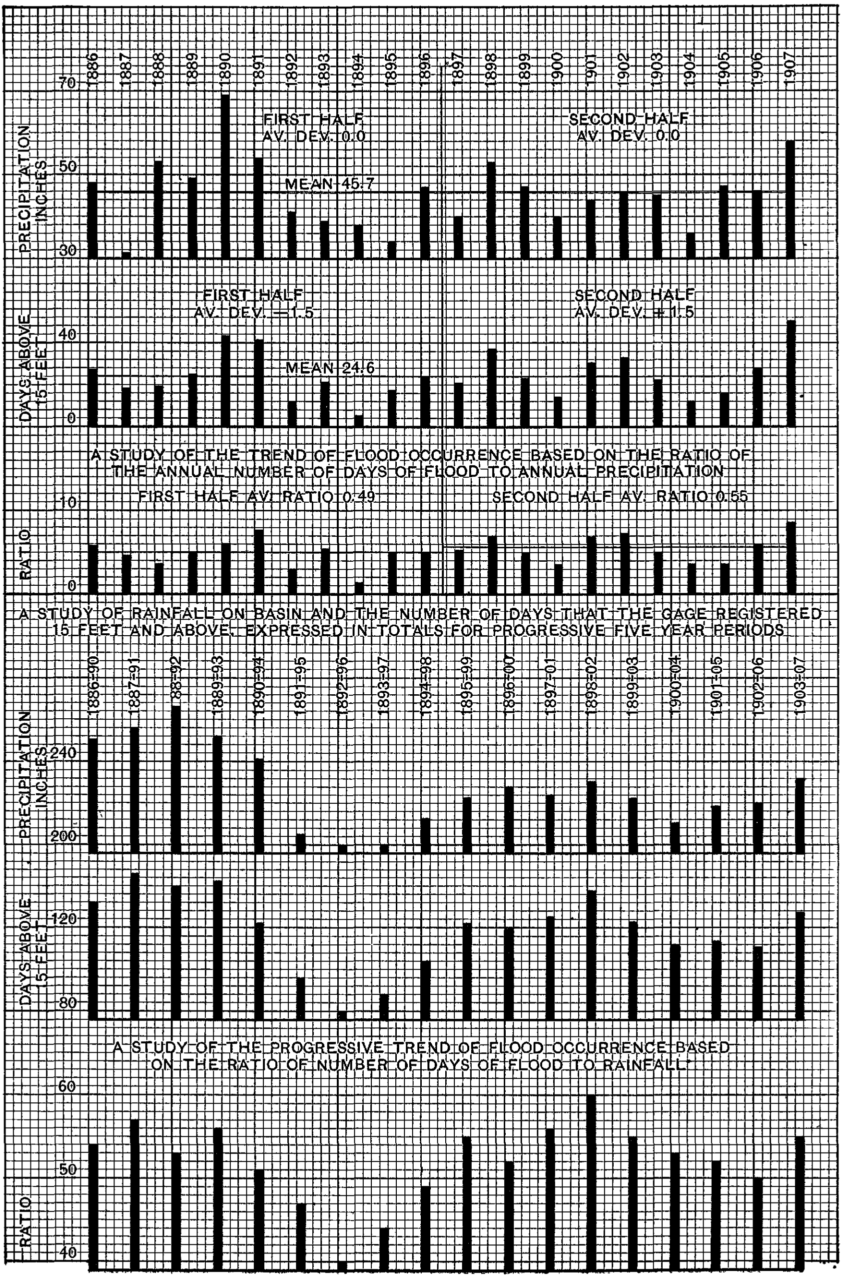
FLOODS ON OHIO RIVER AT WHEELING, W. VA. 1885-1907



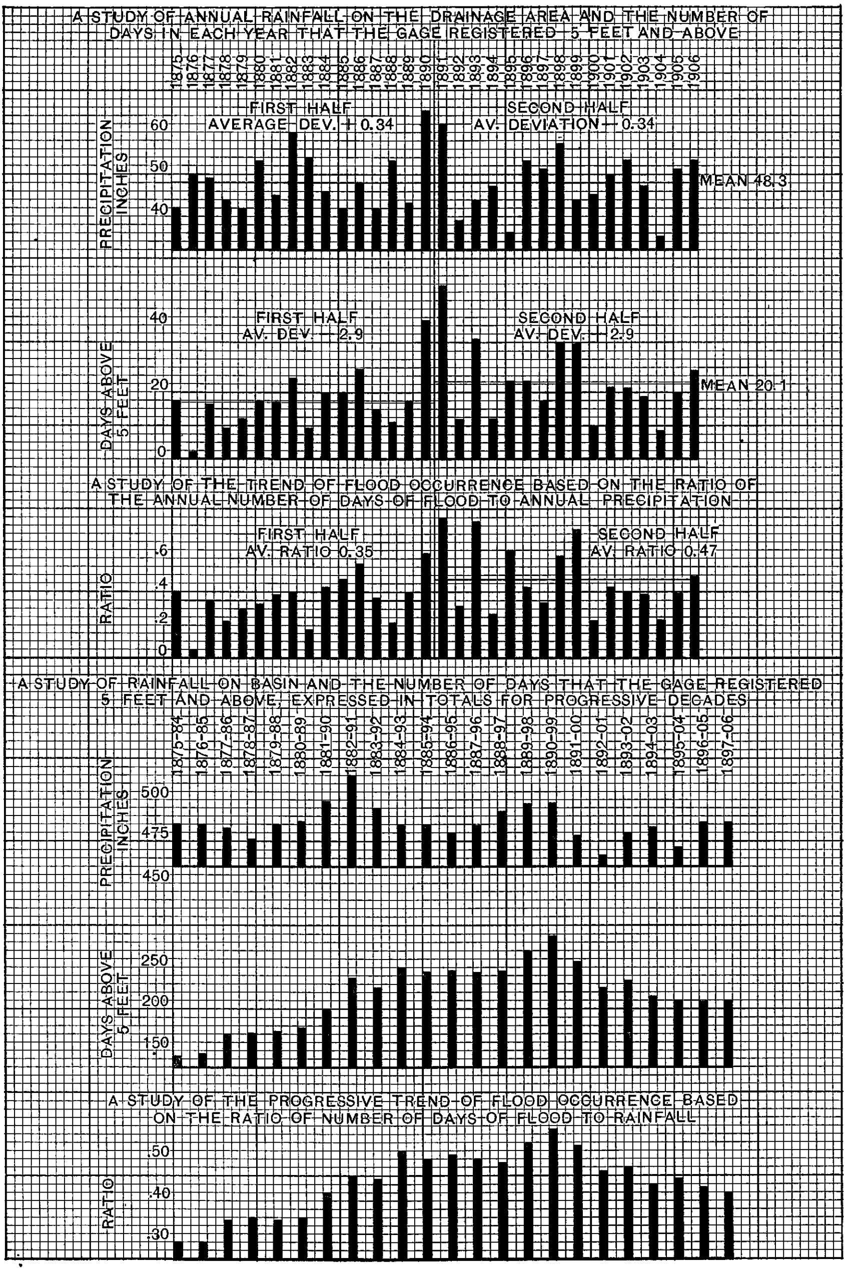
FLOODS ON ALLEGHENY RIVER AT FREEPORT, PA. 1874-1907.



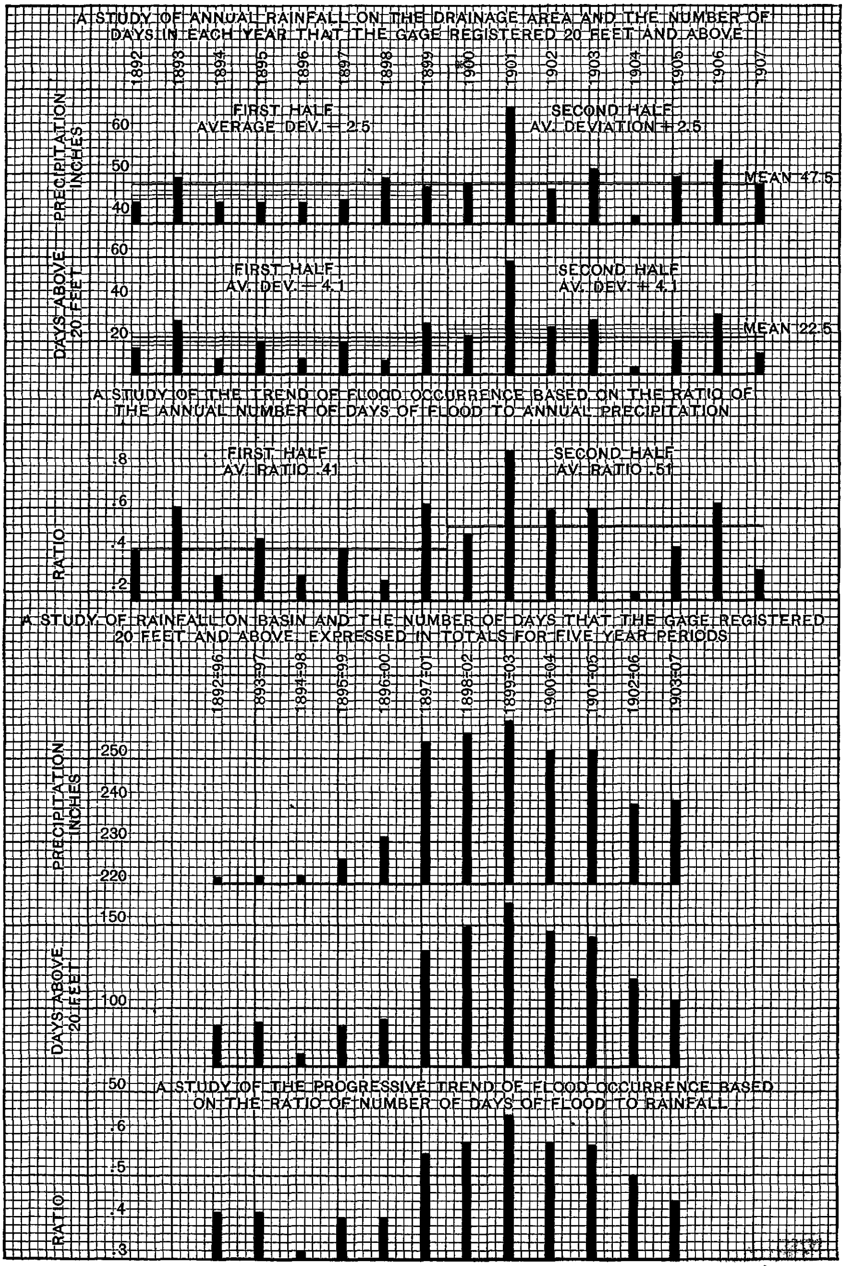
FLOODS ON MONONGAHELA RIVER AT LOCK NO. 4, PA. 1886-1907.



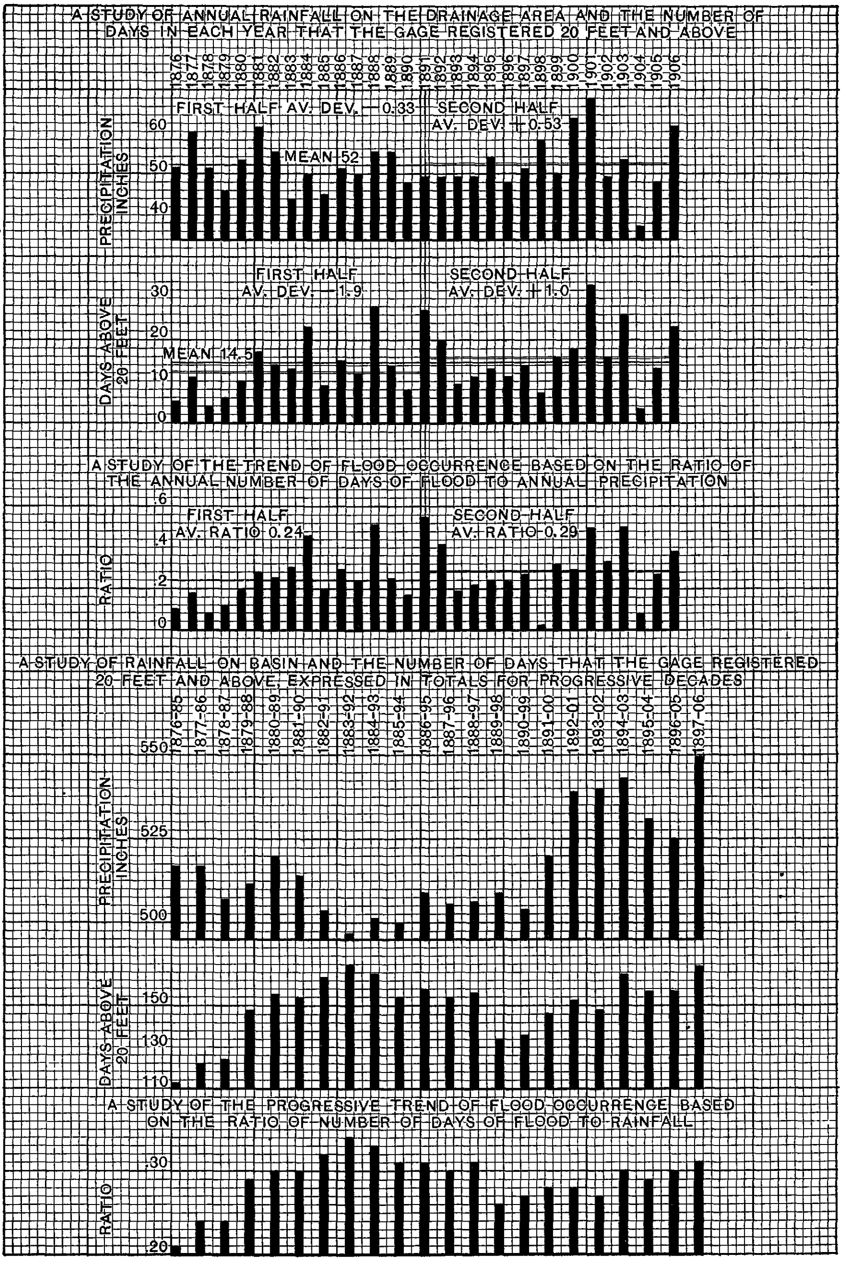
FLOODS ON YOUGHIOGHENY RIVER AT CONFLUENCE, PA. 1875–1906.



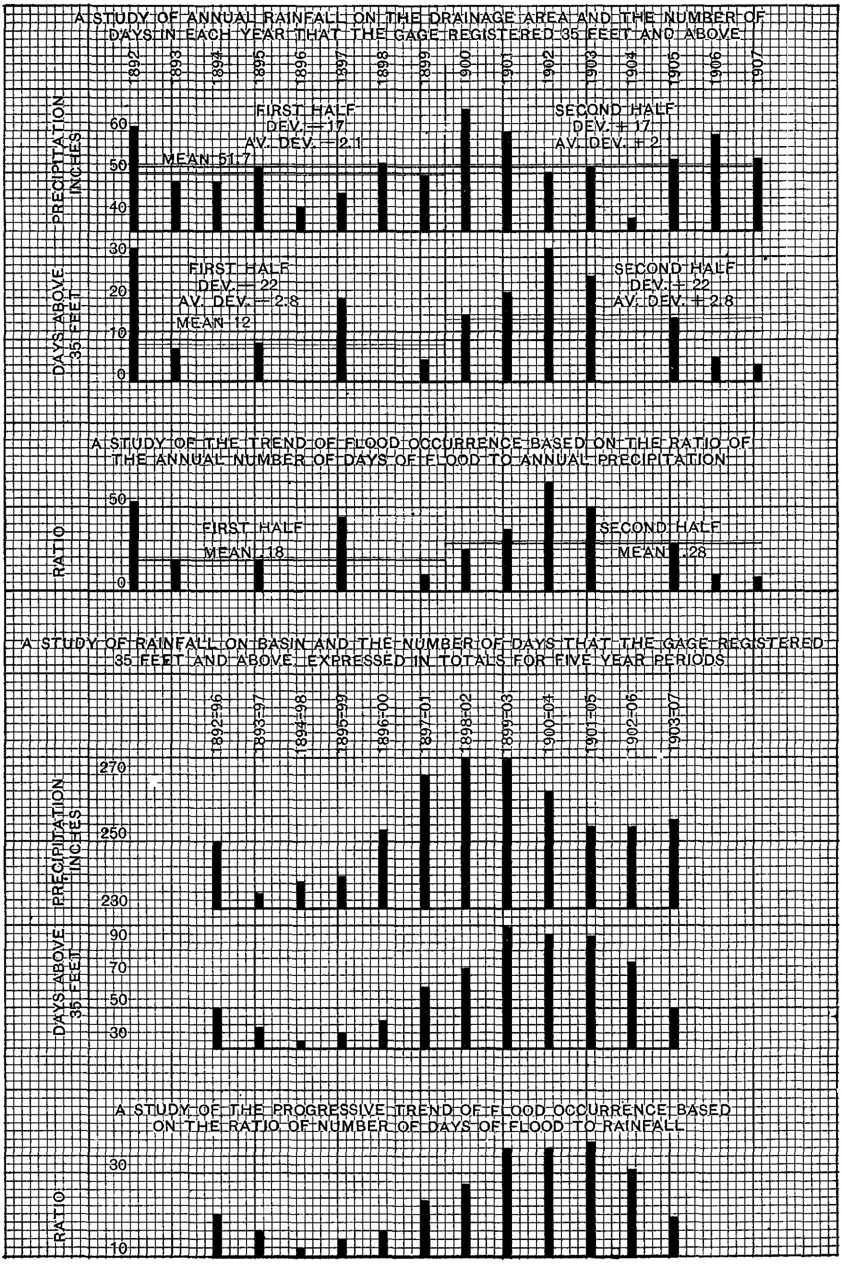
FLOODS ON WATEREE RIVER AT CAMDEN, S. C. 1892-1907.



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



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



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

drainage areas it has occurred by slow progression and on others more rapidly. It is certain that in some areas this forest cutting has caused barren conditions, because the land was of such a character that, after it was relieved of forest protection, it eroded easily and its productive portions were quickly swept into watercourses.

Summarily, therefore, it may be stated with confidence that the increase in flood tendency shown so unmistakably is due in by far the largest measure to the denudation of forest areas.

Diagrams on pages 13 to 16 are expressions of progressive changes in flood occurrence during the series of years indicated thereon. They are all drafted on a uniform basis, the first expression in each case being a record of the annual precipitation in inches; the second gives the number of days in each year that the gage at the point designated registered above a certain stage; the third is a combination of the first two and gives the relation of the number of days of flood to the precipitation. Thus, there is given in one expression the actual trend of flood occurrence in terms of precipitation. This form of expression eliminates one variable in the conditions governing flood occurrence, and the only remaining ones to be considered are vegetation and artificial agencies, as discussed in previous paragraphs.

The second series of diagrams on each sheet gives the same relations except that the amounts are united into progressive decades, or in one case into progressive five-year periods. This form of expression serves to neutralize the variability that occurs in the successive years and gives to the whole diagram a progressive trend which is more comprehensive and more easily interpreted than the statement of actual amounts. Thus, in the diagram on page 13, the first progressive period covers the interval from 1885 to 1894, the second that from 1886 to 1895, and so on, each period representing ten years, and the total amount of rainfall and the total number of days of flood for each decade are expressed, rather than the average amount of these quantities.

In interpreting diagrams of this kind it should be emphasized that the amounts actually shown are not significant, save as they indicate the relative trend of the successive decades. In other words, the diagrams indicate direction, and should be so interpreted.

The data given on the above-mentioned sheets relate to the upper Ohio drainage area, and they show the relation of flood occurrence on the three principal tributaries thereof—the Allegheny, Youghiogheny, and Monongahela rivers—to flood occurrence on the Ohio at Wheeling. It will be seen that in each case there has been a marked increase in the number of days of floods, and the four diagrams can be consistently compared. At Wheeling during the period 1885 to 1907, inclusive, the ratio of flood occurrence to annual precipitation increased from 0.38 in the first half of the period to 0.48 in the second half, and this relation is shown more distinctly in the similar expression with the amounts given in totals for progressive decades. The gage records on the Allegheny at Freeport, Pa., show an increase in this ratio from 0.86 in the first half to 1.04 in the second half of the period 1874 to 1907, inclusive. The Monongahela record shows an increase of ratio during the period 1886 to 1907, inclusive, from 0.49 in the first half to 0.55 in the second half, while a still greater divergence is noted on the Youghiogheny, the ratio for the period 1875 to 1906, inclusive, increasing from 0.35 in the first half to 0.47 in the second half.

