RAINFALL
WATER SUPPLY
WATERWAYS OF THE UNITED STATES

BY

HENRY WAYLAND HILL, LL.D.

President of the New York State Waterways Association

REPRINTED FROM THE 1920 EDITION OF
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what is chiefly a liquor saloon business. The law brought large returns in money for city and State, the city receiving two-thirds and the State one-third of the net income from licenses, but it was generally conceded that this was at the expense of good morals. See LICENSE.

RAINEY, Paul J., American explorer and big game hunter. A man of wealth, he traveled and hunted in the Rocky Mountains, the Arctic region and in Africa and India. He became prominent through the motion pictures of wild life in the jungles of Africa and India which he succeeded in taking during his expeditions of 1910 and 1914 and which attracted worldwide interest. He has contributed to *Outing*, the *Scientific American Supplement* and other periodicals.

RAINFALL. Rainfall or precipitation, the generic term applied to the condensation of aqueous vapor into cloud, fog, dew, rain, snow, frost and hail, varies greatly in the several zones and in the successive seasons and at different altitudes. Temperature, by which is meant the temperature of the air at a given place and elevation, is one of the controlling physical factors in determining its annual rainfall or precipitation. The atmosphere, consisting according to Prof. Julius Hann of the University of Vienna of the following elements and proportions, nitrogen 78.03, oxygen 20.99, argon 0.94, carbon dioxide 0.03, hydrogen 0.01, neon, 0.0015 and helium 0.00015 parts and subject to rapid and continual changes in temperature, largely conditions precipitation over the earth, itself, owing to its varying topography, one of the controlling factors in the problem. The vast expanse of oceans, seas, gulfs and inland waters and the uplift and extent of its various mountain ranges and the expanse and location of its continents in their relation to oceans and to the torrid, temperate and frigid zones, together with the rotation of the earth on its axis and its revolution around the sun, produce different atmospheric conditions, conducive to great variation in precipitation. Furthermore the atmosphere rapidly decreases in density upwards from the surface of the earth and solar radiation likewise decreases in its intensity. The sun's rays penetrate the atmosphere at various angles and these are continually changing so that the amount of radiant energy is neither constant nor uniform in the different latitudes and seasons. Owing to these physical conditions and the inclination of the earth's axis to the plane of the ecliptic, producing unequal day and night in the four seasons, there are ceaseless movements in the atmosphere itself, such as currents, winds and storms, that affect its humidity and the amount of rainfall. Both terrestrial and solar disturbances affect the atmosphere and the amount of rainfall. In some localities periodic winds prevail with such constancy that they are denominated by such terms as «trade winds,» «monsoons,» «land and sea breezes» and some ocean currents are no less constant. All these and other physical phenomena must be considered in accounting for precipitation and its variation in different localities.

Evaporation is the physical transformation of solids and liquids into gases, due to the kinetic energy of their molecules to diffuse themselves through space. Heat increases that energy of the molecules of water in whatever form it may be, though the coefficient of diffusion for aqueous vapor is greatest at the earth's surface. Professor Cleveland Abbe of the United States Weather Bureau has said that «the vapor constituent of the atmosphere is not distributed according to the law of gaseous diffusion, but like temperature and the ratio between oxygen and nitrogen, is controlled by other laws, prescribed by the winds and currents, namely — convection.» That may be either horizontal, due to the winds, or vertical, due to upward or downward currents. Temperature is also one of the most important factors in the problem of evaporation and in the distribution of aqueous vapors. Atmospheric pressure is another important factor in the problem. Atmospheric gases retard the diffusion of aqueous gases and act independently of each other. Professor Adolph F. Meyer of the University of Minnesota states that «water in the gaseous state has a specific gravity of .622, as compared with dry air,» and that «the pressure of water vapor at a given temperature is greater than the pressure of an equal amount of dry air at the same temperature,» so that when dry air is displaced in part by aqueous vapor, the weight of the cubic content is reduced. Professor Meyer maintains that when water at 212° F. passes into a gaseous state, it increases in volume 1,658 times and stores up 970 British thermal units of heat for each pound of water so transformed. The United States Weather Bureau gives the elastic pressure of saturated vapor at 32° F. as 0.180 of an inch of barometric pressure, at 68° F. as 0.684 of an inch of barometric pressure, at 100° F. as 1.916 inches of barometric pressure and at 110° F. as 2.576 inches of barometric pressure. It thus appears that vapor pressure increases much more rapidly than does temperature. Professor Meyer also states that «at ordinary open air temperatures, the elastic pressure» (also known as «vapor tension» and «gaseous pressure») «of saturated water vapor is substantially doubled for every 20° F. increase in temperature,» and «at a given temperature and pressure only a certain definite amount of water can occupy a given space and as soon as the space is saturated with moisture, dew will be deposited.» Then heat is liberated, which tends to retard a further fall in the temperature. The higher the temperature at sea-level, the greater may be the amount of aqueous vapor and stored-up heat and the slower will be the condensation and cooling. In the heat of summer, the air rises, expands, cools and as it does so, it loses its capacity to hold vapor and condensation may ensue. Professor Meyer says that «If the temperature of the vapor is 68° F. it will cool 1° in rising 425 feet.» The heat so liberated warms the surrounding atmosphere and tends to prevent further condensation, so summer showers are often of short duration.

The atmospheric pressure at the level of the sea is 14.7 pounds per square inch, which is equivalent to a column of pure water at 39.2° F. 34 feet in height. That pressure decreases one pound for the first 1,880 feet, and two pounds for the first 3,900 feet, and three pounds for the first 6,080 feet above the level of the sea, and so on until it becomes negligible. The United States Weather Bureau has compiled statistics giving the weight of a cubic foot of aqueous vapor of different percentages of saturation and at various temperatures at the level of the sea. At 32° F. a cubic foot of aqueous vapor ranges from .211 grains with 10 per cent saturation to 2.113 grains with 100 per cent saturation. At 68° F. a cubic foot of aqueous vapor ranges from .748 grains with 10 per cent saturation to 7.480 grains with 100 per cent saturation. At 100° F. a cubic foot of aqueous vapor ranges from 1.977 grains with 10 per cent saturation to 19.766 grains with 100 per cent saturation. At 110° F. a cubic foot of aqueous vapor ranges from 2.611 grains with 10 per cent saturation to 26.112 grains with 100 per cent saturation. Vapor is saturated, when it is at the point of condensation and evaporation goes on as long as there is any deficit below 100 per cent of such saturation. From the foregoing meteorological compilation, it will appear that the point of saturation and weight of aqueous vapors per cubic foot vary greatly at different temperatures. The matter under this sub-title is involved in the problems of WATER SUPPLY and will receive further consideration under that title in a succeeding volume of this encyclopedia.

Controlling Factors in Rainfall.—At sea-level in the tropics over such large bodies of water as the Indian Ocean, the amount of aqueous vapor moving vertically upward may exceed the quantity in a column of air over the Arabian and Sahara deserts. Still the vapor contents of the air over Siberian and Lybian deserts average nearly as much as that of the air over Vienna and Paris. The heat prevents its condensation. Were it cooled, it would produce normal rainfall. Humidity is the amount of aqueous vapor in the atmosphere, as compared with the amount of such aqueous vapor in it, when the atmosphere at a given temperature is 100 per cent saturated. Humidity, therefore, is relative and in some zones and localities it varies inversely, as the temperature, especially where there may be a lack of moisture as there is east of the Rocky Mountains and over the desert regions of the earth. When water is vaporized, pressure is exerted on atmospheric gases. Thus both vertical or convective currents may be generated, clouds may be formed and heavy rainfall may ensue, as a result of the cooling of the saturated water vapor in the upper strata of the atmosphere. The heat, liberated in the cooling process, retards the condensation and checks the rainfall. A rising barometer indicates the absence of vapor pressure, the expansion of dry air, slight evaporation and no rainfall. Humidity, temperature, topography and the physical phenomena already mentioned are factors more or less controlling, in the problem of rainfall over a given territory. There are others, such as the contour of the territory, its elevation above the level of the sea, the extent of its forests, the configuration of its mountains, the influence of continents upon humidity and character of its seasons. Notwithstanding the complexity of the phenomena, conditioning rainfall or precipitation, the same has been observed over long periods and reduced to mean annual tabulations. There have also been deduced formulæ to ascertain the presence and amount of evaporation, which, to slight extent only, indicates the amount of rainfall or precipitation, for the former may be both a contributing cause and one of the results of the latter. Dalton, Bigelow, Russell, Meyer and others have proposed evaporation formulæ to determine evaporation under various conditions of humidity, temperature, wind velocity, vapor tension and barometric pressure. The results obtained from the application of such formulæ are not identical, nor do they always conform to actual measurements, which are difficult to make.

The United States Weather Bureau and the climatological stations of some other nations have compiled statistical tables of evaporation over various land and inland water areas, but not over oceans, seas and gulfs, which altogether cover three-fourths of the surface of the earth. From all such bodies of water evaporation is continuous and the greatest. These great fountains of the deep supply the vapor-laden clouds, which are swept landward and release their waters in refreshing rains, wintry snows or in some other form of precipitation. Frequently such vapor-bearing clouds are swept against mountain ranges, as those rising from the Mediterranean Sea are swept against the Alps and those rising from the Pacific Ocean against the Andes Mountains. In some regions precipitation is much greater than it is in others, and over the same region it varies greatly in different years. That is due to the operation and effect of the physical conditions already stated. However, over cycles of years it is quite uniform, as will hereinafter appear. Deforestation decreases and reforestation increases the general average. Forests promote rainfall, retard evaporation and run off and store up precipitation in pools, ponds and lakes, some of which are the sources of streams and rivers. The United States and many other nations have bureaus, or departments devoted to scientific forestry, one of the most important and necessary functions of government, if the habitable areas of the earth are to be preserved. Deforestation and consequent lack of rainfall have rendered many once populous areas now uninhabitable, as indicated in this article. This and other generations ought not to neglect a matter of such vital importance to themselves and to succeeding generations, but ought to enter upon the systematic reforestation of all properly available areas.

Regional Precipitation.— The amount of precipitation, over many portions of the habitable earth, has been observed for long periods substantially as follows: In the polar regions there is no rainfall. Precipitation there is congealed in snow and icy particles. In the tropics there is little snow except on the highest mountains and most precipitation is in the form of rain. In the upper latitudes of the temperate zones there are both rain and snow. Over the Sahara, Arabia and other desert regions and in the desert regions in Australia and South America there is but little precipitation, while along windward coastal regions the annual precipitation is abundant, as found along the Atlantic and other continental coasts facing eastward. Usually those sides of mountain ranges that face oceans, or large bodies of water, have a much larger rainfall than do the opposite sides, which face inland areas. There is more rainfall on the slopes of the Sierra and Coast ranges where many glacial lakes and ponds exist in the ranges themselves, such as Tahoe, Clear Lake and others, than there is rainfall on their eastern slopes. East of some of these and of the Rocky Mountains the annual precipitation is light and large desert areas had existed, but for irrigation. No one law has been deduced from all these varied phenomena, affecting precipitation over all parts of the habitable globe to determine its amount. Much data has been collated from actual measurements. Some of these will indicate the amount of precipitation in those regions and at various altitudes.

E. S. Bellasis, sometime engineer of the Public Work in India, in substance stated that «the rainfall in India varied from 2 or 3 inches in Scinde to 450 inches at Cherrapunji in the eastern Himalayas and that at two stations in the Bombay hills, only 10 miles apart, the annual rainfall were respectively 300 inches and 50 inches and that in England at Hemstanton, it was about 20 inches, while at Seathwaite it was about 200 inches.» He stated that «the annual rainfall at Mercara in South India was 119 inches, in King William's Town in Cape Colony 27 inches, at Melbury Moor, in England 50.7 inches, at Newport in the Isle of Wight 32 inches, in the basin of the Cataract River in New South Wales from 33.7 inches, in 1896, to 56.4 inches, in 1898 in the basin of the Nepean River in New South Wales 44.3 inches and in 1905 in the valley of Sudbury, Mass., 42.3 inches.»

The water supply of a country is largely conditioned upon its water resources and the latter are dependent to a large extent upon its rainfall, or rather precipitation, which includes rain, hail, sleet and snow. The amount of annual precipitation over a given territory in successive years is not constant, nor is it uniformly distributed, except over a few such States as Wisconsin and Michigan, and over some foreign limited districts.

The annual precipitation in the State of Washington ranges from 12 to 120 inches in different localities, though in Seattle for a period of 19 years it averaged 38.8 inches. In different parts of Oregon it ranged from 8 to 138 inches and in Texas from 9.3 inches at Pasco to 48.2 inches at Houston. Nor is the annual precipitation over a locality constant from year to year. The Weather Bureau's report shows that the precipitation at Dodge City, Kan., has ranged from 9.9 to 33.7 inches. There are dry and wet years as there are dry and wet seasons. In the drought of 1894 and 1895, the deficiency in precipitation measured in the upper Mississippi Valley from 7.8 to 12 inches, in New England from 5.3 to 8.1 inches and in the south Pacific watershed from 4.4 to 4.6 inches. In three months of 1905, there was an excess of 2 inches in the rainfall at Yuma over its mean annual precipitation. In 1900, the rainfall at Bay Saint Louis, Miss., was 101.5 inches which was an excess of about 50 inches over normal precipitation for the State. The difference between the maximum and minimum rainfall on the Croton watershed (New York) in a period of 43 years was 26.8 inches and in Pittsburgh (Pa.) that difference was 25.3 inches in a period of 71 years.

Mean Annual Precipitation in the United States and Canada.— The United States maintains several hundred observation stations in addition to those maintained by the States themselves and by individual and corporate enterprise, where meteorological and climatological observations are made and for half a century have been made and records kept of the annual precipitation at those stations. From all such official and authentic observations and the computations made therefrom, climatological tables have been compiled, showing in most cases over periods of years the mean annual precipitation at scores of stations in the United States. Foreign countries have made similar observations and records. In nearly all of the tables, the measurements are the resultant of many observations and are denominated «the mean annual precipitation.»

From such official and from other well-authenticated measurements, the writer has selected some and averaged others from approved records to ascertain and state the mean annual precipitation over the United States and Canada. The following represent the mean annual precipitation over the localities mentioned, or they are aggregated from a number of stations over large areas, showing such precipitation. Many of these are from the reports of the United States Weather Bureau, extending over a number of years and others from authentic data. The mean annual precipitation in the coastal region of Alaska varies from 60 to 110 inches.

United States.— The greatest annual precipitation in the United States is over the western slopes of the mountains forming the Continental Divide which intercept the vapor-laden clouds from the Pacific and precipitate their moisture in some localities to an average of 70 to 135 inches.

Alabama.— The United States Weather Bureau gives the mean annual precipitation, as measured at 15 stations, as 52 inches, at Montgomery it is 50.8 inches and at Mobile 62.1 inches.

Arizona.—Along the Colorado it is less than 3 inches, at Phoenix 7.4 inches, at Fort Grant 15 inches and at Flagstaff 22 inches.

Arkansas.— It averages 46.7 inches, being 49.6 inches at Little Rock, 55.2 inches at Helena and 41.8 inches at Fort Smith.

California.— It ranges from 32.2 inches over the Sacramento watershed to 10.2 inches at San Diego. Professor Meyer states that it averaged 9.6 inches at San Diego for a period of 65 years. At Berkeley it is 26.47 inches, at San Francisco 23 inches and at Los Angeles 17.6 inches.

Colorado.— It is variable. At Denver it is 14.7 inches, at Pueblo 11.6 inches, at Orchard 17 inches and at Long's Peak 16.7 inches. In other sections it varies from 7.01 to 26 inches and over Colorado River watershed it is 17.7 inches.

Connecticut.— At Hartford it was 44.50 inches, at New Haven 47.2 inches, at New London 48.08 inches and at Waterbury 49.9 inches.

Delaware.— At Millsboro it was 47.3 inches.

Florida.— There is annual precipitation over the State as determined at 13 stations of 54.53 inches. At Tampa it is 53.1 inches, at Key West 37.9 inches, at Miami 58.3 inches and at Jacksonville 53.4.

GEORGIA.— The United States Weather Bureau reported in 1906 that the annual precipitation in the northeastern part of the State was 54.1 inches, in middle Georgia 49 inches, in southeastern Georgia 50.7 inches, at Atlanta, for a period of years, it averaged 49.2 inches, at Savannah 48.67 inches and at Clayton 68.5 inches.

IDAHO.— It varies from 6.3 to 40.4 inches, but in most sections it ranges from 12 to 13 inches.

ILLINOIS.— It averages 36.5 inches. At Chicago for 40 years it averaged 33.5 inches. At Springfield it is 37.4 inches and at Cairo 41.6 inches.

INDIANA.— The mean annual precipitation over the State is 38.4 inches. At South Bend it is 34.5 inches, at Indianapolis 41.9 inches and at Marion 37 inches.

IOWA.— From the measurements at 46 stations scattered over the State, the United States Weather Bureau reported the mean annual precipitation over the State to be 31.5 inches, at Keokuk it was 35.1 inches and at Sioux City 25.8 inches, at Iowa City in 1890, it was 58 inches.

KANSAS.— Measured at 19 stations, it averaged 27.3 inches, at Garden City it was 19.6 inches, at Wichita 30.4 inches, at Atchison 37.1 inches and at Topeka 34.1 inches.

KENTUCKY.— At 10 stations it ranged from 42.5 inches at Lexington to 50.3 inches at Wibblesboro. At Louisville it is 44.5 inches.

LOUISIANA.— There is great variation in the yearly rainfall. In New Orleans the annual rainfall has been as low as 31 inches and as high as 85.6 inches. For 67 years it averaged 56.1 inches. It ranges there from 55.4 to 62.6 inches and over the State from 46 inches over the southern stations to 55 inches over the eastern.

MAINE.— At Portland it was 42.8 inches, at Lewiston 46.2 inches, at Eastport 43.4 inches, at Bar Harbor 48.9 inches, at Mayfield 52 inches.

MARYLAND and DELAWARE.— The annual precipitation ranges from about 44 inches in the former to 47.3 inches in the latter. At Baltimore it was 43.4 inches, at Washington and District of Columbia 43.1 inches, in the valley of the Potomac 35.28 inches. Other unofficial records give annual precipitation at Baltimore as 40.7 inches, at Washington as 40.7 inches and in the District of Columbia at 38.77 inches.

MASSACHUSETTS.— At Boston it ranged from 43.7 to 45.3 inches, at New Bedford from 46.4 to 47.9 inches, at Blue Hill Meteorological Observatory 47.2 inches, at Williamstown 39.41 inches, at Lawrence 43.1 inches, at Fitchburg 45.4 inches, at Amherst 46.3 inches, at Nantucket 36.5 inches, over the Wachusett watershed 47.1 inches and over the Sudbury watershed 45.3 inches.

MICHIGAN.— It averages 32.91 inches and is similarly distributed. At Detroit it has averaged 32.1 inches over a period of 40 years.

MINNESOTA.— It averages 26 inches, while at Duluth it is 29.5 inches, at Saint Paul 28.68 inches, over the Crow Wing Valley 30.81 inches and over Croix Valley 32.58 inches. Professor Meyer gives the mean annual rainfall at Saint Paul for a period of 78 years at 27.3 inches.

MISSISSIPPI.— The mean annual precipitation is about 50 inches. In the Yazoo Valley it is 48 inches, at Natches 50 inches and at Vicksburg 53.8 inches. Over the Tombigbee watershed for a period of 50 years it has averaged 49.2 inches.

MISSOURI.— It ranges from 34 inches in the northwestern counties to 46 inches in the southeastern counties. It averages 39.9 inches at Saint Louis. The general average over the State is 39 inches.

MONTANA.— It ranges from 11.8 to 18.5 inches. At Kipp it is 18.5 inches, at Glendive 15.9 inches, at Butte 12.2 inches and at Great Falls on the Missouri 13.4 inches and at Havre 13.5 inches.

NEBRASKA.—As determined at 6 to 12 stations it averaged 23.5 inches and was principally in rain. At Omaha it was 30.8 inches, at Lincoln 27.7 inches and at North Platte 17.9 inches.

NEVADA.—It ranges from 10.8 inches at Carson City to 11.2 inches at Pioche, but varies in most parts of the State from 3 to 12 inches. At Reno it measures 7.52 inches.

NEW HAMPSHIRE.—At Bethlehem it was 37.7 inches, at Plymouth 42.4 inches, at Concord and at Keene 40.4 inches and at Nashua 43 inches.

NEW JERSEY.— The annual precipitation is 47.7 inches over the State. At Dover it is 51.2 inches, at Asbury Park 48.1 inches and at Atlantic City 42 inches. Over the Pequannock watershed it is 50.1 inches and over the Hackensack River 46.15 inches.

NEW MEXICO.— It varies from 7.2 to 15.8 inches, though there it has had a precipitation of 25 inches. At Sante Fe' it is 14.2 inches. There is slight snowfall, though the State's highest peaks in the north are snow-capped much of the time, and those snows are its principal sources of water supply. Similar conditions prevail in some of the Rocky Mountain States, affording their principal water supply.

NEW YORK.— The mean annual precipitation at the United States Weather Bureau stations over the State for 25 years averaged 39.26 inches. Over Suffolk County it averages 45 inches. Over Long Island for 67 years it has averaged 42.56 inches, at New York City 42.87 inches, over the lower Hudson 44.93 inches, at the Croton Dam from 44.93 to 50.38 inches, over the Esopus watershed 46.6 inches, at Oxford 45.4 inches, at Albany 34.84 inches, at Little Falls 54 inches, at Utica 42.29 inches, at Binghamton 36.98 inches, at Elmira 33.23 inches, at Mount Hope 27.77 inches, at Ithaca 33.97 inches, at Cortland 44.7 inches, at Rochester 33.61 inches, at Buffalo 36.71 inches, at Oswego 36.57 inches, at Ogdensburgh 30.7 inches, at North Lake 55.7 inches and over northeastern New York 38.97 inches. Over the Taconic quadrangle it is 42 inches.

NORTH CAROLINA.— The resultant of measurements at 23 stations was 52 inches. In the western counties occasionally it ranges from 70 to 100 inches, thereby becoming known as a region of extraordinary rainfall.

NORTH DAKOTA.— The mean annual precipitation is from 17 to 18 inches over the State. At Bismark it is 18.8 inches. High winds blow away much of the snows of winter.

OHIO.— This State has an annual precipitation of 38.4 inches, varying from 30.8 inches at Toledo to 42.1 inches at Marietta. At Portsmouth it averages 41.1 inches. Over the Ohio River during a long period it varies from 32.07 to 45.79 inches and over the Muskingum watershed it averages 40 inches. At Cleveland it is 35.6 inches, at Columbus 37.2 inches and at Cincinnati from 38.4 to 45 inches. Professor Meyer states that it averaged there 40.7 inches for a period of 80 years.

Oklahoma.— It was computed by the United States Weather Bureau from the measurements of 10 stations and found to average 31.7 inches, with great variations in succeeding seasons and different years.

Oregon.— It ranges from 8 to 138 inches and at Portland it ranges from 45.9 to 78.2 inches. At Astoria it is 77.2 inches.

Pennsylvania.— The resultant of the measurements of 16 stations is approximately 44 inches. At Erie it is 39.2 inches, at Pittsburgh 36.4 inches, at Harrisburgh 38.1 inches, at York 41.9 inches, at Mauch Chunk 50.5 inches and at Philadelphia 40.6 inches.

Rhode Island.— At Providence it was 44.6 inches, but by the records for 79 years it averaged 45 inches. At Narragansett Pier it was 47.4 inches and at Rock Island 45.3 inches.

South Carolina.— It was estimated from measurements at 12 stations to be 49 inches. Monthly rainfalls in some localities and years have equalled 12 inches for a short period.

South Dakota.— It averages 20.3 inches, but only 1 to 2 inches fall in the form of snow.

Tennessee.— It averages over the State as measured at 18 stations about 50 inches, including 8 inches of snow. At Nashville it is 48.5 inches, at Memphis 50.8 and at Chattanooga 51.6 inches.

Texas.— The mean annual precipitation averages 30.9 inches over the entire State as determined at 19 stations, varying from 9.3 inches at Pasco to 48.2 inches at Houston. At Port Davis for 46 years it was 18 inches. At El Paso for 36 years it averaged 9.6 inches.

Utah.— It averages 11 inches, ranging from 6.1 inches at Saint George to 16.2 inches at Salt Lake, which is mostly snow.

Vermont.— At Burlington 33.3 inches, at Rutland 36.54 inches, at Saint Johnsbury 35.6 inches, at Northfield 33.1 inches, at Woodstock 37.3 inches and at Jacksonville 50.3 inches.

Virginia.— It averaged from the measurements of 15 stations from 39.4 inches at Warsaw and Blacksbury to 50.5 inches at Big Stone Gap. At Rutland it measured 43.6 inches, at Fort Republic 38.77 inches, at Roanoke 39.09 inches and at Norfolk 50 inches.

Washington.— In the northwestern part it ranges from 12 to 120 inches, and between the Olympics and Cascade mountains it ranges from 25 to 60 inches. At Seattle for 19 years it averaged 38.8 inches.

West Virginia.— There are 14 stations distributed over the State and the average of their measurements is 42.48 inches. Over the high plateaus the annual precipitation ranges from 45 to 50 inches, while over the lower levels along some rivers it ranges from 35 to 40 inches. Over the Greenbriar it is 44.48 inches.

Wisconsin.— The mean annual precipitation is 31.5 inches and is uniformly distributed over the State; at Milwaukee it is 31 inches.

Wyoming.— It averages 13 inches, ranging from 8 inches in some places to 20 inches in the Yellowstone Park.

Along the Appalachian altitudes from New York to the Gulf of Mexico there is a greater precipitation than there is at lower levels along the Atlantic Coast. From the United States Weather Bureau reports of the mean annual precipitation, measured at several stations in each New England State over a period of years, it appears that it averaged in Maine 44.6 inches, in New Hampshire 40.6 inches, in Vermont 38.2 inches, in Massachusetts 44.6 inches, in Rhode Island 49 inches and in Connecticut 47.2 inches.