Altogether, these diagrams are extremely significant in showing the progressive increase in flood occurrence on a drainage area the deforestation of which has been constant and rapid for the past thirty years. It began first on the Allegheny and the results are apparent in the diagrams. Subsequently, timber cutting began on the Monongahela and Youghiogheny areas and is occurring at the present time.

Similar results are shown on pages 17 to 19, which give the same data for Wateree River above Camden, S. C., the Savannah above Augusta, Ga., and the Alabama above Selma, Ala.

Page 20 illustrates a record of flood duration on Connecticut River at Holyoke, Mass. This river basin has been subject to continuous deforestation for a long period. Recent testimony shows that for the last twenty years from 50,000,000 to 80,000,000 feet B. M. of timber have been released over the dam at Turners Falls annually. Records of private logging are not available, but it is known that the deforestation of the drainage area commenced some time previous to this period.

There is one point of objection that may reasonably be taken to the diagrams above discussed. It is that they draw comparison between annual precipitation and the number of days of flood. A better comparison would be one 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 gage height extend further 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 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 to May periods warrants the conclusion that the varying climatic conditions in this period are compensated, and the final conclusions drawn from the result must be worthy of confidence. On 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 clearly shown 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.

The relation between storms and floods in the Tennessee basin during the periods December–May, inclusive, 1884–1895 and 1896–1907.

Period.	Storms in inches precipitated.											
	1 to 1.5.		1.5 to 2.		2 to 2.5.		2.5 to 3.		3 to 3.5.		3.5 to 4.	
	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.
1884-1895	7	5	12	6	6	15	5	9	5	13	6	30
1896-1907	8	3	11	10	9	23	11	30	4	13	1	6

The relation between storms and floods in the Tennessee basin during the periods December–May, inclusive, 1884–1895 and 1896–1907—Continued.

Period.	Storms in inches precipitated.											
	4 to 4.5.		4.5 to 5.		5 to 5.5.		6 to 6.5.		7 to 7.5.		8 to 8.5.	
	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.	Storms.	Days of flood.
1884–1895	1	6	2	17	2	18	......	......	2	28	......	......
1896–1907	1	8	3	20	......	......	1	11	......	......	1	17

If we now divide the number of flood days by the number of storms, the result will be the number of days per storm. Applying this to each of the series in the above table, the following result is reached:

Days of flood per storm.

Period.	Storms in inches precipitated.							
	1 to 1.5.	1.5 to 2.	2 to 2.5.	2.5 to 3.	3 to 3.5.	3.5 to 4.	4 to 4.5.	4.5 to 5.
1884–1895	0.7	0.5	2.5	1.8	2.6	5	6	8.1
1896–1907	.4	.9	2.6	2.7	3.2	6	8	6.7
Percentage increase	—43	80	4	50	22	20	33	—17

The algebraic sum of the above 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.

FLOOD DAMAGES.

A complete census of flood damages for any year or series of years has never been attempted. Therefore, it will be impossible to present any figures for which precision may be claimed. The damages for particular floods in certain areas have from time to time and for one or another purpose been assembled and, in a few places, examinations have been made with great care by commissions and boards especially qualified for such work. The results of such examinations may be taken to form a basis for an estimate; but, for the present purpose, a better basis has been made available. During the present year the Geological Survey has made inquiry of all the railroads in the United States concerning flood losses during the period January 1, 1900, to August, 1908. The railroads were selected for this purpose because it is well known that they are, by reason of their location and extent, subject to far greater physical damage than any other single interest, and it was believed that from the figures so procured a fairly representative basis of estimate might be obtained. From previous studies of this matter it appeared that the railroad losses resulting from floods amount to about 10 per cent of the total physical loss arising therefrom, excluding, of course, the largest single item of loss, which is the depreciation of realty values arising from flood menace. The figures here presented will therefore exclude all consideration of this kind of loss.

The proportion of 10 per cent was arrived at from three points of view:

First. It has been the observation of the writer that, as a rule, the reported losses to railroads from floods have amounted to about this proportion.

Second. The actual investigations of flood losses, made by appraisal boards, and individual property returns covering fairly wide areas have approximated this proportion. Undoubtedly the most complete and comprehensive investigation of this kind was carried on by the northern New Jersey flood commission in 1903, after the great flood that arose in October of that year along Passaic River. The region comprehended in this investigation may be considered a typical one. It comprised the usual proportion of farm lands, city areas, highway bridges, railroad property, etc., and the proportion of railroad loss there was almost exactly 10 per cent of the total.

Third. One-tenth of the wealth of the United States consists of railroad property. This proportion was therefore used in the following estimates.

During each of the periods above named the returns from the railroads involved a varying percentage of the total mileage of the country. The mileage involved in each yearly estimate has been expressed as a percentage of the total mileage for that year, as given in the reports of the Interstate Commerce Commission. The several amounts were increased from the percentage that they represented to 100 per cent, to cover the entire mileage of the country. Inspection of the returns showed that this was a fair and reasonable method, because the reports were well distributed and represented a true proportion of that which might be expected to be the damage on the total mileage. This figure was then considered as 10 per cent of the total damage for the whole country and increased accordingly. The results are given in the following table:

Year.	Damage reported.	Percentage of total mileage reported.	Total railroad damage.	Estimated total damage.
1900	$666,253	14.6	$4,567,500	$45,675,000
1901	958,740	21.1	4,543,800	45,438,000
1902	1,225,468	22.2	5,520,100	55,201,000
1903	2,654,192	27.3	9,722,000	97,220,000
1904	2,476,724	31.3	7,884,100	78,841,000
1905	3,286,324	33.3	9,858,972	98,589,720
1906	2,727,511	37.3	7,312,400	73,124,000
1907	4,623,106	39.1	11,823,800	118,238,000
1908	6,517,577	27.4	23,786,000	237,860,000

STORAGE OF FLOOD WATERS.

In the northeastern portion of the country there has been a large installation of reservoirs and a consequent saving of enormous amounts of flood water. The numerous lakes in that part of the United States, irrespective of those that have been developed artificially, have a beneficial effect. It is probable that 10 per cent of the flood waters that originate in New York and New England are saved by storage in artificial reservoirs, lakes, and ponds. In Minnesota, at the head of upper Mississippi River, practically the entire flood drainage from an extensive area is conserved. In the arid West there has been an extensive installation of reservoirs, some of which conserve practically all the flood waters on their respective basins. Considering the country as a whole, however, it is doubtful if more than 1 per cent of the flood water is saved.

The storage of floods is effected by forests and similar surface vegetation and by artificial reservoirs. The amount stored by forests is and probably will for a long time to come be indeterminate, since the forest is merely an agent in assisting the ground to absorb the water. The storage is therefore essentially ground storage and the ability of the forest to enhance this is dependent absolutely on the character of the soil beneath the forest. Therefore, to fully answer the question, "To what extent could flood waters be stored by forests?" it would be necessary to consider minutely the absorption properties of the various kinds of land surface in the United States. It will be possible at some future time to give an approximate and exceedingly useful reply to this question; but before that time arrives we must have more long-term gage records on our rivers. The diagrams presented with this paper (pp. 13 to 20) constitute as useful records as there are extant in the country, and a short consideration of them will plainly reveal the fact that, while they are exceedingly useful in indicating the trend of flood duration and frequency, they do not yet yield sufficient information to give even the widest approximation of the amount of water or the proportion of run-off that can be conserved.

The question is therefore one for the future, and our stream investigations should be carried on with this as one of the purposes in view.

The extent to which flood waters could be stored by reservoirs depends on the available reservoir capacity in the several river basins. As a rule, the more diversified the character of these basins, especially in contour, the greater facilities they afford for reservoir storage.

There is a great portion of the Mississippi Valley in which floods are not subject to correction under the reservoir plan. This is also true of certain coastal-plain streams like the Brazos and Colorado. It is probable that the streams draining one-third of the area of the United States must forever be subject to floods, and the only treatment that now appears feasible for these streams is the construction of levee systems. For the remaining two-thirds of the United States, investigations so far made indicate that from 55 to 60 per cent of the flood waters can be saved by the utilization of maximum storage capacity. Although the cost of such construction would be enormous in the aggregate, it is apparent that the saving that would accrue from relief from flood damages alone would soon return the entire investment. A glance at the estimated flood damages in the United States, page 25, shows the possibilities. In this connection it should be stated that in by far the larger proportion of the basins a saving of 55 to 60 per cent of the flood waters would insure practically entire relief from flood damages. It is not necessary to prevent floods absolutely; or, in other words, it is not necessary to secure uniformity of flow in any river in order to secure relief from flood damages. The construction of the reservoirs necessary to prevent floods would, under proper management, involve an increase in the water-power possibilities of the United States equal to about 60,000,000 horse-power. In the arid West the construction of reservoirs for flood prevention would provide water sufficient for the reclamation of many million acres of now worthless land. All of this, together with the assistance that such reservoirs would lend to navigation, constitutes the saving that would accrue from their construction. We are unable at the present time even to approximate the total figure, and therefore it must be summed up in the term " vast."

DEVELOPED WATER POWERS.

Compiled by the Bureau of the Census, under the direction of W. M. Steuart, Chief Statistician for Manufactures.

Discussion by M. O. Leighton.

SOURCES OF DATA.

A special census of the developed water powers of the United States has been made by the Bureau of the Census for the specific purposes of the conservation report. Previous inquiries of the same kind, made by this bureau, afforded a record of the names and locations of practically all the water-power developments that had taken place up to the dates thereof, and this record was used as the basis for the new census. Information concerning the developments that have been made since the date of the last census was procured through the Geological Survey, Forest Service, Bureau of Corporations, Post-Office Department, and many other agencies, both state and national. Special inquiry blanks were sent to all, including those that had figured in past censuses.

In making the new census it was necessary to procure the data in large measure by mail, and therefore it was necessary to simplify the inquiry and to secure only the facts absolutely necessary to a comprehensive summary of the developed water powers. The inquiry blank used for this purpose is reproduced below:

[Return this card to the Department of Commerce and Labor, Bureau of the Census, Washington, D. C.]

Water Power, 1908.

This office is engaged in the preparation of a report on the developed and undeveloped water power of the United States. If you use water power, please answer the following inquiries. If you do not use water power, please so state, and give the names and addresses of any power plants in your neighborhood. The card should be returned in the inclosed official envelope.

Name --
Post-office ---State-------------------
Location of plant: County--------------------------State-------------------
Name of river or stream on which plant is located-----------------------------
Number of water wheels---------------Maximum horsepower---------------
Horsepower actually developed during low-water season--------------------
Additional power that may be developed at same point on the same river or stream, horsepower ---
Auxiliary steam power used in same plant, horsepower----------------------
Character of industry--
(Give name of principal product.)
Give names and addresses of other power plants in your neighborhood----------

The character of the returns and the proportion of replies received indicate that the census is fairly complete. It is known that a greater number of the plants not accounted for in this census are of small capacity. There is, of course, some deficiency in the total; but it is believed that this is compensated by the general tendency among water-power owners to return statements based on actual wheel capacity installed rather than actual minimum power developed during the extreme low-water season. In all wheel installation it is the practice to develop above the minimum flow, and it follows that in the majority of power plants there must be a tendency to overstate the power actually developed during the lowest water. The final figures represent what is believed by those most conversant with the situation to be a reasonably accurate summary of the water power now developed in the country.

The material procured from the census has been arranged by drainage areas and combined into grand divisions, according to the plan followed in the report on undeveloped water power.

DEVELOPED POWERS.

Accompanying Table No. 1 gives a general summary of the horsepower developed in the United States and the number of wheels used for such development. It will be noted that this table gives results according to States as well as according to grand divisions.

Some interesting facts are shown. The total development in the country is 5,356,680 horsepower over 52,827 wheels, or an average development per wheel of about 100 horsepower. In the Northern Atlantic division there has been a greater water-power development than in any other, the total installation being 1,746,303 horsepower. The only other division that approaches the Northern Atlantic in development is that covering the drainage area of the St. Lawrence, including the Great Lakes, where there has been a development of 1,018,283 horsepower. The great power development in the Northern Atlantic division may largely be explained by the fact that the use of water power therein began at an earlier period than in any other divison. New England and the Middle Atlantic States are and have been essentially manufacturing in character, and water-power development has followed as a matter of course. It is also true that the presence of good powers in large numbers in this region has encouraged such development.

Comparisons of wheel capacities installed in various parts of the country are interesting. While the total figures show that the average power per wheel is 100 horsepower, the units in the various districts vary as follows:

Division.	Unit capacity horsepower per wheel.	Division.	Unit capacity horsepower per wheel.
Northern Atlantic	80	St. Lawrence	148
Southern Atlantic	77	Colorado River	261
Eastern Gulf of Mexico	42	Southern Pacific	515
Western Gulf of Mexico	47	Northern Pacific	295
Eastern Mississippi	60	Interior drainage	328
Western Mississippi	139	Arctic Ocean	125

The large number and small unit capacity of wheels in the eastern part of the country compared with the smaller number and larger capacity in the western portions, including, especially, the rivers draining from the Rocky Mountains and the Sierras, may be explained: First, by the fact that in the eastern and central portions of the country the power privileges are of smaller capacity; and second, by the fact that in the eastern portions of the country a large number of the powers were installed at an early date, when it was the rule to establish small units. More recent practice has involved the establishment of larger units, and as the western installations are all recent, this practice, taken together with the existence of larger power privileges, gives the result that might be expected from a general survey of the situation.

Table 1 shows that New York State has the largest water-power development, the total being 885,862 horsepower. It is proper to add that the Niagara powers on the New York side assist largely in making up this figure. The second State in water-power development is California, the total being 466,774 horsepower, over 1,070 wheels, or a unit installation of about 436 horsepower. Water-power development in California is comparatively recent. The third State is Maine, with 343,096 horsepower, over 2,797 wheels, or an average of 123 horsepower per wheel. As the use of water power in this State is comparatively ancient, the contrast in unit capacity between it and California is significant.

Among the other interesting points is the fact that, although, as shown by the report on undeveloped water power, the Northern Pacific division can be made to furnish about one-third of the total minimum horsepower of the country, there is at the present time a development of only 450,000 horsepower, which indicates clearly that the most fertile field for power development remaining in the United States is this northwestern country.

Table 2 gives the installations by districts and drainage areas, special comment concerning which is unnecessary.

Census returns show that, out of a total of 31,537 powers reported, 602 are of capacity of 1,000 horsepower or more. Recent progress in water-power development has been marked by great installations.

In former years the aggregate water power utilized in the country was made up largely of small units, which, while useful for local purposes and worthy of development, are not relatively important in the great question of power economics. The following summary gives the distribution of the powers of 1,000 horsepower and greater capacity, and it shows clearly that what was formerly believed to be an uncommonly great installation must now be considered a comparatively small feature.

Capacity distribution of powers of 1,000 horsepower and more.

1,000 to 5,000	459
5,000 to 10,000	65
10,000 to 15,000	27
15,000 to 20,000	13
20,000 to 25,000	17
25,000 to 40,000	11
40,000 to 60,000	4
60,000 to 100,000	3
100,000 and over	3
Total	602

Number of water powers by States and Territories, 1908.

United States	31,537
Alabama	1,382
Alaska	31
Arizona	29
Arkansas	203
California	559
Colorado	230
Connecticut	893
Delaware	119
District of Columbia	1
Florida	166
Georgia	1,596
Idaho	199
Illinois	155
Indiana	222
Iowa	207
Kansas	118
Kentucky	691
Louisiana	64
Maine	1,222
Maryland	496
Massachusetts	1,370
Michigan	657
Minnesota	195
Mississippi	273
Missouri	277
Montana	94
Nebraska	157
Nevada	32
New Hampshire	876
New Jersey	560
New Mexico	48
New York	3,148
North Carolina	2,614
North Dakota	9
Ohio	480
Oklahoma	25
Oregon	345
Pennsylvania	3,721
Rhode Island	191
South Carolina	846
South Dakota	45
Tennessee	1,793
Texas	147
Utah	200
Vermont	1,148
Virginia	2,243
Washington	322
West Virginia	525
Wisconsin	580
Wyoming	33

TABLE 1.—*General summary—Drainage basins by States.*

States.	Northern Atlantic.		Southern Atlantic.		Gulf of Mexico.				Mississippi River.			
					Eastern.		Western.		Tributaries from the east.		Tributaries from the west.	
	Wheels.	Horsepower.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
United States	21,864	1,746,303	5,938	459,652	3,342	139,758	258	12,071	8,959	537,080	2,385	331,739
Alabama					1,539	56,603			265	105,091		
Alaska												
Arizona												
Arkansas											255	5,868
California												
Colorado							13	937			146	26,279
Connecticut	1,546	118,145										
Delaware	277	7,976										
District of Columbia	6	1,000										
Florida			13	420	194	4,119						
Georgia			854	90,036	1,307	74,255			153	2,296		
Idaho												
Illinois									413	50,116		
Indiana									298	11,525		
Iowa											461	17,304
Kansas											184	18,606
Kentucky									834	14,156		
Louisiana					35	615	22	296			22	273
Maine	2,797	343,096										
Maryland	679	21,403							15	312		
Massachusetts	2,749	260,182										
Michigan												
Minnesota									100	15,925	361	82,007
Mississippi					267	4,166			69	3,756		
Missouri											397	10,107
Montana											162	140,494
Nebraska											227	12,792
Nevada												
New Hampshire	1,799	183,167										
New Jersey	902	38,011										
New Mexico							32	939			13	251
New York	3,046	304,003							87	3,167		
North Carolina			3,049	140,918					926	21,366		
North Dakota												
Ohio									682	26,291		

Oklahoma											29	2,994
Oregon												
Pennsylvania	5,046	273,426							530	16,849		
Rhode Island	387	37,165										
South Carolina			1,301	207,242								
South Dakota											68	11,112
Tennessee									2,160	95,060		
Texas							190	9,899			5	67
Utah												
Vermont	1,047	90,672										
Virginia	1,440	59,129	721	21,036					850	19,958		
Washington												
West Virginia	143	8,928							529	11,572		
Wisconsin									1,048	139,640		
Wyoming											55	3,585

States.	St. Lawrence River.		Colorado River.		Southern Pacific.		Northern Pacific.		Interior drainage.		Arctic Ocean.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
United States	6,896	1,018,283	285	74,428	822	423,707	1,659	*a* 489,454	353	115,944	66	8,261	52,827	5,356,680
Alabama													1,804	161,694
Alaska							106	17,289					106	17,289
Arizona			37	16,855									37	16,855
Arkansas													255	5,868
California					820	423,597	176	25,440	74	17,737			1,070	466,774
Colorado			194	51,662									353	78,878
Connecticut													1,546	118,145
Delaware													277	7,976
District of Columbia													6	1,000
Florida													207	4,539
Georgia													2,314	166,587
Idaho							261	60,533	24	18,210			285	78,743
Illinois													413	50,116
Indiana	197	17,628											495	29,153
Iowa													461	17,304
Kansas													184	18,606
Kentucky													834	14,156
Louisiana													79	1,184
Maine													2,797	343,096
Maryland													694	21,715
Massachusetts													2,749	260,182
Michigan	1,498	205,019											1,498	205,019
Minnesota	20	46,800									50	7,648	531	152,380
Mississippi													336	7,922

a Includes Alaska.

TABLE 1.—*General summary—Drainage basins by States*—Continued.