Canada.—In Canada it varies in the western, central and eastern provinces as it does in the United States. At Victoria it averaged 37.77 inches, at Port Simpson 94.63 inches, at Regina 9.03 inches, at Prince Albert 14.45 inches, at Winnepeg 19.53 inches, at Port Arthur 23.58 inches, at Toronto 33.94 inches, in Quebec 28.76 to 41.5 inches, in New Brunswick 32.6 inches with 97.5 inches of snow, in Nova Scotia 39.6 inches and 77.5 inches of snow.

Latin America.— In other countries of the western hemisphere records of precipitation are meagre. However, the unofficial reports indicate that the annual precipitation is abundant for the water supply of all the principal cities whether or not they be located on lakes, rivers and other fresh waters. In Mexico, at Vera Cruz, it measured 183 inches as maximum rainfall. In Central America precipitation varies greatly in different sections. Rainfall in the latter ranges from 50 to 200 inches annually. In Cuba at Havana it ranges from 40 to 80 inches. There is a great variation of precipitation in South America owing to its physical formation with the lofty Andes extending along its entire western border and their many lateral ranges, its high arid plateaus and swampy regions, its vast area extending from 12° north latitude across the equator to 55° south latitude and from 35° to 82° west longitude, its tropical heat over most of it and its wintry climate in some other localities and its general location with reference to the Caribbean Sea, the Atlantic and Pacific oceans. The climate is as variable as all such physical conditions can produce. Generally speaking, the precipitation is not only abundant for its water supply in most of its coastal regions, but over some areas it is excessive. Over its interior elevated districts it is slight and great desert regions exist in Brazil, Bolivia, Peru, Argentina and Patagonia, where there is but little precipitation. The annual precipitation at Bogotá is 44 inches, along the coast 73 inches, at Carácas from 24 to 34 inches, at Valdivia 108 to 115 inches, in Uruguay 43 inches, in Argentina from 2 to 63 inches and in Patagonia from 19 to 97 inches. In many parts of Brazil there is heavy rainfall and in other mountain sections there are heavy snowstorms. At Rio de Janeiro it is from 43 to 59 inches, at Blumenau 53 inches and at Ceará 60 inches. The precipitation is abundant in most of the Western States, where high mountains intercept the vapor-laden winds from the Pacific. There are many large lakes high above sea-level, one of them being Lake Titicaca, with an area of 5,000 square miles, 12,545 feet above the sea. It falls in rain and snow and not only waters vast areas but supplies the headwaters of the Amazon and other great rivers.

Europe.— In Europe a few measurements will illustrate the mean annual precipitation. In England the annual precipitation varies from 25 inches or less at the mouth of the Thames to 60 inches in the lake district and in a part of Wales, while in other districts it is 40 inches. In the western counties of England near high hills it ranges from 80 to 150 inches, while in other sections it averages from 30 to 45 inches. In the eastern counties it ranges from 20 to 28 inches. The mean annual rainfall on the Vyrnwy watershed is 65.16 inches. At Litton in Bristol watershed for 58 years it averaged 41.1 inches and at Bristol 30.9 inches. Over the Thames area for 21 years it averaged 26.9 inches. Over Derwent Valley it varies from 35 inches in the south to 61 inches in the north. Over the Sheffield waterworks catchment areas precipitation averaged about 47 inches. The average rainfall over the whole of England is about 30 inches.

In the west of Scotland it ranges from 39.37 to 100 inches while in the eastern counties it is only 26 inches. At Ben Nevis it is 151 inches. Over Edinburgh district waterworks for 6 years precipitation averaged about 48 inches. Over the headwaters of the Usk, Wye and Towy rivers in Wales rainfall ranges from 45 to 75 inches per annum. In Ireland there is heavy precipitation near the high hills in the west though less than in the Highlands of Scotland. Its general average is more than it is in the eastern districts of England. Over the valley of the river Vartry the annual rainfall averages 48.82 inches. In Norway the annual precipitation varies from 12 inches at Dovre Fjeld to 83 inches between Bukken Fjord and Nordfjord. At Bergen it ranges from 73 to 89 inches. In Sweden the annual rainfall ranges from 12.32 inches at Karesuando to 45.82 inches at Cattegat. In Denmark the annual precipitation ranges from 21.58 to 27.87 inches. In Holland it averages 27.99 inches. At Utrecht it is 27.5 inches and at Tilburg it is 27.6 inches. At Amsterdam and The Hague it averages 27 inches. In Belgium the precipitation is approximately 28 inches. At Brussels it is 27.6 inches. The annual precipitation in France averages about 32 inches. For many years it averaged at Marseilles 20.75 inches and at Nantes 35 inches. Over the Rhone it ranges from 20 to 63 inches, averaging 36.32 inches. Over the Meuse it is 28.33 inches, over Yonne 30.80 inches, and over the Seine 22.7 inches. In the south of France precipitation is less than it is along the Atlantic Coast. In Switzerland the annual precipitation has been 21.7 inches, at Sierre, 32.7 inches, at Geneva, 36.6 inches, at Berne, 42.6 inches, at Montreux, 48.7 inches, on the great Saint Bernard, 65.4 inches, at Lugano, 87.3 inches, on San Bernardino Pass, 89.7 inches of rain and snow in the Alps, facing north or south, thereby intercepting vapor-laden winds from the Arctic Ocean or from the Mediterranean Sea. In the valley of the Inn River it ranges from 22.43 to 57 inches. Scores of glaciers are found in the great elevated valleys of the Alps, and these feed the Rhine, the Rhone, the Po and the Inn rivers and their tributaries. The snows and glaciers cover the high ranges and intervening valleys, whose uplift resembles the foaming billowy ocean. At Saint Maria in the Alps the precipitation is 104.35 inches. In Germany it ranges from 20 to 34 inches. At Berlin it is 22.8 inches. Over the Moselle it is 29.48 inches, over the Rhine 36.69 inches, over the Main from 16 to 27.44 inches and over the Oder 24.60 inches. For 10 years it averaged 47.1 inches over the Mangfall Valley near Muhlthal. In Austria the annual precipitation ranges in various sections from 20.24 to 60 inches, and on the Dalmatian Coast it has been as high as 177 inches. At Vienna for 34 years it averaged 23.42 inches. In Hungary it averages 24 inches, at Budapest 34.32 inches, at Zagrab 70.39 inches, at Fiume and over the mouth of the Danube it is 35.12 inches. In Russia, where there are many mountains, high plateaus and extensive plains facing the Arctic Ocean, there is precipitation in the form of much snow, but not extensive rainfall. The average rainfall in Archangel is 16.2 inches, in Helsingfors, Finland, 19.6 inches, in Petrograd 18.3 inches, in Dorpat 24.9 inches, in Moscow 23 inches, in Warsaw, Russia, 22.8 inches, in Odessa 15.6 inches, at Batum 93 inches, at Sochi 80 inches, in Poti 64.9 inches; while in Astrakhan it is only 5.7 inches and over the plains of Russia but 20 inches. In Portugal, whose westerly coast is exposed to the winds of the Atlantic, there are heavy fogs and precipitation in the north occasionally amounts to 192 inches, while in the interior and in the south there is far less rainfall. In Spain rainfall averages at Madrid 15 inches, at Salamanca 11.3 inches, at San Fernando 30 inches, at Bilboa 46 inches, at San Diego 66 inches, at Oviedo 74 inches and over large areas there is but little precipitation and intense heat. Italy has moderate precipitation. The Alps in the north and its Apennines, extending nearly its entire length, intercept the vapor-laden winds of the Mediterranean and Adriatic seas. It projects southerly into warm latitudes and has a hot summer climate. Over it in the classic ages Jupiter Pluvius reigned from sea to sea. Precipitation varies from 36 inches in the north to 20 inches in the south of Italy. In Sicily it averages 15 inches. Sunny Italy is characteristic of its central and southern sections, where there is infrequent and scanty rainfall in summer months. Over the Po the rainfall ranges from 30 to 48 inches and snow in the north and mists along the coast are not uncommon. The precipitation at Tolmezzo is 96 inches. In Lombardy precipitation averages 22 inches, and irrigation canals are necessary to supply the lands with sufficient water for agricultural purposes. Nearly all Italian cities are supplied with water from rivers and mountain or ground sources. Aqueducts and infiltration tunnels through tufa without linings have long been in use to maintain such supplies. Through such tunnels 22 gallons per second are delivered at Mazzara and 40 gallons per second at Zappulla in Sicily.

Dr. Angot calculated the rainfall by months at Rome and found the annual precipitation there to be 12.03 inches and at Milan to be 12.01 inches. In Greece the annual precipitation ranges from 16.1 inches in Attica to 53.34 inches in the Ionian Isles. Olympian Zeus presided over atmospheric changes and his chief weapon was the thunderbolt. The Grecian states are well watered. In Bulgaria the mean annual precipitation is 29.59 inches. In Rumania rainfall ranges from 15 to 20 inches. The water supply of Constantinople is from streams, springs and rainfall in the forests where reservoirs impound the waters that are conducted in aqueducts, one of which was built during the reign of Constantine.

Several rainfall maps of Europe have been made and these may be consulted for further information on this subject. However, it may be stated that all western and northern Europe are abundantly supplied with copious rains and all the mountains with heavy falls of snow that supply the headquarters of its large rivers flowing to the salted seas on the north, west and south. They supply populous areas in many parts of Europe.

Africa.— In the continent of Africa precipitation ranges from 1.5 inches in Egypt to 20 inches on the southwestern coast and to heavy rainfall in its tropical areas. In Abyssinia it ranges from 30 to 40 inches supplying some tributaries of the Nile. Along the southeastern coast facing the Indian Ocean the rainfalls is 50 inches while in the interior of South Africa it ranges from 5 to 24 inches and at some places on the east coast it is only 40 inches. At Johannesburg, it averages 30 inches, at Paarl and Weltevreden in Cape Colony it averaged for 14 years 34.67 to 35.97 inches. The annual rainfall at Durban is 42.46 inches and at East London, South Africa, it is 62.11 inches. Heavy fogs dampen some areas where there is but little rainfall.

Asia.— In Arabia are great waterless deserts while in some mountain areas living springs of water are found. There is some rainfall in northern and central Arabia. At Dhala in 1892 there was over 18 inches, while at Aden it averaged 2.97 inches. Sir A. Houtum-Schindler found the mean annual rainfall at Teheran for 15 years to average 9.86 inches and reported that at 15 stations in Persia for various years it ranged from 3.24 inches at Jask to 56.45 inches at Resht. The average at all these sections was about 17 inches.

Asia presents so many physical formations of mountain ranges, elevated plateaus, great river basins, extensive arid regions, varying climates and oceanic influences as to cause excessive precipitation of rain and snow in some great mountain areas and little in some other sections. Only a few measurements can be given. The mean annual precipitation over the Caspian watersheds is 7 to 8 inches, over the Aral Sea 6 inches, in western Syria facing the Mediterranean a moderate rainfall, at Beirut it is 21.66 inches, at Jerusalem, 36.22 inches. The normal rainfall over Palestine is about 28 inches, while in the vicinity of the Lebanon range it is copious. There is very little rainfall east of Damascus and over eastern Syria. Between the Orontes and Euphrates some of the slight rainfall is caught and stored up for the water supply. The water of the springs in the vicinity of Mount Lebanon is conducted into cisterns and conserved for domestic and agricultural purposes. Hundreds of water-wheels, operated by the current of the Orontes, or by animal power lift its waters to supply communities along its banks and to irrigate agricultural districts. Astride the Orontes 120 miles north of Damascus is the land of Hamath, supplied by six or more great undershot water-wheels, some 80 feet in diameter, that raise the water of the river into conduits extending through the city. Other sections are supplied with water drawn from wells by endless ropes carrying buckets and operated by camels turning vertical spindles. Irrigation in its primitive form is practised in parts of Syria. The Romans also practised it about the Sea of Tiberias, where the remains of aqueducts may still be seen. The waters of the Abana rushing down over wheels placed in the falls of the Anti-Lebanon ranges develop power to propel the street cars of Damascus and to light that ancient city, which obtains its water supply through conduits from the same sources. In Asia Minor swept by the cool winds of the Black Sea there is much snow and there are occasional heavy rains. It has many springs fed by the underground flow produced by the melting snows of its high mountains. It has some lakes, whose waters are somewhat depleted during the long dry season. In 1912, Dutch engineers designed and French contractors constructed irrigation works to utilize the waters of Bey-Sjehir and Jaila lakes and a canal connecting with the Tsjartpjamba River to irrigate 126,000 acres of Konia Plain.

Over the territory extending from the Jordan to the Persian Gulf there is slight rainfall and much of it is a desert uninhabited.

In Siberia there is much snow and little rainfall. The latter ranges from 8 inches from Persia to Tobolsk and increases to 12 inches over Amur watersheds. Snow falls over vast areas in great quantities and in the mountains remains most of the year, feeding its lengthy rivers and its numberless lakes. Some of these, such as Baikal 400 miles long by 20 to 50 miles wide and Lake Kossogol 120 miles long by 50 miles, cover great areas in a basin that was once a much longer lake. In eastern Siberia rainfall averages from 15 to 20 inches. In Manchuria and northern China between the Volga and the Lena the rainfall ranges from 19 to 29 inches.

In China it ranges from 23 inches at Peking to 78 inches at Canton, which is swept by monsoons. It is only 5 to 7 inches in the north of Mongolia. In some coastal regions it amounts to 100 inches. Over the coastal regions of the Malay Peninsula the rainfall ranges from 75 to 200 inches and over places in Java it is 78 inches, at Singapore it is 97 inches. Siam is occasionally swept by monsoons and the rainfall ranges from 180 inches at Mergni to 240 inches at Monlmein. At some other places it averages from 42 to 54 inches.

In India there is the greatest variation in precipitation in Asia. In its western coastal and Himalaya regions rainfall ranges from 75 to 100 inches on the west to 250 inches at elevated localities, also in the west up to 610 inches in the Khasi Hills, where for a decade it averaged 550 inches. If entirely caught and conserved it would form a column of water 45 feet high. At Cherrapunji for 40 years it averaged 426 inches. At Calcutta it averaged 65 inches. At Ceylon from 60 to 80 inches. At Madras 55 inches. At Bombay 75 inches and in the valley of the Ganges it falls to 25 inches and in that of the Indus to 6 inches. At Poovah it is 24 inches. North of Punjab, it ranges from 70 to 80 inches and also that amount on some of the lateral spurs of the Himalayas.

There are no available records of precipitation in countries to the north of India, but they are light, cold and covered with snows, which are their principal source of water supply. In Burma on the west coast it averages from 157 to 196 inches. Over the Irrawadi Valley in Burma it is only 39.27 inches, but in the delta it averages 98.42 inches. In Japan the average rainfall over the whole country is 61.8 inches.

Australasia and Oceanica.— In Australia rainfall varies greatly in different sections. At Brisbane it averages 50 inches, at other places 70 inches. At Melbourne it averages 25.6 inches, at Port Phillip from 20 to 30 inches, at Adelaide 20 inches and in some parts of the Eyre Peninsula only 10 inches and this average extends to more than ⅓ of the continent. In South Australia it averages from 8 to 10 inches. In 1889 the Department of Mines at Sydney collated rainfall data and estimated the amount at 50 or more watering places in Australia. Those showed the weekly rainfall to range from $\frac{1}{10}$ of an inch in some localities to an inch in others and still others it ranged from 2.25 to 3.10 inches. In most of the inhabited regions of New Zealand, rainfall ranges from 30 to 50 inches per annum. In New South Wales it ranges from 12 to 46 inches. At Hay it ranges from 10.94 to 25.84 inches.

In the Philippines there is great variation in rainfall. At Manila it averages 76 inches and ranges from 16.2 to 152 inches over different islands. At Kauai, one of the Hawaiian islands, it averaged for 4 years 518 inches. On the island of Mauritius rainfall on the east coast has been as high as 141 inches and on the west coast at the same time it averaged only 27.95 inches.

In Java a rainfall ranges from 70 inches at Batavia to 174 inches at Buitenzorg.

Except as otherwise stated, the foregoing are approximately the mean annual precipitation over the localities mentioned, as nearly as the measurements extending in most cases over a period of years disclosed. They furnish some data that may be considered in estimating such sources of their water supply.

Robert Lauterberg, meteorologist of Switzerland, once suggested that most measurements fail to give all the rainfall and that ordinary measurements must be increased 25 per cent to arrive at the actual precipitation.

There are, however, many instances of well-known departures from the amounts heretofore given, when in wet years or cycles of years, or localities of excessive precipitation, the maximum precipitation is greater than the mean annual precipitation. There are also dry years or cycles of years and dry localities, when the minimum precipitation is less than the mean annual precipitation. Such extremes are not constant, but may be considered in determining the hydrology of a given locality.

The foregoing records and measurements of rainfall are the mean annual precipitation over periods of years. Excessive precipitation, however, occurs in storms, when the hourly and daily rates in the localities affected may be extraordinary. Such storms are usually of short duration and are confined to small areas. Records of some of such excessive precipitations and of monthly tabulations in localities, where meteorological stations are maintained, are obtainable from the reports of the weather bureaus of this and other countries. Most of such measurements are included in the general averages of mean annual rainfall hereinbefore stated.

Disposition of Precipitation.— The disposition of rainfall or precipitation is quite fully considered in the article on «Water Supply,» which is to follow under that title in a succeeding volume of this encyclopedia.

Henry W. Hill,
President of the New York State Waterways Association; author of ‘Waterways and Canal Construction in the State of New York,’ etc.

RAINIER, rā'nēr', **Mount.** An old volcanic cone in central western Washington named from Admiral Rainier of the British navy by Vancouver the navigator, who saw it from Puget Sound in 1793. It is also known by the Indian name of Tacoma Peak and rises about 56 miles southwest of the city of Tacoma. Its altitude is 14,408 feet or about 8,000 feet higher than the adjoining Cascade Mountain region. It was once thought to be the highest peak in the United States but Mount Whitney in California is 93 feet higher and a few peaks in the Rocky Mountains in Colorado exceed it slightly. Its upper part is mostly covered by snow and ice, the latter in 11 main glaciers radiating from the summit like the arms of a great starfish. The glaciers are from four to six miles long and equal in size and beauty those in the Alps. The larger one extends down to 4,000 feet. A luxuriant forest extends part way up the slopes, and the timber line is between 7,000 and 7,500 feet. Around the base are many natural meadows of most picturesque character with profusion of summer flowers. The peak, «the noblest of the fire-mountains which, like beacons, once blazed along the Pacific Coast,» is the remains of a huge volcano built up of thick layers of lava and originally 2,000 feet or more higher, its top having been blown off by a great explosion a few centuries ago. A large crater resulted from this eruption and several small cones and craters have since been built. The latest eruptions were slight ones in 1843, 1854, 1858 and 1870. Now the only activity is a slight emission of steam at one locality. The first ascent by a scientific observer was made by S. F. Emmons in 1870.

In 1897 it was ascended and thoroughly explored by a large party. «Almost 250 feet higher than Mount Shasta, its nearest rival in grandeur and in mass,» they described it as «overwhelmingly impressive both by the vastness of its snow-capped summit, its glacial mantle and by the striking sculpture of its cliffs.» The total area of its glaciers amounts to 45 square miles, an expanse of ice far exceeding that of any other single peak in the United States. The region now forms the fully protected Mount Rainier National Park created by act of Congress approved 2 March 1899. Centred by the towering mass of Mount Rainier, the park reserve is nearly a perfect square, the sides of which are 18 miles in length and contains 324 square miles, or sections of 640 acres each (207,360 acres). It is completely surrounded by lands embraced within the Rainier National Forest. Every year large numbers of tourists visit the park to camp in its meadows, and occasional ascents are made to the summit

When water is made to flow through a layer of sodium permutit, the latter exchanges its soda for the calcium and magnesium salts of the water and the degree of hardness in the latter is reduced to zero. The permutit has to be regenerated as it grows lax in action. This is easily accomplished by washing it for a few hours with a solution of common salt. Manganese permutit in connection with marble dust removes all iron and acids from waters thus affected.

The practice of softening the entire water supply of a municipality has grown steadily and in not a few large manufacturing cities the municipal softening plant is saving the citizens hundreds of thousands of tons of coal per annum and adding years of life to the community's boilers. The principal requirements are (1) mixing chambers, in which the softening chemicals are thoroughly mixed with the water; (2) capacious settling basins sufficient to give the necessary time for the slower reactions when the temperature is low, as in winter; (3) a device for adding a coagulant (alum or ferrous sulphate) at both the entrance port and the exit port of the water into and from the settling basins; (4) substantial mechanical filters. In addition, as one of the requisites should be a special apparatus to slake the lime, reduce it to a proper emulsion and feed it in proper quantity automatically into the flowing water.

At the municipal water softening plant at Cleveland, Ohio, 150,000,000 gallons of water per day require the daily application of 40 tons of quicklime. This is slaked with hot water, mixed into an emulsion in an agitator, taken to tanks where it is cooled and diluted to the proper consistency and finally pumped at a uniform rate into the flowing water.

In a recent report (1916) upon a water supply for the city of Sacramento, Cal., the relative hardness of the available waters was considered in estimating the cost of the project. The engineers showed that while a supply of water from ground wells would be cheapest in initial outlay, that the water of the Sacramento River would be more economical for the consumers because of its lower degree of hardness; the ultimate figures being $38.40 per 1,000,000 gallons for the river water as against $42.40 per 1,000,000 gallons for well water. On the basis of the city's daily consumption of 30,000,000 gallons the saving in soap alone to the consumers amounted to $120 per day. Consult Booth, W. H., 'Water Softening and Treatment' (London 1906); Christie, W. W., 'Water: Its Purification and Use in the Industries' (New York 1912); Whipple, G. C., 'The Value of Pure Water' (New York 1907).

C. Herschel Koyl,
Consulting Engineer, New York.

WATER SUPPLY: For Municipal, Domestic and Potable Purposes, Including Its Sources, Conservation, Purification and Distribution. Introduction.—This article does not treat of water supply for navigation, irrigation or power development, but is confined principally to the consideration of the sources, collection, conservation, purification and distribution of water for municipal, domestic and potable purposes. This is becoming an increasingly engrossing subject for all progressive communities, since scientific research has shown that many natural waters are the media for the propagation and dissemination of countless colonies of micro-organisms of vegetative and animal growths, including bacteria, some of which are pathogenic. Some water bacteria have been localized and classified as shown by Prescott and Winslow in their 'Elements of Water Bacteriology.' Many other micro-organisms have also been localized and classified as shown by George C. Whipple in his 'Microscopy of Drinking Water.' The nature and characteristics of some of these organisms must be studied in all water supply problems and therefore will be considered to some extent under some of the subtitles to follow.

In 1857 Nägel suggested the name «schizomycetes» for all micro-organisms and that designation is used by some bacteriologists for all such organisms. Botanists use that designation for vegetative organisms. «Bacteria,» however, is the name usually applied to living organisms in water. Many of these infest surface and ground waters. Neither lakes, rivers, ponds, nor wells are free from such micro-organisms. Not infrequently thousands of bacteria are found in a cubic centimeter of natural, which is usually denominated «raw» water. Dr. A. H. Hassall of London (1850) is reported to be the first to identify living organisms in drinking water. He was followed by E. N. Horsford, L. Radlkofer, Ferdinand J. Cohn, James Bell, L. Hirt, W. G. Farlow, Ira Remsen, H. C. Sorby, J. D. Hyatt, George W. Rafter, George C. Whipple and others. Dr. A. C. Houston of the London Metropolitan Board in 1912 reported 10,315 microbes per centimeter of raw Thames water, although says Prof. William P. Mason «it is now generally admitted that such a medium is not favorable to their growth.» Dr. Houston found that they lived longer in deep Loch Katrine water, one of the sources of supply for Glasgow, than they did in the Thames.

Dr. Robert Koch traced the cholera epidemic of 1892, in Hamburg, which did not prevail in Altona across the Elbe, to the contamination of its unfiltered raw river water supply by the cholera germ, *spirillum choleræ Asiaticæ,* or *comma bacillus,* discovered by Koch in 1884. Altona used filtered water from the Elbe and largely escaped that cholera epidemic. Since the discovery of the specific cholera germ by Dr. Koch, greater caution is exercised by municipalities to prevent the contamination of their water supplies by the *spirilla choleræ Asiaticæ,* and cholera epidemics are less frequent. In 1887 Messina, Sicily, had an epidemic of cholera due to polluted water. Typhoid epidemics have occurred more frequently than Asiatic cholera, for the typhoid bacilli (*B. typhosi*) are more generally distributed and the contamination of water supplies thereby has been not uncommon. George C. Whipple in 'The Microscopy of Drinking Water,' p. 80, says, «All quiescent surface-waters are liable to contain microscopic organisms in considerable numbers. The water that is entirely free from them is very rare.»

From the 'Waterworks Handbook' of Flinn-Weston and Bogert and other publications are excerpted the following data as to bacterial contents of a few river waters per cubic centimeter.

Bacteria in the Niagara vary from 10,000 to 300,000 per cubic centimeter; in the Seine from 300 per cubic centimeter above Paris to 200,000 per cubic centimeter below Paris; in the Spree from 82,000 per cubic centimeter above Koepenick to 10,000,000 per cubic centimeter at Charlottenburg; in the Ohio they averaged 16,500 per cubic centimeter; in the Delaware 7,680 per cubic centimeter; in Crystal Lake, Mass., 185 per cubic centimeter; in Lake Ontario 7,040 per cubic centimeter; in the Mississippi upwards of 2,000 per cubic centimeter; in the Potomac upwards of 4,000 per cubic centimeter and in the Merrimac upwards of 11,000 per cubic centimeter; in raw Thames water 10,315 microbes per cubic centimeter; and in the Isar at Munich opposite an effluent of sewage 121,861 per cubic centimeter. In some waters bacteria have exceeded 200,000 per cubic centimeter. Nearly all surface waters have some bacterial content and in many cases the bacteria are pathogenic. Neither are all springs nor well waters entirely free from bacterial infusion. This may not be sufficient nor of the kind to pollute such waters for some genera are not pathogenic. However, it has been contended that some non-pathogenic bacteria may become pathogenic under favorable conditions. That is notably so in the case of *bacillus coli communis* (*B. coli*), when nourished on sewage and on other typhoid waste.