States.	St. Lawrence River.		Colorado River.		Southern Pacific.		Northern Pacific.		Interior drainage.		Arctic Ocean.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
Missouri													397	10,107
Montana							42	7,558					204	148,052
Nebraska													227	12,792
Nevada			1	3			7	252	31	20,322			39	20,577
New Hampshire													1,799	183,167
New Jersey													902	38,011
New Mexico			10	1,120									56	2,310
New York	3,380	578,692											6,513	885,862
North Carolina													3,975	162,284
North Dakota											16	613	16	613
Ohio	191	8,549											873	34,840
Oklahoma													29	2,994
Oregon					2	110	586	231,203	2	66			590	231,379
Pennsylvania	20	715											5,596	290,990
Rhode Island													387	37,165
South Carolina													1,301	207,242
South Dakota													68	11,112
Tennessee													2,160	95,060
Texas													195	9,966
Utah			38	4,656					222	59,609			260	64,265
Vermont	971	79,604											2,018	170,276
Virginia													3,011	100,123
Washington							475	147,041					475	147,041
West Virginia													672	20,500
Wisconsin	619	81,276											1,667	220,916
Wyoming			5	132			6	138					66	3,855

TABLE 2.—*Drainage basins in the United States.*

I. NORTHERN ATLANTIC

Drainage basins.	Maine.		New Hampshire.		Vermont.		Massachusetts.		Connecticut.		Rhode Island.		New York.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	2,797	343,096	1,799	183,167	1,047	90,672	2,749	260,182	1,546	118,145	387	37,165	3,046	304,003
St. Johns River	147	13,681												
St. Croix River	89	20,500												
Penobscot River	518	70,454												
Kennebec River	659	63,936												
Androscoggin River	590	101,355	93	22,100										
Presumpscot River	179	20,569												
Saco River	169	22,302	68	3,030										
Merrimac River			877	90,082			589	71,251						
Connecticut River			574	50,977	929	85,512	1,117	123,309	490	33,101				
Blackstone River							182	14,111			156	17,324		
Thames River							88	8,499	478	45,214	1	25		
Housatonic River							138	14,206	364	31,685			17	459
Hudson River					118	5,160	54	5,245					2,083	275,125
Passaic River													30	775
Raritan River														
Delaware River													208	5,924
Susquehanna River													645	20,187
Potomac River														
James River														
Minor streams (Chesapeake Bay)														
Minor streams (northern Atlantic)	446	30,299	187	16,978			581	23,561	214	8,145	230	19,816	63	1,533

TABLE 2.—*Drainage basins in the United States*—Continued.

I. NORTHERN ATLANTIC—Continued.

Drainage basins.	New Jersey.		Delaware.		Pennsylvania.		Maryland.		Virginia.		West Virginia.		District of Columbia.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	902	38,011	277	7,976	5,046	273,426	679	21,403	1,440	59,129	143	8,928	6	1 000	21,864	1,746,303
St. Johns River															147	13,681
St. Croix River															89	20,500
Penobscot River															518	70,454
Kennebec River															659	63,936
Androscoggin River															683	123,455
Presumpscot River															179	20,569
Saco River															237	25,332
Merrimac River															1,466	161,333
Connecticut River															3,110	292,899
Blackstone River															338	31,435
Thames River															567	53,738
Housatonic River															519	46,350
Hudson River	17	680													2,272	286,210
Passaic River	179	12,805													209	13,580
Raritan River	204	6,309													204	6,309
Delaware River	427	15,327	167	5,314	1,616	47,649									2,418	74,214
Susquehanna River					3,233	222,530	71	2,217							3,949	244,934
Potomac River					197	3,247	260	4,766	462	11,457	142	8,920	6	1,000	1,067	29,390
James River									607	40,165	1	8			608	40,173
Minor streams (Chesapeake Bay)			35	901			346	14,389	363	7,429					744	22,719
Minor streams (northern Atlantic)	75	2,890	75	1,761			2	31	8	78					1,881	105,092

II. SOUTHERN ATLANTIC.

Drainage basins.	Virginia.		South Carolina.		North Carolina.		Georgia.		Florida.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	721	21,036	1,301	207,242	3,049	140,918	854	90,036	13	420	5,938	459,652
Chowan River	113	2,381			64	1,147					177	3,528
Roanoke River	607	18,647			198	17,419					805	36,066
Tar River					166	6,431					166	6,431
Neuse River					317	11,365					317	11,365
Cape Fear River					673	27,539					673	27,539
Pedee (Yadkin) River			228	7,867	1,124	50,432					1,352	58,299
Santee River			573	179,708	478	26,028					1,051	205,736
Savannah River			294	16,178			245	43,357			539	59,535
Ogeechee River							88	1,965			88	1,965
Altamaha River							506	44,531			506	44,531
Minor streams (southern Atlantic)	1	8	206	3,489	29	557	15	183	13	420	264	4,657

III. EASTERN GULF OF MEXICO.

Drainage basins.	Florida.		Georgia.		Alabama.		Mississippi.		Louisiana.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	194	4,119	1,307	74,255	1,539	56,603	267	4,166	35	615	3,342	139,758
Suwanee River	16	265	29	962							45	1,227
Apalachicola River	36	565	784	62,991	114	7,717					934	71,273
Mobile River:												
Tombigbee River					340	5,193	79	1,097			419	6,290
Alabama River			464	9,869	799	37,892					1,263	47,761
Pearl River							86	1,532	18	312	104	1,844
Minor streams (eastern Gulf of Mexico)	142	3,289	30	433	286	5,801	102	1,537	17	303	577	11,363

TABLE 2.—*Drainage basins in the United States*—Continued.

IV. WESTERN GULF OF MEXICO.

Drainage basins.	Louisiana.		Texas.		New Mexico.		Colorado.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	22	296	190	9,899	33	939	13	937	258	12,071
Sabine River	11	126	24	263					35	389
Neches River			35	538					35	538
Trinity River			12	279					12	279
Brazos River			13	448					13	448
Colorado River (of Texas)			25	1,503					25	1,503
Guadalupe River			69	6,447					69	6,447
San Antonio River			6	215					6	215
Nueces River			3	36					3	36
Rio Grande			1	102	16	370	13	937	30	1,409
Pecos River			2	68	17	569			19	637
Minor streams (western Gulf of Mexico)	11	170							11	170

V. MISSISSIPPI RIVER (TRIBUTARIES FROM THE EAST).

Drainage basins.	Mississippi.		Alabama.		Georgia.		Tennessee.		North Carolina.		Virginia.		West Virginia.		Kentucky.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	69	3,756	265	105,091	153	2,296	2,160	95,060	926	21,366	850	19,958	529	11,572	834	14,156
Yazoo River																
Minor eastern tributaries, lower Mississippi River	61	709					62	796							4	67
Ohio River:																
Tennessee River	8	3,047	265	105,091	153	2,296	1,691	85,548	710	19,260	378	6,214			8	103
Cumberland River							397	8,576							284	4,431
Green River							10	140							205	3,634
Kentucky River															158	2,916
Licking River															52	928
Big Sandy River											20	261	20	320	91	924
Kanawha River									216	2,106	452	13,483	282	7,023		
Monongahela River													129	2,324		
Youghiogheny River													3	50		
Minor southern tributaries													95	1,855	32	1,153
Allegheny River																
Beaver River																
Muskingum River																
Scioto River																
Great Miami River																
Wabash River																
Minor northern tributaries																
Illinois River																
Rock River																
Wisconsin River																
Chippewa River																
St. Croix River																
Minor eastern tributaries, upper Mississippi River																

TABLE 2.—*Drainage basins in the United States*—Continued.

V. MISSISSIPPI RIVER (TRIBUTARIES FROM THE EAST)—Contiuued.

Drainage basins.	Pennsylvania.		Ohio.		Indiana.		Illinois.		Wisconsin.		Minnesota.		New York.		Maryland.		Total for drainage basins.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower	Wheels.	Horsepower.	Wheels.	Horsepower.
	530	16,849	682	26,291	298	11,525	413	50,116	1,048	139,640	100	15,925	87	3,167	15	312	8,959	537,080
Yazoo River																		
Minor eastern tributaries, lower Mississippi River																	127	1,572
Ohio River:																		
Tennessee River																	3,213	221,559
Cumberland River																	681	13,007
Green River																	215	3,774
Kentucky River																	158	2,916
Licking River																	52	928
Big Sandy River																	131	1,505
Kanawha River																	950	22,612
Monongahela River	18	262															147	2,586
Youghiogheny River	56	1,205													15	312	74	1,567
Minor southern tributaries	3	70															130	3,078
Allegheny River	331	8,146											87	3,167			418	11,313
Beaver River	121	7,154	44	2,320													165	9,474
Muskingum River			204	8,880													204	8,880
Scioto River			69	2,045													69	2,045
Great Miami River			187	8,245	27	1,224											214	9,469
Wabash River					238	9,993	4	72									242	9,665
Minor northern tributaries	1	12	178	4,801	24	465	6	118									209	5,396
Illinois River					9	243	222	36,162	29	893							260	37,298
Rock River							167	13,214	210	10,967							377	24,181
Wisconsin River									476	74,491							476	74,491
Chippewa River									157	24,976							157	24,976
St. Croix River									58	11,025	13	1,750					71	12,775
Minor eastern tributaries, upper Mississippi River							14	550	118	17,288	87	14,175					219	32,013

VI. MISSISSIPPI RIVER (TRIBUTARIES FROM THE WEST).

Drainage basins.	Louisiana.		Arkansas.		Texas.		Oklahoma.		New Mexico.		Colorado.		Kansas.		Missouri.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	22	273	255	5,868	5	67	29	2,994	13	251	146	26,279	184	18,606	397	10,107
Minnesota River																
Wapsipinicon River																
Des Moines River																
Missouri River:																
Big Sioux River																
James River																
Milk River																
Marias River																
Jefferson River																
Madison River																
Gallatin River																
Minor northern tributaries															38	938
Musselshell River																
Yellowstone River																
Little Missouri River																
Cheyenne River																
White River																
Niobrara River																
Platte River											126	21,803				
Kansas River											1	75	122	10,192		
Osage River													1	18	71	1,448
Minor southern tributaries													1	15	31	502
Arkansas River			74	1,100							19	4,401	22	1,205	194	5,874
Cimarron River:																
Canadian River							7	291	13	251						
Minor tributaries			108	3,797			4	160					38	7,176		
Red River	22	273	73	971	5	67	18	2,543								
Minor western tributaries Mississippi River															63	1,345

TABLE 2.—*Drainage basins in the United States*—Continued.

VI. MISSISSIPPI RIVER (TRIBUTARIES FROM THE WEST)—Continued.

Drainage basins.	Iowa.		Nebraska.		Wyoming.		Montana.		South Dakota.		Minnesota.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	461	17,304	227	12,792	55	3,585	162	140,494	68	11,112	361	82,007	2,385	331,739
Minnesota River											40	1,712	40	1,712
Wapsipinicon River	54	1,655											54	1,655
Des Moines River	27	1,360									3	198	30	1,558
Missouri River:														
Big Sioux River	8	261							15	3,115			23	3,376
James River									20	411			20	411
Milk River														
Marias River														
Jefferson River							38	20,619					38	20,619
Madison River							13	17,336					13	17,336
Gallatin River							6	405					6	405
Minor northern tributaries	62	2,274					44	67,215	11	231			155	70,658
Musselshell River														
Yellowstone River					19	1,389	26	6,224					45	7,613
Little Missouri River														
Cheyenne River					20	331			22	7,355			42	7,686
White River			1	30									1	30
Niobrara River			30	950									30	950
Platte River			74	5,572	16	1,865							216	29,240
Kansas River			89	5,156									212	15,423
Osage River													72	1,466
Minor southern tributaries			33	1,084			35	28,695					100	30,296
Arkansas River													309	12,580
Cimarron River:														
Canadian River													20	542
Minor tributaries													150	11,133
Red River													118	3,854
Minor western tributaries Mississippi River	310	11,754									318	80,097	691	93,196

VII. ST. LAWRENCE RIVER.

Drainage basins.	Minnesota.		Wisconsin.		Michigan.		Indiana.		Ohio.		Pennsylvania.		New York.		Vermont.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	20	46,800	619	81,276	1,498	205,019	197	17,628	191	8,549	20	715	3,380	578,692	971	79,604	6,896	1,018,283
Lake Superior	20	46,800	6	2,227	73	34,775											99	83,802
Lake Michigan			613	79,049	963	145,179	172	16,463									1,748	240,691
Lake Huron					213	13,878											213	13,878
St. Clair River					85	3,331											85	3,331
Lake Erie					164	7,856	25	1,165	191	8,549	17	593	129	4,838			526	23,001
Niagara River													103	191,426			103	191,426
Lake Ontario											3	122	2,025	209,368			2,028	209,490
Lake Champlain (Richelieu River)													373	50,345	971	79,604	1,344	129,949
Minor St. Lawrence tributaries													750	122,715			750	122,715

VIII. COLORADO RIVER.

Drainage basins.	Arizona.		New Mexico.		Colorado.		Wyoming.		Utah.		Nevada.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	37	16,855	10	1,120	194	51,662	5	132	38	4,656	1	3	285	74,428
Gila River	26	16,611	7	995									33	17,606
Williams River	1	9											1	9
Little Colorado River	8	185											8	185
San Juan River			3	125	45	18,260							48	18,385
Grand River					145	32,132			1	6			146	32,138
Green River					4	1,270	5	132	17	3,378			26	4,781
Fremont River									4	93			4	90
Virgin River									9	188	1	3	10	193
Minor tributaries	2	50							7	991			9	1,041

TABLE 2.—*Drainage basins in the United States*—Continued.

IX. SOUTHERN PACIFIC.

Drainage basins.	California.		Oregon.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	820	423,597	2	110	822	423,707
Minor streams	74	50,183			74	50,183
San Francisco Bay	11	6,455			11	6,455
Sacramento River	576	280,735	2	110	578	280,845
San Joaquin River	159	86,224			159	86,224

X. NORTHERN PACIFIC.

Drainage basins.	Oregon.		Idaho.		Wyoming.		Montana.		Washington.		California.		Nevada.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	586	231,203	261	60,533	6	138	42	7,558	475	147,041	176	25,440	7	252	*a* 1,553	*a* 472,165
Columbia River:																
Willamette River	299	92,531													299	92,531
Des Chutes River	17	60,832													17	60,832
John Day River	24	22,083													24	22,083
Snake River	55	35,771	186	36,402	6	138			28	4,728			7	252	282	77,291
Spokane River			70	23,176					33	14,473					103	37,649
Pend Oreille (Clark Fork)			2	600			37	6,838	7	237					46	7,675
Yakima River									52	8,838					52	8,838
Minor tributaries	55	10,176							186	33,099					241	43,275
Kootenai River			3	355			5	720							8	1,075
Puget Sound									139	84,270					139	84,270
Minor streams, northern Pacific	136	9,810							30	1,396	176	25,440			342	36,646

a Exclusive of Alaska, with 106 wheels, of 17,289 horsepower.

XI. GREAT BASIN.

Drainage basins.	Utah.		Nevada.		California.		Oregon.		Idaho.		Total.	
	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.	Wheels.	Horse-power.
	222	59,609	31	20,322	74	17,737	2	66	24	18,210	353	115,944
Wasatch Mountains drainage	222	59,609							24	18,210	246	77,819
Humboldt River			31	20,322			2	66			33	20,388
Sierra Nevada drainage					74	17,737					74	17,737
Minor streams in Great Basin												

XII. HUDSON BAY.

Drainage basins.	North Dakota.		Minnesota.		Total.	
	Wheels.	Horsepower.	Wheels.	Horsepower.	Wheels.	Horsepower.
	16	613	50	7,648	66	8,261
Red River of the North	16	613	50	7,648	66	8,261
St. Marys River						

UNDEVELOPED WATER POWERS.

By M. O. Leighton.

The surveys and examinations necessary to a thorough and accurate report of the water-power resources of the United States have never been completed. In certain parts of the country the facts are sufficiently well known to make it possible to present a tolerably accurate statement. In other parts the information is fragmentary, and therefore power estimates must be considered approximate. Taken as a whole, however, the schedule here appended will be sufficient for the purposes for which it was prepared.

In order to present the information in a systematic way, the drainage areas of the United States have been united into groups according to geographic distribution. These group boundaries have been arbitrarily determined according to what seems to be the most convenient arrangement for the purposes of this report. The grouping is as follows: Atlantic Ocean, Pacific Ocean, Arctic Ocean, and interior drainage. These groups have been subdivided into 12 principal divisions, as follows: I. Northern Atlantic; II. Southern Atlantic; III. Eastern Gulf of Mexico; IV. Western Gulf of Mexico; V. Mississippi River (tributaries from the east); VI. Mississippi River (tributaries from the west); VII. St. Lawrence; VIII. Colorado River; IX. Southern Pacific; X. Northern Pacific; XI. Great Basin; XII. Hudson Bay.

SOURCES OF DATA.

The data used in this report have been obtained from the following sources:

The records of flow are mainly from the reports and files of the water-resources branch of the United States Geological Survey. As the period over which these records extend varies in length, a seven-year period, extending from 1900 to 1906, inclusive, was taken as a basis and all values of flow are the mean for these years.

The profiles and elevations have been obtained as follows:

(*a*) River surveys made by the United States Geological Survey, U. S. Army Engineer Corps, and others.

(*b*) Elevations as given by railroad and other levels.

(*c*) Dictionary of Altitudes, Bulletin No. 274, United States Geological Survey.

(*d*) United States Geological Survey topographic maps.

(*e*) Miscellaneous maps and reports of various State and other organizations.

In the use of maps the following preferences have been given: (1) United States Geological Survey topographic sheets; (2) special detailed surveys; (3) General Land Office maps; (4) United States post-route maps; (5) Rand & McNally Atlas sheets.

WATER POWER.

The schedule presented in this report gives the amount of available water power according to three classifications—(1) that which may be produced by the minimum flow; (2) the assumed maximum development; and (3) the additional power that may be recovered by developing the available storage capacity in the upland basins and using stored water to compensate the low-water periods. The data as a whole have been considered without reference to present practicability of development or present market. For the purposes of this report it has been assumed that all the power in the United States will some day be required. Such an interpretation is the logical one when natural resources are being considered. In other words, the schedule here presented must be interpreted for the future rather than for the present. The reader should not assume that all the power here shown is economically available to-day. Much of it, indeed, would be too costly in development to render it of commercial importance under the present conditions of market and the price of fuel power. The schedule shows therefore what will be the maximum possibilities in the day when our fuel shall have become so exhausted that the price thereof for production of power is prohibitive, and the people of the country shall be driven to the use of all the water power that can reasonably be produced by the streams.

Consideration has been given to all the conditions that determine the possibilities of power production on the various rivers of the country. Especially has the slope of the stream channels been scrutinized. Theoretically, of course, the energy developed by the various rivers is that produced by the total fall of the water from source to mouth, but it has not been assumed that, even under ideal conditions of market, all this power will ever be commercially available. The flatter portions of the river channels can never be profitably developed for power and they have not been included in the schedule. The rivers have been divided into sections of varying length, determined by channel slope, and the fall and flow of each section have been obtained from the best available source of information. The records of stream flow collected by the water-resources branch of the Geological Survey have almost uniformly been the only available resort, although acknowledgments should be made to the state water-supply commissions of New York and Pennsylvania; the state engineers of New York, Colorado, California, Oregon, and Nebraska; the territorial engineer of New Mexico; the state geological surveys of Maine, New Jersey, North Carolina, Virginia, Georgia, and Wisconsin; and various other bodies and individuals, public and private, who in the past have maintained measurements in cooperation with the United States Geological Survey or independently. Use has also been made of certain river gage records of the United States Weather Bureau and of the Corps of Engineers, U. S. Army.

In determining the flow for the various sections the data of flow per square mile, procured from the sources above enumerated, have been applied. The drainage areas above the upper and the lower limits of each section have been determined and a mean taken for the whole section. This has been used as a factor along with the flow per square mile in determining the minimum flow for that section. This figure, together with 90 per cent of the total fall from head to foot, has been used to determine theoretical horsepowers, according to the usual formulas. It is obvious that in practice the entire fall along any stretch of river or at any power privilege can not be effectively utilized. In few places can even 90 per cent be utilized at the present time; but, inasmuch as these figures are supposed to cover future as well as present practice, and inasmuch as it may reasonably be assumed that future practice in water-power installation will improve, it is believed that 90 per cent of the fall along any particular power privilege or section may eventually be realized.

The results of calculations of theoretical power on 90 per cent total fall have been reduced 10 per cent to allow for inefficiency of wheels. It is recognized that 90 per cent efficiency is too high to be used in calculations of power at the present time, 75 or 80 per cent being the usual installation maximum. Here again, however, we are computing for future conditions, as well as present ones, and it may confidently be expected that, with the improvement of turbines, a greater percentage of the theoretical power will be realized on the shaft and improvements will before long render possible a 90 per cent efficiency.

In determining the minimum horsepower, the minimum flow for the lowest two consecutive seven-day periods in each year was determined and the mean of these values for the period of record was taken as the minimum flow. It is obvious that this is somewhat higher than the absolute minimum, but the latter is usually of so short duration that it does not equal the practicable minimum that may profitably be installed.

The assumed maximum economical development has been determined on the assumption that it is good commercial practice to develop wheel installation up to that amount the continuance of which can be assured during six months of the year, on the assumption that the deficiency in power during the remainder of the year can be profitably provided by the installation of fuel power plants as auxiliaries. In many parts of the country it has been shown conclusively that it is economical to develop up to that amount which can be had continuously during the highest four months of the year, and, while it is probable that there are parts of the country where the limit should be the highest eight or ten months, it is believed that the period used in these schedules is a very conservative average. The minimum weekly flow for each month of the year has been arranged according to magnitude, and the sixth value has been taken as the basis for estimating the power, the mean of these values for the record period in each case being that used in the computations.