Ground waters, including wells, in some localities are infested with *crenothrix* at the number of 20,000 per cubic centimeter and with similar organisms, where iron and manganese are found. The *crenothrix* flourishes in waters impregnated with iron and *crenothrix* itself secretes iron and clogs water pipes. Many other species have been found in ground waters, though they may not all be pathogenic. Some time ago the Massachusetts Board of Health tabulated those found in ground waters. In recent years, possibly from China, there have been imported with livestock, or by means of their hides, the dread anthrax spores (*B. anthracis*) discovered by Robert Koch in 1876, which have been discharged from tanneries into rivers. They are immune to the ordinary agencies used for the sterilization or purification of water supplies. Turneaure and Russell reported in their ‹Public Water Supplies› that in Medford, Wis., a well was contaminated by surface water draining into it from a field, where cattle had died of anthrax or splenic fever.

The *bacilli tetani* (*B. tetani*) and many other species have been discovered in raw river water. In 1900, George C. Whipple compiled data showing the relative abundance of *diatomaceæ, chorophyceæ, cyanophyceæ* and *Protozoa* in 57 lakes, ponds and storage reservoirs of Massachusetts. Consult Whipple's ‹Microscopy of Drinking Water› pp. 139–141. None of such waters were entirely free from some one or more genera of such organisms. They may be considered as fairly representative of all surface waters.

As a result of the prevalence of pathogenic bacteria in water supplies, waterborne diseases are many and include those already mentioned and many other intestinal, tubercular and other disturbances. It is the aim of modern research to prevent all such diseases and to that end new processes for the purification of water supplies have been perfected. New standards of purity and wholesomeness have been established to which water supplies must conform before they are considered safe for potable uses. Some of these will be considered in this article, which will comprise several subtitles.

Primitive Conditions.—In the primitive conditions of society the water supply of a territory received but little attention. The early inhabitants of the world were more interested in its availability and abundance than they were in its quality. Accordingly the most populous settlements were those along oceans, seas, gulfs, bays, lakes, rivers and watercourses generally. Early palæolithic remains have been found along the Thames. In the Stone and Bronze ages dwellings for human habitation were built on poles in the lakes of Switzerland, the British Islands and elsewhere and mounds were constructed along the coasts in Scandinavia. Their occupants were thus abundantly supplied with water as well as protected from the ferocity of wild animals. Primitive peoples, however, knew little or nothing about the animal and vegetative organisms, in surface, running or stored-up water. At first there was little, if any pollution of watercourses by human agencies. The early inhabitants supplied their needs from nature's inexhaustible reservoirs without fear or even the knowledge that water in any of its manifold forms might be unsafe for domestic or for general potable uses. That is a matter of recent deduction from the slow discovery of species of pathogenic bacteria, in surface and other polluted waters. Some of these develop and propagate readily when taken into the human system as do *bacilli coli communis*.

Prior to the 19th century of our era there are few extant records of the ravages of diseases and the destruction of human life, attributed to the potable uses of unwholesome water. Many wasting fevers, pestilences and plagues are recorded in history prior to the discovery of the deadly species of microscopic organisms in contaminated water, but their causes were unknown. As the population increased and extended from watercourses inland, tanks, storage reservoirs and canals were constructed as they were in Assyria, Babylonia, Egypt and China. The sources of the Tigris and Euphrates and the waters of those rivers themselves were conveyed through a network of canals to water the many cities of Mesopotamia whose water jars have been found at Nippur and elsewhere. Khammurabi provided for the protection of some of such canals in his Code of Laws, promulgated 2250 B.C. Egypt was watered by the Nile, whose constant flow was maintained by drawing upon the impounded waters of Lake Moeris. Asia Minor had many springs, notably those in the valley of the Mænander. The Arabians utilized extinct volcanic craters as reservoirs for the accumulation of waters. Greece had its rivers, springs and infiltration galleries. Rome had its lakes, springs, aqueducts, reservoirs and rivers. Carthage and Palestine had their wells, cisterns and pools, supplied by mountain streams. India had its rivers, canals and reservoirs. All those ancient peoples and also the Chinese had their deeply driven wells, which supplied their best waters. Herodotus, Hippocrates, Strabo, Pliny and others wrote on the water supply of various countries.

Æschylus in his 'Eumenides' speaking through Athena said:

Κακα'ς ἐπιρροαισι· βορβόρῳ θ'ὕδωρ
λαμπρὸν μιαίνων οὔποθ' εὑρήσεις ποτόν.

which has been translated as follows:

"But if with streams defiled and tainted soil
Clear river thou pollute, no drink thou'lt find,"

thus warning the Athenians of the dangers in polluted water.

Hippocrates recommended that drinking water be filtered and boiled before using it. That is some proof that he realized that raw water ought to be sterilized before it was drunk. The Romans knew that some waters were unsuitable for drinking purposes and used their poorer qualities for irrigation, municipal fountains and other public non-potable purposes. Not until the advancement of science in the 19th century had revealed waterborne diseases, did the quality of the water supplies of communities arouse public attention.

The Germ Theory of Disease.— The modern sciences of bacteriology and biology revealed the nature and activities of myriads of microscopic organisms in impure water hereinbefore partially described and how they become the media of infection and the agencies for spreading diseases. After the discoveries of Theodor Schwann, Louis Pasteur, Robert Koch, Ferdinand J. Cohn, Joseph Lister and others during the last century «the germ theory of disease» was generally accepted. Those pathologists turned their attention to the discovery of means of combating the active agencies that were destructive of human life. They made several important discoveries of antitoxins, serums and lymphs of inestimable pathological utility to the race. These, however, were insufficient to check the ravages of all infectious diseases, some of which, as was stated, are transmitted through living organisms in potable waters. That led to the study of the water supplies of communities, one of the most engrossing subjects of the last and present century. Municipalities and communities generally for their own welfare must consider and solve this problem regardless of the expense thereby entailed upon taxpayers, for it is growing in importance in many habitable parts of the globe with the ever-increasing density of population. Before entering upon the study of the processes for the purification of water supplies, it may be well to consider some of the physical conditions that contribute to the production of the abundant waters, found in the habitable portions of the earth.

Earth's Water Supply.— Three-fourths of its surface is covered with salt water and from those inexhaustible fountains of the deep the heat of the sun is continually drawing invisible vapor up into the strata of the atmosphere, where the aqueous vapor is cooled and becomes visible and is wafted landward over continents. It comes in contact with hills and mountain ranges and is precipitated in rain and snow and so replenishes the infinite watersources of the uplands of the earth. Whether in some one of its varied forms, it accumulate in insurmountable masses of snow, giving mountain ranges their names as it did the Himalayas, or in another form it become rivers of ice, like Alpine glaciers to form such commerce-bearing rivers as the Rhone, or in another form it roll in ceaseless tidal billows encircling the globe, or still in another form it float in vaporous clouds landward to fall in refreshing rains over vast areas of territory to percolate the soil and be stored in an infinite number of natural reservoirs, whence it flows in countless streams to nourish the fruits of the earth and supply the wants of man, it conditions and largely controls the activities of every generation and will continue so to do for all time.

Next to the free air we breathe, water is man's greatest earthly possession. Water is freely showered upon the earth in abundance and is stored up in countless pools, ponds, ground waters, subterranean springs and other natural reservoirs and is accumulated in brooks, creeks, streams, rivers, lakes, sounds, bays, seas and the oceans, covering three-fourths of the earth's surface and making habitable a large part of the remaining fourth. Its distribution is affected by the uplift and physical configuration of continents and their relation to oceans, the rotation of the earth upon its axis, the temperature, humidity, succession and varying seasons, climate and trade and other prevailing winds. All of these and other natural phenomena more or less condition the amount of precipitation over different areas. Some lofty mountain ranges, continually intercepting vaporous clouds swept inland from the oceans and seas, are capped with permanent masses of snow, which are unfailing sources of water supply for great rivers like the Amazon, the Yukon, the Rhone, the Ganges and others. Other mountain ranges cause almost daily precipitation in the form of rain, which collects in innumerable natural basins on the surface and below it, but high above the sea-level. These are the source of mountain streams and of the occasional underground flow found in some mountain regions. The amount of precipitation varies over different areas. In the polar regions there is no rain and all precipitation there is congealed in the form of snow and icy particles. Rainfall or precipitation is quite fully treated in the special article under the title, RAINFALL, in Volume 23 of this Encyclopedia, to which reference is herein made for the amount thereof over various areas of the habitable globe.

Under the operation of natural laws only a part of rainfall can be collected, conserved and made available for human needs. As announced under the article on RAINFALL communities must also consider its disposal. That will appear from what follows.

Disposal of Precipitation.— Water from rain or melting snows disappears from the catchment areas, (1) by evaporation, (2) by transpiration, (3) by runoff and (4) by percolation. These methods dispose of varying amounts dependent somewhat upon the surfaces, whether land, or water, the seasons, climate, temperature, locality, altitude, vegetation, character of the soil and other physical conditions. They may be briefly stated as follows:

(1) Evaporation to some extent already considered under the article on RAINFALL may

dispose of any part or all of the rainfall over a limited area and in some instances evaporation may exceed rainfall, as it did in Massachusetts in 1883. Evaporation goes on from ice and snow less rapidly than from land or water surfaces. Vegetation and trees intercept precipitation and also retard evaporation. They tend to increase percolation for the moisture penetrates the soil in and about the roots and is held there until it percolates into the deep strata of the earth. Various formulæ have been deduced to determine evaporation, as stated in the article on RAINFALL. These, however, are not conclusive.

Capillary attraction acts upon water 30 or more inches below the surface and occasionally lifts a film of water 6 to 30 inches above the ground-water level and so aids evaporation. Wilton Whitney, in 1897, reported ('Agriculture Year Book') that capillarity drew moisture up 20 feet or more to nourish crops in the soils of California. Prof. J. B. Stewart of the Agricultural College of Michigan reported that capillarity operated upon water from 45 to 70 inches below the surface. The depth of the water-table below the surface is not uniform and varies in different localities. In the Central States it was found by W. J. McGee to be about 22 inches below the surface. Charles H. Lee of the Geological Survey was of the opinion that the capillarity lift is limited to four feet in coarse sandy soil and to eight feet in fine sandy and clay soils. Thus by the operation of natural laws is the verdure of the earth nourished and sustained from the waters below, though there be insufficient precipitation from above. Warm sunshine and gentle winds increase evaporation.

From some soils evaporation averages 16.68 inches annually, where the rainfall is 30.29 inches and the percolation 13.61 inches. Over the Ohio River watersheds, where the rainfall averages 41.1 inches, the evaporation averaged 14.8 inches; over the James River watersheds, where the rainfall averaged 42.1 inches, the evaporation averaged 16.3 inches; and over the Sacramento River watershed, where the rainfall averaged 32.2 inches, the evaporation averaged 8.5 inches. Evaporation from the Croton watershed was computed by John R. Freeman for a period of 32 years at 24.74 inches. Evaporation has been computed over the Sudbury watershed at 23.63 inches and at Nashua at 23.76 inches. From water surfaces evaporation is much greater than from land surfaces. From the Chestnut Hill reservoir near Boston for a period of years it averaged 39.2 inches and from a water surface at Croton, N. Y., it averaged 39.68 inches. From Mount Hope reservoir at Rochester for 10 years, it averaged 44.45 inches, from the Muskingum River 40 inches, from Owens Lake, California, 80 inches, from Yakima River, Washington, 32.8 inches, from East Lake, Birmingham, Ala., it ranged from 52.1 inches to 69.4 inches.

The United States Weather Bureau and United States Department of Agriculture for some years have compiled a record of evaporation from the principal watersheds of the United States. These show that about two-thirds of rainfall or precipitation over the United States is disposed of by evaporation. In Massachusetts in 1883, evaporation was 39.12 inches and rainfall was only 32.78 inches.

From a water surface at Lea Bridge, England, it averaged 20.6 inches, whereas for 14 years it averaged 18.14 inches from land surfaces, where the rainfall was 25.72 inches. At Rothamsted, England, evaporation averaged 16.68 inches, where rainfall averaged 30.29 inches. From Talla reservoir, Edinburgh, it averaged 15 inches. The characteristics of land areas and their general physical conditions, together with atmospheric influences, affect evaporation.

(2) Transpiration also disposes of an appreciable amount of rainfall in some localities through grasses, grains, other vegetation, shrubbery and trees and by them returned to the atmosphere. *Bulletin No.* 285 of the Bureau of Plant Industry of the United States Department of Agriculture shows the water requirements of various cereals and plants. Prof. Adolph T. Meyer states that "For grasses and grains the ratio of pounds of water used to pounds of dry substance produced varies from 300.1 to 600.1." B. E. Livingston has undertaken to show (40 *Botanical Gazette* 31) that there is a direct relationship between transpiration and the weight of vegetables produced. The Department of Agriculture of the United States has also undertaken to show that the yield of grain of an area is approximately proportionate to the water consumed. It will thus be seen that large quantities of water are taken up by the growing vegetation and forests of the earth and returned to the atmosphere. Growing crops absorb from 9 to 10 inches of rainfall and brush and trees from 4 to 12 inches of rainfall according to estimates made by Professor Meyer. Nearly all such water escapes from the stomata of leaves into the air, for the amount retained is very slight. Raphael Zon of the United States Forestry Bureau reported in 1913, that one acre of oak forest in Austria absorbed upwards of 2,227 gallons of water daily, which was equivalent to a rainfall of 12½ inches in a period of five months. These figures indicate the enormous quantities of water given off by forests into the air.

The United States Department of Agriculture collected data in Central Europe showing the transpiration from forests to equal one-fourth the rainfall there. From deductions of M. W. Harrington it appears that much of the rainfall is transpired into the atmosphere by green crops and three-fourths of it from some forests and less than one-third from bare soil. During the growing season plants and trees draw moisture and water from the subsoils and thence it escapes into the atmosphere. The amount of water so taken from the ground by the capillary attraction in vegetation, plants and trees and by them transpired into the atmosphere varies greatly under different physical conditions, but enough has been stated to indicate that an appreciable part of the precipitation is thus disposed of and under some conditions that amounts to 20 inches.

(3) The runoff from different watersheds also varies greatly, depending upon their physical characteristics, including their geological structures and configuration. Sandy surfaces freely absorb water and from them there

is little runoff, whereas clay and rocky soils absorb but little rainfall and from such surfaces the runoff is large. Steep slopes also shed water freely, whereas forest-clad areas retard, absorb and retain a large part of the rainfall. The following data will illustrate the amount of water disposed of in the localities mentioned by runoff. The runoff waters from catchment areas or watersheds accumulate in pools, ponds, lakes and rivers and become one of the two available sources of water supply, the other being ground-waters. From the Genesee River at Mount Morris, N. Y., from 1892 to 1898, the runoff ranged from 6.67 to 19.38 inches. averaging about 12 inches.

Prof. Adolph F. Meyer in his work on ‘Elements of Hydrology’ says that evaporation and transpiration dispose of 15 to 25 inches of rainfall and the remainder represents runoff which includes seepage and percolation. The latter will be considered under the next sub-title. From the map of the Geological Survey prepared by Henry Gannett, it appears that the surface runoff over different watersheds ranges from three inches in the States east of the Rocky Mountains to 60 or 80 inches in the northern Pacific States. In the Central and Eastern States, it approximates 20 inches. Each watershed, however, must be independently studied to determine its runoff. This varies greatly in the different months and necessarily averages much less than the rainfall. Where the mean precipitation over the upper Mississippi reservoirs was 24.62 inches, the mean runoff was only 3.61 inches and the percolation averaged 14.7 inches. Over the Mississippi watershed it averaged 5.31 inches, or nearly 25 per cent of the rainfall. The rate of runoff to rainfall ranged from 15 per cent in the Missouri Basin to 24 per cent in the Ohio Basin. In Ohio it amounted to 22 inches. At Saint Croix, Wis., it was 9.6 inches, at Roanoke, Va., it was 17.7 inches. In the Yazoo and Saint Francis basins, the runoff was 90 per cent of the rainfall. Over the Connecticut River where the precipitation for nine years averaged 36 inches, the runoff averaged 21.9 inches. From the James River watershed for seven years, it averaged 18 inches. At Tohickon Creek for 24 years, it averaged 26.10 inches. At Tombigbee, Miss., it averaged 17.10 inches, at Sacramento, Cal., it averaged 20.4 inches. Over the Sudbury River, where the precipitation for 25 years averaged 45.4 inches, the runoff was 21.5 inches. In the State of New York it averaged about 45 per cent of the rainfall.

John C. Hoyt and Robert Anderson in their ‘Hydrography of the Susquehanna River Drainage Basin,’ reported that the runoff in that part of the basin above Harrisburg from 1891 to 1904, averaged from 49 to 55 per cent of the rainfall and at other places in the basin from 49 to 63 per cent of the rainfall. Over the Nashua River where the precipitation for 13 years averaged 47.3 inches, the runoff averaged 23.9 inches. The runoff averages nearly 50 per cent of the rainfall in New England. Over the Croton River, where the precipitation for 43 years averaged 48.9 inches, the runoff averaged 23.3 inches. Over the Milburn-Massapequa watershed, Long Island, N. Y., where the mean precipitation was 46.41 inches the runoff was about 30 per cent thereof. Over the Susquehanna River, where the precipitation for 10 years averaged 38.4 inches, the runoff averaged 21.3 inches. Over the James River in Virginia, where the precipitation for 14 years averaged 42.3 inches, the runoff averaged 17.9 inches. Over the Potomac River, where the precipitation for 14 years averaged 37.4 inches, the runoff averaged 14.4 inches. Over the Muskingum, where for seven years precipitation averaged 41.21 inches, the runoff averaged 14.20 inches. Over the Rock River, Illinois, where the precipitation for five years averaged 33.88 inches, the runoff averaged 10.03 inches. George W. Rafter in ‘Water Supply and Irrigation Papers No. 80 United States Geological Survey’ gives the runoff for various years over 12 watersheds, and it averaged from one-third to one-half the rainfall.

Over Saale River, in Germany, where for 14 years precipitation averaged 23.78 inches, the runoff averaged 7.17 inches. Over Remsched Dam in Germany, where for nine years precipitation averaged 45.62 inches, the runoff averaged 30.78 inches. Over the Woodburn River in Ireland, where precipitation was 36.29 inches, the runoff was 23.04 inches. Over the Buffalo River in South Africa, where precipitation was 29.52 inches, the runoff was 5.30 inches.

The mean runoff from 20 watersheds in France is nearly 50 per cent of the precipitation, while in Germany the mean runoff from nine watersheds does not, excepting in three instances, exceed one-third the precipitation.

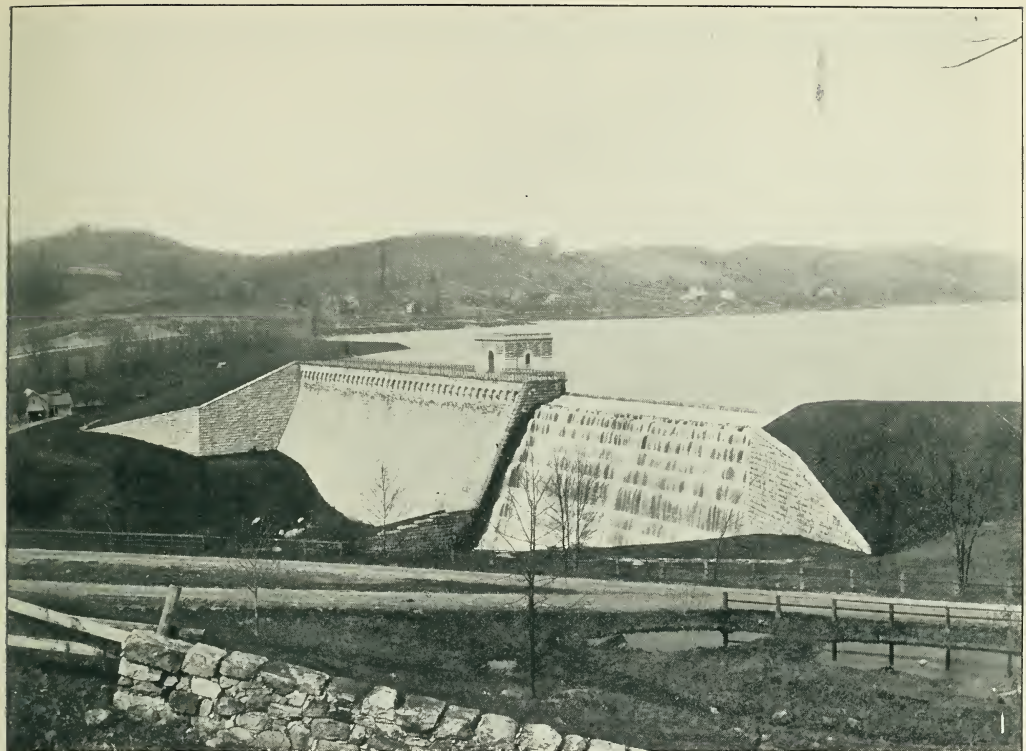
The mean runoff from the watersheds of Great Britain ranges from 50 per cent to 75 per cent of the precipitation. The foregoing data, largely from approved reports, indicate observed runoffs. They are not merely estimates from curves which are fraught with more or less error, owing to the failure in some instances to take into consideration all the necessary physical elements of a given watershed to determine its actual runoff.

The French physicist, G. Lidy, proposed the equation of $P + E + R = R''$, wherein P stands for percolation, E for evaporation, R for runoff and R″ for rainfall, but that does not always accord with actual measurements. Atmospheric and material conditions may so affect the factors of the equation as to make an unbalanced equation.

T. U. Taylor, of the Society of Civil Engineers, well says: «Runoff is a complex factor depending on rainfall topography, vegetation, kinds and condition of the soil at the time of the rains.» (Proceedings of the Society of Civil Engineers, Vol. XL, p. 166).

(4) Percolation is the descent of water from rain or snow, or from other sources into the porous strata of the earth due to gravity. Water thus descends to the saturated horizon usually a little above the water-bearing level of the ground water. As the latter is drawn upon by capillarity and ceaselessly flows away between the strata of the earth, it is depleted and the percolating waters replenish the losses. Such «gravity waters» descend, where the soils do not admit of capillarity. Ground waters fill the subterranean channels, supply springs and wells and descend

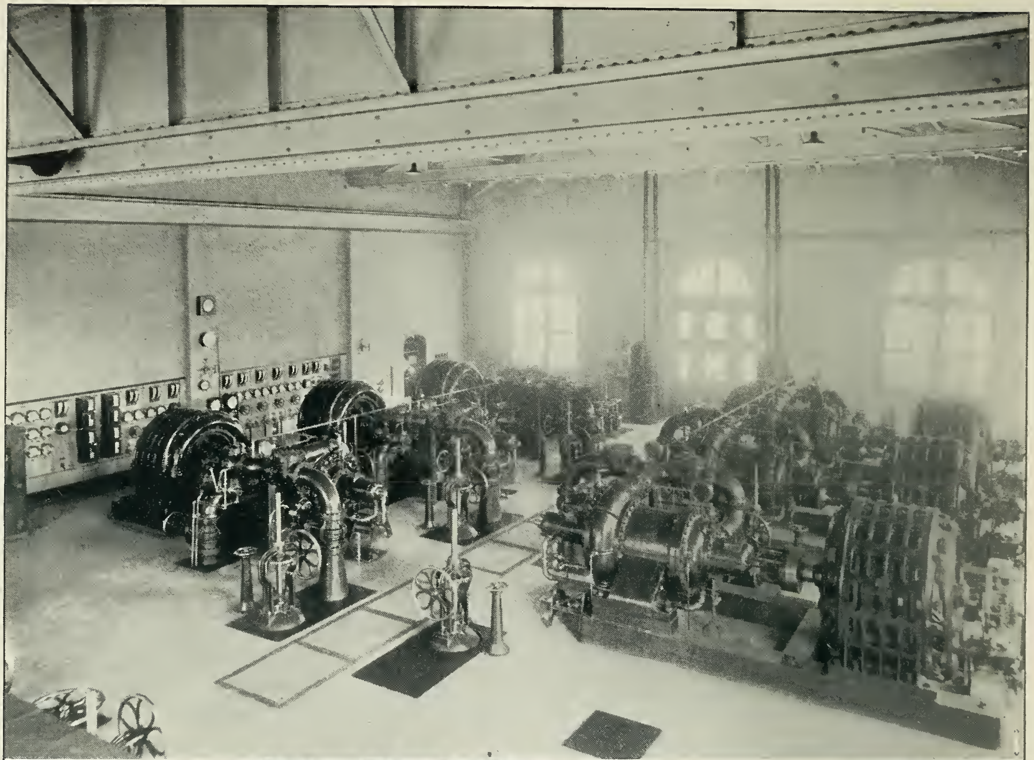
> "Through caverns measureless to man
> Down to a sunless sea."



1 Titicus Reservoir and Dam, New York Water Supply

2 Chain of Rock Filters, Saint Louis System

WATER SUPPLY



1 High Pressure Fire Service Pumping Station, New York

2 Water Laboratory, New York

The subterranean Rubicon in Belgium is a river of ground waters.

Ground waters are well nigh unfailing sources of water supplies as we shall see from what follows. As already stated, percolation disposes of what is left after evaporation, transpiration and runoff have eliminated a large part of the rainfall. It is conditioned somewhat upon the physical formation of the territory and also upon climate, temperature, elevation and slope of watershed. On mountain slopes and hillsides, where the surface and strata are tilted, there is little percolation, but excessive runoff. Permeability of the strata determines their storage capacity. Soils, unconsolidated deposits, sands, gravels, sandstones, porous limestones, slate, till, conglomerate quartzite and other rocks absorb quantities of water dependent upon their porosity. The denser rocks, such as granites, gneisses and schists are relatively impervious to saturation and in such geological formations only in joints, faults, bedding planes, caverns and subsurface basins and channels is water collected. The porosity of all these different strata and the physical conditions of the earth's crust largely control the amount and depth of percolation, which ranges in different locations from 10 per cent to 50 per cent of the precipitation.