An endeavor has been made to determine the maximum power that might be produced if the practicable maximum storage available on the drainage areas were established. Surveys on many of the basins make possible a fairly close statement; but, inasmuch as fully three-fourths of the country has not been surveyed in a manner suitable for this purpose, only rough estimates can be given for the entire area. There are two methods by which an approximate estimate of total power can be made.

The first is to consider the power on those drainage areas for which suitable surveys are available and to increase the amount by the equivalent of the proportion left unsurveyed. An examination of the facts will show that the amount obtained by this method will be too low. It is apparent from a review of the index map showing the areas covered by such surveys that a fairly large proportion, probably one-third, comprises country in which good reservoir sites are either lacking or are uncommon in occurrence. Such portions include large parts of the Dakotas, Nebraska, Kansas, Oklahoma, Texas, and Louisiana, together with great areas on the Atlantic and Pacific coastal plains. Therefore to increase the total available water power from storage that may be computed on surveyed portions by the ratio of total surveyed portions to the entire country would hardly do justice to the situation. Nevertheless, the figures are here presented.

It is found that the total power available in the surveyed portions, including storage, is about 53,000,000 horsepower. If this be considered as one-fourth, to correspond with the portion of the country surveyed, the total power of the country, with practical maximum storage will be about 212,000,000 horsepower.

The second method of computation involves consideration of the increase of power available from storage in the several portions of the country in which surveys have been made, and applying the ratio of increase to unsurveyed and similar country in those regions. The topographic surveys, while they cover only one-fourth of the total area of the country, have nevertheless been prosecuted in all sections, so that the storage data are applicable to all physiographic types that are comprised within the United States. Applying the information in this way, we obtain a grand total of 230,800,000 horsepower, which, it appears to the writer, is a more accurate figure than that obtained by the first method.

In any case, therefore, it may be assumed with confidence that, were all practicable storage sites utilized and the water properly applied, there might be established eventually in the country a total power installation of at least 200,000,000 horsepower and probably much more.

In the actual management of storage for water power or for any other water utilization the stored waters are released according as needed, and they must be distributed according to the condition of the river and the length of the dry season. Therefore, water from storage is required for a varying number of months, according to the climatological conditions governing the river discharge. Some assumption in this matter has been necessary, and it is believed from the experience that has been gained in the study of rivers throughout the country that it will be fair and conservative to assume that, if any given storage be considered as released uniformly during six months of the year, and the natural flow from the unconserved areas be considered as sufficient to maintain at least an equal flow during the remaining six months, the results will not depart too widely from the actual conditions as regards total power that may be achieved in practice, unless, indeed, they are too conservative. It is well known that on some rivers an economical use of stored water would involve a shorter period of total release than six months to insure the most uniform distribution of discharge. This would provide for a greater power development than the six months of distribution. Nevertheless, the latter has been considered a fair average, and has been used in the accompanying schedule.

Summing up the whole country according to the divisions thereof heretofore discussed, we obtain the general summary given below. Especial mention should be made of the fact that the results here given do not include the State of Pennsylvania, the figures for which had not been furnished up to the date of this report.

Estimate of stream flow and water power in the United States.

Principal drainages.	Drainage area in square miles.	Flow per annum in billion cubic feet.	Horsepower.	
			Minimum.	Assumed maximum development.
North Atlantic to Cape Henry, Va.	159,879	8,942	1,712,050	[a]3,186,600
Southern Atlantic to Cape Sable, Fla.	123,920	5,560	1,253,000	1,957,800
Eastern Gulf of Mexico to Mississippi River	142,220	6,867	559,000	963,000
Western Gulf of Mexico west of Vermilion River	[b]433,700	2,232	433,760	822,600
Mississippi River (tributaries from east)	333,600	12,360	2,619,590	[a]5,344,600
Mississippi River (tributaries from west, including Vermilion River)	905,200	9,580	3,948,970	7,085,000
St. Lawrence River to Canadian line	[c]299,720	8,583	6,682,480	8,090,000
Colorado River above Yuma, Ariz.	225,000	521	2,918,500	5,546,000
Southern Pacific to Point Bonita, Cal.	70,700	2,193	3,215,400	7,808,300
Northern Pacific	290,400	15,220	12,979,700	24,701,000
Great Basin	223,000	....	518,000	801,000
Hudson Bay	62,150	614	75,800	212,600
Total	3,269,490	72,672	36,916,250	66,518,500

[a] Not including area in Pennsylvania.
[b] Includes Rio Grande in Mexico.
[c] Includes drainage in Canada.

It will be noted from the foregoing that the region furnishing by far the greatest water-power possibilities is the northern Pacific, which comprises essentially the basins of Columbia and Sacramento rivers, the power possibilities there being about one-third those of the whole United States.

The following schedules give in detail figures concerning run-off and potential water power over the various drainage areas included within the several districts:

Estimate of stream flow and water power in the United States.

I. NORTHERN ATLANTIC.[a]

Stream.	States drained.	Drainage area (square miles).	Flow from area. Second-feet.	Flow from area. Second-feet per square mile.	Per annum. Depth in inches.	Per annum. Billion cubic feet.	Horsepower. Minimum.	Horsepower. Assumed maximum development.
St. Johns[b]	Maine	7,500	13,200	1.76	23.90	416	30,500	73,800
St. Croix	do	1,630	4,260	2.61	35.40	134	28,700	49,000
Penobscot	do	8,500	16,700	1.96	26.60	526	157,000	298,000
Kennebec	do	5,970	11,000	1.84	25.00	347	144,000	284,000
Androscoggin	Maine, New Hampshire	3,500	7,500	2.14	29.00	236	168,000	218,000
Presumpscot	Maine	600	1,010	1.68	22.80	32	(c)	(c)
Saco	Maine, New Hampshire	1,720	4,060	2.36	32.00	128	20,900	69,000
Merrimac	New Hampshire, Massachusetts	5,020	8,140	1.62	22.00	257	111,000	190,000
Connecticut	Vermont, New Hampshire, Massachusetts, Connecticut	11,100	22,100	1.99	27.00	697	230,000	491,000
Blackstone	Massachusetts, Rhode Island	(c)	....	(c)	(c)	(c)	5,280	12,700
Thames	Massachusetts, Connecticut, Rhode Island	(c)	....	(c)	(c)	(c)	14,400	28,600
Housatonic	New York, Massachusetts, Connecticut	1,980	4,300	2.17	29.40	136	43,100	66,200
Hudson	New York, Massachusetts, Vermont, New Jersey	13,400	25,400	1.90	25.80	802	298,000	473,000
Passaic	New York, New Jersey	949	2,060	2.17	29.40	65	10,000	22,000
Raritan	New Jersey	1,110	2,390	2.15	29.20	75	4,370	9,710
Delaware	New York, New Jersey, Pennsylvania, Delaware	13,100	25,800	1.97	26.70	814	....	....
Susquehanna	New York, Pennsylvania, Maryland	27,400	42,800	1.56	21.20	1,350	....	....
Potomac	Maryland, Virginia, West Virginia, Pennsylvania	14,300	17,300	1.21	16.40	545	176,000	462,000
James	Virginia	10,400	14,000	1.35	18.30	442	196,000	300,000
Minor streams (Chesapeake Bay)	Virginia, Maryland	12,800	20,300	1.59	21.60	640	43,300	82,000
Minor streams (northern Atlantic)	Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, Virginia.	18,900	41,200	2.18	29.60	1,300	31,500	57,600
Total	....	159,879	....	....	....	8,942	....	....

[a] St. Johns to Cape Henry, Va. [b] Drainage in United States only. [c] Included in minor streams (northern Atlantic).

II. SOUTHERN ATLANTIC.[a]								
Chowan	Virginia, North Carolina	5,000	7,000	1.40	19.00	221	5,100	10,100
Roanoke	do	9,740	12,200	1.25	17.00	385	205,000	343,000
Tar	North Carolina	4,360	5,500	1.26	17.10	174	4,000	8,000
Neuse	do	5,550	7,320	1.32	17.90	231	5,000	10,000
Cape Fear	do	9,030	11,100	1.23	16.70	350	40,000	80,000
Pedee (Yadkin)	North Carolina, South Carolina	10,600	16,900	1.60	21.70	533	222,000	334,000
Santee	do	14,800	24,500	1.66	22.50	772	400,000	590,000
Savannah	South Carolina, Georgia	11,100	17,500	1.58	21.40	552	290,000	438,000
Ogeechee	Georgia	5,140	6,530	1.27	17.20	206	4,300	10,700
Altamaha	do	14,100	17,700	1.26	17.10	558	57,600	94,000
Minor streams (southern Atlantic)	Virginia, North Carolina, South Carolina, Georgia, Florida	34,500	50,100	1.45	19.70	1,580	20,000	40,000
Total		123,920				5,560	1,253,000	1,957,800
III. EASTERN GULF OF MEXICO.[b]								
Suwanee	Florida, Georgia	9,970	15,000	1.50	20.40	473	(c)	(c)
Apalachicola	Alabama, Georgia, Florida	18,800	30,300	1.61	21.80	956	204,000	326,000
Mobile	Alabama, Georgia, Mississippi	42,100	66,200	1.57	21.30	2,090		
Tombigbee	Alabama, Mississippi						50,000	100,000
Alabama	Alabama, Georgia						275,000	487,000
Pearl	Mississippi, Louisiana	8,650	12,300	1.42	19.30	388	(c)	(c)
Minor streams (eastern Gulf of Mexico)	Florida, Alabama, Mississippi, Louisiana	62,700	93,800	1.50	20.40	2,960	30,000	50,000
Total		142,220				6,867	559,000	963,000
IV. WESTERN GULF OF MEXICO.								
Sabine	Texas, Louisiana	20,700	16,700	0.807	11.00	527	2,020	5,050
Trinity	Texas	17,700	9,370	.529	7.18	295	3,180	12,800
Brazos	Texas, New Mexico	48,800	9,760	.200	2.72	308	7,460	20,900
Colorado (Texas)	do	39,000	3,790	.097	1.32	120	28,100	55,700
Guadalupe	Texas	10,500	3,750	.357	4.84	118	36,000	43,400
Rio Grande[d]	Texas, New Mexico, Colorado	248,000	7,880	.032	.43	249	267,000	545,000
Pecos	Texas, New Mexico						55,000	87,800
Minor streams (western Gulf of Mexico)	Louisiana, Texas	49,000	19,500	.398	5.40	615	35,000	52,000
Total		433,700				2,232	433,760	822,650

[a] Cape Henry, Va., to Cape Sable, Fla.
[b] Eastern Gulf of Mexico included between Cape Sable, Fla., and Mississippi River.
[c] Included in minor streams (eastern Gulf of Mexico).
[d] Includes drainage area and flow in Mexico, but does not include power.

Estimate of stream flow and water power in the United States—Continued.

V. MISSISSIPPI RIVER (TRIBUTARIES FROM THE EAST).

Stream.	States drained.	Drainage area (square miles).	Flow from area: Second-feet.	Flow from area: Second-feet per square mile.	Flow from area: Per annum: Depth in inches.	Flow from area: Per annum: Billion cubic feet.	Horsepower: Minimum.	Horsepower: Assumed maximum development.
Mississippi [a]		1,238,800	696,400	0.562	7.63	21,940	147,000	335,000
Eastern tributaries lower Mississippi, below Missouri River (exclusive of Ohio).		42,800	50,100	1.17	15.90	1,580	15,000	30,000
Ohio	Kentucky, Tennessee, Mississippi, Maryland, Pennsylvania, New York, Ohio, Illinois, Indiana, Alabama, Georgia, North Carolina, Virginia, West Virginia.	204,000	270,000	1.32	17.90	8,500	[b] 40,000	[b] 100,000
Tennessee	Kentucky, Tennessee, Mississippi, Alabama, Georgia, North Carolina, Virginia.						1,210,000	1,950,000
Cumberland	Kentucky, Tennessee, Virginia						76,800	159,000
Green	Kentucky, Tennessee						11,400	28,500
Kentucky	Kentucky						18,100	45,100
Licking	do						5,360	13,400
Big Sandy	Kentucky, West Virginia, Virginia						21,700	57,600
Kanawha	West Virginia, Virginia, North Carolina						402,000	1,020,000
Monongahela	West Virginia, Pennsylvania						71,000	283,000
Minor southern tributaries (Ohio)	Tennessee, Kentucky, West Virginia, Pennsylvania						31,800	7,700
Allegheny	New York, Pennsylvania							
Beaver	Pennsylvania, Ohio						6,000	18,300
Muskingum	Ohio						16,500	53,100
Scioto	do						3,630	17,200
Great Miami	Ohio, Indiana						28,700	74,600
Wabash	Indiana, Illinois						40,600	119,000
Minor northern tributaries (Ohio)	Illinois, Indiana, Ohio, Pennsylvania						10,000	41,200
Eastern tributaries, upper Mississippi, above Missouri River.	Illinois, Wisconsin, Minnesota	86,800	72,300	.833	11.30	2,280		
Illinois	Illinois						167,000	261,000
Rock	Illinois, Wisconsin						20,800	46,400
Wisconsin	Wisconsin						121,000	244,000
Chippewa	do						99,000	238,000
St. Croix	Wisconsin, Minnesota						39,000	90,000
Minor eastern tributaries upper Mississippi (above Missouri River).	Illinois, Wisconsin, Minnesota						17,200	43,200
Total		333,600				12,360		

VI. MISSISSIPPI RIVER (TRIBUTARIES FROM THE WEST).

Western tributaries upper Mississippi (above Missouri River).	Minnesota, South Dakota, Iowa, Missouri	84,700	42,500	0.501	6.79	1,340		
Minnesota	Minnesota, South Dakota						17,300	46,600
Wapsipinicon	Iowa, Minnesota						4,380	10,700
Des Moines	do						59,800	222,000
Minor western tributaries upper Mississippi (above Missouri River).	Minnesota, South Dakota, Iowa, Missouri						132,000	275,000
Missouri [c]	Missouri, Louisiana, Minnesota, South Dakota, North Dakota, Montana, Wyoming, Colorado, Nebraska, Kansas.	527,000	[d]94,000	.178	2.41	2,960	300,000	600,000
Big Sioux	Iowa, Minnesota, South Dakota						21,600	38,900
Milk	Montana						30,000	50,000
Marias	do						55,600	75,400
Jefferson	do						317,000	482,000
Madison	do						216,000	276,000
Gallatin	do						94,000	126,000
Minor northern tributaries (Missouri).	Missouri, Iowa, North Dakota, South Dakota, Montana						170,000	230,000
Musselshell	Montana						23,100	26,400
Yellowstone	Montana, Wyoming						1,430,000	2,170,000
Niobrara	South Dakota, Nebraska						122,000	140,000
Platte	Nebraska, Wyoming, Colorado						290,000	657,000
Kansas	Colorado, Nebraska, Kansas						105,000	287,000
Osage	Missouri, Kansas						7,890	19,000
Minor southern tributaries (Missouri).	Missouri, Kansas, Nebraska, South Dakota, North Dakota, Montana.						190,000	360,000
Western tributaries lower Mississippi, below Missouri River (exclusive of Arkansas).	Missouri, Arkansas, Texas, Oklahoma	116,000	102,000	.880	11.90	3,220		
Arkansas	Arkansas, Missouri, Kansas, Oklahoma, Colorado, New Mexico, Texas.	177,500	65,500	.369	5.00	2,060	110,000	182,000
Cimarron	Oklahoma, Kansas, New Mexico, Texas						11,500	44,000
Canadian	Oklahoma, Texas, New Mexico						83,900	348,000
Minor tributaries Arkansas	Arkansas, Missouri, Kansas, Oklahoma, Colorado, New Mexico, Texas.						67,000	145,000
Red	Louisiana, Arkansas, Texas, Oklahoma						48,900	148,000
Minor western tributaries lower Mississippi (below Missouri River).	Minnesota, Iowa, Missouri						42,000	126,000
Total		905,200				9,580	3,948,970	7,085,000

[a] Includes all drainage from the Mississippi to Vermilion River, inclusive.
[b] Horsepower at Louisville, Ky.
[c] Includes flow but exclusive of power in Canada.
[d] Mean annual discharge 1879–1890, inclusive, from Annual Report Chief of Engineers, 1891, p. 3826.

Estimate of stream flow and water power in the United States—Continued.

VII. ST. LAWRENCE RIVER.[a]

Stream.	States drained.	Drainage area (square miles).	Flow from area.				Horsepower.	
			Second-feet.	Second-feet per square mile.	Per annum.		Minimum.	Assumed maximum develop-ment.
					Depth in inches.	Billion cubicfeet.		
St. Lawrence at Ogdensburg, N. Y		288,000	252,000	0.876	11.90	7,950		
Lake Superior	Minnesota, Wisconsin, Michigan	76,100	77,300	1.02	13.80		120,000	236,000
Lake Michigan	Michigan, Wisconsin, Illinois, Indiana	68,900	60,500	.878	11.90		246,000	356,000
Lake Huron	Michigan	68,900	60,000	.871	11.80		83,400	110,000
St. Clair	do	214,000	198,000	.926	12.60		3,380	6,760
Lake Erie	Ohio, Pennsylvania, New York, Michigan	[b] 40,800	22,000	[b] .540	7.33		28,000	62,300
Niagara	New York	255,000	220,000	.863	11.70		5,800,000	[c] 6,500,000
Lake Ontario [d]	do	33,000	32,100	.973	13.20		200,000	400,000
Lake Champlain (Richelieu River)	New York, Vermont	7,750	13,500	1.74	23.60	426	102,000	147,000
Minor St. Lawrence tributaries in New York (below Ogdensburg).	New York	3,970	6,550	1.65	22.40	207	99,700	272,000
Total		299,720				8.583	6,682,480	[e] 8,090,060

VIII. COLORADO RIVER.

Stream.	States drained.	Drainage area (square miles).	Second-feet.	Second-feet per square mile.	Depth in inches.	Billion cubicfeet.	Minimum.	Assumed maximum develop-ment.
Colorado River above Yuma, Ariz	Utah, Nevada, California, Arizona, New Mexico, Colorado, Wyoming.	225,000	16,500	0.0733	1.00	521	1,150,000	2,080,000
Gila	Arizona, New Mexico						72,500	241,000
Little Colorado	do						12,000	24,000
San Juan	Arizona, New Mexico, Utah, Colorado						149,000	341,000
Grand	Colorado, Utah						703,000	1,310,000
Green	Utah, Wyoming, Colorado						812,000	1,510,000
Minor tributaries	Arizona, New Mexico, Utah, Nevada, California						20,000	40,000
Total		225,000				521	2,918,500	5,546,000

IX. SOUTHERN PACIFIC.[f]

Stream.	States drained.	Drainage area (square miles).	Second-feet.	Second-feet per square mile.	Depth in inches.	Billion cubicfeet.	Minimum.	Assumed maximum develop-ment.
Minor streams (southern Pacific)	California	22,800	7,410	0.325	4.42	233	36,400	88,300
San Francisco Bay:								
Sacramento	California, Oregon	31,400	45,500	1.45	19.70	1,430	2,420,000	4,580,000
San Joaquin	California	[g] 16,500	[g] 16,800	[g] 1.02	[g] 13.80	[g] 530	[h] 759,000	[h] 3,140,000
Total		70,700				2,193	3,215,400	7,808,300

X. NORTHERN PACIFIC.[i]

Columbia [j]	Oregon, Idaho, Wyoming, Montana, Washington, Nevada	231,400	312,000	1.35	18.30	9,850	4,060,000	6,250,000
Willamette	Oregon						602,000	1,670,000
Des Chutes	do						953,000	1,920,000
John Day	do						79,700	158,000
Snake	Oregon, Washington, Idaho, Wyoming, Nevada						1,880,000	4,300,000
Spokane	Washington, Idaho						237,000	610,000
Pend Oreille (Clark Fork)	Idaho, Montana						1,530,000	2,620,000
Yakima	Washington						194,000	626,000
Kootenai	Montana, Idaho						207,000	357,000
Minor tributaries, Columbia	Oregon, Washington						718,000	1,230,000
Puget Sound	Washington	14,300	59,200	4.15	56.30	1,870	719,000	1,400,000
Minor streams, Northern Pacific	California, Oregon, Washington	44,700	111,000	2.48	33.60	3,500	1,800,000	3,560,000
Total		290,400				15,220	12,979,700	24,701,000

XI. GREAT BASIN.

Wasatch Mountains drainage	Utah, Wyoming, Idaho	44,300	7,620	0.172	2.33		92,000	149,000
Humboldt	Nevada	25,200	2,420	.096	1.30		20,000	30,000
Sierra Nevada drainage	California, Nevada, Oregon	[h] 55,900	[h] 18,900	[h] .338	[h] 4.58		[k] 396,000	[k] 607,000
Minor streams in Great Basin	California, Nevada, Utah, Oregon	97,600	10,100	1.03	1.40		10,000	15,000
Total		223,000					518,000	801,000

XII. HUDSON BAY.

Red (of the North) [l]	North Dakota, Minnesota	50,000	6,420	0.128	1.74	203	25,000	52,000
St. Mary	Montana	650	1,510	2.31	31.40	48	30,500	120,000
Rainy [m]	Minnesota	11,500	11,500	1.00	13.60	363	20,300	40,600
Total		62,150				614	75,800	212,600

[a] Values of drainage areas and discharge of the Great Lakes drainages derived chiefly from report of E. S. Wheeler, assistant engineer, U. S. Army. The discharge value is given for each of the Great Lakes as a unit from 1860 to 1892, and includes the run-off from both land and water surfaces. It shows the total discharge from both United States and Canadian territory.

[b] Includes Lake St. Clair.

[c] 3,500,000 horsepower at Niagara Falls on the basis of mean annual discharge.

[d] Includes Oswegatchie River and minor St. Lawrence tributaries above Ogdensburg, N. Y.

[e] Total horsepower of Niagara River and of tributaries to the Great Lakes in the United States.

[f] Southern Pacific included between Mexican line and Point Bonita, Cal.

[g] Exclusive of Tulare Lake drainage (see Sierra Nevada drainage).

[h] Includes Tulare Lake drainage.

[i] Northern Pacific included between Point Bonita, Cal., and Canadian line.

[j] Includes drainage area and flow in Canada, but does not include power.

[k] Does not include Tulare Lake drainage (see San Joaquin River).

[l] Includes drainage area and flow of Pembina and Mouse rivers in Canada, but does not include power.

[m] Drainage in United States only.

Estimate of stream flow and water power in the United States—Continued.

GENERAL SUMMARY.

Principal drainages.	Drainage area (square miles).	Flow per annum (billion cubic feet).	Minimum.	Assumed maximum development.
Northern Atlantic to Cape Henry, Va.	159,879	8,942	....	....
Southern Atlantic to Cape Sable, Fla.	123,920	5,560	1,253,000	1,957,800
Eastern Gulf of Mexico to Mississippi River	142,220	6,867	559,000	963,000
Western Gulf of Mexico west of Vermilion River	a 433,700	a 2,232	433,760	822,650
Mississippi River (tributaries from east)	333,600	12,360	....	....
Mississippi River (tributaries from west, including Vermilion River)	905,200	9,580	3,948,970	7,085,000
St. Lawrence River to Canadian line	b 299,720	b 8,583	6,682,480	8,090,060
Colorado River above Yuma, Ariz.	225,000	521	2,918,500	5,546,000
Southern Pacific to Point Bonita, Cal.	70,700	2,193	3,215,400	7,808,300
Northern Pacific	290,400	15,220	12,979,700	24,701,000
Great Basin	223,000	....	518,000	801,000
Hudson Bay	62,150	614	75,800	212,600
Total	3,269,489	72,672	....	....

a Includes Rio Grande in Mexico.

b Includes drainage in Canada.

IRRIGATION.

By F. H. Newell,
Director United States Reclamation Service.

LEGAL STATUS.

The National Government has passed three important laws for the encouragement of irrigation; (*a*) The desert land law, which was best adapted to individual enterprise in the development of comparatively small tracts of land by irrigation systems of moderate size; (*b*) the Carey Act, which was designed to encourage corporate irrigation of public land under state auspices; (*c*) the Reclamation Act, which provides for construction of irrigation works by the National Government itself. Enumeration was made by the United States census of the acreage irrigated in 1889, 1899, and 1902. With those figures as a guide, and by the use of the general information possessed by the Reclamation Service, an estimate has been made of the acreage irrigated in 1907. The results given in the following table include very large areas which receive only one or two irrigations by flood water, and others where the supply is inadequate.

Irrigation in the United States.

NUMBER OF FARMS IRRIGATED.

Year.	United States.	Arid region.	Semiarid region.	Rice region.
1907	[a] 167,200	152,000	7,800	7,400
1902	133,356	122,156	7,021	4,179
1899	110,117	102,819	4,897	2,401
1889	54,136	52,584	1,552	....

[a] Estimated.

NUMBER OF ACRES IRRIGATED.

Year.	United States.	Arid region.	Semiarid region.	Rice region.
1907	[a] 11,000,000	9,700,000	425,000	876,000
1902	9,681,289	8,471,641	405,449	600,199
1899	7,778,904	7,963,273	266,417	251,214
1889	3,631,381	3,564,416	66,965	....

[a] Estimated.

Irrigation by individual effort has been undertaken in each instance in a small way, but in the aggregate this method has led to the most important development and has resulted in the largest total acreage. It is also being developed to some extent by corporate enterprise, but results from this source are relatively meager, except where the corporations are of a community character. Cooperative communities have done much in the past and their future works will probably be important. Development by States under the provisions of the Carey Act promises well in some localities where there is efficient state supervision, as in Idaho, Wyoming, and Oregon; large results have already been accomplished in the first-named State. National development through the agency of the Reclamation Act is beginning to show results and is steadily proceeding. It has been confined mainly to those enterprises which are too large, too costly, or too slow in producing returns to tempt private or corporate investments.

The Reclamation Service has 29 projects in various stages of construction; these contemplate the ultimate irrigation of 2,700,000 acres, against a total acreage of 367,023 for which water was furnished in 1908. The following table shows the distribution of the projects, the total ultimate irrigable area under each, and the irrigated areas for 1908 and 1909:

Irrigation projects.

State.	Project.	Irrigable area.	Irrigated 1908.
		Acres.	*Acres.*
Arizona	Salt River	272,000	115,000
California	Orland	14,000	....
California-Arizona	Yuma	92,000	3,800
Colorado	Grand Valley	62,000	....
	Uncompahgre	147,000	15,600
Idaho	Minidoka	74,000	24,464
	Payette-Boise	315,000	55,000
Kansas	Garden City	8,500	5,558
Montana	Huntley	28,000	4,400
	St. Mary	....	....
	Sun River	256,000	....
Nebraska-Wyoming	North Platte	164,000	23,220
Nevada	Truckee-Carson	200,000	27,450
New Mexico	Carlsbad	20,000	8,000
	Hondo	10,000	1,500
	Rio Grande	180,000	17,000
North Dakota	Buford-Trenton	12,500	1,200
	Williston	12,000	2,000
North Dakota-Montana	Yellowstone	66,000	....
Oklahoma	Cimarron	....	....
Oregon	Umatilla	20,000	2,500
Oregon-California	Klamath	187,000	9,378
South Dakota	Belle Fourche	100,000	5,000
Utah	Strawberry	60,000	....
Washington	Okanogan	10,000	1,353
	Sunnyside	90,000	42,000
	Tieton	30,000	....
	Wapato	120,000	....
Wyoming	Shoshone	150,000	2,600
		2,700,000	367,023

Under the Carey Act there have been approved 1,716,424 acres for construction, and patents have been granted covering 293,083 acres.

The following table shows the location of the lands being irrigated under this act:

Segregations applied for under the act of August 18, 1894 (28 Stat. L., 372–422), and the acts amendatory thereof, with the action taken thereon, from the passage of the act to July 1, 1908.

[Areas in acres.]

State.	Selected.	Rejected, relinquished, etc.	Approved, not patented.	Approved and patented.
Colorado	59,807.94	5,704.95	54,102.99	....
Idaho	1,180,566.17	265,828.94	662,254.00	156,954.90
Montana	104,587.98	2,792.53	83,498.54	18,296.91
Nevada	12,644.61	8,000.00	....	....
Oregon	432,202.53	78,507.31	245,287.52	50,063.13
Utah	328,327.40	236,980.83	48,226.74	....
Washington	155,649.39	155,649.39	....	....
Wyoming	965,598.64	198,994.18	623,054.44	67,768.72
Total	3,239,384.66	952,458.13	1,716,424.23	293,083.66

Oregon segregation list No. 5, covering 58,344.57 acres, is now pending before the Secretary on appeal from the decision of the General Land Office rejecting it.

Wyoming segregation list No. 27, covering 26,936.03 acres, was rejected by the General Land Office, which decision was affirmed by the department, but said decision has not yet become final.

Irrigation under the Indian Service is rapidly increasing.

The extent to which the irrigated area in the arid and semiarid regions can be increased can not be accurately estimated with present knowledge. If all the run-off waters of the arid region could be conserved and employed in irrigation, the total area might, perhaps, be brought to nearly 60,000,000 acres. This is very uncertain, however, as our knowledge of run-off is confined to only a portion of the streams, and is incomplete; furthermore, such an estimate involves assumptions regarding the duty of water that may introduce large errors.

It is known, however, that large portions of the water of the arid region can not be used in irrigation, as no irrigable land exists upon which it can be brought at feasible cost. In general, it may be stated that the value of irrigated land is increasing, and certain developments are tending to decrease costs of construction, so that it is impossible to draw any approximate line of demarkation, even if we had full knowledge regarding present costs. This would require elaborate surveys, which have not been made. For these reasons any present estimate of the total irrigable area would necessarily be little better than a guess. With present data, the closest statement is probably between 40,000,000 and 50,000,000 acres, including that now under ditch.

The subjects of irrigation, forestry, navigation, power, domestic water supply, and drainage are all closely interrelated and should be thoroughly studied together, not only in the arid but in the humid regions. No one of these questions can be properly treated without full regard to all the others. Proper study of these comprehensive questions should include more extended observations of rainfall and evaporation, especially in high altitudes, and of the annual flow of all streams. Comprehensive topographic maps should be made showing the areas of drainage basins, the location of reservoir sites, and their relation in altitude and location to irrigable lands and to power and navigation resources. Such maps are the basic information most urgently needed for all land classification, and without them no wise policy can be adopted.

WATER LAWS.

Both state and national laws are incomplete in permitting and encouraging the settlement and improvement of lands which should be reserved for reservoir sites. Thorough surveys should be made and all feasible reservoir sites discovered and reserved for development.

The present laws in some States tend to promote irrigation, but in others they do not. The most primitive form of regulation of the use of water in irrigation is best exemplified by the present laws of the State of California. These declare the principles of priority and beneficial use, and provide that claims to the use of water shall be recorded in the form of a notice of appropriation, and shall be perfected by application to a beneficial use. At the same time they try to recognize as concurrent on the same stream rights derived by prior appropriation and rights depending on riparian ownership. The riparian doctrine of water rights should be definitely and permanently abrogated in all arid regions. This has been done in some States by constitutional provision and in some by judicial decision. In all the States of the arid region where the riparian doctrine is recognized, material modifications in the old common-law doctrine have been made and put into effect.

The form and theory of these laws have been developed by several of the States, elaborating upon the principles of the California laws and the methods established in that State.

The operation of the earlier forms of these laws places no restraint upon appropriations of water. The courts in passing upon the claims of the appropriators, having scant information concerning the amount of water available for use, with no guide to the quantities which should be applied in the cultivation of crops, and confronted with the excessive claims of the parties, have often adjudicated rights to the use of water many times in excess of the amount carried by the stream.

The knowledge obtained during recent years concerning the discharge of streams and the use of water has caused such decrees to become exceptional in present practice. Nevertheless, the need for a more careful regulation of the appropriation and use of water has been apparent for many years.

In 1890 the State of Wyoming enacted a code of water laws providing for supervision of the utilization of the water supply through a state engineer and state board of control who adjudicate rights to the use of water in the first instance. The division superintendents and water masters have immediate charge of the distribution of the water in the various water divisions.

Nebraska subsequently adopted a code of water laws similar to the laws of Wyoming.

Idaho, Utah, and Nevada in 1903 adopted codes of water laws based upon those of Wyoming with, however, a number of important modifications dictated by experience and the development of irrigation practice.

At the sessions of the legislatures of Oregon and Washington in 1903, the governors were directed to appoint commissions to prepare and submit drafts of a code of irrigation law.

At a joint session of the two commissions with the then chief engineer and other members of the Reclamation Service held in August, 1904, the fundamental principles of a modern irrigation code were discussed. There was also some consideration of the provisions which should be incorporated in such a code to facilitate the operations of the Federal Government in carrying on the work of constructing the irrigation systems contemplated by the act of Congress approved June 17, 1902 (32 Stat., 388), known as the Reclamation Act.

After this meeting, a state code of water laws was drafted by Mr. Morris Bien, supervising engineer of the United States Reclamation Service, which, in 1905, was adopted without material change by the legislatures of North Dakota, South Dakota, and Oklahoma. The legislatures of Oregon, Washington, and New Mexico adopted parts of this code, but omitted some of the most important features. This code does not involve any new principles, but constitutes a revision and combination of the features of the more modern statutes, arranged as a consistent and complete code.

PROPOSED WATER CODE.

A state code of water laws should provide for the appropriation, adjudication, and apportionment of the waters of the State, and divides itself naturally into four branches.

First. A declaration of the fundamental principles upon which the right to use water shall be based.

Second. The adjudication of rights to the use of water claimed under the previous laws, thus determining the unappropriated public waters.

Third. The regulation, control, and determination of the rights to water to be subsequently acquired.

Fourth. The regulation and control of the distribution of water, rights to the use of which have been established.

The code under discussion is arranged to provide appropriate procedure for the application of these principles.

Under the first heading the fundamental principles are few and well established, namely, that all the waters within the limits of the State belong to the public and are subject to appropriation for beneficial use, except from sources of supply which are navigable; that the prior appropriation of water shall be the basis, and beneficial use the measure and the limit of the right; that the use of water is a public use, and private parties may exercise the right of eminent domain for the utilization thereof; and that water used for irrigation shall be appurtenant to the land on which it is used.

Under the second heading, providing for the adjudication of rights claimed under prior laws, it is now generally conceded that the final adjudication must be by the courts. The codes of the different States contemplate various forms of procedure. In the code referred to, a state engineer, appointed for six years by the governor subject to confirmation by the Senate, is to make a complete hydrographic survey of a stream system, obtaining all the data necessary to determine the amount of water available and the rights of the parties entitled to the use of it. This material is turned over to the attorney-general of the State, who is required to enter suit promptly for the determination of the rights of all parties and to prosecute the same diligently to a conclusion. In all suits for the determination of the right to the use of the waters of any stream system, all who claim the right to use such waters shall be made parties. In all suits involving the determination of water rights, the attorney-general is required to intervene on behalf of the State, if in the opinion of the state engineer the public interest requires it.

The third subject, namely, that of the regulation, control, and determination of rights to the use of water to be acquired, is placed in the hands of the state engineer. The procedure proposed is substantially the same as that adopted in the other States having a modern irrigation code with some differences of detail.

The principal feature to be noticed is that before any work looking to the construction of an irrigable system is commenced, and after the state engineer has passed upon the form and substance of the application, the intention to appropriate the water shall be published in a newspaper circulated in the community. After such publication the state engineer will approve the application if no valid objection is presented.

When the construction is completed, the works are to be inspected and approved by the state engineer, who will then determine their capacity, which will limit the amount of the appropriation. Afterwards when the water is applied to a beneficial use, the state engineer makes a further inspection, whereupon he issues a license for the appropriation of the amount of water which has been applied to a beneficial use. A time limit is fixed for completion of construction and for beneficial use.

For the distribution of the water, which comes under the fourth branch, the States are divided by the law into water divisions by drainage areas, each under the supervision of a water commissioner appointed by the supreme court of the State. Their function being the distribution of water under judicial decree or appropriation, they may be regarded as, in a sense, officers of the court. The water commissioners with the state engineer constitute a board of water commissioners, of which the latter is president. The water commissioners each serve six years, their terms being so arranged that a new one is appointed every two years. This board has general supervision over the waters of the State.

The actual work of distributing the waters to those entitled to use them is performed by water masters appointed by the water commissioners with the approval of the state engineer. Each water master has charge of a water district set apart by the state engineer, as found necessary from time to time. The operations of the water master are under the supervision of the water commissioner, and their acts are subject to appeal to the state engineer.

The cost of the water distribution is borne by the water users. The general expenses of the state engineer and the water commissioners are paid by the State. The greater part, if not all, of this expense will be returned to the state treasury by the fees collected by the state engineer and by the repayment of the cost of hydrographic surveys by the parties to the suits for adjudication.

Special reference should also be made to the features of the draft relating to the work under the federal Reclamation Act.

In order that the State may obtain the full benefit of this work and to prevent serious interference with, and perhaps the entire abandonment of, the projects which are considered for investigation, it is provided that the water supply for such projects shall be reserved from general appropriation until the investigations of the Reclamation Service shall determine the precise amount required for the project, the remainder being then released from such reservation.

It is also provided that state lands coming under such project shall be disposed of in harmony with the plans for the disposition of the lands of the United States, and that lands required for the reclamation project for irrigation works shall be transferred to the United States without charge.

In all sales of state lands after the enactment of the code, the conveyance is to reserve right of way for ditches or canals constructed by authority of the United States.

The theory of these provisions is that the State regulates the appropriation of the water, exercising this power and holding the land in trust for the public, and when the interests of the public are so directly involved as in these large irrigation projects, and when, further, there is no element of individual speculation or profit in the construction of the works, which are for the purpose of establishing the maximum number of homes on the land, it is the duty of every State to which the Reclamation Act is applicable to assist with every resource under its control.

It will be of interest to review several of the other provisions of the draft.

Units of measurement are established; the cubic foot per second for the flow of water and the acre-foot for volume. The miner's inch is fixed as one-fiftieth of a cubic foot per second, unless a different ratio has been agreed upon by contract or established by actual measurement or use. The miner's inch has been used in some States as a unit, but it is unsatisfactory, because it is not easily defined with exactness.

The amount of water which may be appropriated for irrigation is limited to 1 cubic foot per second for 70 acres or its equivalent.

While it is conceded that water used for irrigation must be appurtenant to the land, the fact should be recognized that conditions may arise to make it impracticable or uneconomical to continue to irrigate a particular tract. Provision is made so that the use of water may be severed from the land after application to the state engineer, due publication of notice of such intention, and approval by the state engineer. Similar provision is made for a change in the nature of the use to which the water is applied, or in the place of diversion, storage, or use.

The subject of seepage water is one that has given much trouble, and provision is made for the appropriation thereof in the same manner as other waters, with the requirement that the appropriator must pay reasonable charges for storage or carriage to the owners of the irrigation works from which it comes, provided that the seepage can be traced to such works beyond reasonable doubt.

All decisions of the state engineer or water commissioners affecting a substantial right are subject to appeal to the courts.

RECENT STATE LAWS.

In the session of 1907 the Montana legislature considered a draft of a code prepared by a commission appointed by the governor which followed substantially the code referred to, but it was not adopted. The same is true with the legislature of Oregon.

During the year 1908 there has been a general movement toward the preparation of a code substantially in the form considered in the State of Oregon, and it is probable that it will be strongly urged upon the legislature early next year.

In many of the States statutes have been adopted tending toward the system discussed, and as this procedure is gradually enforced and modified as may be found advisable after experience, those States in which such laws have been enacted will do much toward the proper promotion of the irrigation industry.

It is generally conceded that those States in which statutes of this kind are not in force can best assist in the development of irrigation by following the principles and procedure there indicated.

One important feature of the law of irrigation has thus far received no attention in legislation, namely, the regulation of interstate waters. The decision of the United States Supreme Court in the Kansas-Colorado case (206 U. S., 46) and the decisions of some of the district courts of the United States in other cases, together with some decisions by state courts, have shown a tendency to consider this question, but in no case has there been an announcement of a principle which tends to meet the complicated conditions.

All the cases concerning interstate waters have involved only specific rights of the litigants; nothing has yet been accomplished outlining the method of providing for an adjudication of the waters of an interstate stream in such manner as to determine all the rights involved.

The principal difficulties arise from the fact that suit may be brought by one party against another and a decision obtained, which would not, however, bind anyone who is not party to the suit, and the complications in judicial procedure are such as to make it difficult, if not impracticable, under present conditions and rulings to bring into consideration in any one case all rights on interstate streams in two or more States and so arrange that one adjudication shall determine the rights of each party as against all other users of water from that stream.

Whether this matter can be adjusted by the courts themselves without the assistance of legislation or whether legislation is absolutely necessary has not yet been demonstrated.