Into some soils over which the rainfall is 30.29 inches the percolation averages 13.61 inches thereof. On Long Island it was estimated by the Burr-Hering-Freeman Commission to be from 30 per cent to 50 per cent of the rainfall and to range from 15 to 25 inches, conditioned upon the dry and wet years. In Muhlthal, Germany, where the rainfall was 47.1 inches, the percolation was found by Walter E. Spear to equal 30.42 inches. He estimated the percolation in Germany to equal 50 per cent of the rainfall, in Holland to range from 11.1 inches to 15.3 inches of the rainfall and in Belgium to range from 6 to 9.7 inches of the rainfall. Herbert E. Gregory estimated that 25 per cent of the 46.89 inches of rainfall over Connecticut is absorbed in the ground, while in some sections of the United States such absorption is greatest during the period of heaviest rainfall and then it ranges from 80 per cent to 95 per cent of the precipitation. In this manner water enters the strata of the earth and forms underground streams or is collected in springs and in subsurface basins. Such waters are known as ground waters and supply wells and also flow toward river beds and to adjacent waters, such as lakes, seas and oceans. Ground waters are also supplied from streams flowing over the surface. Large habitable areas are supplied from underground flow by means of innumerable wells, tapping that flow, or by means of springs or by means of conduits, as on Long Island, or by means of infiltration galleries, as in some parts of Belgium, Holland and Germany.

I. M. de Varona found that the amount of ground water recovered from Ridgewood drainage area of 65.4 square miles in 1890, when the rainfall was 52.15 inches, was 17.68 inches, which was 33.9 per cent of the former. For several years in that area such amount ranged from 28 per cent to 33 per cent of the precipitation. The Board of Water Supply estimated that, if the Ridgewood watershed were completely developed, the yield of ground waters in normal rainfall years would be nearly 1,000,000 gallons a day for each square mile of area. They reported that the old watershed was yielding 900,000 gallons a day per square mile and the new one was yielding 700,000 gallons a day per square mile. The Burr-Hering-Freeman Commission from its investigations concluded that, in addition to the water being pumped in 1903 for Brooklyn, there might be obtained 200,000,000 gallons per day from the southern watersheds of Long Island.

The underground reservoirs of California are structural basins filled with the alluvial debris, due to the weathering of the adjacent mountain ranges. Through such alluvial deposits precipitation percolates to the impervious rock below. The ground waters are thus collected and their only escape is through some possible subterranean or known surface channel, evaporation or springing or seeping through the overlaying deposits at the lower side of the tilted, but elevated, basin. Such ground waters may be used and in some mountain localities are being drawn and conducted to irrigate desert areas and to supply needy communities with wholesome waters.

The report of the State Water Conference of California in 1916 shows that many of California's water problems were considered and recommendations made for drawing upon the ground waters in the San Joaquin and Sacramento valleys and elsewhere to irrigate the arid lands where there is insufficient precipitation to make such lands productive and also to supply waters for municipal purposes.

The extent and quality of some ground waters are shown in the Water Supply Papers of the United States Geological Survey as follows: for Connecticut in Paper 232, for Kansas in Paper 273, for Iowa in Paper 293 and for Owen Valley, California, in Paper 294.

Some of the legal principles applicable to ground waters in Europe and America are stated in Bradford Corporation v. Ferrand, 2 Ch. 655; also fully reported in two British Ruling Cases, 980; The People v. New York Carbonic Acid Gas Co., 196 N. Y. 421; Lindsley v. National Carbonic Acid Gas Co., 220 U. S. 61; and in the annotations to the first of said cases and in the other cases referred to in said cases. Consult 'Water Supply and Irrigation Paper No. 122,' United States Geological Survey.

The Board of Water Supply of New York reported in 1912 that the Brussels watershed of 4.6 square miles yielded 2,100,000 gallons a day; that The Hague sand dune catchment area of 7 square miles yielded 5,100,000 gallons a day; that the Amsterdam sand dune catchment area of 11.6 square miles yielded 6,100,000 gallons a day, and that the Muhlthal watershed of 14.7 square miles yielded 21,300,000 gallons a day.

These few records indicate the large quantities of ground waters obtainable from the watersheds mentioned for water supply purposes. They also indicate the quantities of percolation into the strata of the areas described. They also indicate the amount of water stored in the earth's strata for water supply purposes. Some of the ground waters, however, find their way to the surface by seepage through sands and gravels, emerging in ponds, streams and springs. Such seepage is the outflow through the surficial layers of ground waters flowing downward from the water-tables above. Wherever the ground water level is higher than the surface or depressions in the surface, the water «seeps» through the sands and gravels and appears as already stated. This is noticeable in marshy areas in the period of heavy rainfall and also in the many mineral and other seepage springs found in mountainous districts as well as in such streams as those on Long Island. The amount of ground water thus returned to the surface is but a small percentage of the volume of underflow, the amount and rate of which in some localities have been determined and reported by Charles S. Slichter of the Geological Survey. The winter flow of Minnesota streams is largely seepage waters.

Ground waters are being continuously replenished by percolating waters coming from precipitation, the amount of which the world over must be known to ascertain the volume of surface and ground waters available for the water supplies of the inhabitants of the earth. They are also replenished to some extent from surface waters in some regions.

Percolating waters descend to the surface of the saturated strata and become part of the permanent ground waters of the region. The saturated strata known as «water-bearing formations» are several hundred feet in thickness and overlie the strata that are impervious to water. The surface of saturation is known as «the ground-water level» and may be within a few feet of the surface. Above this saturation is not constant. Hence, to insure a continuous supply, wells must be deep enough to reach the ground water level, and as that fluctuates in different regions and in the wet and dry seasons, it is necessary to drive wells some distance below the level. From the several water horizons, comprising strata, consisting of different geological formations, various qualities and quantities of water are obtainable. Geological and water supplies reports of this and other countries may be consulted for specific information in relation to the nature of the ground waters of any region covered in such reports. Myron H. Fuller and others of the United States Geological Survey have compiled much valuable data on the ground waters of the United States of America. From their reports as well as from others it appears that the water-bearing horizons are not always horizontal, but incline either up or down in most watersheds, and the force of gravity causes a flow of ground waters between the layers of such horizons, «mainly,» says Herbert E. Gregory, «in the same direction as the slope of the surface.» Such flow is very slow, being from a few feet to a mile or more a year, depending on several conditions, such as character of the water-bearing formations, temperature, slope, percolation and other physical elements. The flow, however, is continuous and replenishes wells, springs and streams, as they are drawn upon, or otherwise discharge their waters. Springs and flowing wells exist in Connecticut, Michigan, Iowa, California and elsewhere. These and thousands of other wells in all lands are fed from the inexhaustible ground waters of the earth to supply human needs. Copenhagen draws its entire supply from wells down through glacial drift to chalk deposits.

Some of these may be hereinafter mentioned, as they are the principal sources of the water supply of most rural populations.

Water supplies are obtained from waters that run off from catchment areas and from waters that percolate the strata of the earth. Before considering any particular water supply and a few only need be considered as they are necessarily local and special in their characteristics, may be considered the important matter of the purification of water supplies. That subject is of general interest to all communities.

Purification of Water Supplies.

Introduction.— This is so important that it must be considered at some length and under several subheadings. Enough has already been said to show that nearly all waters in their natural or raw state are unsuitable for potable uses, but most unpolluted surface waters may be rendered wholesome. Under this subtitle some of the processes in use for that purpose will be described.

Purification of water supplies is no longer effected by the lyre of Empedocles as stated by Matthew Arnold, whose music did

" Cleanse to sweet airs the breath of poisonous streams."

Absolute self-purification of running waters has not been conclusively demonstrated, though partial purification is undoubtedly effected. (Consult Phelps, Earle B., 'Studies on the Self-Purification of Streams,' United States Public Health Service). Where oxygen from the air is dissolved in water oxidation of organic matter takes place and bacteria in time are destroyed provided such running water be not further polluted by sewage and other contaminating refuse. Where waters are covered with ice and oxygen is excluded therefrom, there may be an increase in their bacterial content. Prof. H. Marshall Ward has reported that the blue and violet rays of sunlight destroy bacteria near the surface but have little or no effect upon the germs a few feet below the surface. In darkness some genera are propagated. The *B. coli communis*, *B. typhosus* and others will live several days in running water and multiply therein, if there be waste material thrown into it.

To aid natural purification, «filter wells,» «filter galleries» and «filter cribs» have been installed at some places in West Virginia, Pennsylvania, Indiana, Ohio, Massachusetts and elsewhere, which are of doubtful utility for they merely clear the water of visible pollution, while they may concentrate the bacteria and promote their propagation.

Polluted waters percolating into some soils are subjected to nitrification, which William P. Mason describes, as the tearing asunder of the objectionable nitrogenous organic materials, securing their union with the oxygen of the air and thus converting them into harmless inorganic forms. The action of nitrifying bacilli is mainly confined to upper layers of soil. Mason on 'Water Supply,' p. 221.

George A. Johnson of the United States Geological Survey says in his valuable Water Supply paper that «a majority of the cities and towns of the United States take their water supply from ground sources . . . and as a rule they are pure, clear and colorless, although they are very hard and others contain much iron in solution.» Recent bacteriological and microscopic examinations, however, show many ground waters and consequently wells and springs are not wholly free of pathogenic bacteria. All waters collected for potable purposes ought to be tested before they are used. Most of them in their natural state contain micro-organisms, some of which are pathogenic and others are harmless as stated by Dr. Maximilian Marsson of Berlin in his lectures on «The Significance of Flora and Fauna in Maintaining the Purity of Natural Waters.» Each water supply from whatever source ought to be tested before use. Iron is found in the ground waters of Germany, Holland, the Netherlands, Britain, the United States and elsewhere.

In his valuable work entitled ‹The Purification of Public Water Supplies,› John W. Hill, at page 278, says «the dimensions of the bacteria (*B. typhosi*) are stated in microns, designated by the Greek letter μ, which is 1/1000 millimeter, equal to 1/25000 of an inch. Thus the typical dimensions of *B. typhosus* are .5 to .8 μ wide, by 1.5 to 2.5 μ long, or about 1/50000 to 1/31250 of an inch wide or thick and 1/16666 to 1/10000 of an inch long. Taking the average length of the typhoid bacillus as two microns (μ) it would require 12,500 of these placed end on end to make an inch.»

All such bacteria are invisible and may be detected only by some one of the modern scientific tests. (Consult Hasseltine, H. E., ‹The Bacteriological Examination of Water,› United States Public Health Service). Some bacteria are non-pathogenic and, with such knowledge as we now have of their characteristics, are considered harmless, while others are themselves destructive of lower bacteria, as are the *Rotifera*. Bacteriologists are studying these lower forms of life to determine their nature and activities in relation to other forms of animal life and are making new discoveries from time to time of vital importance to the welfare of the race.

Bacteria and Other Micro-organisms in Water.— Migula undertook to classify all bacteria into five families, namely, (1) Coccaceæ, (2) Bacteriaceæ, (3) Spirillaceæ, (4) Chlamydo-bacteriaceæ and (5) Beggiatoaceæ.

That grouping is still maintained by some bacteriologists. Other and additional families have also been suggested. Some species are pathogenic. Some bacteria already localized are *B. aerophilum, B. alcaligenes, B. anthracis,* also known as the *microspira comma bacillus,* the cause of anthrax, or splenic fever, *B. clocæ, B. coscorobæ, B. coli communis,* under certain conditions pathogenic, one of the widely disseminated microbes, *B. communior, B. cuticularis sporogenes, B. diphtheriæ, B. enteritidis sporogenes* in sewage, *B. influenzæ, B. lepræ, B. pestis,* causing Bubonic plague, *B. prodiglosus, B. ruminatus, B. salmoni,* causing hog-cholera, *B. shigæ,* found in cases of diarrhea, dysentery and cholera infantum, *B. simplex, B. streptococci, B. subtilis, B. tuberculosis, B. tumescens, B. typhosus, B. welchii, M. agilis, P. miribilis, B. vesiculosi* and others.

Nearly all of these subsist in natural and polluted waters and increase rapidly under favorable conditions. Thousands of some of them have been found in a single cubic centimeter of raw water. They are found in natural, unpolluted pools, brooks and ponds in rural and even in mountain regions. From official reports it may be seen how prevalent they are in nearly all waters and the processes that are being adopted to eliminate or destroy them. Some of these will be considered in this article. In 1906, S. D. Gage concluded that they propagate more rapidly in warm weather than they do in cold weather. Millions of some species have been found in a cubic centimeter of sewage, thus showing the danger of pollution therefrom.

In addition to the bacteria proper are the innumerable micro-organisms, comprising both animal and vegetative growths in drinking water. Prof. George C. Whipple has described and enumerated in his ‹Microscopy of Drinking Water› 200 or more of such species. He has classified vegetative organisms into such groups as (1) Diatomaceæ, (2) Schizophyceæ, comprising Schizomycetes and Cyanophyceæ, (3) Algæ, (4) Fungi and (5) various higher plants. Under Diatomaceæ is the species Asterionella, which infested Mount Prospect reservoir in Brooklyn in 1897 and necessitated its non-use until they could be removed.

He has classified the animal micro-organisms into (1) Protozoa, comprising rhizopoda, mastigophora (flagellata), and infusoria; (2) Rotifera; (3) Crustacea, comprising entomostraca; (4) Bryozoa; (5) Spongidæ, and (6) various higher animals.

Other sanitary engineers, biologists and bacteriologists have localized and classified other species, of which these may be legion. Some of these have been studied and subjected to various tests to determine their characteristics and their effect upon water and water supplies. Some live but a short time, while others live for days, weeks and even months. Some after brief existence die and impart a disagreeable taste or an offensive odor to water. Some genera are pathogenic, that is they produce disease in human beings and other genera are harmless, so far as known at the present time.

Prescott and Winslow in their ‹Elements of Water Bacteriology› describe still other characteristics of some of the countless colonies of animalcula infesting the surface and ground waters of the earth. Bacteria are found in shallow wells and even in deep well waters. Prescott and Winslow found them in deep wells and springs in Worcester, Waltham, Hyde Park, Mass., in Newport, R. I., and at Saranac Lake, N. Y. They have been found in well waters at Mainz, Leitmeritz and Kiel in Germany and elsewhere. Quantitative bacteriological examinations and the microscope are now revealing bacteria in many waters not detected by any of the tests formerly applied, and that may account for the failure to discover them. Consequently bacteria in ground waters escape detection and such waters were formerly considered pure and wholesome. «Even rain and snow,» say Prescott and Winslow in their ‹Elements of Water Bacteriology,› «are by no means free from germs, but contain them according to the amount of dust present in the air at the time of the precipitation. . . . Janowski, in 1888, found in freshly fallen snow from 34 to 463 bacteria per cubic centimeter of snow water. . . . It is difficult to find a river in inhabited regions, which does not contain several hundred or thousands of bacteria to the cubic centimeter."

In ground waters are found such microscopic organisms as *crenothrix, cladothrox, lepothrox, asterionella, anærobia* and typhoid bacteria. The latter were reported as occurring in some ground waters in Germany, probably due to surface pollution. Still many communities obtain their supply from surface waters such as springs, streams, rivers, ponds and lakes, all of which are fed primarily by the waters and snows, precipitated over the earth's surface to the extent already shown. Most of said waters are consumed in their natural state without purification by filtration, sterilization or otherwise. As already stated, it is a well-known fact that most surface waters are unsafe for potable uses. Such waters are frequently polluted by the inflow of sewage and become the purveyors of deadly organisms.

The investigation of the pollution and sanitary conditions of the Potomac watershed under the supervision of the United States Hygienic Laboratory reported in Bulletin No. 104 disclosed 20 or more genera of living organisms, including *bacilli coli communes* in great quantities. Spore-forming *anærobia,* gas producing organisms, were found in parts of the river unpolluted by sewage, thus proving that those living organisms may be found in any surface waters. The biology of rivers has been treated by Dr. S. A. Forbes, Prof. R. E. Richardson and others in this country and by Dr. A. C. Houston in his 'Report on Research for The Metropolitan Water Board of London' and by W. G. Savage of England. The American Public Health Association in its report on 'Standard Methods of Water Analysis' in 1912, suggested tests to discover bacteria in water. Typhoid fever and other deadly diseases may have their inception from the bacteria in such unwholesome waters. It is, therefore, of vital importance to all communities, that they be provided with pure water supplies. This may be accomplished by treating such waters in a manner to rid them of bacteria and all other foreign organisms. Other bacteria will be mentioned under the several processes for their elimination.

The general acceptance of "the germ theory of disease" led to investigation into the media of transmission of pathogenic microbes. Potable water was found not only to be a purveyor of such bacteria but a medium for their propagation. The epidemic of Asiatic cholera in Europe in 1847 and in 1850 has since been attributed largely to contaminated water supplies. The British Parliament, suspecting that such might be the case, in 1852 passed its first act requiring the filtration of the Metropolitan Water Supply. Later Dr. Robert Koch actually discovered the cholera bacillus (*B. choleræ Asiaticæ* or *comma bacillus*) and found that it would exist for some time in water. He thereby demonstrated that cholera might be spread through water supply of communities, as it appeared to have been spread during the epidemic of 1847 and 1850. Upon the surface of an open sand filter at Boston six genera and four and one-third million organisms were found in one square centimeter of sand. All were not pathogenic but some are an aid to filtration. However when the decomposition of such organisms in water sets in, it may impart offensive odors. These have been grouped as aromatic, grassy and fishy, thereby indicating the genus undergoing decomposition and disclosing the character of pollution.

The most numerous and prevalent pathogenic microbes found in American and foreign surface waters are the typhoid bacilli, which caused a death rate of 23.3 per 100,000 population in 48 cities of the United States in 1910. That is four times the death rate per 100,000 population in Berlin, Vienna and London from typhoid fever per annum. But the death rate from typhoid in America is being lowered, as greater efforts are being made to secure pure waters for municipal and general potable purposes. Fortunately for rural populations most of their supplies are from ground waters, which are free or largely so from bacteria, except where such ground waters are near enough the surface to be polluted.

Dr. Koch discovered a method of eliminating bacteria from surface waters, which was to allow the water to percolate through slow filters. Those were found to remove most of the microbes from the water as it percolated through such layers of sand and gravel. A single filter, however, did not always arrest all the living organisms in the water, so that two or three sand filters came into use. The filter beds at first are not wholly impervious to the transmission of bacteria. It was learned from experiments that the surface must first be coated with a film of mud and microbes before the latter were entirely arrested. When such a film is completely formed over the surface of the layer of sand, then the filter is efficient and may be kept in operation as long as water continues to percolate through it. Then its layers may be washed by drawing off the water standing in the basin and by forcing filtered water up through the layers of sand and of coagulated matter. While the filtered water is being so forced up through the layers, they and the coagulated matter thereon may be agitated by raking as is done in the works of Pittsburgh, or they may be agitated by mechanical devices. In this manner the coagulated matter is lifted and freed from the surface of the sand. Filtration may then be resumed. This may be repeated once or twice before it is necessary to scrape off the coagulated matter and the upper layer of sand to the depth of one or two inches, which is all that is necessary to remove, in order to dispose of the pathogenic microbes and other foreign bodies and the mud and silt. The layers of sand so removed may then be cleansed, dried and replaced in the filter basin and filtration may be resumed. There are various methods of renovating sedimentary and infiltration basins, but the foregoing methods illustrate some of the processes in general use. It is a well-known fact that bacteria propagate rapidly and there is always a possibility that some may pass through a filter and contaminate the water that has passed through such filter.

The processes in general use for the purification of water include: (1) Sedimentation with or without chemicals; (2) preliminary treatment for slow sand filters; (3) slow sand filtration; (4) rapid sand filtration; (5) the disinfection of water supplies by various chemicals; (6) the application of (a) ozone, or (b) ultra-violet rays of light, and (7) by sterilization. Two or more of these processes may be used in succession in the same plant, or they may form parts of a single system though operating independently of each other.

In the application of these processes many subsidiary details are involved and the completed waterworks of a city are often its most costly, complex and elaborate public works.

A brief description of each of these several processes for the purification of water may show something of their value and adaptability to the services which they are required to perform in rendering water suitable for domestic and potable purposes.

1. Sedimentation is the clarification of turbid or of other waters holding particles of foreign matter in suspension. This may be aided by the introduction of such chemicals as tend to promote coagulation of the particles in suspension in the water. Sedimentation is the process used in the removal of such large particles as are found in the waters of the Hudson above Poughkeepsie, in those of the Potomac above Washington, in the Ohio above Cincinnati and Louisville and in the Mississippi above New Orleans, in all of which cities sedimentation reservoirs and coagulation basins are in use. The process removes most of the colloidal material in suspension. Percy Frankland found that sedimentation removed 82 per cent of the bacteria in the Grand Junction Company's reservoir and about 87 per cent of the bacteria from the water that had passed through to storage reservoirs of the West Middlesex Company. Official reports show that from 87 per cent to 97 per cent of the bacteria were removed from the waters after 32 days subsidence in the reservoirs at Cincinnati and Covington; Dr. A. C. Houston reported to the London Metropolitan Board that "thirty days' storage of river-water is tantamount to sterilization" as to pathogenic microbes. William P. Mason, however, states that "bacteria sink but slowly in water." If that be so, a long period of subsidence is necessary to make sedimentation an efficient process for their removal from water supplies.

2. The preliminary treatment of water for slow sand filters may be affected by the use of sulphate of lime to coagulate the clay particles in suspension as in the Potomac, or by the use of concrete sedimentation basins with roughing filters of coarse stone, called baffles, to strain out the coarser materials in some waters coagulated by the introduction of chemicals and removed therefrom before the water passes into the sedimentation basins, as in the filtration plant at Pittsburgh, or still by the use of such preliminary filters without coagulation, as those of the Torresdale type in use at Philadelphia, where since their installation it has been found necessary to install a sedimentation basin for the use of coagulants on account of the large quantity of turbid waters to be treated, or still by the use of such prefilters as those described by William F. Johnson, in the Puech-Chabal system extensively used in Europe. That system consists of a series of decreasing in size roughing filters, a subsiding basin and a coagulating basin.

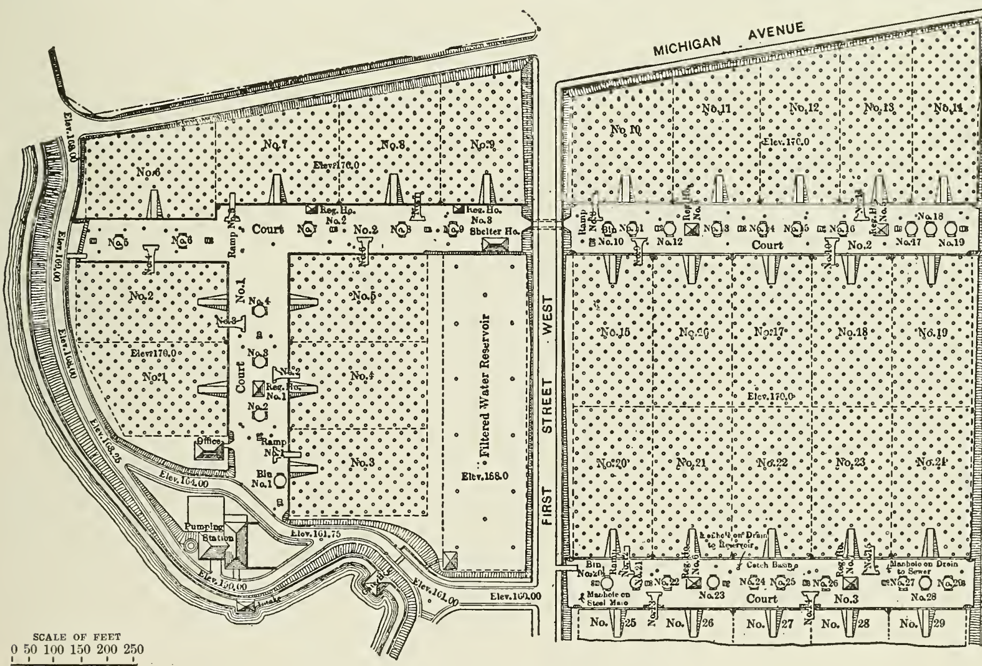


FIG. 1.—General Plan of Filtration Plant, Washington, D. C.

3. The slow sand filtration process is in use in Washington, D. C. A large area of sand is required and many water-tight basins of sand are necessary, where a large volume of water is to be clarified. The Belmont and Queen Lane filters of Philadelphia are of this type and comprise many shallow sand beds underlain with layers of gravel. Such filters

have masonry or concrete walls and are covered over where necessary to prevent freezing. Philadelphia has five slow sand filtration plants, known as the Upper and Lower Roxborough, Belmont, Torresdale and Queen Lane plants, with an aggregate daily capacity of 405,000,000 gallons, the largest in the world. Some of these have settling basins, sedimentation basins, covered preliminary filters, filtered water reservoirs, the Torresdale plant of 240,000,000 gallons daily capacity having 120 covered mechanical preliminary filters. Philadelphia obtains its supply from the Schuylkill and Delaware rivers and the latter is becoming so polluted, that other sources may be required. The arrangements there for treating water with chemicals were elaborate and it was necessary to use chlorine, for the Torresdale filters did not remove all the bacteria.

From Hugh S. Cumming's ‹Investigation of the Potomac Watershed,› it appears that the District of Columbia obtains its supply of water from the Potomac River at Great Falls 150½ feet above tide-water. The water is conducted through a circular conduit nine feet in diameter most of the 15 miles distance by gravity to the Dalecarlia, Georgetown and McMillan Park reservoirs, from the latter of which the water is pumped up 21 feet to the slow sand filtration plant, one of the best in the country, comprising 29 filters, each having an area of an acre, altogether having a daily capacity of upwards of 100,000,000 gallons. In the Georgetown reservoir the water is sometimes treated with sulphate of aluminum, used as a coagulant to assist sedimentation before slow sand filtration and in some cases it is used where no filtration is employed.

Plants for supplying such preparation of alum as a coagulant have recently been installed at Trenton, N. J., Springfield, Mass., Columbus, Ohio, and at Omaha, Neb. Slow sand filters were used by the Chelsea Water Company of London in 1829 to remove turbidity from water. As now constructed their daily capacity is from 2,000,000 to 3,000,000, and in some exceptional cases as high as from 6,000,000 to 8,000,000 gallons per acre. When they become clogged, as they necessarily do, then the coagulated deposit is removed. Then the superficial layers of sand from one-half to one and one-half inches in depth are scraped off, then washed and dried and replaced. There are several means for sand washing, including the Nichols separator, the Blaisdell filter sand-washing machine and surface raking, which increases the efficiency of the process of slow sand filtration. In all such plants at least 12 inches of sand must be maintained and from two to three feet of sand is much more efficient. Many cities and villages are using the slow sand filtration process for the filtration of water, including New Orleans, Pittsburgh, Superior, Zurich, Yokohama and Osaka, where in 1905, the bacteria were reduced from 200 to 25 per cubic centimeter, while at Lawrence, Mass., the bacteria in the Merrimac River water were reduced from 12,700 to 70 per cubic centimeter as a result of the installation of the slow sand filtration plant there in 1893. The chlorine disinfection of that water was reported on by Clark and Gage in 1909, showing the reduction of bacteria at different temperatures of the water. Such plants are at Albany, N. Y., and at Wilmington, Del., and many are in use in Europe. Some of them are equipped with automatic controllers. The rate of filtration is slow and the filter must be cleaned and that is done by scraping off the superficial layers of sand and then washing, drying and replacing them. Allen Hazen says that «sand filtration alone, without preliminary treatment, is able to remove nearly all of the objectionable bacteria, as well as other organisms, from many waters, at the same time purifying them in other ways.» The bacterial content of the filtered water is very low, but not entirely free from organisms. It was on the report of James P. Kirkwood of his investigations in Europe in 1866, that Slow Sand Filtration plants were subsequently constructed at Poughkeepsie, Lowell, Columbus and Toledo.

4. Rapid sand filters, by some also denominated mechanical filters, require less area than do the former type, but they are more elaborate and somewhat complex in construction. Typical plants comprise pumping stations, preliminary settling basins, coagulation basins for the treatment of the waters by chemicals, chemical rooms and mixers, filter tanks with connecting pipes, cleaning apparatus, controlling mechanism, covered reservoirs for the filtered water, a drainage system and other equipment to meet existing conditions, as to locality, characteristics of raw water and amount of filtered water desired. Filters of this type will clarify 125,000,000 gallons of water a day per acre of its turbidity and of 90 per cent to 99 per cent of its bacteria. Strictly modern rapid sand filter plants under skilful management with the proper use of germicidal chemicals are nearly 100 per cent efficient in the elimination of all bacteria from ordinary running surface waters. Some waters, however, carry in solution an abnormal amount of foreign substances and those may partially neutralize the germicidal agents of the usual dosage and in such cases the bacterial content may not be entirely negligible. In such cases the foreign matter may partially consume the disinfectant, so that some of the bacteria may escape and appear in the effluent. Such effluents may then be treated with chlorine, which will destroy the remaining bacteria, unless they be of a class immune to such treatment.

Rapid sand filters of the improved type are in use in Little Falls, N. J., Cincinnati, Columbus, Cleveland, Youngstown and Toledo in Ohio, Louisville, Ky., Saint Louis, New Orleans, Harrisburg, Minneapolis, Baltimore and elsewhere. The Cincinnati, Louisville, New Orleans and some others also have preliminary settling basins, where the suspended colloidal matter in the water settles. The water is then drawn off into the coagulation basins and therein coagulation is effected by the introduction of common alum, or aluminum sulphate alone or with caustic lime or ferrous sulphate (copperas) or other chemical coagulant. When brine is used in some cases caustic alkali is also needed.

Joseph W. Ellms, author of ‹Water Purification› states that «such electrolytes as acid basis and salts will coagulate colloidal suspensions and so will hydrochloric acid, caustic soda, caustic lime or ordinary salt solutions.» In that manner all organic matter including bacteria and inorganic matter suspended in the water are entangled and deposited on the layer of sand at the bottom of the basin. The bacteria and colloidal matter so deposited form a coating, or film over the surface of sand impervious to bacteria and other suspended matter but not so to water, which flows rapidly through it. Many devices serve to facilitate the operation of that process of the purification of the raw river waters, which are the source of supplies for such cities.

Rapid sand filtration operates rapidly, owing in part to the reverse flow of water through the sand, which flow washes away the accumulation of coagulated matter and bacteria into the drainage pipes. Several hundred cities are using this process for the purification of their waters, including many foreign cities. The bacteria in the Polar River water at Bethmangalia, India, were reduced from 4,350 to 13 per cubic centimeter.

The construction and operation of the rapid sand filtration plant at Baltimore will suffice to illustrate that process of purification of water supplies.

Baltimore formerly obtained its water supply from Gunpowder River, collected into Loch-Raven and from Jones Falls collected into Loch Roland. Both sources were polluted by pathogenic bacteria, including *B. typhosi* and *B. coli communes* in great quantities.

Baltimore still obtains its principal water supply from the new impounding reservoir at Loch Raven, which has been enlarged by a new dam 48 feet above the bedrock. The water is drawn through a tunnel 12 feet in diameter into Lake Montebello and from that lake it is pumped through a venturi meter, an ærator gate house, head house with tower 80 feet high containing chemical storage bins, a mixing basin, coagulating basins and thence to the filters. The design involves the handling of wash waters in the settling reservoirs, a drainage system, effluent pipe details, a head house, a pumping station, a baffle mixing chamber, two coagulating basins, covered filtered water reservoirs and other equipments.

A nine-foot conduit, recently built, connects the Montebello reservoirs with the distributing system at Lake Clifton. Altogether the Baltimore new mechanical filtration plant, also known as the rapid sand filter, at Lake Montebello, has 32 units, each with a capacity of 4,000,000 gallons daily.

5. The disinfection of water supplies by various chemicals. In 1774 the Swedish chemist, Karl Wilhelm Scheele, made an analysis of manganese dioxide and from that he was led to the discovery of chlorine. Hydrochloric acid, consisting of chlorine and hydrogen, was isolated by J. Priestly in 1772. Chlorine depends upon the oxidation of that acid, whose salts are known as chlorides. In 1800 chlorine was used as a disinfectant in France and in England. In 1854 it was used in London to deodorize sewage. Another chlorine disinfectant was Eau de Javelle made by Percy, near Paris in 1792, also known as Labarraque solution, chloros and chlorozone, according to Joseph Race. The germicidal nature of chlorine, however, was not understood until after the discovery of living organisms in water. Experiments were made with chlorine in France, England, Germany and in the United States. In 1890 a plant was erected for its manufacture at Bradford, England, and in 1893 one was erected at Brewster, N. Y., and «electrozone» was applied to the sewage then polluting the Croton water supply. Dr. A. C. Houston of London is said to be the first to apply chlorine to the purification of water. The history of disinfectants now very widely and generally used is given to show the slow progress made in the evolution of such agencies for the purification of water supplies. Had chlorine been in general use within half a century after its discovery, the appalling mortality in London in 1854, due to cholera, and in Germany in 1892–93, also due to cholera, might have been avoided.

The chemicals now in use as such disinfectants are liquefied chlorine gas, calcium hypochlorite or bleaching powder, sodium hypochlorite, copper sulphate in minute quantities, sulphate of ammonia, sulphate of iron, caustic and hydrated lime, carbonate of soda, chloramine and possibly others or compounds of some of these. Most of these germicides are of recent discovery and their application to water supplies has necessitated the renovation of most of the water plants of this and other countries. Since the proposal of Webster in 1889 to use electrolyzed sea-water as a disinfectant, several processes have been utilized for the transmission of a current of electricity through some of the foregoing and other substances to produce coagulants and disinfectants.

In 1859 James Watt discovered that hypochlorites were produced by the electrolysis of the chlorides of alkalies and alkaline earths.

Joseph Race, in his ‹Chlorination of Water,› p. 106, maintains that in the electrolysis «of the solution of sodium chloride, the chlorine may combine with the sodium hydrate formed by the action of the sodium on the water to form sodium hypochlorite, one-half of the chlorine produced is found as hypochlorite and the other half reforming sodium chloride. . . . The electrolytic hypochlorite method offers some advantages, but in the great majority of plants it cannot economically compete with bleach.»

Commercial bleaching powder is formed by passing chlorine gas over slacked lime. It is also known as calcium hypochlorite and as stated by Joseph W. Ellms in his ‹Water Purification,› p. 369, consists of several chemicals formed by the reaction of chlorine and calcium, such as calcium oxychloride, calcium chloride, calcium chlorate, calcium hydroxide, calcium carbonate, calcium sulphate, oxides of Na.K.Mg.Fe and Si. and moisture. These undergo reactions resulting in the evolution of oxygen which is set free and is destructive of micro-organisms. Oxygen is the potential energy that destroys them.

Calcium hypochlorite was first used effectively in this country to purify the waters of the Benton reservoir at Jersey City of bacteria. Since that it has been and is still extensively used as a disinfectant. Its germicidal energy is said to equal ozone as an oxydizing and sterilizing agent, and is much cheaper than ozone.

Hypochlorite of sodium, obtained by the

electrolysis of salt, has some advantages over hypochlorite of calcium, which produces sludge, that clogs orifices and is dangerous to fish, when dumped into running waters.

Joseph Race, in his 'Chlorination of Water,' p. 17, says that "on dissolving bleach in water the first action is the decomposition of calcium oxychloride into an equal number of molecules of calcium hypochlorite and calcium chloride." At page 20 he says: "The addition of small quantities of sodium chloride (0.1 per cent) increases the hydrolysis of bleach solutions but much larger quantities tend to the opposite direction . . . . Sodium chloride in the absence of hypochlorites was found to have no influence upon the viability of *B. coli* in water."

Bleaching powder is one of the most efficient germicidal agents. The neutralizing chemical for an overdose of bleaching solution is sodium thiosulphate at one-half the amount of the former.

F. Raschig, Samuel Rideal and Joseph Race have developed the new germicide, known as chloramine (NH_2Cl), formed by adding ammonia to bleaching solution, which increases the germicidal action of the latter. Joseph Race has stated that from numerous experiments he concluded that the most efficient proportion of the compound was two parts by weight of chlorine to one part by weight of ammonia. Consult Race, J., Chlorination of Water' (p. 118).

On a recent inspection of the operation of the chloramine process at Ottawa, the author learned that the after-growth noted after the use of hypochlorite in some plants amounting to 20,000 bacteria per cubic centimeter has been eliminated and that the *B. coli communes* had been nearly all destroyed. Race reported that similar results followed the application of chloramine at the Capitol Hill reservoir in Denver, where bacteria dropped from 15,000 to 10 per cubic centimeter. It is important to the health of a community that some process be adopted that will eliminate or destroy pathogenic bacteria, so that less than 100 bacteria per cubic centimeter survive whatever process of purification that community may adopt. Otherwise, its water supply is not of that degree of purity which hygienic standards require for potable uses. Such standards have been greatly raised in the last half century, and no enlightened community would be suffered to use such water supplies as were in general use before the nature and characteristics of the micro-organisms in such waters were discovered and partially understood. Therefore the modern processes for the purification must be efficient, and to be so they must conform to scientific standards. Communities will not be permitted longer to provide water laden with pathogenic microbes, and if any one of the foregoing processes of purification fail to eliminate or destroy such organisms, then it ought to be superseded by the installation of a more efficient process, as was done at Ottawa by the substitution of the chloramine in place of liquid chlorine.

Lieutenant Nesfield of the Indian Medical Service is said to have used liquid chlorine gas as a disinfectant of water in 1903. Since 1910 liquified chlorine gas has been used in several cantonments of the United States army and at Wilmington, Philadelphia, Brooklyn, New York and in many other places. On the Western Front during the Great World War it was successfully applied by means of liquid chlorine machines. The Dunwoodie chlorinating plant for New York City has a daily capacity of 400,000,000 gallons. The chlorine gas is introduced into the water in the aqueduct as it leaves the Kensico reservoir to ensure practical sterilization of the water before it reaches the city of New York. This process has some advantages over the hypochlorite or ozone process, though there is danger of injury to operators from leakages of the gas, which is injurious to the lungs and deadly if inhaled in concentrations of .06 per cent. The relative efficiency and cost of installation of these several processes are usually considered before any one is installed. Recently halazone ($Cl_2N \cdot O_2S \cdot C_6H_4 \cdot COOH$) has been found to be an efficient chemical for sterilizing heavily polluted waters.

6. The Application of (a) Ozone, or (b) Ultra Violet Rays of Light.—(a) "Ozone is produced," says Allen Hazen in his 'Clean Water and How to Get It,' p. 101, "by the discharge of high-tension electricity through air under certain conditions. The air is afterward pumped through the water to be treated or otherwise the water is showered downward through towers in which the ozonized air is circulated." Ozone, being a modification of oxygen, is a more active oxidizing agent than oxygen and is a powerful disinfectant. There are many devices for the application of ozoned air to the purification of water, but the process is equally efficient but more expensive than the application of the chemicals hereinbefore described. The De Frise system at Saint Maur gives satisfaction in sterilizing the Marne water after sedimentation and filtration. Sanitary commissions, health authorities and specialists have extensively experimented with it in Europe and found ozonized air, when properly applied, was destructive of bacteria in water. The application of the ozonized air produced by the ozonizers, of which there are several in use, such as the large plant of 128 Siemens and Halske ozonizers at Petrograd, with five sterilizing towers, is as follows:

The ozonized air enters the bottom of water towers and is absorbed by the water as it descends through the layers of gravel in some and sieves in other towers after the water has first passed through sedimentation and preliminary sand-filter basins. Such water as it enters the sterilizer may still contain several hundred bacteria per cubic centimeter. The pathogenic bacteria, such as typhoid and cholera microbes, are destroyed by ozonized air, though the more hardy and harmless ones may escape destruction. In the higher towers, the sterilizing ozonized air is injected at several levels, as at Ginnekin, Holland, where all pathogenic bacteria are destroyed. The process is more costly than the hypochlorite process, but it has been pronounced by an English expert as "ideal." It is in use in Brussels, Ginnekin, Paris, London, Berlin, Petrograd, Florence, Chartres, Nice, Saint Maur, Wiesbaden, Paderborn and in many other European cities, and at one plant in Philadelphia and in Ann Arbor, Herring Run, Md., and a few other places, but it is not at present extensively used in America. It has some advantages over the chlorine processes. The Otto process in use in Nice purifies 5,000,000 gallons daily. Its general use in Europe, after most thorough tests as to its efficiency, may result in its more general use in America.

(b) Ultra-violet rays of light. One of the recently discovered processes for the destruction of pathogenic bacteria is the application of ultra-violet light to the flow of water through flumes, so that the organisms are exposed to the concentration of its rays. Several ultra-violet ray sterilizers have been devised and successfully used in the rapid destruction of bacteria. It was demonstrated, by experiments made by Henri Helbronner and others at Sorbonne University in Paris, that bacteria cannot long endure the direct ultra-violet rays of three ten-thousandths of a millimeter in length. American tests have shown that it required only one-twentieth of a second to kill bacteria with such rays, but they must not be intercepted by suspended organic matter in the water. It is, therefore, necessary that the water be rid of turbidity before applying the ultra-violet ray process to its sterilization, for Dr. Von Reckling-Hausen declared that it is the light and not chemical reaction that produces the germicidal results. Ultra-violet ray tests made at Luneville, France, on water containing 60,000 germs per cubic centimeter reduced the number to 10 germs per cubic centimeter and destroyed all *B. coli*. The death rate of 70 to 160 of typhoid fever also became negligible. Since devastations of the Great World War began, the water supply of northern France has been contaminated at the rate of 4,600 putrescent bacteria and 1,000 *B. coli* per cubic centimeter and they may go on for years in an increasing ratio, in consequence of the countless burials and pollution of the underground waters of the war zone. The Quartz-Mercury lamp is sometimes used to produce ultra-violet rays for the sterilization of water. That process eliminated nearly all the bacteria from the raw Durance river water at Marseilles.

7. By Sterilization.— Purification is also generally effected by sterilization, which is used in conjunction with several of the processes already mentioned. By reason of the various chemicals used and their germicidal action on micro-organisms, irrespective of the other agencies employed, too much attention cannot be given to the process of sterilization.

In recent years some public water supplies have been purified by sterilization, where sewage bacteria now known as *anærobic spore-forming bacilli,* including *B. ærogenes capsulatus, B. enteritidis,* or *B. sporogenes* and *B. streptococci* were present. Active agents were necessary to destroy them. The basins or reservoirs where the process of sterilization is in operation must be cleansed two or more times a day.

In 1892, the English employed calcium hypochlorite to disinfect sewage. In the following year the American Public Health Association recommended its use as a disinfectant. It was known in 1892 that hypochlorites were efficient water sterilizers. In 1897 they were first used at Maidstone, England, to purify its water supply, after a typhoid epidemic. In 1904 they were applied to disinfect the water pipes in London. Thereafter they came into quite general use in this and other countries. Hypochlorite of lime and hypochlorite of soda are the principal chemicals used. Where hypochlorite of lime is used its solutions are thoroughly mixed with the raw water in the proportion of 5 to 10 pounds of the powder to 1,000,000 gallons of water, which is destructive of such pathogenic germs as typhoid, cholera and other bacilli. The objection to this chemical is that a sludge is formed, which interrupts the flow through the orifices and is also injurious to aquatic life, when deposited in fresh waters. Hypochlorite of soda, electrolytically produced, is somewhat more destructive of pathogenic bacteria than hypochlorite of lime. It is not difficult to produce and does not form sludge. The hypochlorites, however, are not a substitute for filtration, but rather additional agencies, that may be used to ensure complete destruction of pathogenic germs. Some spore-forming bacteria in water are not pathogenic and not all of these are destroyed, because they are hardy and not affected by any of these chemicals, when in such small proportions as not to affect the water deleteriously, but made sufficiently active to destroy pathogenic germs, which are less hardy. Many cities in this and in other countries use the hypochlorite processes in connection with sedimentation and filtration.

Francis F. Langley reported (*American Journal Public Health,* 4 Dec. 1914) that two billion gallons of water per day were being treated with bleaching powder, or chlorine gas. As already stated, liquid chlorine being the liquification of chlorine gas, produced by the electrolysis of sodium chloride in the manufacture of caustic soda, is also used to sterilize water supplies. There are several devices for applying the gas, which is eliminated from the liquid by heat, to the tanks of water to be treated. The gaseous vapor is diffused through the water and destroys the pathogenic germs. Some of the chlorinated water so sterilized in the tower of Wilmington contained only from 6 to 50 bacteria per cubic centimeter. Liquid chlorine is one of the sterilizing agencies used in Chicago Stock Yards, at Philadelphia, Pa., Saint Louis, Mo., Trenton and Newark, N. J., Cincinnati, Ohio, Niagara Falls and Ossining, N. Y., Hartford and Stamford, Conn., Saint Catherines and other places in Canada and at Honolulu, Hawaii, and elsewhere.

The ferrochlorine process of sterilization has been tested in Paris and found to be an efficient bactericide, though on account of its cost it is not in general use. Another sterilizing chemical was proposed in the form of copper sulphates, but that has not been generally adopted. It was proposed as a sterilizing process to dispose of microscopic organisms. The research work of the Bureau of Plant Industry of the United States Department of Agriculture, D. D. Jackson in his work on 'Odors and Tastes of Surface Waters,' and especially George C. Whipple, department engineer under the Burr-Hering-Freeman Commission, on the Additional Water Supply of New York City, and others have called attention to algæ, and *spore-forming diatomaceæ (diatoms)*, or *bacillarieæ,* now classified as vegetative organisms, varying in diameter from one thousandth of a millimeter to one millimeter. Several species of these microscopic organisms are found in fresh waters. Several species of *Anopheles* have been localized in the waters of Alabama, South Carolina and North Carolina by Dr. H. R. Carter and others of the United States Public Health Service. *Anopheles* are the cause of malaria. Mosquito-eating fish are being introduced to rid such waters of the *Anopheles* larvae.

Dr. Zacharias has identified the animalcula known as *flagellata,* which multiply rapidly and discolor surface waters. *Rhizopods,* including *amoebæ, difflugia* and other genera; and *infusoria* which are the highest type of *Protozoa,* are also microscopic. Some are free-swimming and others attached animalcula. They exist in countless colonies and some of them are internal parasites. These infest reservoirs and other potable waters. The larvæ of *chironomus* are found in upper layers of sand of waterworks in great colonies. Green and blue *algæ* known in Germany as "water blossoms," *zooglœa, beggiatoa* and innumerable other micro-organisms infest waterworks, form slimy organic patches and undergo putrefactive changes. These decompose and produce odors and give water an unpleasant taste. George T. Moore and Dr. Karl F. Kellerman of the United States Department of Agriculture recommended the use of copper sulphate, but that does not always destroy all the typhoid bacilli and is a dangerous chemical to use, except in the smallest quantities, and when so used it is less efficient than the chlorides. Therefore it has not come into general use.

Nearly all the processes of sterilization are of recent discovery and those in general use are ridding potable waters of most of their pathogenic bacteria. Prior to their discovery half a century ago, they were the causes of epidemics that wasted away communities and historians referred to them as pestilences and plagues. It may be assumed that polluted water has destroyed as many human lives as the wars of all the ages.

Progressive nations are fast coming to realize that impure water is one of the greatest known menaces to health and to life itself. In this modern era the researches of scientists and experiments by health authorities have demonstrated that most pathogenic bacteria and nearly all living organisms in surface and other waters may be eliminated therefrom and all such waters may be made safe for potable and all other uses.

Communities are no longer limited to lakes, mountain streams, springs and other ground sources for their water supply, but may draw raw water from rivers, streams, lakes and ponds provided such waters be treated by some of the processes heretofore mentioned, that will render such waters pure and wholesome, as is being done by scores of cities in this and other countries. The water supply of a community is now largely a matter of purification, and while turbid or bacteria-laden waters are not desirable on account of the expense involved in carrying on the processes of purification, still if other adequate sources be not available, river and other surface waters may be made safe for potable purposes. Thus it is possible for communities to obtain their supply from nearby surface waters.

The Hudson, the Ohio, the Mississippi, the Niagara, the Saint Lawrence, the Thames, the Seine, the Rhine, the Rhone, the Elbe, the Danube, the Volga, the Nile, the Ganges, the Irrawaddy, the Yangtse-Kiang and scores of other rivers, as well as the Great Lakes in North America, the British, Swiss, Italian, African and innumerable other lakes are the sources of the water supply for millions of population. When such waters are scientifically treated by some of the processes hereinbefore described, they are safe and palatable. The importance of preserving all such surface waters from artificial contamination has led to the enactment of many laws to prevent such contamination. In America and Europe water supply authorities are usually empowered to acquire catchment areas and in some instances large parts of watersheds to prevent artificial contamination as well as to procure additional sources as has been done by New York City in acquiring the Catskill watershed and certain British cities in acquiring large additional areas to ensure wholesome water supplies. Rather slowly the public conscience is being enlightened and awakening to the dangers of the contamination of water supply sources, in permitting the inflow of sewage, effluents from industrial plants, gas refuse, chemical works and other artificial wastes, all of which pollute and render waters noxious in their natural state. Most of these, however, are susceptible of such treatment as to ensure their wholesomeness for potable purposes.

The introduction and general adoption of scientific processes for the purification of water for municipal and domestic purposes hereinbefore described and others have necessitated the discontinuance of the use, or the demolition of many old and the installation of many new waterworks in this and other countries. The needs of each community and the physical conditions of the territory of each whence its supply must come, as well as the water sources themselves, become matters of public investigation and of scientific study. This was demonstrated in the undertaking on the part of the city of New York to obtain its additional water supply, commencing in 1896 and continuing for 20 years or longer. Such progress has been made in the scientific treatment of water for municipal purposes, that, in addition to a score or more of processes for its purification in most any state, its acidity may be neutralized, as at Mossley, England, it may be softened by any one of several processes, or it may be hardened and it may be deferrized as in Germany to get rid of the microscopic crenothrix and other bacteria absorbing iron into their tissues and closing water mains.

In all these matters conditions differ and it is necessary to specialize in the treatment of each municipal water supply. No two are identical, unless they form parts of the same system, as now does the supply for several boroughs of New York City, when the same general principles may apply, as to the collection, purification and distribution of water for such boroughs. But in most cases, each supply must be studied independently of all others and provided for, with special reference to its peculiar characteristics, which are as variable as earth's watersheds.

Removal of the Salts of Calcium, Magnesium, Iron and Manganese.— In some well

1 Coagulating Basins with Filter House on Left, Cincinnati, O.

2 Filter House Interior, Cincinnati, O

1 Toronto Drifting Sand Filters (view from south west)
2 Toronto Drifting Sand Filters — Filter Gallery and Filters (looking north)

and other ground waters such minerals as salts of calcium, magnesium, iron and manganese are found in solution. An artificial zeolite, known as "Permutit," was produced by Dr. Richard Gans and is used to rid water of its calcium and magnesium. Caustic soda, the silica of sodium, barium carbonate and other chemicals are also used for that purpose. The Reisert zeolite and other water softeners are in use in this and other countries. C. P. Hoover and R. D. Scott in Ohio, R. N. Kimmard, Dr. Edward Bartow, Samuel A. Greeley, Francis G. Wickware and others have written on the subject of water softening by the "Permutit" or other processes. There is a large plant for softening at Winnepeg, Canada, and smaller ones at Oberlin, Ohio, and elsewhere in the United States.

The extraction of iron and manganese has also been studied by Dr. Gans, M. S. Applebaum, Dr. H. Luhrig, Frank E. Hale, R. S. Weston, F. C. Amsbary and others. Plants for deferrization of water have been installed at Middleboro, Mass., at Rotterdam, at Dresden, Breslau and Hamburg in Germany and elsewhere. The process is described in the reports of those specialists and is generally effective in eliminating those minerals from such waters, though there may remain in water pipes the *crenothrix, cladothrix, clonothrix, chlamydothrix* and *gallionella* organisms that flourish in such solutions. Karl Kraepelin found 60 species of animalcula, infesting the water pipes of Hamburg and known as "pipe moss" comprising *sponges, spongilla fluviatilis* and *lacustris, molusca, snails,* "water lice," *asellus aquaticus,* "water crabs" (*Gammarus pulex*) and other species. Rotterdam, Boston and Brooklyn have encountered troublesome growths in their water pipes.

Minor Processes.— Some of the minor processes of purification involve the use of the small mechanical filters, consisting of small basins of layers of sand, over which gelatinous films of aluminum hydrate are found. Water passes through these rapidly and the bacteria are caught in gelatinous material and removed. Such filters are used to clarify muddy waters during freshets and in limited areas, where sufficient land cannot be economically obtained for sedimentary and the slow sand filter beds. There are several hundred in use in America. Where properly constructed and operated, satisfactory results are obtained, but they must be cleansed twice or more times a day and the chemicals used in sterilization are expensive. Several such filters, including the Candy and Reisert types, are in successful operation.