It has been proposed by some that Congress should provide for a tribunal empowered to investigate claims to the use of water of interstate streams and to prepare reports upon all facts affecting priorities and the use of water, the same to be submitted to the federal courts for adjudication, following in general the procedure outlined in the proposed code in regard to the adjustment of water rights within the State.

UNDERGROUND WATERS.

By W. C. Mendenhall.

INTRODUCTION.

Underground waters constitute one of the three natural subdivisions of precipitation. These subdivisions are evaporation, surface run-off, and percolation. That part of the precipitation which passes below the soil surface by seepage into the soil pores becomes thereby a part of the body of underground waters. Eventually it is returned to the air to begin again its circuit through the air and back to earth. This return to the air may be accomplished very quickly or very slowly. Capillarity and evaporation may withdraw the earth moisture and return it to the atmosphere before it has reached any considerable depth in the soil mantle, or it may pass beyond the reach of these forces and begin a journey through the soil pores or the rock masses that may continue for a few hundred feet or a few hundred miles. The waters may even accumulate in a porous rock mass and may remain there stored and practically motionless for centuries or for geologic epochs. All of that portion of the precipitation that is absorbed and remains underground for either a long or a short period, following a long or a short course, constitutes the ground water. There is, in addition, a certain amount of original water, either magmatic or included with the sediments at the time of their deposition. The aggregate quantity of this is undoubtedly very great, but as it is in general inaccessible to man, little attention need be given it in a discussion of water as a resource.

An estimate of the quantity of surface waters is a large but a relatively simple problem. It can be solved by the patient application through long periods of well-determined engineering methods. The resulting estimates, since they are those of the engineer and the mathematician, are correct within a limited percentage of error, because all the factors of the problem are capable of close determination. But although the quantity of surface waters is measurable, its maximum possible use is not rigidly determinable, because that problem contains a number of variable factors. Man's mastery over the mechanic arts is constantly increasing. That which is impossible to him to-day becomes possible to-morrow. Furthermore, economic controls are constantly shifting. A water power that is not available this year, not because of unsolved mechanical problems, but because of cost, may be easily available next year, because a railroad has been built, or a mine has been opened, or population has shifted. These are things that neither the mathematician nor the economist can predict. They introduce into the problem of determining the possible future use of any resource a factor so variable that the result is of doubtful value. Suggestions only can be made; rigid determinations are not possible.

As to ground waters, neither the determination of the total quantity nor of the maximum use is capable of close solution. The first involves general estimates of factors not directly measurable, such as the percentage of pore space in deeply buried and inaccessible material, soils, and rocks. These estimates must be made by the deductions of an inexact science, geology, instead of through the measurements of an exact science, engineering. The same variables enter into the determination of the maximum possible use of ground waters as into the maximum possible use of surface waters, namely, different and constantly shifting economic controls. It may be highly profitable to pump ground waters 500 feet vertically for the irrigation of citrus lands in southern California whose product is worth $250 per acre per year, whereas it may not be possible to pump 50 feet vertically in another locality, where the products are not worth $10 per acre per year. Notwithstanding, some such crude estimate as may be made of the quantity of these resources is helpful, since it gives us a concrete conception of the amounts with which we are dealing.

QUANTITY.

Estimates that vary widely have been made as to the total amount of this ground water. These estimates range from an amount sufficient to cover the earth to a depth of 96 feet (Fuller) to an amount sufficient to cover it to a depth of 7,500 feet (Delesse). The lower estimate is the later and may be regarded as of the greater value. The determination of the total quantity of underground water in existence, however, while a question of scientific interest, is of no practical moment, since only a very small proportion of the total is accessible to man and can therefore be made use of by him. And again, of the relatively small amount that is within reach, only that proportion that, if withdrawn, will be restored annually can be utilized, because, obviously, withdrawals in excess of this mean reduction of the principal and eventual bankruptcy.

Hence, although impressive estimates of the total may be made—as, for instance, the statement that there are 600 cubic miles of potable ground waters beneath the State of Florida, 800 cubic miles in the Great Central Valley of California, 1,000 cubic miles in the Dakota sandstone aquifer, and 10,000 cubic miles in the sediments of the Atlantic and Gulf coastal plains—these statements are not merely valueless, they are sadly misleading, because, if issued without explanation, the inference would follow that such a tremendous amount of water could be extracted from these districts and used by man. This inference is wholly unjustified for a number of reasons. In the first place, only a limited although variable percentage of the water that saturates those parts of the rock or soil masses that are within reach of pumps can be extracted in development: the remainder, much the larger proportion, being capillary and subcapillary, is not capable of extraction in any commercial way.

Again, these estimates of total ground waters include those at great depth, utterly beyond the reach of any pumps or known devices for their recovery. And, finally, of the very small proportion of the total that can be brought to the surface and made useful to man, only an amount should be taken out that is equal to the annual restorations; otherwise there will be a gradual depletion of the supply and a corresponding increase in the cost of the product. Hence, as a practical people, we are not in the least concerned with the total quantity of ground waters, but only with the possible annual accessions to the total, for this controls use.

USE.

The use of ground waters in a limited way for domestic and farm supplies is well-nigh universal. Municipal use, although not so general, is also extensive; whereas use for irrigation, confined, of course, to the arid and semiarid States, has begun to attract attention only since power development, either by the utilization of the energy of running water or by means of small power plants of the steam or internal combustion type, has become general. With the imperfect data at hand it is not possible to estimate the total volume of ground waters now used throughout the United States, but it is believed that in Florida at least 2,000 second-feet are developed and in California more than one-half as much. The development in these two States, therefore, representing as they do more than the average development in the East and the West, is about 3,000 second-feet. Florida and California include about 7 per cent of the area of the United States. If the development throughout our domain can be regarded as on the average one-half as intense as in these two States, the total ground waters used if united in one stream would equal twice the volume of the Potomac at Point of Rocks, Md., in 1903, with a drainage area of 9,650 square miles, or if a smaller factor is used and the average intensity of development be regarded as one-third that of the two States named, we reach the conclusion that the ground waters now in use would make a river the size of the Colorado at Yuma, Ariz., with a drainage area of 225,000 square miles. Expressed in still another way, this volume is equal to somewhat less than 1 per cent of the total stream flow in the United States. It is to be clearly understood that this represents only artificial development, a direct product of man's activity, and does not include the natural springs which represent the unassisted return of ground waters to the surface. To these is due a very large although undetermined proportion of the low-water flow of all our streams.

PRESENT TENDENCIES.

One of the late phases of the irrigation movement involves the use of ground waters for this purpose. This movement has been inspired by the success of certain communities that have developed such waters and reclaimed a large acreage by their use. The southern California communities, one-half of whose irrigation is accomplished in this way, illustrate what can be done. In the San Joaquin Valley development of this type is under way and will inevitably be greatly extended. Three hundred second-feet of ground waters are now used there; probably 3,000 second-feet are available, and colonies are being continually established and individual settlers are constantly entering the valley who are reclaiming more and more acreage by the use of this resource. In other western valleys, as in Utah and in Arizona, development of the same type is under way. Among the famous ground-water districts is that of the Great Plains, east of the Rocky Mountains, underlain by the Dakota sandstone, that yields some of the largest flowing wells of the United States. Another important district includes parts of Minnesota, Iowa, and Wisconsin, beneath whose surface lie water-bearing beds older than the Dakota sandstone, but the beds are locally quite as important. In these latter States irrigation is not practiced, but the ground waters are of great importance as sources of domestic and municipal supplies. In the Eastern and Southern States, those of the Atlantic and Gulf coastal plains are most favorably situated in regard to their ground-water supplies and in them development is more intense than elsewhere in the East. Attention has already been called to Florida, in which nearly 2,000 second-feet of ground waters are developed, nearly one-half of this amount being used for irrigation and domestic purposes. Mississippi, Louisiana, and Texas have abundant underground supplies extensively drawn upon in certain localities, but capable of much more extensive use. Data are not at hand for estimating the amount withdrawn at present.

WASTE.

Attention is usually first centered upon the use of ground waters by the development of flowing wells in areas where they may be secured. The advantages of a supply of this type are many. The waters usually cost little, they are protected from contamination, the output is regular, at least until development becomes too intense for the supply, and the quality is constant. But in regions in which flowing waters are used for irrigation and may be procured at shallow depths the resource is often shamelessly wasted. More wells are drilled than are needed and the water is used during but a small portion of the year, but is nevertheless allowed to flow with consequent reduction of head and depletion of supply and often in addition direct damage to the lands upon which it wastes. This waste is not so serious in humid regions in which the loss is quickly replaced by rainfall, but it goes on with equal recklessness in arid and semiarid sections in which the damage is irreparable. This waste is often in direct violation of state statutes, framed especially to prevent it. Where ground waters do not flow out upon the surface but are developed by pumping, waste does not take place, since the cost of production regulates automatically the amount of water withdrawn. Irrigation practice under these conditions is always superior, as the water user, paying for each gallon that he applies to his land, reduces this amount to the lowest effective quantity in order to save cost. Hence almost invariably better results are obtained with a lower duty in districts where irrigation water must be pumped than in those in which it flows.

In the humid regions ground waters—almost everywhere available—are particularly useful as sources of farm, domestic, and municipal supplies and for certain industrial purposes. They are especially beneficial and of particularly good quality in the coastal plain of the Atlantic and Gulf States and in the glaciated regions where the mantle of drift or of unconsolidated sediments forms a reservoir of great capacity, whose supply is rapidly renewed when drawn upon because of the abundant rainfall. Outside the coastal plain and the drift-covered areas conditions are variable, but generally they are inferior to those in the regions named, because the soil mantle over the rocks is often thin and irregularly distributed and in addition is frequently clayey and of small holding capacity. Within either of these regions there may occur synclinal basins of porous rock like the St. Peter sandstone and associated beds in Minnesota or the Dakota sandstone in the Great Plains, both of which form most important reservoirs. Usually, also, the fractured upper surface of whatever rock lies immediately below the soil carries a supply that may be drawn upon by town and farm wells.

IMPORTANCE.

The importance of these supplies in humid regions to the dwellers there is illustrated by Mr. Frank Leverett's careful determination of the fact that 75 per cent of the population in Michigan are directly dependent for water upon the underground supply, and since the constancy of the lakes and the flow of the streams upon which the remaining 25 per cent depend is also related to the ground waters, the importance of these is really greater than the given percentage indicates. A recent investigation of 19 counties in north-central Indiana again indicates the vital relation that ground water bears to daily life. Of 54 communities in these 19 counties having public supplies, 45 use wells alone and 3 others use both streams and wells. The urban population is therefore largely dependent upon the subsurface supplies and the rural population depends almost entirely upon them. It is estimated that in Florida 750,000,000 gallons of ground waters are used daily for town and country domestic supplies, while an additional 11,500,000 gallons are used by the cities and 500,000,000 gallons for the irrigation of tobacco, citrus fruits, and vegetables. One-half of the irrigation and the greater part of the city supplies in southern California, amounting to more than 300,000,000 gallons daily, are drawn from the sands and gravels that underlie the valleys, while in central California a smaller but nevertheless important draft is made upon the same source.

These available facts, selected from widely scattered localities, indicate clearly that in addition to the almost universal dependence of the rural population upon underground waters for culinary and domestic purposes, an important and growing use is made of them for irrigation and for town supplies. It is probable that it would be safe to apply percentages but slightly less than that determined in the State of Michigan to the entire United States, and to state that nearly 75 per cent of our population depends directly upon underground waters.

RELATION TO STREAM FLOW.

The indirect dependence of mankind upon ground waters is difficult to determine. The greater part of the low-water flow of those of our streams that have no large lakes, swamps, or glaciers in their drainage basins is sustained by the slow escape from soil and rock and vegetable mulch of water that is stored there during rains and the melting of snow. An amount equivalent to the low-water flow is also contributed of course during high-water periods, so that only that part of the annual run-off of ordinary streams that is represented by the excess of flood flow over low-water flow is discharged directly from the surface, without joining the body of the percolating waters.

The remainder, for a longer or shorter part of its journey from the clouds to the sea, has been stored underground and the rate of its seaward passage thereby notably checked. The greater the proportion of precipitation within a drainage basin that joins the underflow, therefore, the more regular the streams of that basin. Areas of little or no underground storage are areas of violent floods and extreme droughts, while areas with a large proportion of underground storage are areas of slight floods and large and well-sustained low-water flow. Hence as a national policy all should be done that can be done to increase underground storage.

The factors that affect it favorably or adversely are many, and too few of them are within the control of man. Hence those that he can control should be used to the best possible advantage. Among these controlling factors are the character of the precipitation, the topography, including the steepness of slopes and of stream channels, the geology—that is, the character of the rocks and the soils—and finally the vegetation.

If the precipitation is violent and is concentrated within a short period, much less opportunity is afforded for its absorption than if the rain falls gently for a longer period. Brief violent storms are characteristic of our deserts where destructive floods are followed by long-continued droughts.

The effect of the topographic character of a drainage basin is obvious. There will be relatively little run-off from a perfect plain if the rocks or soil beneath it have absorptive capacity. In a region of steep slopes and stream channels of high gradient, on the contrary, water does not stand, and a comparatively slight precipitation will be followed promptly by a notable run-off, unless other favorable factors serve to prevent it.

The influence exerted by geology is also a powerful one. The type of rock, the presence and depth or the absence of soils derived from it, and the existence of a mantle of glacial drift often make the difference between a region well supplied with ground waters and drained by streams of regular flow and a region without ground waters and with most erratic and uncontrollable streams. Loose sandstones absorb water like sponges, to yield it slowly at some lower point, perhaps in a distant drainage basin. Cavernous limestones may offer tortuous underground passages through which water escapes slowly; the loose heaps of glacial débris permit but little surface escape, so thoroughly do they absorb the water that falls upon them. The deep mantle of decayed rock that covers many of our Southern States is equally effective in this respect. Polished glacial surfaces, on the contrary, such as exist in parts of the Sierra, shed water as effectively and promptly as a roof. Dense slates, fresh and unfractured granites, or close-grained metamorphic rocks absorb little or no water and contribute practically nothing to the underground supply.

Finally, the various cover growths are of the utmost importance in modifying absorption and run-off. Trees, brush, grasses, and growing crops act in many ways to this end. Everywhere the roots, penetrating the soil and decaying there, leave little channels for the circulation of the water; on mountain slopes and rocky areas they hold loose fragments of rock by their binding root systems and prevent them from being washed away so soon. The crevices about the rock fragments which are thus held become little storage reservoirs. The trees aid in making these crevices by the prying action of their roots and by the disintegrating action of the vegetable acids that are yielded by their decay. The various growths build up a porous absorptive soil by the litter which they shed and the rock sand which becomes enmeshed in their roots, and they protect the soil which thus accumulates and prevent it being swept away. Finally, they interfere directly with run-off by the obstacles which their roots, stems, and fallen leaves and branches offer to the flow of water over the surface. In all of these functions the immediate escape of rains as sudden floods is checked and their absorption, to be slowly released later, is encouraged. It is because of the full recognition of this part that forests play in the conservation of ground waters and the regulation of run-off that engineers and geologists who have made a special study of ground-water supplies and their relation to surface waters are such earnest advocates of the conservation and extension of forest cover.

LIMITATIONS AND METHODS.

Something has been said of the wide extent of ground waters, of their enormous aggregate volume, of the direct dependence of man upon them, of their critical relation to the more obvious stream flow, and of the growing recognition of their latent value and industrial possibilities. A word should be added as to the danger of exaggerating their utility or their practical quantity in some places and the complex problems involved in their utilization.

They are ultimately dependent upon rainfall. Therefore, like surface waters, they are less abundant in arid than in humid regions, and when used there they will be less rapidly renewed. But because of the greater need more attention is paid to them in the dry than in the wet States; they are more vigorously developed there and there is more danger that they may be overdrawn.

Many gravel-filled valleys west of the Rocky Mountains contain both surface and underground waters, not enough of either alone to irrigate all of the tillable lands, but when both are used together much more valuable than when either is used alone. Often power can be developed upon surface streams and this power applied to the recovery of the earth waters that saturate the lower valley lands. This mountain water coming down to the lands from above is made to lift the underground water to the lands from below—a most admirable combination and one excellently illustrated in the case of the Santa Ana River in southern California.

A part of the water of this river is stored in a reservoir in the San Bernardino Mountains and the flow of the stream thereby regulated. After it escapes from the reservoir it is diverted through a power plant and electric power is generated. Below the first power plant it is rediverted and passed through a second power plant. Below this it is all distributed and used for municipal and irrigation purposes about Redlands and Highlands. The waters that return from the irrigation are recovered in springs and flowing wells and by pumping plants, a portion of the power developed higher up on the stream being used for the latter purpose. This recovered water is used for irrigation about San Bernardino and Riverside. A part of it reappears in the river above Riverside Narrows, where it is again taken out into a power ditch whose waters are returned to the river above Corona. A few miles below it is picked up by canals and distributed to the orange and deciduous groves about Anaheim and Santa Ana. The portion of it that returns there, by irrigation, to the ground water is once more recovered by the many pumping plants and flowing wells west of Santa Ana in the lower coastal plain.

A single drop of water in its progress from the mountains to the sea, a distance of only 100 miles, may thus be used as many as eight times for power and irrigation. This is an almost ideal use of water. The combination of power development and the recovery of underground waters to supplement the surface flow results in a minimum of waste and a maximum of economy. Development of this type is being rapidly extended now over parts of the West and will receive still further extension in the future.

But care must always be taken not to tax too severely the underground basins from which the water is drawn. They are not by any means inexhaustible. When rainfall is light, the quantity of water returned to the reservoirs each year may be small, although the quantity stored there is large. However large it may be, if more is withdrawn each year than is replaced, there will be gradual lowering of the ground-water level and ultimate disaster. Therefore, users of ground waters in arid regions must study carefully the effects of development in order to be sure that they are not prospering during the present at the expense of disaster in the future. Furthermore, in many sections where water is badly needed ground waters do not exist. Residents of such sections, urged on by their need, do not always realize this, and attempts that are hopeless from the beginning are made to procure them. Each field is a particular problem with its own solution. General rules have only a limited application.

RELATIONS TO OTHER RESOURCES AND TO CONSERVATION.

Ground waters and surface waters are, of course, intimately related. All usable ground waters were first surface waters, although perhaps only momentarily, and the greater part of them eventually become surface waters again after their journey underground is completed. It is thus that they sustain stream flow during dry periods and so are closely related to power development and to irrigation, both of which are much more successful with a sustained and regular than with an erratic run-off.

Practically all vegetable life depends upon the existence of ground water. It sustains our crops and our forests and is in turn protected by them through functions already outlined. Seventy-five per cent of our population depends directly upon it, and an important additional percentage indirectly. It is used in irrigation, in industry, in transportation, in all the many activities of life. But, being one of the resources that is constantly renewed by natural processes, we need only exercise reasonable care in our use of it to have it to draw upon perpetually. There are districts in the United States, fortunately few in number and small in area, where the ground waters are being extracted faster than they are renewed. There are other areas in which they are being contaminated and rendered useless or harmful by the careless discharge of industrial waste or sewage or brines from deep wells. There are still other areas in which, through the stripping of the natural cover growths, the annual accessions to the supply are materially reduced. These conditions must be met and remedied; then nature, through her annual rainfall, will repair the harm, as yet slight, that has been done.

DENUDATION.

By R. B. Dole and H. Stabler.

INTRODUCTION.

The accompanying tables present estimates of the rate of denudation in the United States. The figures show the rate at which the earth's crust is being moved as solid particles carried in suspension by streams and as matter carried in aqueous solution. The first table is a summary of the estimated denudation for the whole United States and for the primary drainage basins; the other tables contain detailed estimates for smaller areas. The map indicates graphically the rates of denudation in different parts of the country.

SOURCES OF DATA.