The Lawrence filter first installed in the United States was the forerunner of other mechanical filters, that have proved quite efficient in purifying municipal water supplies.

Porcelain Filters.— Prof. Louis Pasteur and others have suggested porcelain and baked infusorial earth, as additional safeguards, but the necessity of their frequent sterilization and the cost of such filters render them impracticable for general water-supply purposes. Bacteriologists now contend that microbes are propagated in and are not eliminated by porcelain filters. There are other minor processes for the purification of water, such as granular bed filters, charcoal filters, porous wall filters Berkefeld system, Maignen method and the boiling of water. None of these processes are efficient in disposing of all the pathogenic bacteria. Some of these, such as *B. anthracis* and its spores, *B. typhosus* and others, are very persistent and live a long time in water. H. D. Fisher, Prof. John Tyndall and French and German bacteriologists have insisted that the boiling of water at 212° F. does not destroy the spore-bearing bacteria, though it may and does destroy many other species.

Collection, Impounding and Distribution of Water Supplies.

In the collection, impounding and distribution of water for water-supply purposes, a few systems will suffice to illustrate how many operate. As already stated, many communities obtain their supply from ground waters by means of wells and springs.

Batavia in the East Indies, notorious for its unhealthfulness, supplies its 240,000 inhabitants from ordinary wells. Many ground waters are polluted by surface waters.

Amsterdam derives its supply from open canals containing the waters collected from sand dunes and also from the river Vecht. Such waters are filtered. Antwerp derives its supply from polluted river water, which is treated and also filtered.

Rotterdam obtains its supply from Maas (Rhine), which is then filtered.

Magdeburg and Altona obtain their supplies from the Elbe, which are treated and filtered. Breslau obtains its supply from the Oder, Budapest from the Danube, Petrograd from the Neva, and Warsaw from the Weichsel River. All such raw waters are filtered and some, or all of them, treated with germicidal disinfectants.

Constantinople obtains its supply from streams, springs and forest catchment areas, where the waters are collected in impounding reservoirs and conducted in aqueducts to the city.

Damascus obtains its supply from the Abana River through conduits, which also convey water for power purposes. See *Syria* in article on Rainfall.

Jerusalem obtains its water from springs, cisterns and pools, fed by conduits bringing water from Ain Saleh and other distant springs. Water from the Virgin Fountain flows through a tunnel to the Pool of Siloam.

In Phœnicia near Tyre were waterworks, consisting of towers, into which the artesian well waters flowed upward to a height of 20 feet or more above ground. Those waters were then conducted into reservoirs for the supply of that ancient port.

Berlin, Germany, obtains most of its water from deep boreholes near the shores of Lake Tegel, an expansion of the Havel River, and from Lake Muggel, one of the expansions of the Spree. These contain some iron in solution, as do most ground waters of Germany. It also obtains part of its supply from wells, since it has succeeded in eliminating iron from its ground waters.

The Spree was said to contain 2,500,000 more bacteria per cubic centimeter below Berlin than it contained above Berlin.

In 1878 *crenothrix* was found in the raw water of the Spree and in wells at Charlottenburg. Dr. Richard Gans' new method and Herr Piefke's process were used to eliminate the iron and the bacteria, such as *crenothrix* and other micro-organisms dependent thereon. There are 60 or more sand filters with an aggregate area of 35 or more acres and other processes used to purify daily 66,000,000 gallons of water which is pumped into the city. The bacterial reduction in 1900 was from 896 to 27 per cubic centimeter in Muggelsee Works and from 345 to 22 per cubic centimeter in the Tegeler Works. There the death rate from typhoid fever and other diseases traceable to pathogenic bacteria is low. A new testing station of its water supply and sewage disposal is maintained in Berlin. In 1911 Berlin daily consumed 22 gallons for each of its 2,200,000 inhabitants. One of the most extensive plants in Germany for removing iron from ground water is that at Erlenstegen for removing the iron from the ground water supply of Nuremberg. Munich obtains its water supply chiefly from spring and infiltration galleries constructed in the layers of sand and gravel in the western slopes of the Alps. Those galleries of concrete in some parts intercept the flow of ground waters. The water so collected is conducted to the city, which in 1911 consumed daily 57 gallons for each of its 571,000 inhabitants.

Hamburg obtained its water from the river Elbe and prior to the epidemic of Asiatic cholera in 1892, that water was unfiltered. In 1893 a municipal filtering plant was installed. Later a deferrization plant was also installed there. In 1913 Hamburg daily consumed 37 gallons for each of its 977,000 inhabitants. Double filtration is employed in Altona, Bremen and Schiedam.

Vienna obtains its supply of pure water through masonry-arched aqueducts, whose interior measurements are 0.84 by 0.93 meters from springs 913 feet and 1,196 feet, respectively, above sea-level and about 400 feet to 600 feet above distributing reservoirs in the city and from ground waters in the Schneeberg region 59 miles distant in the Alps, and from other springs and the Salza River, 114 miles distant. These are gravity systems, but in the city some pumping is necessary to fill the highest service reservoirs about 550 feet above sea-level. Since its introduction and the use of sterilizing agencies typhoid has nearly disappeared. Such Alpine sources, however, are quite devoid of pathogenic bacteria. In 1914 Vienna consumed 25 gallons per day for each of its 2,066,000 inhabitants.

Rome for centuries has obtained its water supply from the Tiber and springs along its left bank and later from such Apennine sources as the Appia, the Anio Vetus, Aqua Tepula and Lacus Alsietinus and from such springs as fed the Aqua Virgo, Aqua Marcia and Aqua Claudia and from the Rivus Herculaneus. The Aquia Trajana drew its waters from springs west of Lacus Sabatinus, whose polluted waters contaminated those of the aqueduct. Aqua Alexandrina drew its waters from springs that now supply Aqua Felice. The Aqua Marcia drew its waters from numberless springs, discovered by Marcius in 145 B.C. Most of the longer aqueducts were partially subterranean and some have entirely disappeared.

From ‹The Aqueducts of Ancient Rome,› by John Henry Parker, the following important facts are derived as to the water supply of Rome, one of the problems for engineers to solve.

In the time of Nerva and Trajan from 94 to 107 A.D. Sextus Julius Frontinus was water commissioner of Rome and has left a report of some of its remarkable works. At that time he says nine aqueducts entered the city, namely, (I) Aqua Appia; (II) Aqua Vetus; (III) Aqua Marcia; (IV) Aqua Tepula; (V) Aqua Julia; (VI) Aqua Virgo; (VII) Aqua Alsietina; (VIII) Aqua Claudia, and (IX) Aqua Novus. Seven were constructed later, namely, (X) Aqua Sabbatina, A.D. 110; (XI) Aqua Trajana, A.D. 120; (XII) Aqua Aurelia, A.D. 185; (XIII) Aqua Severiana, A.D. 190; (XIV) Aqua Antoniniana, A.D. 215; (XV) Aqua Alexandriana, A.D. 225; (XVI) Aqua Algentiana, A.D. 300. In the Middle Ages two more were constructed, namely, (XVII) Aqua Carbra and Marrana, A.D. 1124, and (XVIII) Aqua Felice. Some of these are also known by other names, namely (VII) Aqua Claudia as Cerulea; (IX) Aqua Novus as Attica; (XVII) Aqua Crabra and Marrana as Herculea; (I) Aqua Appia as Augustea; (IX) Aqua Claudia, or (X) Sabbatina as Ciminia and Cloaca Maxima as Damnata, which forms the lake of Curtius.

The Roman engineers so constructed conduits that they had frequent openings and angular turns with possible intercepting bars or baffles to check the flow of matter in suspension and thereby rid the water of some of its impurities, which, except those brought by the Paola (or ancient Sabatina) aqueduct, were few on account of its Apennine and other sources. There were many *piscinæ* or *castella aquæ* or reservoirs, where sedimentation and some filtration took place and visible foreign matter was removed. The Romans had many thermæ and fully understood the importance of pure water. The Piscina Mirabilis at Baiæ is well preserved, which place the author visited in 1905.

William P. Mason in his ‹Water Supply› quotes a passage from Pliny's ‹Natural History› which has been translated as follows: «Among the blessings conferred on the city by the bounty of the gods is the water of the Marcia, the cleanest of all the waters in the world, distinguished for coolness and salubrity.» The Romans had such baths as those of Caracalla, Diocletian and Titus where they repaired for hot and cold baths, for hygienic exercises and where they engaged in the discussion of political, philosophical and other topics. They gave much consideration to their water supply. They built aqueducts to bring water from distant mountain sources, that have been the admiration of later ages. Modern Rome has a daily supply of 65,000,000 gallons obtained largely through the Vergine, Felice, Paolo and Pia (or ancient Marcia) aqueducts and from springs. The Vergine aqueduct is 11.8 miles long and daily conveys its 14.08 million gallons of spring water 79 feet above sea-level, discharging it in Rome 66 feet above sea level. The Felice aqueduct daily conveys its 4.4 million gallons of spring water, the intake being 217 feet above sea-level, 22 miles from Rome, the aqueduct running over arches 6.25 miles and the remainder of the distance underground and delivers its waters 202 feet above sea-level. The Paolo aqueduct daily draws 17.6 million gallons from Lake Bracciano, 538 feet above sea-level and from springs in Manziano, Bracciano and Ficarello 32.33 miles from Rome and delivers its supply partly in Rome at an elevation of 246 feet above sea-level to supply the fountains of the Piazza Saint Pietro and partly to supply the town of Leonina. The Pia or Marcia aqueduct, 33 miles long, is fed by a number of springs near Subiaco 1,000 feet above sea-level. It follows that valley of the Anio to Tivoli and conveys 27 or more million gallons daily into the ancient Varo reservoir, having a capacity of 214,000 gallons and being 578 feet above sea-level, and thence to Rome. The water is conducted through three cast-iron pipes 24 inches in diameter into different parts of Rome. It also derives some of its waters from springs nearer Rome than the above sources. Its numerous fountains are supplied with waters conducted through some of the old aqueducts, whose names have undergone some change, as above stated, in consequence of the discovery of additional sources by various emperors and the connection thereof with the old aqueducts. The poorer qualities of water were used for fountains, public baths and other non-potable municipal purposes.

In 1900 some of the waters in their natural state carried too large a number of bacteria for safety, but since that time it is possible that some of the recent processes of purification may have been utilized. The ozone process is adequate to rid such waters of their pathogenic germs. In 1911 modern Rome daily consumed 120 gallons of water for each of its 542,000 inhabitants. During the Roman era it consumed approximately 32,000,000 gallons daily. The remains of Roman aqueducts still exist in Asia Minor, Algeria, France, Spain and elsewhere, showing that the Romans took great pains and went to great expense to provide their cities with the best natural waters obtainable. Some of the aqueducts were of superb construction, as were the Pont-du-Gard, the aqueduct at Segovia and the Aqua Claudia, extending along the Roman Campagna.

Naples obtains its supply in part from ground waters collected in filtration galleries 2,000 feet or more in length, constructed in a stratum of gravel 30 feet below the surface, wherein are daily collected 38,000,000 gallons. Five parallel tunnels have been formed in the old quarries of Capodimonte for impounding such waters. The Apulian aqueduct in the southeastern part of Italy is of masonry construction for 151 miles. Its main trunk line and lateral branches altogether are 1,690 miles in length. Its waters supply 152 service reservoirs and nearly 2,000,000 of people. Italy has both the Alps and the Apennines to intercept the vapor-laden clouds, whose waters supply its many streams and its dense population.

Paris has two general systems for supplying water under different pressures, namely, (1) a high-pressure system for its domestic or potable supply, (2) a low-pressure system for industrial, street-cleaning and general municipal, other than potable purposes.

1. Paris obtains its high-pressure supply for domestic purposes from four sources, namely, (a) from the springs that are tributaries of the Vanne River 108 miles distant, conducted through the Vanne aqueduct into the two-story reservoir at Montrouge 262 feet above sea-level; (b) from springs that are tributaries to the Loing and Lunain rivers, whose waters are conducted through the Loing and Lunain aqueduct into the Monsouris reservoir (that supply and the Syphon aqueduct are described and illustrated in 'La Derivation du Sources du Loing et du Lunnain' par Bechmann et Babinet, published at Paris 1905); (c) from the Dhuis springs 82 miles distant, flowing from the east through the Dhuis aqueduct into reservoirs at Menilmontant having an elevation of 354 feet above the sea, and (d) an additional supply for domestic purposes from the springs of the Avre, 63 miles west of the city, flowing through an aqueduct into Saint Cloud reservoir. During the World War the Dhuis supply was cut off and the demands on the other sources were greatly increased.

2. Paris obtains its low-pressure supply for industrial and general municipal, other than potable, purposes from the Seine pumped at Ivry and at other places on that river and from the Marne at Saint Maur and from the Ourcq Canal and from artesian wells, and water is also obtained through the Arcueil aqueduct from Rungis.

The works at Saint Maur include sedimentation basins, sand filters, ozone sterilizers and a bacteriological laboratory. In pre-war 1914 conditions, the raw Marne water carried 12,000 *B. coli* per cubic centimeter. After passing the sand filters these were reduced to 300, which disappeared as the water passed through the ozone sterilizers. An additional supply for domestic purposes was found necessary and river water was thoroughly treated, purified and used. The entire supply for domestic and potable purposes before the World War was about 40 gallons per day for each resident of the city. The supply for other municipal purposes is three times per capita the amount used for domestic and potable purposes. Since the World War, the Marne and other rivers in northeastern France, in which are countless human remains, have carried a great increase of pathogenic and other bacteria. The water supply of the entire war zone has been polluted.

The ozone treatment was so successful at Saint Maur that it was adopted by the municipality of Paris to purify the water of the Seine, taken to supplement its general municipal water supply. Miquel in 1896 found 300 bacteria per cubic centimeter in the Seine above Paris and Clichy found 200,000 bacteria per cubic centimeter in the Seine below Paris.

The Belleville reservoir has two stories. The upper receives water from the Dhuis aqueduct and the lower from the river. The Montrouge receives water from the Vanne aqueduct into its upper stories and water from the river into its lower story. The Montmartre reservoir receives spring water into its three upper stories and river water into its lower story.

The water supply of the city of London is obtained from the yield of the watersheds of the Thames, the Lea and the New River, comprising an area of 620 square miles and from springs and many wells in those watersheds and in the chalk deposits of Kent. Formerly eight or more companies pumped the water from the Thames, the Lea and the New rivers and from springs and wells into 65 or more reservoirs. Some of the principal ones were included in the works of the New River Company, the East London Waterworks Company, The Southwark and Vauxhall Water Company, the Company of the West Middlesex Works, the Company of Proprietors of Lambeth Waterworks, The Governor and Company of Chelsea Waterworks, The Grand Junction Waterworks Company, The Company and Proprietors of the Kent Waterworks and The Staines Reservoirs Joint Committee, supplying Kempton Park reservoir. In the literature on the subject these legal titles are omitted and the popular names of the particular companies are used.

From the Thames above its tidal flow and above Teddington lock, 185½ million gallons were available, from the Lea all its flow except 5,400,000 gallons left for navigation and from the New River 22½ million gallons were pumped. Upward of 33,000,000 gallons were obtained from springs and wells. In 1900 London consumed 226.000,000 gallons of water daily, which was distributed through 3,500 miles of pipes. The Thames, the Lea and the New rivers 20 years ago were subject to pollution from the inflowing surface waters, and their filtered waters as well as waters obtained from wells contained from 15 to 100 bacteria per cubic centimeter. In 1902 an act was passed creating the Metropolis Water Board. It was authorized to acquire the properties of the eight or more water companies above named and to enforce rigid regulations for the protection from pollution of the sources of London's water supply. Royal commissions investigated and reported on the purity of the supply, and out of the 294 experiments made by Dr. A. C. Houston in 1907–08, not a *bacillus typhosus* was isolated, though millions of bacteria were discovered, the Lea being most heavily laden with them.

The Metropolitan Water Board was created by the act of 1907. That board took over the properties and facilities of the Metropolis Water Board. The New Works Act of 1911, authorized the Metropolitan Water Board to construct large storage reservoirs at Staines, Laleham and Shepperton. New service reservoirs were constructed on Horseendon Hill, Greenford and on Barn Hill.

In January 1913 the Metropolitan Water Board, through the various intakes, drew daily from the Thames 132,859,184 gallons and from the Lea 55,300,700 gallons and from springs and wells 36,712,390 gallons and from ponds 203,600 gallons. The aggregate of that supply was 225,075,874 gallons, which was at the rate of 33.44 gallons per person. New reservoirs are being constructed to provide additional waters and the daily consumption in 1918 was reported at 39 gallons per capita for a total population of 6,783,897.

Parliament has passed several acts for the conservancy of the waters of the Thames, Lea, New and other rivers and has empowered boards and commissions to take such action as may be necessary to protect the waters of said rivers from pollution by regulating the uses of their watersheds and otherwise by enforcing sanitary ordinances on the part of cities, towns and villages.

Most thorough and exhaustive investigations have been made in both London and Paris to ascertain the quality and the bacteria in the raw waters, which are the sources of supply for those cities and every precaution is taken to rid all such potable waters of their pathogenic species.

The official reports of Dr. A. C. Houston, director of the Metropolitan Water Board, over a series of years and of his skilled staff of experts at London are exhaustive. They show all phases of the water supply of London, including its sources, amount, quality, bacteriological and chemical tests, the processes for its purification, the results obtained, its distribution and all other conditions incidental thereto. In his official report for 1913 Dr. Houston said that "about eighty percent of the London Water Supply is derived from rivers polluted directly or indirectly with sewage, . . . that the three factors of sedimentation, devitalization and equalization are indeed of supreme importance in connection with the storage of impure water antecedent to its filtration. . . . The practice of occasionally 'dragging' or 'raking' the surface of the filter beds to increase the yield of water or to prolong their working periods should be discontinued altogether, or only resorted to under quite exceptional circumstances. . . . Over eight years' work on the London water question has convinced me that to a progressively increasing extent the Water Board are securing the reasonable if not absolute 'safety' of the Metropolitan Water Supply. This opinion will carry the more weight since I have been, and still remain, a somewhat merciless critic of any imperfections in processes of water purification. . . . As a counsel of perfection, I still feel bound to advocate the choice of an initially pure source of water supply; but my own results and experiments do seem to indicate clearly that the evil effects even of an impure source can be largely, if not entirely, annulled by adequate storage and efficient filtration. . . . In conclusion, my opinion is that the '*quality* policy' of the Metropolitan Water Board should be directed towards securing an 'epidemiologically sterile' water (i.e., a water containing none of the microbes associated with waterborne epidemic disease) *antecedent* to filtration by means of storage (sedimentation, devitalization and equalization) aided, if need be, by the occasional employment of supplementary processes of water purification."

For the years 1906–13 the average number of microbes per cubic centimeter as reported by Dr. Houston in raw Thames water were 4,894, in the raw Lea water were 13,293 and in the raw New River water were 2,081.

He also reported that by the processes of subsidence and filtrations the number in raw Thames water was reduced from 5,250 to 16.1 per cubic centimeter, in raw Lea water from 9,263 to 30.9 per cubic centimeter and in the raw New River water from 2,172 to 14.1 per cubic centimeter. In all these cases the reduction was upward of 99 per cent. The filtered waters from Kent had but 7 microbes per cubic centimeter and there were in the Chelsea filtered supply only 7.3 microbes per cubic centimeter.

Dr. Houston in his report for 1913 also stated that «The striking fact has been shown in my last reports that London is not really drinking merely filtered raw river water but raw river water, which by storage processes has been purified bacteriologically antecedent to filtration to a reasonable extent. . . . When it is remembered 90.5 per cent of the samples of raw Thames contain typical *B. coli* in each cubic centimetre and that 84.8 per cent of the samples of raw Lea water also contains typical *B. coli* in each cubic centimetre, the transformation which the river water has undergone previous to filtration becomes strikingly apparent.» Dr. Houston strongly advises storage preliminary to filtration and storage he says means sedimentation, devitalisation and equalization. Nearly the entire supply for London is stored antecedent to filtration. Dr. Houston also stated that «99.9 per cent of the typhoid bacilli could not be recovered after one week.»

Down to 1913 storage and sand filters had efficiently purified the waters used for potable purposes in London. Dr. Houston, however, in his report for the year recommended supplementary processes of purification. Since 1917 the entire water supply of London has been treated with chlorine. Before filtration, it receives a dose of calcium hypochlorite. Slow-sand filters are now used at the various works.

The twelfth annual report of Director Houston for the year 1917–18, contains an exhaustive report of chlorination, super-chlorination and de-chlorination experiments with 224 microphotographs.

The thirteenth annual report of the director for the year ending 31 March 1919, discusses the scientific results of the chlorination of the Thames and New River raw river waters and chlorination in relation to filtration and the condition of the raw and filtered waters. On 31 March 1919, the equipment of the London water supply under the Metropolitan Water Board comprised 48 storage reservoirs with a total capacity of 1,981,500,000 gallons and 86 service reservoirs for filtered water with a capacity of 310,900,000 gallons and its 172 filter beds had a total area of 170.7 acres.

Liverpool obtains its supply from wells, from eight impounding reservoirs in the watershed, Ravington having a capacity of 4.1 billion gallons and from the impounding reservoir, the largest in Europe, 825 feet above sea-level, formed by a dam 1,172 feet long and 84 feet high across the valley of the Vyrnwy River, formerly a glacial lake in north Wales, having a capacity of 12 1/7 billion gallons. The impounded waters from the Ravington reservoirs are delivered through a 44-inch cast-iron pipe 24½ miles long to Liverpool and from Vyrnwy reservoir through a 39-inch cast-iron pipe 63 miles long and a tunnel 4 miles long to Prescott reservoir at Liverpool. The water is filtered through sand filters and otherwise treated. Upward of 38,000,000 gallons are consumed daily in Liverpool, which is at the rate of 40 gallons per capita per day. An additional reservoir has been constructed near Malpas and a high-level tank has been built at Woolton Hill.

Manchester obtains its water supply from the elevated Longdendale watershed with seven or more impounding reservoirs along the Etherow River and from Lake Thirlmere 2¾ miles long and 533 above sea-level in the northwestern part of England. The outlet of the lake is closed by a masonry structure 857 feet long and 104½ feet high from the lowest part of the gorge outlet. That enlarges the lake to three and one-fourth miles in length and gives it a capacity of eight and one-seventh billion gallons. The aqueduct leading to the city is 95 miles long and carries 50,000,000 gallons per day. The storage reservoirs of Manchester have a capacity of upward of 41,000,000 gallons. Its daily consumption is 40 gallons per capita and aggregates 50,000,000 gallons. A third conduit has recently been constructed from the lake to the city.

Birmingham, England, formerly obtained its water supply from five local streams and eight wells. From these the water was pumped into six service reservoirs at different elevations and into a stand-pipe. All such waters were filtered. In 1900 there were 12 sand filter beds with a total area of eight and one-fourth acres. In 1892 Parliament authorized Birmingham to draw an additional supply from Elan and Claerwen rivers in Wales. It constructed six long reservoirs by building masonry dams across the narrow valleys of those rivers, one of which dams was 600 feet long and some were more than 100 feet in height above the bed of the gorges so closed. They had a combined capacity of 18,000,000,000 gallons. There were also constructed 30 filter beds for the filtration of all such waters. This improvement contemplated a supply of 75,000,000 gallons a day for service in addition to 27,000,000 gallons to compensate for losses to riparian operators along the Wye.

The water flows by gravity through the Elan aqueduct 73.3 miles to Birmingham. From the elevated sources to the high service reservoirs in Birmingham there is a fall of 170 feet.

In 1913 there were consumed 27,471,991 gallons daily, which was an average of 32.24 gallons for each resident.

Glasgow obtains its water supply from Brock Burn six miles from the city through its Gorbals works into four impounding reservoirs, having a combined capacity of 1,000,000,000 gallons or more and also from Loch Katrine 364 feet above sea-level, having a storage capacity of five and two-thirds billion gallons. The water was conducted by gravity through aqueducts and tunnels 27 miles to Mugdock and Craigmaddie reservoirs, having a combined capacity of one and one-fifth billion gallons. Reservoirs have been constructed in the valley of the Teith to compensate for waters drawn by the city. In 1895 it was decided to connect by the tunnel Loch Arklet 455 feet above sea-level with Loch Katrine and raise the outlet of the latter five feet and thereby secure a storage capacity of 2.05 billion gallons in the two lochs. An additional reservoir with a capacity of 694,000,000 gallons has been constructed. In 1913–14 Glasgow daily consumed 75 gallons per capita or an aggregate of 85,000,000 gallons.

Edinburgh obtains its water supply from the Esk, the water of Leith and from the streams fed by the Pentlands, the Moorfoot Hills and from Talla Water reservoir. Talla Water is an affluent of the River Tweed.

In 1913 the daily consumption of water in

Edinburgh and Leith was 56 gallons per capita.

The Derwent Valley Water Supply under an Act of Parliament, is distributed to Derby, Leicester, Nottingham and Sheffield, the expense of which is borne by said several corporations in proportion to their several allotments or percentages of water consumed, all drawing from the same source, made available by their joint effort. That plan might be carried out in other countries where a common supply may be available for several municipalities.

In 1907 the Earl of Cromer reported that the Assouan reservoir would supply one-fourth of all the water needed in Egypt. That water flowed from the upper Nile 1,800 miles to reach Egypt. The evaporation in those torrid and tropical regions was 103,000,000 cubic meters out of 2,300,000,000 cubic meters of supply and the loss by absorption and filling the Nile trough was 260,000,000 cubic meters, and the consumption in middle Egypt was 850,000,000 cubic meters, which left only 1,087,000,000 cubic meters for use in Lower Egypt at Cairo. That statement shows the great losses of river or canal waters due to evaporation and percolation or absorption. Under all conditions they are factors to be considered in determining the amount of water supply for a community. Long before the Assouan reservoir was constructed, Jacob had dug a well near the site of Cairo and still earlier the Fayum depression was embanked and Lake Moeris was formed, around whose shores were settlements from the Neolithic age down through many centuries.

In 1914 Cairo used for all purposes an amount equivalent to 25 gallons for each of its 700,000 residents. Its water is clarified by passing it through rapid sand filters. Alexandria has a similar plant of 12,000,000 gallons daily capacity, where sulphate of aluminum is used as a coagulant.