The computations of denudation factors are based on figures representing the amount of mineral matter carried by streams, the size of the areas tributary to the streams, and the quantity of water discharged by the streams. The run-off data are derived principally from measurements made by the water-resources branch of the United States Geological Survey; some of the measurements, especially in lower Mississippi Valley and on the Great Lakes, were made by the Engineer Corps, U. S. Army; the Weather Bureau, Department of Agriculture, has contributed series of gage heights in several streams; and estimates of run-off based on the best available information have been made for areas regarding which no measurements are at hand. The estimates of the size of the drainage basins are either copied from printed reports or measured from the best available maps. The greater part of the chemical data are derived from complete mineral analyses of river waters, about 5,000 in all, performed for the water-resources branch under the direction of R. B. Dole by W. M. Barr, F. W. Bushong, C. K. Calvert, W. D. Collins, F. M. Eaton, J. R. Evans, P. L. McCreary, Chase Palmer, J. L. Porter, M. G. Roberts, F. C. Robinson, Walton Van Winkle, and A. J. Weith. Daily samples of water were collected for one year from about 150 rivers and lakes in California and in the States east of the one hundredth meridian. Ten consecutive samples were then united and the composites thus obtained were subjected to complete mineral analysis. The information regarding dissolved and suspended matter in the streams of the arid States, except California, has been furnished by the United States Reclamation Service from work done under the direction of W. H. Heileman, but unfortunately the detailed analyses could not be procured and therefore the comparative accuracy of the estimates is unknown. In the California and the Reclamation Service work 50 cubic centimeters of filtered and 50 cubic centimeters of unfiltered sample were evaporated, dried at 110° C., and weighed to determine suspended and dissolved solids. In the other analyses the suspended matter in 500 cubic centimeters of the sample was removed by filtration through a Gooch crucible, dried at 180° C., and weighed for suspended solids; the filtrate was then evaporated, dried at 180° C., and weighed for dissolved solids. Some error is introduced by comparing solids determined at 180° with solids determined at 110°. The size of the error varies with the amount of organic matter and water of crystallization present and with the character of the solids themselves, and is probably variable for different rivers and for the same river from time to time; consequently no correction for it has been made. In most cases, however, this circumstance introduces less than 10 per cent error.

The figures for Kennebec River are computed from analyses by G. C. Whipple and E. C. Levy. The dissolved solids for Connecticut River and for Housatonic River are from reports of the Connecticut state board of health; for Merrimac River, from reports of the Massachusetts state board of health; for Blackstone River, from reports of the Rhode Island state board of health. The data for Hudson River at Albany, N. Y.; Potomac River at Great Falls, Md.; and Allegheny River at Pittsburg, Pa., are from reports of water-supply investigations at those places. The figures for Colorado River at Yuma, Ariz., are computed from analyses by R. H. Forbes and from others made in continuation of his work by the Reclamation Service. The data for Ohio River at Louisville, Ky., and at Cincinnati, Ohio, are quoted from reports by G. W. Fuller. The data at West Alton and at Jefferson Barracks, Mo., are quoted from analyses by A. W. Palmer in connection with the case of the State of Missouri against the State of Illinois and the sanitary district of Chicago. The estimates of suspended and dissolved solids at New Orleans, La., are computed from fifteen years' sediment determinations by the Engineer Corps, U. S. Army, and from five years' determinations by the New Orleans water and sewerage board. In all the quoted analyses the estimates are given by weight and not by volume, and in nearly all cases they show the average condition of the water for one or more years.

METHODS OF COMPUTATION.

The estimates of denudation, computed from the above-mentioned data by H. Stabler, indicate the removal in solution and suspension of solids from the primary and secondary drainage basins of the United States as classified by the Geological Survey. The determinations on which the computations are based are given in detail. The eleven primary basins are designated by Roman numerals. Under the secondary basins, which are designated by Arabic figures, important tributaries and the sampling stations are indicated.

The second, third, fourth, and fifth columns of the tables give, respectively, the areas of the basins, the dissolved solids, the suspended solids, and the annual run-off per square mile. In columns 6 and 7 the annual denudation in tons per square mile for the areas above the points at which samples were collected is computed by multiplying together solids in parts per 1,000,000, run-off in second-feet per square mile, and 0.985; in all other regions the denudation is estimated from the data for known areas. Columns 8 and 9 show the total denudation in thousands of tons per year, computed for the secondary areas by multiplying denudation in tons per square mile per year by the drainage area in thousands of square miles.

The depth in millionths of an inch per year covered by the material removed is found by dividing the tons per square mile per year by 0.1917 and the last three columns bear reciprocal relations to columns 10, 11, and their sum. Any attempt to estimate erosion in volumetric terms from determinations of dry suspended matter and dissolved solids involves the use of factors which are by no means absolute. The actual specific gravity of the mineral substance carried in streams in the United States is not greatly different from 2.6. This figure is practically identical with that commonly assumed for the specific gravity of the earth's crust and corresponds to a weight of 165 pounds per cubic foot. Each 165 pounds of substance found in water, therefore, represents the erosion of approximately 1 cubic foot of the crust of the earth, and estimates of ultimate rock losses based upon these figures are probably not in error more than 8 or 10 per cent. Common earth or loam, however, contains a large amount of air space, or voids, and dry earth is estimated as weighing 80 to 110 pounds per cubic foot. If an estimate of erosion be made upon this basis the error for a large area will probably not be great, but may amount to 20 per cent or more when calculations are made for small areas. Finally a third factor for calculation is based upon an attempt to determine the volume of river sediment or mud banks that a given weight of suspended matter may form. Investigators working upon different streams in the United States have obtained results indicating that a cubic foot of sediment may be produced by 50 to 125 pounds of dry material. The compactness of the mud is so variable that an estimate of this nature based upon an average of 90 pounds per cubic foot is likely to be in error by about 45 per cent. In view of the widely divergent values given for river sediment and for surface loam, the estimates for denudation expressed in millionths of an inch in depth from the entire drainage area and in years required for the erosion of 1 inch from the drainage area are based upon the assumption that 165 pounds of suspended or dissolved solids represent the removal of 1 cubic foot of the earth's crust. The factor 0.1917 has been computed on that basis. For the convenience of those who prefer a different basis of calculation, the following table of ratios is presented. The figures given in this report for denudation in inches can be recomputed by dividing them by the ratio corresponding to the weight given in column 1.

Ratios for recomputing denudation in inches.

Weight of material per cubic foot.	Corresponding specific gravity.	Ratio.
Pounds.		
165	2.64	1.00
150	2.40	.91
140	2.24	.85
130	2.08	.79
120	1.92	.73
110	1.76	.67
100	1.60	.61
90	1.44	.55
80	1.28	.49
70	1.12	.42
60	.96	.36
50	.80	.30

The estimates for the primary basins and for the whole United States are based upon the estimates for the secondary areas.

PROBABLE ACCURACY.

The majority of the figures for run-off per square mile per year are based upon discharge measurements extending over periods of seven years or more and are, with a few exceptions, within 10 per cent of the true average values. The drainage areas in square miles are so nearly correct that their errors are negligible in these calculations. The estimates of dissolved solids represent the average condition of the water for a period of one year or more. By comparison of annual averages for several streams in different years it has been estimated that the average for one year is generally not over 10 per cent from the correct average value, and it is undoubtedly true that the average total solids does not vary from year to year nearly so much as the average run-off. On the other hand, suspended solids are subject to greater variation than run-off. Floods are always attended by extreme rises in suspended solids, and the amount of suspended matter is subject to enormous variation from place to place on account of changes in stream velocity, the character of the river bed, and other features. In consequence of these facts, it is possible that denudation estimates, based on average suspended matter for one year, may be in error as much as 50 per cent. When all these facts are considered in conjunction with the distance of the sampling stations from the mouths of the rivers, it may be estimated that the calculated figures for denudation are generally within 20 per cent of the true values. Only two significant figures, therefore, have been retained in the last five columns. In many streams of the arid and semiarid regions the yearly fluctuations in run-off are very great and the mineralization of the waters is very high, so that estimates of denudation in that part of the country are not so reliable as similar estimates for eastern rivers. As the analytical data for the northern Pacific, Hudson Bay, and western Gulf of Mexico basins are extremely meager, the estimated denudations for those areas may be more than 20 per cent in error, and further investigations in those regions must be made before reliable values can be calculated.

DISCUSSION OF SUMMARY.

The summary presents in tabular form denudation estimates for the primary drainage basins and for the whole United States. The figures for dissolved solids practically represent material carried into the ocean; the figures for suspended solids, on the other hand, represent more properly material carried to tide water, because the decrease in stream velocity at that point occasions a gradual deposition of the matter transported in solid form. The tons per square mile per year removed from different basins show interesting comparisons. In respect to dissolved matter, the southern Pacific basin heads the list with 177 tons, the northern Atlantic basin being next with 130 tons. The rate for Hudson Bay basin, 28 tons, is lowest; that for the Colorado and western Gulf of Mexico basins is somewhat higher. The denudation estimates for the southern Atlantic basin correspond very closely to those for the entire United States. The amounts are generally lowest for streams in the arid and semiarid regions, because large areas there contribute little or nothing to the run-off. The southern Pacific basin is an important exception to this general rule, presumably because of the extensive practice of irrigation in that area. The amounts are highest in regions of high rainfall, though usually the waters in those sections are not so highly mineralized as the waters of streams in arid regions.

Colorado River brings down the most suspended matter, delivering 387 tons per year for each square mile of its drainage basin. Though many small streams bring silt into the Great Lakes, sedimentation clears the water, and practically no suspended matter is transported by St. Lawrence River. In general much less suspended matter is carried by northern than by southern rivers, a phenomenon influenced probably more by the texture of the soil and the subsoil and the geologic character of the rocks than by stream velocity.

The detailed estimates throw considerable light upon the progress of erosion in different sections of the river valleys. The Mississippi, for instance, apparently discharges more material than is brought in by its tributaries, thus indicating that its lower valley is still being eroded. The lower Colorado, however, appears to be receiving deposits from both dissolved and suspended matter taken from its upland drainage area. The Rio Grande is similar to the Colorado in this respect.

The estimates reveal that the surface of the United States is being removed at the rate of thirteen ten-thousandths of an inch per year, or 1 inch in 760 years. Though this amount seems trivial when spread over the surface of the country, it becomes stupendous when considered as a total, for over 270,000,000 tons of dissolved matter and 513,000,000 tons of suspended matter are transported to tide water every year by the streams of the United States. This total of 783,000,000 tons represents more than 350,000,000 cubic yards of rock substance, or 610,000,000 cubic yards of surface soil. If this erosive action had been concentrated upon the Isthmus of Panama at the time of American occupation, it would have excavated the prism for an 85-foot level canal in about seventy-three days.

Summary.

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dis-solved.	Sus-pended.		Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Total.
I. Northern Atlantic	159,400	......	......	......	130	39	20,800	6,100	680	200	1,500	5,000	1,100
II. Southern Atlantic	123,900	......	......	......	94	176	11,700	21,800	490	920	2,000	1,100	710
III. Eastern Gulf of Mexico	142,100	......	......	......	117	144	16,600	20,400	580	750	1,700	1,300	750
IV. Western Gulf of Mexico	315,700	......	......	......	36	72	11,400	22,700	190	380	5,300	2,700	1,800
V. Mississippi River	1,265,000	......	......	......	108	269	136,400	340,500	560	1,400	1,800	710	500
VI. Laurentian Basin	175,000	......	......	......	116	1	20,400	180	600	5	1,700	200,000	1,610
VII. Colorado River	230,000	......	......	......	51	387	11,700	89,000	270	2,000	3,800	500	440
VIII. Southern Pacific	72,700	......	......	......	177	75	12,800	5,500	920	390	1,100	2,600	760
IX. Northern Pacific	270,000	......	......	......	100	20	27,000	5,400	520	100	1,900	9,600	1,600
X. Great Basin	223,000	......	......	......	90	50	20,100	11,200	470	260	2,100	3,800	1,400
XI. Hudson Bay	62,000	......	......	......	28	21	1,700	1,300	150	110	6,800	9,100	3,900
Total	3,048,800	......	......	......	......	......	290,600	524,080	......	......	......	......	......
The United States	3,088.500	......	......	......	94	170	290,600	524,080	490	890	2,040	1,130	730
The United States (Great Basin denudation being taken as zero)	3,088,500	......	......	......	87	166	270,500	512,880	460	870	2,190	1,150	760

Detailed estimates.

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dis-solved.	Sus-pended.		Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Total.
I. Northern Atlantic	159,400				130	39	20,795	6,147	680	200	1,500	5,000	1,100
1. St. Johns (in United States)	7,500			1.76	85	7	638	53	440	37	2,300	27,000	2,100
2. St. Croix (in United States)	1,100			2.61	100	8	110	9	520	42	1,900	24,000	1,800
3. Penobscot	8,500			1.96	90	8	765	68	470	42	2,100	24,000	2,000
4. Kennebec	5,970			1.84	85	7	508	42	440	37	2,300	27,000	2,100
Waterville, Me.	4,270	48	4.0	1.76	83	7.3							
5. Androscoggin	3,500			2.14	100	8	350	28	520	42	1,900	24,000	1,800
Brunswick, Me.	3,500	48		2.14	101								
6. Presumpscot	600			1.68	85	7	51	4	440	37	2,300	27,000	2,100
7. Saco	1,720			2.36	100	8	172	14	520	42	1,900	24,000	2,100
8. Merrimac	5,020			1.62	65	7	326	35	340	37	3,000	27,000	2,700
Lawrence, Mass.	4,550	41		1.58	64								
9. Connecticut	11,100			1.99	90	8	999	89	470	42	2,100	24,000	2,000
Goodspeeds, Conn.	10,900	45		1.99	88								
10. Blackstone	460				125	7	58	3	650	37	1,500	27,000	1,500
Valley Falls, R. I.	440	74		1.71	125								
11. Thames	1,450				125	7	181	10	650	37	1,500	27,000	1,500
12. Housatonic	1,980			2.17	195	8	386	16	1,000	42	980	24,000	940
Gaylordsville, Conn.	1,020		4.0	2.15		8.5							
Derby, Conn.	1,920	92		2.15	195								
13. Hudson	13,400			1.90	190	30	2,544	402	990	160	1,000	6,400	870
Albany, N. Y.	8,800	107	17.0	1.80	189	30							
Hudson, N. Y.	9,530	108	16.0	1.82	193	29							
Mechanicsville, N. Y.	4,500			1.81									
Dunsback Ferry (Mohawk River)	3,440			1.73									
14. Passaic	950			2.17	180	75	171	71	940	390	1,100	2,600	750
15. Raritan	1,110			2.15	180	75	200	83	940	390	1,100	2,600	750
Bound Brook, N. J.	800	85	36.0	2.14	179	76							
16. Delaware	13,100			1.97	150	55	1,964	721	780	290	1,300	3,500	940
Lambertville, N. J.	6,860	70	26.0	2.19	151	56							
17. Susquehanna	27,400			1.56	165	35	4,520	960	860	180	1,200	5,500	960
Danville, Pa.	11,070	112	21.0	1.71	188	35							
Williamsport, Pa.	5,640	74	18.0	1.68	123	30							
18. Potomac	14,300			1.21	125	95	1,787	1,358	650	500	1,500	2,000	870
Piedmont, W. Va.	410			1.70									

Detailed estimates—Continued.

Drainage basin.	Physical and chemical data.				Estimated denudation.									
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.			
		Dis-solved.	Sus-pended.		Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Total.
I. Northern Atlantic—Continued.													
18. Potomac—Continued.													
Cumberland, Md	620	130	29.0	1.70	217	49							
Millville, W. Va. (Shenandoah River)	3,000	140	39.0	1.07	147	41							
Point of Rocks, Md	9,650			1.07									
Great Falls, Md	11,400	115	85.0	1.12	127	94							
19. James	10,400			1.35	115	95	1,195	988	600	500	1,700	2,000	900
Cartersville, Va	6,230			1.33									
Richmond, Va	6,820	89	71.0	1.33	117	93							
20. Minor Chesapeake Bay	12,800			1.59	130	40	3,870	1,193	680	210	1,500	4,800	1,100
21. Minor North Atlantic	17,000			2.18									
II. Southern Atlantic	123,900				94	176	11,688	21,775	490	920	2,000	1,100	710
1. Chowan	5,000			1.40	85	80	425	400	440	420	2,300	2,400	1,200
2. Roanoke	9,750			1.25	101	256	984	2,490	530	1,300	1,900	750	540
South Boston, Va. (Dan River)	2,750	71	264.0	1.34	94	348							
Randolph, Va	3,080	79	127.0	1.39	108	174							
3. Tar	4,360			1.26	85	80	371	349	440	420	2,300	2,400	1,200
4. Neuse	5,550			1.32	86	80	477	444	450	420	2,200	2,400	1,200
Raleigh, N. C	1,000	73	68.0	1.19	86	80							
Selma, N. C	1,170			1.19									
5. Cape Fear	9,030			1.23	69	25	623	226	360	130	2,800	7,700	2,000
Wilmington, N. C	9,030	57	21.0	1.23	69	25							
6. Pedee (Yadkin)	10,600			1.60	113	154	1,198	1,630	590	800	1,700	1,200	720
Salisbury, N. C	3,400			1.69									
Pee Dee, N. C	6,100	69	94.0	1.66	113	154							
7. Santee	14,800			1.66	107	233	1,583	3,445	560	1,200	1,800	820	560
Camden, S. C. (Wateree River)	4,500	73	214.0	1.44	104	303							
Waterloo, S. C. (Saluda River)	1,060			1.85									
Columbia, S. C. (Saluda River)	2,350	62	54.0	1.85	113	98							
8. Savannah	11,100			1.58	98	232	1,088	2,575	510	1,200	2,000	830	580
Augusta, Ga	7,300	60	142.0	1.66	98	232							

9. Ogeechee	5,140			1.27	90	225	463	1,156	470	1,200	2,100	850	610
10. Altamaha	14,100			1.26	85	215	1,198	3,030	440	1,100	2,300	890	640
Macon, Ga. (Ocmulgee River)	2,420	69	174.0	1.31	86	224							
Dublin, Ga. (Oconee River)	4,180	68	171.0	1.24	83	209							
11. Minor South Atlantic	34,500				95	175	3,278	6,030	500	910	2,000	1,100	710
III. Eastern Gulf of Mexico	142,100				117	144	16,610	20,430	580	750	1,700	1,300	750
1. Suwanee	9,970			1.50	100	150	997	1,500	520	780	1,900	1,300	770
2. Apalachicola	18,800			1.61	103	159	1,936	2,988	540	830	1,900	1,200	730
Albany, Ga. (Flint River)	5,000	67	58.0	1.56	103	89							
West Point, Ga. (Chattahoochee River)	3,300	52	136.0	1.98	102	265							
3. Mobile	42,100			1.57	129	151	5,190	6,350	670	790	1,500	1,300	680
Selma, Ala. (Alabama River)	15,400	82	100.0	1.81	146	178							
Epes, Ala. (Tombigbee River)	8,830	94	100.0	1.06	98	104							
4. Pearl	8,650			1.42	75	58	649	502	390	300	2,600	3,300	1,400
Jackson, Miss.	3,120	59	46.0	1.29	75	58							
5. Minor Eastern Gulf	62,700			1.50	125	145	7,838	9,090	650	760	1,500	1,300	710
IV. Western Gulf of Mexico	315,700				36	72	11,370	22,740	190	380	5,300	2,700	1,800
1. Brazos	48,800			.200									
Waco, Tex.	32,300	1,136	1,188.0	.082	92	96	2,970	3,100					
2. Colorado (of Texas)	39,000			.097	24	26							
Austin, Tex.	35,000	321	351.0	.075	24	26	878	952					
3. Rio Grande	248,000			.032									
United States area	130,000				25	78	3,250	10,140					
El Paso, Tex.	38,600	700	14,140.0	.030	21	418							
Laredo, Tex. (United States area)	123,000	791	2,475.0	.032	25	78							
Pecos River	56,000				90	60							
Dayton, N. Mex.	16,300	2,988	2,150.0	.032	94	68							
Carlsbad, N. Mex.	19,800	2,680	331.0	.035	92	11							
V. Mississippi River:													
1. Main stream—													
Minneapolis, Minn.	19,600	200	7.9	.810	159	6.3	3,120	124	830	33	1,200	30,000	1,200
Quincy, Ill.	135,500	203	119.0	.538	108	63							
Jefferson Barracks, Mo.	700,700	206	964.0	.263	53	250							
Menard, Ill.	711,900	269	634.0	.263	70	164							
Memphis, Tenn.	941,000	202	519.0	.546	109	279							
New Orleans, La.	1,261,000	190	600.0										
At mouth	1,265,000			.560	105	331							
2. Minor lower eastern— Tributaries	29,000				80	60	2,320	1,740	420	310	2,400	3,200	1,400
3. Ohio River	214,000				190	200	40,600	42,750	990	1,000	1,000	960	490
Tennessee River	39,000				159	200							
Chattanooga, Tenn.	21,400			1.71									
Gilbertsville, Ky.	38,400	101	127.0	1.60	159	200							
Cumberland River	18,600				171	227							
Kuttawa, Ky.	18,200	124	165.0	1.40	171	227							

Detailed estimates—Continued.