The importance of wholesale water supplies to communities cannot be too emphatically stated, when we recall the ravages of diseases due to the contaminated water supplies in India. Prior to the British sovereignty of that Peninsula nearly all well, river and surface waters were unfit for potable purposes. Conditions there were appalling. The waters of the Indus, the sacred Ganges, the Brahmaputra and of all other rivers were laden with putrescent matter and some with decomposing human remains. Even the wells were contaminated and the thousands of reservoirs and tanks were used as bathing pools by thousands of dust begrimed and filthy pilgrims in their annual tours of parts of India. They were ignorant of the laws of health and oblivious of all hygienic and sanitary regulations. That was the commencement of water purification in central India. There are now many sand filtration plants in India.

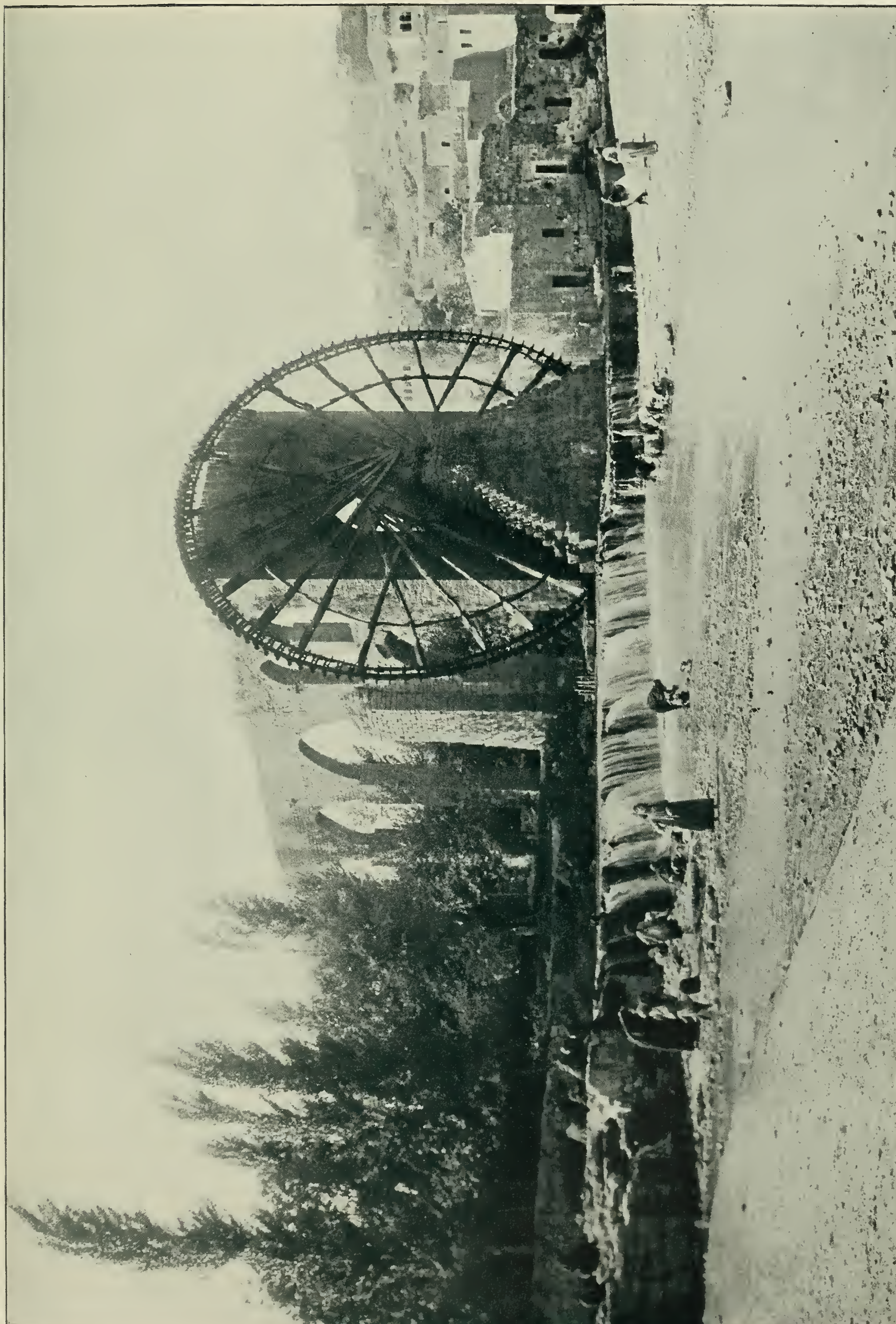
The Hindus were enjoined to drink the water of the Ganges, as a sacred duty. Cholera and other deadly epidemics depopulated whole districts. When the British officials began to exercise authority, they undertook to remedy conditions wherever they were able so to do, but the superstition and prejudices of the natives were such under their Indian cults, that progress was slow.

In 1893, the Balram Dass Waterworks were constructed at Raipur in the central provinces. Those consisted of an infiltration gallery 100 feet from and paralleling the Karoun River whose level was raised at that point six feet by a dam and its waters percolated the intervening sand layers and weeped through holes into the gallery. Thence they were pumped up through a conduit of masonry and cut through the rock into tanks for distribution. The supply was six and one-half gallons a day per capita. Consult Vol. 143 of Proceedings of Institution of Civil Engineers, pp. 262 et seq., London.

In 1901 the British favored the construction of works for the extension of irrigation from 47,000,000 to 53,500,000 acres.

In 1905 to 1912, they aided in the construction of the Punjab Triple Canal system, which had an excellent effect upon the quality of flowing water for the thousands dependent thereon for drinking purposes. Consult Vol. 201 of Proceedings of Institution of Civil Engineers, pp. 24 et seq.

Prior thereto the inhabitants in that part of India obtained their supply from polluted ponds and other unwholesome sources. The irrigation works of India are extensive and have done something to relieve the deplorable conditions of the millions untutored in hygienic science. All such Indian watercourses as the extensive Punjab Triple Canal system, the Bengal system, the Madras canals, the Ganges and the Indus systems supplied waters for irrigation and formerly to some extent waters for navigation. In a land of such intense heat and extensive barren areas, most of such watercourses supplied all the water obtainable for potable as well as for all other purposes. Slowly the people of the peninsula are beginning to understand some of the causes of the cholera, typhoid and other fatal epidemics that have swept over India from the Buddhist period, commencing 520 B.C. down to recent years. Who can estimate India's mortality directly attributable to its pathogenic-bacteria-polluted water supplies? What costly sacrifices the race has made to its ignorance of and failure to observe the laws of health! Polluted waters are disease producers, as unfailing as the forces of gravity on falling bodies. India with its dense population and appalling pestilential epidemics is an inimitable example of the dreadful results of the use of unwholesome waters for domestic and potable purposes. Modern modification processes have been installed in its principal cities and ports, so the danger of infection in those towns is constantly lessening. In 1914 Bombay consumed 27 gallons, and Calcutta 62 gallons daily per capita. In the waterworks of Calcutta alumino-ferric is used as a purifier, which is an impure sulphate of aluminum. That is generally used as a coagulant elsewhere in India. Mechanical filters at Betmangula, India, reduced the bacteria in Palar River water from 4,350 to 13 per cubic centimeter. The training of some of the river courses, such as the Rangoon, has resulted in the improvement of their waters for domestic uses. Gradually the people are beginning to realize the importance



The great waterwheel at Hamâ, Syria, used for pumping the water out of the Orontes River

of preserving their streams and watercourses, including reservoirs, tanks, etc., from pollution.

China and Japan in the past centuries were hardly less oblivious of hygienic and sanitary laws, though less frequently swept by epidemics attributable to waterborne diseases. The Chinese obtain their water supplies from wells, springs and their rivers. There appears to be some natural purification of their waters and less human pollution of them. They are accustomed to boil their drinking water and that disposes of many bacteria.

Japan is abundantly supplied with lakes, rivers and waterfalls and is fast advancing in sanitary science. It has already commenced to adopt some western methods for the purification of its water supplies. George A. Johnson of the United State Geological Survey says: That «the water purification works at Osaka, Japan, having a daily capacity of 25,000,000 gallons, include open sedimentation basins and also sand filters.» One was completed in 1903. Bacteria in Yodo River water were reduced from 200 to 25 per cubic centimeter. There is also a slow sand filtration plant at Yokohama, whose water supply is taken from the Sagamigawa. Water purification is also effected to some extent in Tokio, where were consumed in 1914, daily 32 gallons by each of its 1,500,000 residents. It takes its water from the river Tama into the city reservoir at Yodobashi, located high enough to afford nearly 100 feet pressure. There potash alum was used as a purifier. At Kyoto there is a large rapid sand filtration plant.

Melbourne in Australia derives its water supply from the Yan Yean system, consisting of Silver Creek, Wallaby Creek and the Plenty watershed yielding 33,000,000 gallons daily and from the Maroondah or Watts River system yielding 25,000,000 gallons daily, and from Survey Hills yielding 9,000,000 gallons daily. There are six service reservoirs with a combined capacity of 45,000,000 gallons. The daily supply in 1905 was 63 gallons per capita. In 1899 the waters in the service reservoirs and mains carried from 146 to 398 bacteria per cubic centimeter. *B. coli* were found in some reservoirs fed from drainage areas, where there was no sewage and other micro-organisms were also found. That shows how prevalent they may be when least expected. The presence of such bacteria is usually attributable to pollution by sewage. The obtaining of pure and wholesome water is not the least of municipal problems nor of rural communities.

In New South Wales a dozen or more narnow gorges have been dammed and their waters impounded for domestic purposes. So in all inhabited parts of the world, the problem of water supply is of first importance,. and is becoming increasingly so as the population increases in density.

Some American City Supplies.— In addition to the municipal supplies already mentioned, the following illustrate the methods adopted in the United States for obtaining wholesome water supplies.

Boston, Mass., is in the Metropolitan Water District, which obtains its supply from lakes and rivers, whose waters are impounded in reservoirs. Cochituate Lake, Sudbury River and the south branch of the Nashua River are its principal sources. The first of these comprises a series of ponds three and one-half miles long, and their waters flow through an aqueduct into Chestnut Hill reservoir, having a capacity of 23,000,000 gallons a day. On the Sudbury River four storage reservoirs, an aqueduct and a conduit were built. They carry 108,000,000 gallons a day, 15.9 miles to the Chestnut Hill reservoir. The waters of the south branch of the Nashua are impounded in the large Wachusett reservoir, at Clinton, having a capacity of 64,500,000,000 gallons in its 6.46 square miles of area. It is 12 miles from the Sudbury reservoir, into which its waters are conducted by the Wachusett aqueduct, and from one of the Sudbury reservoirs by the Western aqueduct built in 1904, to the westerly part of the metropolitan district. The daily capacity of the Wachusett aqueduct is 300,000,000 gallons. The site and shores of the Wachusett reservoir were stripped and that proved satisfactory, for algæ and other plant organisms do not thrive where rock constitutes the bottom and sides of such reservoirs. The water in the reservoirs is not polluted and is remarkably free of organisms, due to the stripping of the sites and the freedom of the catchment areas from pollution, except such as are within the towns of Marlborough and South Borough. *Diatomaceæ* have been found in Lake Cochituate and occasionally small numbers of harmless bacteria in the tap water.

In the Metropolitan Water District of Boston are several other corporations and the supply is metred for different uses.

New York City obtains its water supply from six different sources. Those are with their respective available daily yields: (1) The Croton watersheds with 336,000,000 gallons; (2) The Bronx and Bryan watershed with 18,000,000 gallons; (3) the Esopus watershed with 250,000,000 gallons to be augmented by the Schoharie Creek addition of 250,000,000 gallons; (4) the Long Island watersheds comprising the Ridgewood and other systems, and including Queens (in reserve) with 150,000,000 gallons; (5) the Staten Island watershed, in reserve, with 12,000,000 gallons, and (6) private water companies with 34,000,000 gallons. The foregoing amounts, except that from Schoharie Creek, soon to be added, are given in the instructive paper of Dr. Frank E. Hale, chief chemist of the Department of Water Supply, Gas and Electricity. No other modern system has involved a greater expenditure, except possibly that of London, and none is delivering a greater quantity unless it be that of Chicago. Certainly its quality is as pure and wholesome as that of any city in the world. All its catchment areas are under the supervision of sanitary inspectors and its Catskill supply is largely from lands owned and cleared by the city. Every precaution has been taken to avoid pollution of the sources, and some of which are in the foot-hills and slopes of mountains. Physical, chemical, bacterial and microscopical examinations are periodically made of the various sources.

Several modern processes of purification including liquid chlorine at several plants are in use. They comprise an aerator at the Ashokan reservoir, a coagulation plant above the Kensico reservoir on the Catskill aqueduct, a Dunwoodie chlorination plant on the new Croton aqueduct, a chlorination plant on the Catskill supply below Kensico reservoir, following aeration, a slow sand filter plant below Oakland Lake in Queens County, whose bacterial efficiency is supplemented by liquid chlorine and several slow and several rapid sand filter plants located on various conduits of the minor sources of supply. One of the latter is at Baisley Pond. Micro-organisms which are destroyed by treatment with copper sulphate, and iron, have been found in some of the waters. The processes used have been efficient in purifying any waters that have been so infested.

and other supplies, including about 96,000,000 gallons of ground waters from Long Island.

In 1918 there were daily distributed for all purposes in all the boroughs of Greater New York approximately 600,000,000 gallons, that being a little more than the rate of 100 gallons per capita.

The waters of the Schoharie Creek or watershed are to be impounded in a reservoir at Gilboa dam, and carried in a tunnel 18 miles long under the Shandaken Mountains into the upper reaches of the Esopus Creek and thence into the Ashokan reservoir to double the present (1919) supply. When that improvement is completed there will be 500 million gallons available a day for New York city, from the Catskill and Scho-

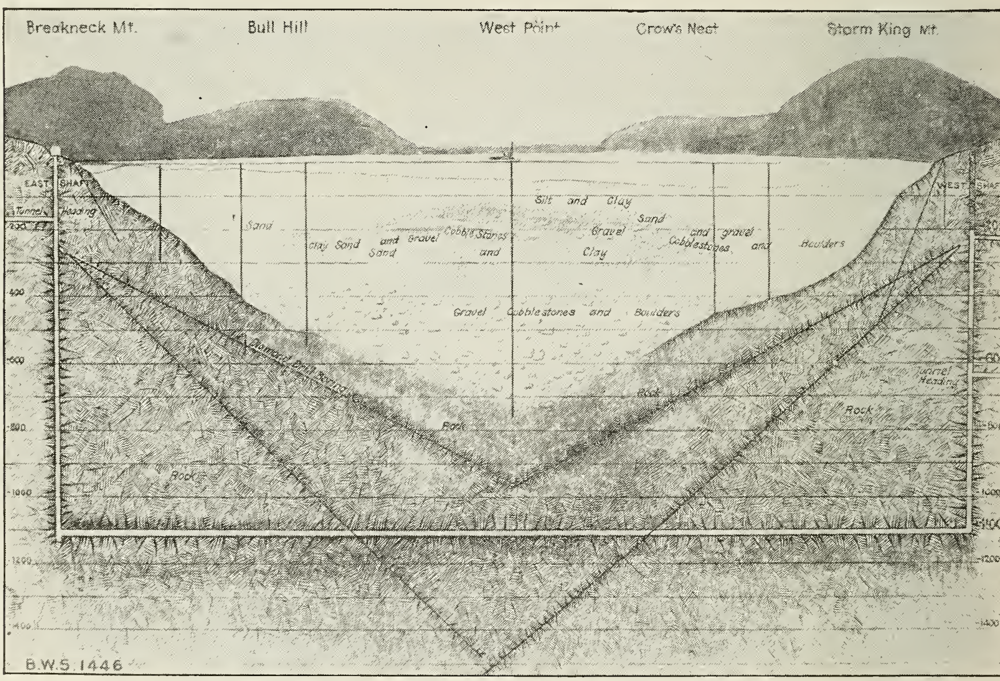


FIG. 2.

Bacteria in the waters of the several Croton and Catskill aqueducts varied from 17 to 68 per cubic centimeter, but chlorination reduced the number from 46 to 91 per cent. In 1918 storage in the Ashokan reservoir reduced *B. coli* 99.8 per cent and other bacteria 69 per cent. Several species of *Diatomaceæ Cyanophyceæ, Protozoa* and *Crenothrix* have been localized in the waters of the New York supply.

The Esopus supply is from several streams, whose waters are conducted into the Ashokan reservoir 91 miles northwest of the city and thence are conducted in an aqueduct having a daily capacity of 500,000,000 gallons down the west side and under the Hudson 1,100 feet below its surface (Fig. 2) and up to the Kensico reservoir, thence to the Hill View reservoir with an elevation of 295 feet, which determines the "head" of the Catskill supply and thence in a tunnel extending down through New York City to the distributing reservoirs in the several boroughs. These receive also the Croton

harie watersheds, having an area of 571 square miles. The Ashokan reservoir has an elevation of 587 feet above tide-water and its outlet is 495.5 feet above tide-water. Its capacity is 128 billion gallons. The Gilboa reservoir will have a capacity of 20 billion gallons, and has an elevation of upwards of 1,100 feet above tide water and is 125 miles from New York City.

Albany takes its supply from the raw Hudson River water through screened intakes and passes it through two 18-inch inlets and one 36-inch inlet into a sedimentation basin. After sedimentation, it passes roughing filters into the slow sand filters where the daily rate of filtration is 3,000,000 gallons per acre. It then passes into the covered filtered water reservoirs. Its capacity is 21,000,000 gallons per day and its bacterial efficiency is 99 per cent. The usual bacterial efficiency of slow sand filters ranges from 98 to 99 per cent.

Chicago obtains its daily supply of 1,000,000,000 gallons from Lake Michigan, through nine intake tunnels, reaching seven intake cribs two or more miles from shore.

In 1915 the Chicago Board of Experts reported that its water from Lake Michigan was turbid, polluted and unsafe for drinking purposes. The opening of the Drainage Canal in 1901 to send the flow of sewage down the Illinois River lessened the pollution of near shore lake waters, but did not wholly remedy the difficulty. City sewage still flows to a limited extent into the lake and pollution continues. The problem is a serious one for Chicago as it is for all other cities similarly situated. The intakes of other Great Lake cities, however, are not so near the effluents of their sewage and there is less direct pollution therefrom. Chlorination was tried in one of the districts in Chicago in 1912, and was attended with good results, except that during the winter months the plant was affected by the severe cold. Undoubtedly Chicago will adopt some modern process for the sterilization of its water supply.

In Milwaukee hypochlorite has been used to eliminate gas-forming bacteria from its Lake Michigan supply, but such large dosages were necessary, that the taste was affected and odors were produced. The water before treatment contained 2,590 microbes per cubic centimeter. Milwaukee's consumption in 1915 was 48,000,000 gallons a day, which was equivalent to 111 gallons per capita.

Cleveland in 1911 completed its new intake and a marked improvement followed. It installed a rapid sand filtration plant and also used calcium hypochlorite as a germicidal disinfectant. Its supply in 1912 was at the rate of 133 gallons per capita a day.

Superior, Wis., has a slow sand filtration plant comprising three units with a total capacity of 300,000 gallons a day.

Kansas City, Missouri, obtains its supply from the Missouri River at Quindaro above the inflowing polluted Kansas River. The raw Missouri River water is pumped into a reservoir of 90,000,000 gallons capacity at Quindaro where there is preliminary sedimentation. The water is thereafter treated with alum and lime. The clear water then returns to the pumping station and is treated in its passage with calcium hypochlorite and aerated. It is then pumped into Turkey Creek reservoir, where a high pressure service is maintained and thence it is let into the mains. The raw river water in 1911 contained as high as 30,000 *B. coli* per cubic centimeter and they were reduced by such treatment as stated to less than 100 per cubic centimeter, which is the standard of purity established in 1914 by the Treasury Department of the United States Government. The purification at Kansas City, Mo., whereby large colonies of pathogenic bacteria in its raw river water supply were eliminated, well illustrates how Missouri River water may be purified and made safe for potable uses.

Buffalo obtains its supply from Lake Erie and it is purified by chlorination at the intake pier in Lake Erie. The daily consumption is approximately 125,000,000 gallons.

New Orleans obtains its supply from the Mississippi River. A Sewerage and Water Board was created in 1899 and aerial cisterns were ordered closed. They were breeding places of the *stegomyiæ* which cause yellow fever. In 1909 a new rapid sand filtration plant was installed having a daily capacity of 40,000,000 gallons and the water was first put through sedimentation aided by sulphate of aluminum and ferrous sulphate as coagulants. In 1910 the rate was 5.99 million gallons per acre per day. New Orleans has two filter plants, namely the Carrollton Filters and the Algiers Filters. From an official report it appears that the rate of filtration through the former in 1914, was fivefold that of the latter. In 1915 the daily consumption was 20,000,000 gallons, which was at the rate of 57 gallons per capita,

Omaha, Neb., obtains its supply from the Missouri River which requires purification. Accordingly a series of basins were constructed for sedimentation of much of the suspended matter. That was accompanied by coagulation produced by the use of alum. There is also used hypochlorite without filtration. Since the installation of the foregoing processes of purification, there has been a great reduction in typhoid and other diseases produced by pathogenic bacteria.

Pittsburgh obtains its supply from the Allegheny River, which has several inflowing tributaries. One of these is the Kiskiminetas which receives waste products from oil refineries, tanneries and other plants. The water carries much colloidal matter. Its waterworks plant comprises concrete sedimentation basins, holding 120,000,000 gallons with 24 roughing filters of coarse stone and two hollow frame baffles, extending the full length of the sedimentation basins. These rid the water of much of the matter in suspension. It also comprises slow sand filters and a covered filtered water reservoir. The plant is unique and illustrates another type of construction to overcome conditions quite extraordinary. Its service reservoir is at Highland Park 367 feet above the river. It has several reservoirs for service in different parts of the city.

Los Angeles formerly obtained its supply from ground waters by means of infiltration galleries. Its daily consumption was 26,000,000 gallons. It is soon to obtain its supply from Owens Valley where the city owns a large catchment area. Long Valley and Tincmaha reservoirs are to be constructed with a combined capacity of 150,500,000,000 gallons. The aqueduct consists of open canal sections, masonry sections and tunnels and several intercepting reservoirs, each of many million gallons capacity which regulate the flow and develop power. It is so constructed that ground water near the surface may be pumped into it and augment its volume. It has 23 inverted siphons and serves both for water supply and power purposes and is one of the large water supply projects on the Pacific Coast.

San Diego has a municipal pressure filter of 5,000,000 gallons capacity.

San Francisco is supplied by five independent systems owned by a private corporation. The waters are drawn from artesian wells.

In June 1919, Sacramento decided to install a modern filtration and pumping plant with filter beds of 30,000,000 gallons daily capacity and is to use sulphate of aluminum as a coagulant. Its water supply is from river water, mountain sources and from wells.

In addition to those already mentioned, purification plants have been constructed at Wilmington, Cincinnati, Cleveland, Columbus, Toledo, Lorain, Youngstown, Louisville, Saint Louis, Des Moines, Minneapolis, Grand Rapids, Mich., Little Falls, N. J., Harrisburg and Bethlehem, Pa., Middleboro, Mass., and at many other places in the United States and other countries.

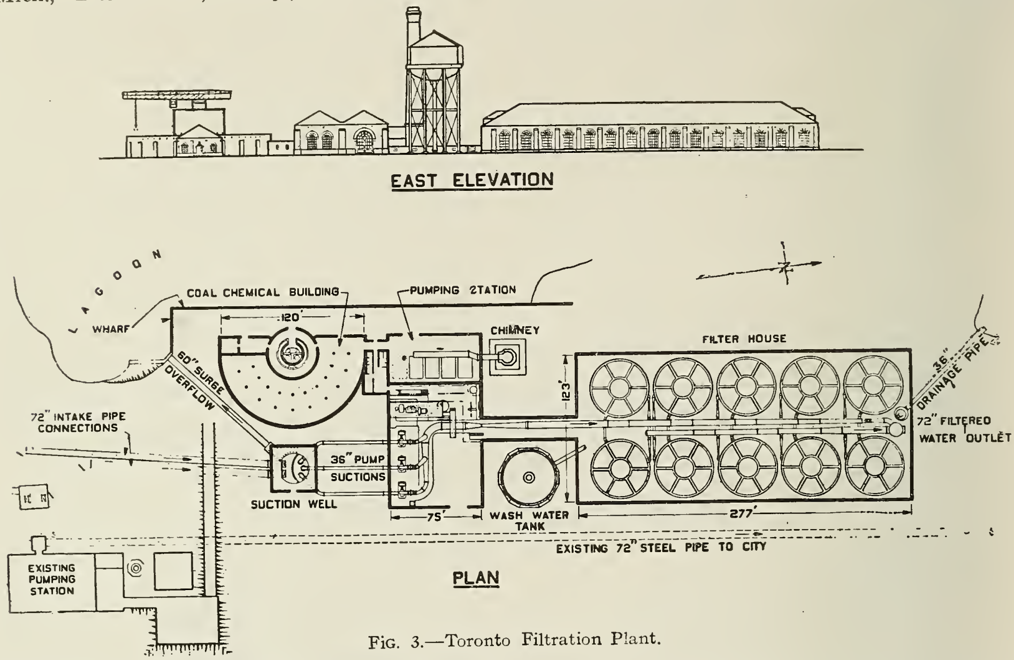


Fig. 3.—Toronto Filtration Plant.

The water supply in Canada is illustrated in the following few cases:

The Victoria aqueduct conveys waters from mountain reservoirs 37 miles away.

At the present time Winnipeg obtains waters that require softening and that involves large expense annually. It has recently decided to obtain soft water from Shoal Lake, some distance away.

Toronto obtains its supply from Lake Ontario. Its filter beds of its slow sand system have a capacity of 5,000,000 gallons per acre per day. It has recently installed drifting sand filters. These consist of 10 units, each having a capacity of 6,000,000 gallons daily. In them there is a constant vertical circulation of water through the filters, so that a part of the bed of sand is kept in suspension in the water, while some of the sand is being constantly removed and washed in transit and replaced in filters. A coagulant apparatus is attached and the coagulant goes directly to the filters. The bacteria are caught up and carried along out with the drifting sand. The process is rapid and may be expensive. The average amount of chlorine applied was .2 parts per million in 1918. In 1911 Toronto daily consumed 118,000,000 gallons.