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dissolved.	Suspended.		Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Dissolved.	Suspended.	Total.
V. Mississippi River—Continued.													
3. Ohio River—Continued.													
Green River	8,580				165	225							
Kentucky River	7,870				164	220							
Frankfort, Ky	5,140	104	142.0	1.60	164	223							
Licking River	3,300				160	220							
Big Sandy River	4,000				160	200							
Kanawha River	11,000				160	180							
Monongahela River	7,620				217	203							
Elizabeth, Pa	5,580	81	84.0	1.80	143	149							
McKeesport, Pa. (Youghiogheny River)	1,770	197	163.0	2.30	446	369							
Allegheny River	11,100				160	60							
Kittanning, Pa	8,690	87	30.0	1.62	139	48							
Brilliant, Pa	11,000	116	48.0		185	77							
Beaver River	.3,100				180	65							
Muskingum River	7,740				232	67							
Zanesville, Ohio	5,830	244	70.0	.966	232	67							
Scioto River	6,400				220	68							
Great Miami River	5,400				210	68							
Dayton, Ohio	2,450	289	94.0	.737	210	68							
Wabash River	33,000				249	86							
Terre Haute, Ind	12,200			.737									
Vincennes, Ind	12,720	336	193.0		244	140							
White River	10,800				290	38							
Indianapolis, Ind. (West Fork)	1,520	450	38.0	.792	351	30							
Azalia, Ind. (East Fork)	2,100	279	48.0	.900	247	43							
Shoals, Ind. (East Fork)	4,900			.924									
Embarass River	2,450				212	49							
Lawrenceville, Ill	2,390	283	66.0	.76	212	49							
Little Wabash River	2,600				133	52							
Carmi, Ill	2,500	176	68.0	.77	133	52							
Minor tributaries	56,800												
Main stream:													
Wheeling, W. Va	23,800			1.72									

Cincinnati, Ohio	72,400	120	230.0	1.60	189	363							
Louisville Ky	85,000	150	350.0	1.50	221	517							
4. Big Muddy River	2,370				170	98	400	230	890	510	1,100	2,000	720
Murphysboro, Ill	2,250	225	129.0	.77	170	98							
5. Kaskaskia River	5,880				180	92	1,060	540	940	480	1,100	2,100	700
Carlyle, Ill	2,720	248	126.0	.74	180	92							
6. Illinois River	27,900				218	118	6,030	3,290	1,100	620	886	1,600	570
Kampsville, Ill	26,730	267	145.0	.83	218	118							
7. Rock River	10,970				200	180	2,190	1,970	1,000	940	960	1,100	500
Rockton, Ill	6,150			.773									
Rock Falls, Ill	8,640	267	236.0		203	179							
8. Wisconsin River	12,280				140	7	1,720	86	730	37	1,400	27,000	1,300
Necedah, Wis	5,800			1.45									
Portage, Wis	8,600	98	4.6		140	6.6							
9. Chippewa River	9,570				116	5	1,110	48	600	26	1,700	38,000	1,600
Eau Claire, Wis	6,740	90	3.7	1.31	116	4.7							
10. St. Croix River	7,660				120	5	920	38	630	26	1,600	38,000	1,500
11. Minor upper:													
Eastern tributaries	10,000				180	90	1,800	900	940	470	1,100	2,100	710
12. Minnesota River	16,100				89	26	1,420	418	460	140	2,200	7,400	1,700
Mankato, Minn	13,400			0.186									
Shakopee, Minn	15,100	480	142.0		88	26							
13. Wapsipinicon River	2,570				145	50	370	128	760	260	1,300	3,800	980
14. Iowa River	12,400				145	50	1,800	620	760	260	1,300	3,800	980
Iowa City, Iowa	3,320	247	120.0	.573	139	68							
Cedar Rapids, Iowa (Cedar River)	6,320	228	61.0	.656	147	39							
15. Des Moines River	14,700				169	349	2,480	5,130	880	1,800	1,100	550	370
Keosauqua, Iowa	14,300	312	642.0	.551	169	349							
16. Missouri River	528,000				50	290	26,400	153,100	260	1,500	3,800	660	560
Florence, Nebr	323,000	454	2,059.0	.154	69	312							
Omaha, Nebr	323,000			.154									
Kansas City, Mo	430,000	426	2,032.0	.143	60	286							
Ruegg, Mo	528,000	346	1,890.0	.157	53	292							
West Alton, Mo	528,000	294	1,138.0	.157	45	176							
Milk River	26,700												
Havre, Mont	7,300	712	1,331.0	.035	25	46							
Yellowstone River	69,700												
Glendive, Mont	66,090	375	853.0	.188	70	158							
Platte River	83,800												
Fremont, Nebr	71,400	302	392.0		39	51							
Columbus, Nebr	70,400			.132									
Kansas River	61,400												
Lecompton, Kans	58,600			.191									
Holliday, Kans	61,100	383	612.0		72	115							
17. Arkansas River	189,000				120	140	22,700	26,450	630	730	1,600	1,400	740
Arkansas City, Kans	44,500	1,284	1,736.0	.045	57	77							
Little Rock, Ark	158,000	630	748.0	.197	122	145							
18. Red River	90,000				160	240	14,400	21,600	840	1,300	1,200	800	480
Shreveport, La	56,900	561	870.0	.285	157	244							
19. Minor western tributaries	63,000				145	50	9,140	3,150	760	260	1,300	3,800	980

Detailed estimates—Continued.

Drainage basin.	Physical and chemical data.				Estimated denudation.								
	Area (square miles).	Solids (parts per million).		Run-off (second-feet per square mile).	Tons of solids per square mile per year.		Thousand tons of solids per year.		Millionths of an inch per year.		Years required for 1 inch.		
		Dis-solved.	Sus-pended.		Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Dis-solved.	Sus-pended.	Total.
V. Mississippi River—Continued.													
Cumulative summary:													
1. Above Quincy, Ill.:													
Mississippi at Minneapolis, Minn.	19,600				159	6.3	3,120	124	830	33	1,200	30,000	1,200
Minnesota River	16,100				88	26	1,420	418	460	140	2,200	7,400	1,700
Wapsipinicon River	2,570				145	50	370	128	760	260	1,300	3,800	980
Iowa River	12,400				145	50	1,800	620	760	260	1,300	3,800	980
Des Moines River	14,700				169	349	2,480	5,130	880	1,800	1,100	550	370
St. Croix River	7,660				120	5	920	38	630	26	1,600	38,000	1,500
Chippewa River	9,570				116	5	1,110	48	600	26	1,700	38,000	1,600
Wisconsin River	12,280				140	7	1,720	86	730	37	1,400	27,000	1,300
Rock River	10,970				200	180	2,190	1,970	1,000	940	960	1,100	500
Minor streams	29,650				157	63	4,660	1,880	820	330	1,200	3,000	870
Mississippi at Quincy, Ill.	135,500												
Estimated from tributaries					146	77	19,790	10,442	760	400	1,300	2,500	860
Actually determined					108	63	14,640	8,540	560	330	1,800	3,000	1,100
Average					127	65	12,215	9,491	660	340	1,500	3,000	1,000
2. Above Menard, Ill.:													
Mississippi at Quincy, Ill.	135,500				146	77	19,790	10,442	760	400	1,300	2,500	860
Illinois River	27,900				218	118	6,080	3,290	1,100	620	880	1,600	570
Missouri River	528,000				50	290	26,400	153,100	260	1,500	3,800	660	560
Kaskaskia River	5,880				180	92	1,060	540	940	480	1,100	2,100	700
Minor streams	14,620				145	50	2,120	731	760	260	1,300	3,800	980
Mississippi at Menard, Ill.	711,900												
Estimated from tributaries					78	236	55,450	168,103	410	1,200	2,500	810	610
Actually determined					70	164	49,850	116,700	360	860	2,700	1,200	820
Average					74	200	52,650	142,402	390	1,000	2,600	960	700

3. Above Memphis, Tenn.:													
Mississippi at Menard, Ill.	711,900				78	236	55,450	168,103	410	1,200	2,500	810	610
Big Muddy River	2,370				170	98	400	230	890	510	1,100	2,000	720
Ohio River	214,000				190	200	40,600	42,750	990	1,000	1,000	960	490
Minor streams	12,730				145	50	1,840	636	760	260	1,300	3,800	980
Mississippi at Memphis, Tenn.	941,000												
Estimated from tributaries					104	225	98,290	211,719	540	1,200	1,800	850	580
Actually determined					109	279	102,500	262,400	570	1,500	1,800	690	490
Average					106	252	100,395	237,060	550	1,300	1,800	760	540
4. Mouth of river:													
Mississippi at Memphis, Tenn.	941,000				104	225	98,290	211,719	540	1,200	1,800	850	580
Arkansas River	189,000				120	140	22,700	26,450	630	730	1,600	1,400	740
Red River	90,000				160	240	14,400	21,600	840	1,300	1,200	800	480
Minor streams	45,000				103	56	4,640	2,540	540	290	1,900	3,400	1,200
At mouth	1,265,000												
Estimated from tributaries					111	208	140,030	262,309	580	1,100	1,700	920	600
Determined from analyses at New Orleans					105	331	132,820	418,720	550	1,700	1,800	580	440
Average					108	269	136,425	340,514	560	1,400	1,800	710	510
VI. Laurentian Basin: [a]													
United States area	175,000				116	1	20,360	181	600	5	1,700	200,000	1,600
1. Lake Superior	76,100			1.02	60	1							
United States area	48,600				60	1	2,920	49	310	5	3,200	200,000	3,100
Saulte Ste. Marie, Mich.	76,100	60	Trace.										
2. Lakes Michigan-Huron	137,800			.874									
United States area	71,300				126	.8	8,950	59	660	4	1,500	250,000	1,500
3. Lakes Superior-Michigan-Huron	213,900			.924	99	.9							
United States area	119,900				99	.9	11,870	108	520	5	1,900	200,000	1,900
Chicago, Ill. (drainage canal)	213,900	130	Trace.	.022	3	.0							
Port Huron, Mich. (St. Clair River)	213,900	108	Trace.	.902	96	.9							
4. Lake Erie	40,800			.539									
United States area	23,400				184	.5	4,310	11	960	3	1,000	330,000	1,000
5. Lakes Superior-Michigan-Huron-Erie	254,700			.863	113	.8							
United States area	143,300				113	.8	16,180	119	590	4	1,700	250,000	1,700
Chicago, Ill. (drainage canal)	254,700	130	Trace.	.018	2.3	.0							
Buffalo, N. Y. (Niagara River and New York canals)	254,700	133	Trace.	.845	111	.8							

[a] Figures are based upon assumption that unit denudation above Ogdensburg is the same for the United States and Canada.

Detailed estimates—Continued.

Drainage basin.	Area (square miles).	Physical and chemical data: Solids (parts per million): Dissolved.	Physical and chemical data: Solids (parts per million): Suspended.	Physical and chemical data: Run-off (second-feet per square mile).	Estimated denudation: Tons of solids per square mile per year: Dissolved.	Estimated denudation: Tons of solids per square mile per year: Suspended.	Estimated denudation: Thousand tons of solids per year: Dissolved.	Estimated denudation: Thousand tons of solids per year: Suspended.	Estimated denudation: Millionths of an inch per year: Dissolved.	Estimated denudation: Millionths of an inch per year: Suspended.	Estimated denudation: Years required for 1 inch: Dissolved.	Estimated denudation: Years required for 1 inch: Suspended.	Estimated denudation: Years required for 1 inch: Total.
VI. Laurentian Basin—Continued.													
6. Lake Ontario	33,000			1.04									
United States area	18,000				144	1	2,600	18	750	5	1,300	200,000	1,300
7. Lakes Superior-Michigan-Huron-Erie-Ontario	287,700			.884	116	.9							
United States area	161,300				116	.9	18,780	137	600	5	1,700	200,000	1,600
Chicago, Ill. (drainage canal)	287,700	130	Trace.	.016	2.1	.0							
Buffalo, N. Y. (New York canals)	287,700	133	Trace.	.008	1.1	.0							
Ogdensburg, N. Y. (St. Lawrence River)	287,700	134	Trace.	.859	113	.9							
8. St. Lawrence River (below Ogdensburg, N. Y.)—													
United States area	13,660				116	3.2	1,580	44	600	17	1,700	59,000	1,600
Oswegatchie River—Ogdensburg, N. Y	1,580	77	10.0	1.72	130	17							
Lake Champlain	7,900	66	Trace.		113	1.7							
Rouses Point, N. Y	7,750			1.74									
VII. Colorado River:													
United States area	230,000				51	387	11,730	89,010	270	2,000	3,800	500	440
Yuma, Ariz	225,000	710	5,354.0	.0733	51	387							
1. Gila	71,100				80	a 225	5,690	16,000	420	1,200	2,400	860	630
Salt River	13,000				150	235							
Roosevelt, Ariz	5,760	646	1,300.0	.238	151	304							
McDowell, Ariz. (Verde River)	6,000	363	1,137.0	.141	50	158							
Mesa, Ariz	12,260	1,090	1,274.0	.189	203	237							
Gila River					13	210							
San Carlos, Ariz	13,500	811	4,682.0	.015	12	69							
Florence, Ariz	17,850	944	14,130.0	.015	14	209							
2. Little Colorado	31,000				11	134	340	4,150	57	700	18,000	1,400	1,300
Woodruff, Ariz	6,000	602	7,149.0	.019	11	134							
3. Grand	26,200				198	470	5,190	12,310	1,000	2,400	970	410	a 290
Palisades, Colo	8,550	a 429	b 1,358.0	.546	230	730							
Whitewater, Colo. (Gunnison River)	7,870	484	553.0	.350	167	190							

4. Green	41,000				90	165	3,690	6,760	470	860	2,100	1,200	750
Jensen, Utah	26,600	369	679.0	.247	90	165							
VIII. Southern Pacific	72,700				177	75	12,850	5,460	920	390	1,100	2,600	760
1. Minor Southern Pacific	22,800			.325	196	71	4,470	1,620	1,000	370	980	2,700	720
Soledad, Cal. (Arroyo Seco)	215	284	33.0	.793	222	26							
Santa Maria, Cal. (Santa Maria River)	1,000	2,412	1,302.0		204	110							
Santa Barbara, Cal. (Santa Ynez River)	207	714	64.0	.495	348	31							
Calabasas, Cal. (Malibu Creek)	97	717	61.0	.375	265	23							
Mentone, Cal. (Santa Ana River)	182	139	53.0	.409	56	21							
Pala, Cal. (San Luis Rey)	318	321	142.0	.352	111	49							
2. San Francisco Bay	49,900				168	77	8,380	3,840	880	400	1,100	2,500	780
Sacramento River	31,400			1.45	172	86							
Sacramento, Cal	29,500	121	60.0	1.45	172	86							
San Joaquin River [c]	16,500			1.02	162	60							
Lathrop, Cal	12,500	161	60.0	1.02	162	60							
IX. Northern Pacific	[d] 270,000				100	20	27,000	5,400	520	100	1,900	9,600	1,600
X. Great Basin	[d] 223,000				90	50	20,070	11,150	470	260	2,100	3,800	1,400
XI. Hudson Bay (in United States)	62,000				28	21	1,740	1,300	150	110	6,800	9,100	3,900
Red River of the North— Total area in United States	50,000				28	21	1,400	1,050	150	110	6,800	9,100	3,900
Grand Forks, N. Dak	25,000	[e] 200	[e] 150.0	.141	28	21							

[a] Suspended matter probably far too low.
[b] Analyses cover only portion of year. Results appear too high for an average.
[c] Excluding Tulare Lake.
[d] Analytical data extremely meager.
[e] Estimated from four analyses.

CONTROL OF CATCHMENT AREAS.

By Horatio N. Parker.

Catchment areas, annual consumption, and total money investment of the water works of 42 cities which derive their water supplies from impounded surface waters and which have populations of over 30,000.

City.	Catchment area.	Reservoir capacity.	Annual consumption.	Total investment.		
				Cost of construction.	Bonded indebtedness.	Maintenance.
	Sq. miles.	*Gallons.*	*Gallons.*			
Altoona, Pa	9.00	a 425,000,000	547,500,000	$910,148	$479,000	$45 090
Baltimore, Md	347.00	2,310,000,000	22,995,000,000	12,000,000	850,000	400,000
Boston, Mass	b 212.38	82,966,530,000	40,250,000,000	40,459,778	40,500,000	318,052
Bridgeport, Conn	40.80	10,000,000	7,300,000,000	....	....	....
Brockton, Mass	7.70	5,700,000,000	714,340,000	1,713,300	1,485,000	38,000
Butte, Mont	....	290,000,000	2,190,000,000	....	....	....
Cambridge, Mass	6.80	2,270,000,000	3,386,180,000	6,467,153	3,787,600	75,702
Charleston, S. C	49.00	3,127,820,000	1,204,500,000	2,456,682	1,250,000	52,245
Denver, Colo	3,910.00	110,000,000,000	15,881,000,000	....	....	....
Elmira, N. Y	....	117,500,000	1,546,900,000	895,000	....	115,000
Fall River, Mass	27.54	....	1,640,000,000	2,076,450	1,550,000	124,972
Fitchburg, Mass	7.40	2,000,000	1,095,000,000	1,400,000	446,000	37,300
Hartford, Conn	13.00	2,035,000,000	2,190,000,000	3,567,191	675,000	150,000
Haverhill, Mass	20.10	128,000,000	1,839,000,000	1,463,047	610,833	25,137
Holyoke, Mass	18.05	1,600,000,000	2,127,840,000	1,295,308	350,000	61,712
Jersey City, N. J	....	129,200,000	12,045,000,000	5,200,000	600,000	445,000
Johnstown, Pa	5.50	283,000,000	....	1,500,000	....	....
Los Angeles, Cal	502.50	898,000,000	11,680,000,000	c 3,983,693	d 3,480,250	201,107
Lynn, Mass	....	....	1,873,450,000	2,900,891	1,778,500	117,389
Newark, N. J	....	9,000,000,000	93,482,500,000	8,959,790	7,993,500	250,000
New Bedford, Mass	e 12.80	f 5,550,000,000	2,524,661,000	3,332,800	1,638,000	109,443
New Haven, Conn	56.40	2,837,000,000	8,395,000,000	....	....	....
New York, N. Y. (boroughs of Manhattan and Bronx)	g 382.00	h 108,638,000,000	h 119,720,000,000	i 86,359,562	....	1,000,000
Norfolk, Va	....	....	2,482,000,000	1,250,000	....	....
Oakland, Cal	....	6,300,000,000	....	4,520,000	....	100,000
Pawtucket, R. I	27.80	1,475,600,000	2,633,000,000	1,946,848	1,285,000	53,153
Portland, Me	....	30,000,000	2,190,000,000	2,677,970	....	....
Portland, Oreg	....	6,000,000	6,935,000,000	5,204,650	2,900,000	78,516
Reading, Pa	218.60	186,022,000	3,768,260,000	33,213,725	400,000	50,316
Rochester, N. Y	j 66.20	229,500,000	5,621,000,000	9,028,000	5,610,000	115,000
St. Paul, Minn	....	18,000,000	3,732,000,000	4,517,329	2,367,000	60,337
Salem, Mass	....	20,000,000	1,090,426,000	1,947,200	143,000	31,306
Salt Lake City, Utah	....	9,012,000	5,110,000,000	4,810,000	1,575,000	55,000
San Francisco, Cal. (prior to fire)	....	29,000,000,000	12,344,665,000	....	....	554,000
Scranton, Pa	....	2,000,000,000	9,125,000,000	....	....	....
Springfield, Mass	k 18.00	1,500,000,000	4,000,000,000	2,509,525	555,000	54,700
Syracuse, N. Y	70.25	121,000,000	4,380,000,000	5,000,000	4,075,000	100,000
Taunton, Mass	52.00	10,300,000,000	818,774,000	1,367,801	853,500	33,988
Waterbury, Conn	19.50	920,000,000	2,728,831,000	1,819,640	865,000	24,000
Wilkesbarre, Pa	....	4,000,000	....	....	....	....
Worcester, Mass	....	2,550,000,000	2,954,617,000	4,406,202	3,830,000	60,000

a Exclusive of a reservoir of 300,000,000 gallons capacity.
b Metropolitan Water Works.
c Amount spent since the works were taken over by the city in February, 1902.
d Original, 4,017,500.
e Exclusive of a storage reservoir in Acushnet, which has a catchment area of 5.25 square miles.
f An additional storage reservoir of 1,600,000,000 gallons capacity is under construction.
g On Croton, Bronx, and Byram rivers.
h On Croton River, including the new Croton reservoir to be finished in 1911, and on Bronx and Byram rivers.
i 1832 to 1898, inclusive.
j Exclusive of Hemlock Lake.
k Little River supply, now 40 per cent completed, is to replace present supply; will have a catchment area of 48 square miles and storage capacity of 2,600,000,000 gallons.

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