Montreal obtains its supply from the Saint Lawrence and Ottawa rivers. The waters are conducted into the main reservoir 200 feet above the Saint Lawrence River. That reservoir has a capacity of 36,500,000 gallons. There is another high service reservoir still higher. Purification of the water supply of Montreal is effected by chlorination and an electrolyser of the Allen-Moore cell, adopted by the Montreal Water and Power Company. The equipment comprises four cells, each having a capacity of 32 pounds of chlorine per day. The process has been credited with 93 per cent efficiency. In 1914 Montreal supplied an amount equivalent

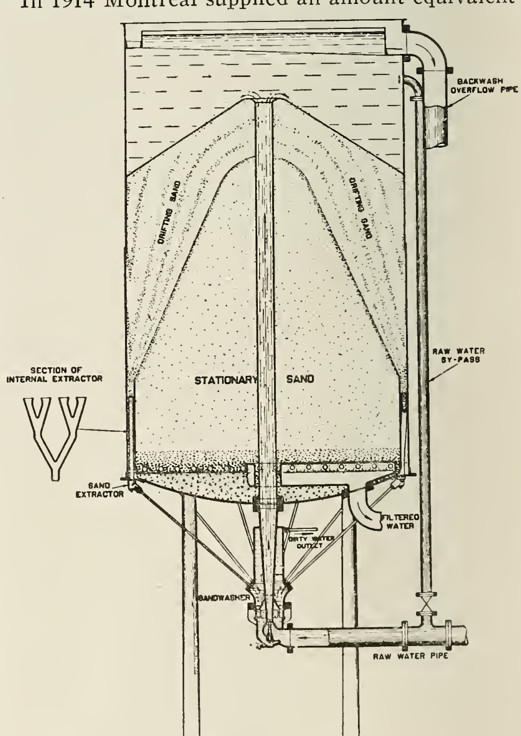
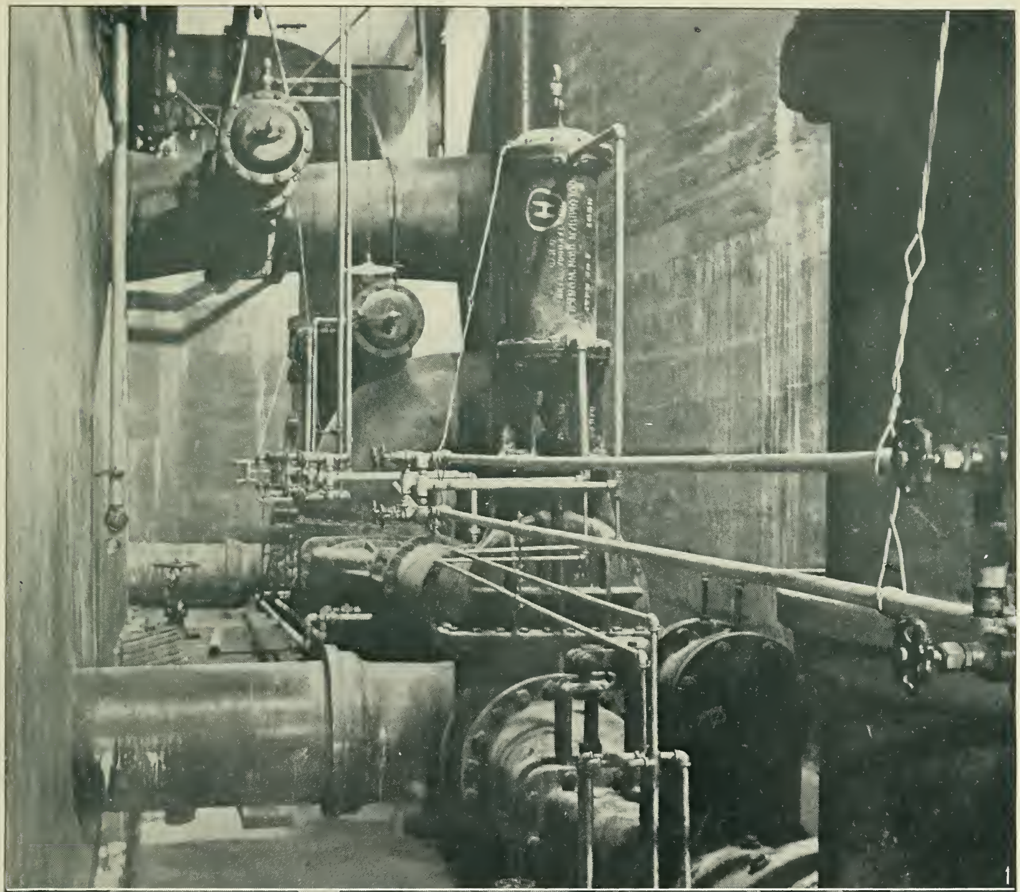
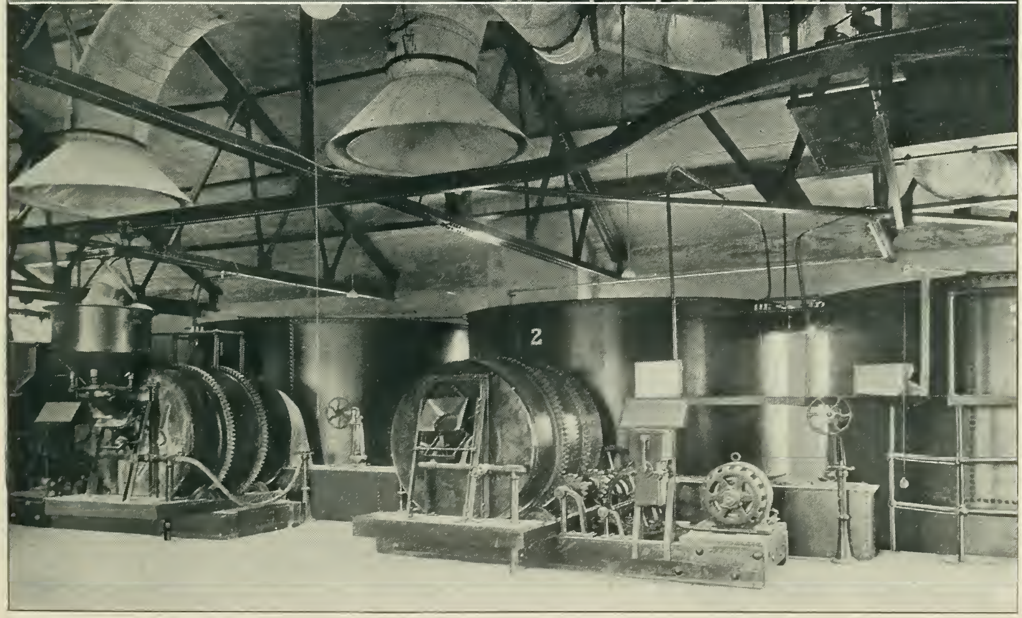


Fig. 4.—Drifting Sand Filter—Gravity Type.





1 Filter Pipe Gallery, Montebello Filters, Baltimore, Md.

2 Lime Mixers and Lime Tanks, Montebello Filters

to 153 gallons for each of its 600,000 inhabitants.

The republics of South America are likewise appreciating the necessity of providing pure water for their inhabitants. In 1867–68, there was an epidemic of cholera in Buenos Aires, Argentina, which had 1,500 victims, and in 1871 yellow fever followed, which had 2,600 victims, both due to unsanitary water supply. Aroused by this condition the city employed eminent engineers and constructed a system of modern waterworks. The city obtains its water from the Estuary at Belgrano. It is then conducted three and one-half miles to Recoleta, where there are settling basins of 12,000,000 gallons capacity and six acres of covered filters. The filtered water is then pumped to great distributing reservoirs at Colles Cordoba and Viamonte, which cover an area of four acres and have a capacity of 13,500,000 gallons. Buenos Aires now has a good water supply. Argentina is enforcing hygienic regulations in all of its coast cities.

Rio de Janeiro obtains its waters from mountain sources. The waters are conducted into receiving reservoirs and then are carried 33 miles from their sources through conduits to distributing reservoirs, in the course of which there is some purification.

The foregoing will suffice to show the world-wide interest now being taken in water supplies and the researches of scientists and efforts that have been made and are being put forth by all progressive communities to secure for themselves pure and wholesome water for potable and other domestic purposes.

Enough has already been said to demonstrate the vital importance of water supplies to communities and to individuals. In this article the problems involved in the construction of waterworks have not been discussed for they are engineering problems and do not come within its scope. The larger and more important problems of water supplies, however, have been presented at some length in order that readers of the ENCYCLOPEDIA AMERICANA may understand what is involved in obtaining such supplies and the menace to health and to life in drinking impure water.

There is always the possibility that the purification of municipal water supplies may be incomplete or that contamination may ensue from private wells or other auxiliary supplies into water mains forbidden in New York except with the approval of the Board of Health or may be contamination may ensue from sewage or other subterranean pollution in cities, so that pathogenic bacteria may still exist in public water supplies, as they may exist in well waters and in all other kinds of raw waters. Such menace to health may be avoided, however, by the installation of approved purification processes in private dwellings, hotels, hospitals, schools, offices, factories, etc.

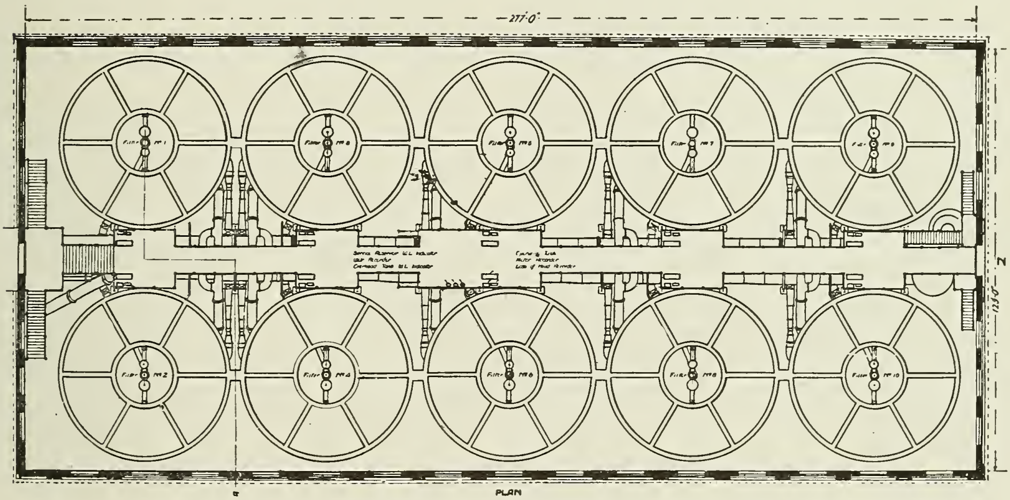


FIG. 5.—Toronto Filtration Plant — General Arrangement of Pipes in Filter House.

The matter is of such transcendent importance that the Treasury Department of the United States Government called together a corps of distinguished specialists in 1914, and they formulated standards of purity for water to be consumed by the public, which was being supplied by common carriers in interstate commerce.

The article is contributed in the hope that it may awaken a deeper interest in the subject than that taken by individuals and communities which have suffered most seriously from unwholesome water supplies in the past.

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Henry Wayland Hill,

President of the New York State Waterways Association. Author of «Waterways and Canal Construction in New York» and of the Articles on «Rainfall» and «Waterways» in this Encyclopedia.

WATER TABLE, *in architecture,* a projecting stone sloped on the roof to throw off water. It occurs in buttresses and other parts of Gothic architecture.

WATER THERMOMETER. See Thermometer.

WATER-THRUSH, an American warbler of the genus *Seiurus,* brownish to yellowish in color, having terrestrial habits and frequenting preferably the borders of streams; its domed nest in the woods gives the name oven-bird to the common resident species (*S. auricapillus*). The Louisiana variety (*S. motacilla*) is distinguished by a white superciliary line. See Warblers; Wagtail.

WATER TURBINE. See Turbine; Water Wheel.

WATER-TURKEY. See Darter.

WATER VALLEY, Miss., city, one of the county-seats of Yalobusha County, on the Illinois Central Railroad, about 140 miles north by east of Jackson, the State capital, and 15 miles north of Coffeeville, the other county-seat. It was settled in 1855 by William Carr; incorporated in 1867, and chartered as a city in 1890. It is in an agricultural region, in which cotton is one of the principal products. It has considerable lumbering interests. The chief manufacturing establishments are cotton mills, railroad repair and construction shops, in which there are 500 men employed, a lumber mill, foundry and machine shops, and woodworking factory. The city owns and operates the electric-light plant and the waterworks. There are seven church denominations, the Methodist State Orphans' Home, the McIntosh Training School, and public schools for both races. There are two banks and two newspapers. The government is vested in a mayor and board of aldermen consisting of seven members elected every two years. Pop. 4,708.

WATER WHEEL, a machine by which the energy in falling water is utilized to perform mechanical work. Water, through its tendency to seek the lowest level — the point nearest to the centre of the earth — acts as a motive power by its weight. When the water is confined, as in a vertical pipe, this weight becomes pressure. When the water has acquired a velocity in flow its motive power is called impulse. Water wheels adapted to these various conditions may be divided into two general classes — the «vertical,» consisting of the «overshot,» «breast» and «undershot» wheels; and the «horizontal,» which includes a great variety of turbine or reaction wheels. The impact or impulse wheels are represented in both classes. The term water wheel is correctly applicable to all forms of water motors that rotate, but in this article it will be restricted to those of the vertical class. For those belonging to the horizontal class, see Turbine.

The overshot wheel is so called because the actuating water is fed to it from the top. It is provided with a number of buckets fixed to its periphery in such a way that as the wheel revolves the buckets on the descending side have their tops upward, and being filled with water at or near the top of the wheel, the weight of the water exerts a downward pull and the axle of the wheel being free to turn in its bearings, a rotary motion is imparted to the axle from public library. There are two banks. Pop. about 1,410.

WATERVLIET, wâ-tėr-vlēt', N. Y., city in Albany County, on the Hudson River and on the Delaware and Hudson Railroad, opposite Troy and six miles north of Albany. Electric railways connect the city with Albany, Troy, Schenectady and Cohoes. A steel bridge over which pass electric cars for both passengers and freight spans the river at this point. It is at the head of river navigation and has by means of the Hudson River water connections with New York and intermediate points. Watervliet is a factory city having plants making woolen goods, shirtwaists, collars, bells, iron products, sashes, doors and blinds, metal harness parts, street cars, car-journal bearings, machine-shop products and boats. In 1807 the United States government established here the Watervliet Arsenal for the construction of siege ordnance and field and coast defenses; in 1919 negotiations were opened for the purchase of some 35 acres of land comprising many city blocks, the plan being to enlarge the original reservation of 109 acres with its wharfage of 1,000 feet, and to make the plant the largest of its kind in the country. The construction works have been constantly in operation and some of the largest guns in the United States' service have been made here. The place was the scene of great activity during the World War; at an expenditure of between 12 and 14 million dollars the normal output was tripled, the maximum number of employees reaching 5,125. Within the arsenal reservation are quarters for officers and barracks for soldiers. There is also a large stone magazine. The city has 12 churches representing six denominations; a high school established in 1899, Saint Patrick's Academy and public and parish schools. There is a graded school in connection with Saint Colman's Orphanage, and also with Fairview Home. Watervliet was settled about the time the first settlements were made at Albany and other places on the Hudson. It was incorporated as a village, and called West Troy in 1836. In August 1897 it was chartered as a city under its present name. Its industrial growth has been closely connected with the work of the government arsenal. It has many of the social and educational advantages of Troy and Albany. The waterworks are owned by the city, and on 10 June 1919 the commission form of government was adopted. Pop. about 18,000.

WATERWAYS OF THE UNITED STATES, The. The atlas of the world shows that three-fourths of its surface is covered with water. The waters of the earth comprise oceans, seas, straits, gulfs, bays, lakes and rivers. In the main these are navigable, but where not navigable, much has been done to make them so. In addition thereto, extensive systems of intersecting canals have been constructed, so that natural and artificial waters of the world, known as «waterways,» comprise all its oceans, seas, gulfs, sounds, bays, many of its lakes and rivers, and all navigable canals.

In the United States the ebb and flow of the tide is not the test of navigability as it was in England before it was abolished by 24 Vict., ch. 10. The Supreme Court of the United States held in the Daniel Ball, 10 Wall. 557, that a different test than tidal variations must be applied here to determine navigability. The courts say that those rivers must be regarded as public navigable rivers in law, which are navigable in fact; and they are navigable in fact when they are used, or are susceptible of being used, in their ordinary condition, as highways for commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on water. The commercial power of Congress authorizes such legislation as will insure the convenient and safe navigation of all navigable waters of the United States, whether that consists in requiring the removal of obstructions to their use, in prescribing the form and size of the vessels employed upon them, or in subjecting the vessels to inspection and license. The power to regulate commerce comprehends the control for that purpose and to the extent necessary, of all navigable waters of the United States which are accessible from a State other than those in which they lie. For this purpose they are the public property of the nation, and subject to all the requisite legislation of Congress. In the case of Perry *v.* Haines, 191 U. S. 17, the same court decided that admiralty jurisdiction extends to cases of maritime liens upon vessels navigating the Erie Canal, as that formed part of a navigable highway for interstate commerce between Lake Erie and the ocean. Thus artificial as well as natural navigable waters are being recognized as public waters in the sense in which Bracton used that term in the rule that *publica vero sunt omnia flumina et portus.* Years ago the English courts decided that the river Severn was a public highway, and the courts of the United States have followed the decisions of the Supreme Court of the United States heretofore stated in regard to public navigable waterways. An interior nation has a servitude along natural watercourses to reach the highway of nations, known as *jus transitus,* which is recognized by the law of nations. The right of transit over the Danube below the Iron Gates is secured by agreement. In the United States and in Canada, the rivers do not generally flow in foreign territory, so that it is not necessary to invoke the doctrine of *jus transitus,* except in a few cases, as along the Richelieu and lower Saint Lawrence.

The Atlantic Coast. *Maine.*— The waterways of Maine include 240 miles of seacoast, with many bays indenting it and scores of islands strewn along it. The Saint Croix River on the east is the outlet of Grand Lakes. It forms part of the international boundary and is navigable from its mouth up to Calais. Its tonnage in 1917 was 61,896 tons. The Penobscot is 275 miles long and navigable to Bangor by large vessels. It is the outlet of several lakes in central Maine and flows into Penobscot Bay, 30 miles long and 15 miles wide. Its tonnage in 1917 was 340,198 tons. The Kennebec is 160 miles long and navigable to Augusta. It is the outlet of Moosehead Lake, which is 36 miles long and from 8 to 12 miles wide, and navigated by pleasure steamers.

The Kennebec has a channel 150 feet wide and from 18 to 16 feet deep up to Gardiner and thence a channel 125 feet wide and 11 feet deep up to Augusta. The tonnage on that river in 1917 was 123,855 tons. The Androscoggin

River drains the famous Rangeley lakes and other lakes, and flows 200 miles into the Kennebec near its mouth. It is navigable only in part and by river craft. Sebago Lake is 12 miles long and 10 miles wide and navigable by small steamers.

Its principal seaport is Portland, but it also has other improved harbors, among which are Bar Harbor, Stockton, Camden, Rockport, Rockland, Matinicus, South Bristol, Boothbay, Sasanoa and others.

Portland has a developed waterfront of four miles in extent. It has 47 wharves, 12 of which are used for transportation terminals. Its tonnage in 1917 was 2,905,428 tons.

The tonnage of Bar Harbor in 1917 was 27,723 tons.

Saco River, 105 miles long, has a channel seven feet deep and from 100 to 200 feet in width for six miles up-stream. In 1917 its tonnage was 53,216 tons.

New Hampshire and Massachusetts.— New Hampshire has Portsmouth as its principal fortified harbor. Its rivers are few. Cochero and Exeter rivers are navigable a few miles for light draft vessels and the channel of the Merrimac has been improved to Haverhill, 16½ miles, to a depth of seven feet. Fourteen wharves extend along the Merrimac. Its tonnage in 1917 was 18,031 tons. Portsmouth and other harbors have been improved.

Pepperells Cove is a part of Portsmouth Harbor and has been improved for anchorage purposes, the controlling depth being 11 feet. Its tonnage in 1917 was 109,781 tons.

The inland lakes of New Hampshire are navigable by small pleasure boats. The same is true of the rivers of Massachusetts. It has, however, Boston Harbor, Massachusetts Bay, Cape Cod Bay, which is connected with Buzzard's Bay by a canal across Cape Cod, Nantucket Sound, Vineyard Sound, Buzzard's Bay and several other small bays, all in communication with the ocean. Boston has a land-locked harbor of 47 square miles in area. It has several improved channels from 23 to 40 feet deep and from 100 to 1,200 feet wide. Its inflowing tributaries, Chelsea Creek, Fort Point Channel, Charles River and Mystic River have all been made navigable. In 1917 the tonnage on Chelsea Creek was 532,200 tons; on Fort Point Channel 1,116,204 tons; on Mystic River 5,082,250 tons. It has four or more miles of fully-developed waterfront with wharves of various types devoted to ocean commerce. Gloucester, Beverly, Salem and Lynn harbors have all been improved. In 1917 the tonnage of Gloucester Harbor was 239,272 tons; of Beverly Harbor, 444,695 tons; of Salem, 58,158 tons and of Lynn Harbor, 338,783 tons.

Taunton River is navigable to Taunton, 15 miles from its outlet, which empties into Mount Hope Bay. The Malden, Weymouth Fore and Weymouth Back rivers are navigable at their mouths only. Salem, as a commercial port, has a reputation far more enviable than that for witchcraft.

Vermont.— Vermont has part of Lake Memphremagog, which is navigable by lake steamers, and part of Lake Champlain, 120 miles long and 15 miles wide in its extreme width, which has been, since its discovery on 4 July 1609, a highway of commerce for the aborigines, for the colonists and for Americans generally. It is navigated by large lake steamers, by scores of other steamers and by many yachts and sailing vessels. It is one of the most picturesque lakes in America and forms an important portion of the 467 miles of waterway between the Saint Lawrence on the north and New York Bay on the south. It contains several beautiful islands, such as Isle La Motte, North Hero and South Hero. Lake Champlain is connected with the waters of the Hudson River at Fort Edward by the Champlain Barge Canal, having a depth of 12 feet of water, so that vessels drawing 11 feet may pass from Lake Champlain through into the Hudson River.

Whitehall, Port Henry, Burlington, Plattsburgh and Rouses Point are the principal improved ports of Lake Champlain. Its principal tributaries are the historic Otter Creek, where Commodore Macdonough built his fleet in 1814, the Missisquoi River and the Champlain or Big Chazy River. Its outlet is the Richelieu River, a tributary of the Saint Lawrence.

Rhode Island.— Rhode Island has Narragansett Bay, Mount Hope Bay, Providence and Seekonk rivers. These are navigable by large passenger and other vessels. Narragansett Bay, about 20 miles long and 12 miles wide, has channels through it to Providence and Fall River. Along its eastern margin is Sakonnet River with Portsmouth Harbor at the head of it. The Pawtucket River, 50 miles long, is improved in its lower section for a distance of five and two-tenths miles. Its tonnage in 1917 was 490,594 tons. Providence River and Harbor has been dredged to a depth of 30 feet over an area one and six-tenths miles in length and one-quarter mile in width. Its tonnage in 1917 was 3,406,224 tons. Fall River Harbor, at the mouth of Taunton River, has a channel 300 feet wide and 25 feet deep, extending out to Narragansett Bay. The steamers of the Fall River Line enter that harbor. In 1917 its tonnage was 1,469,750 tons. Newport Harbor, R. I., is an improved waterway with a channel 750 feet wide and 18 feet deep at low water. Its tonnage in 1917 was 204,701 tons.

Connecticut.— Connecticut has part of Long Island Sound, the Thames River, navigable to Norwich, the Connecticut River, the Naugatuck River, navigable by small craft for a few miles and the Housatonic, 150 miles long and navigable to Shelton. It has several towns along its waterways, such as Stonington, Norwich, New London, New Haven and Bridgeport.

The tonnage of the Connecticut River below Hartford in 1917 was 602,008 tons. That river has been improved as far as Holyoke, a distance of 85.9 miles from its mouth.

There are numerous harbors along the north shore of Long Island Sound with inflowing tributaries, many of which have been improved sufficiently to be navigable by coastwise vessels.

New London has an entrance channel 600 feet wide and 33 feet deep and is well equipped with wharves and other terminal facilities. In 1917 its tonnage was 690,977 tons.

The channel at New Haven is 400 feet wide and 20 feet deep, three miles up from Long Island Sound, and it has been somewhat extended at lesser depths and widths up-stream. In 1917 the tonnage at that port was 1,868,649


NAVIGABLE WATERWAYS
OF THE
UNITED STATES.
PREPARED IN THE OFFICE
OF THE
CHIEF OF ENGINEERS,
U. S. ARMY
1920
129°
125°
121°
117°
113°
109°
105°
101°
45°
41°
37°
33°
29°
25°
PACIFIC OCEAN
CAN
WASHINGTON
SEATTLE
SNAKE R.
COLUMBIA R.
PORTLAND
SALEM
OREGON
IDAHO
BOISE CITY
MONTANA
FT. BENTON
HELENA
NORTH DAKOTA
BISMARCK
SOUTH DAKOTA
PIERRE
YELLOWSTONE LAKE
WYOMING
CHEYENNE
NEBRASK
SALT LAKE
SALT LAKE CITY
CALIFORNIA
SACRAMENTO R.
SACRAMENTO
SAN FRANCISCO
CARSON
TAHOE LAKE
NEVADA
UTAH
COLORADO
DENVER
KANS
SANTA FE
OKLA
PRESCOTT
ARIZONA
NEW MEXICO
LOS ANGELES
SAN DIEGO
TEX
MEXICO
RIO GRANDE

93°
89°
85°
81°
77°
73°
69°
65°
LAKE OF THE WOODS
RED LAKE
LEECH LAKE
DULUTH
LAKE SUPERIOR
KEWEENAW
SAULT STE. MARIE
LAKE HURON
LAKE MICHIGAN
WISCONSIN
ST. PAUL
MISSISSIPPI
FOX R.
MILWAUKEE
LANSING
DETROIT
ST. CLAIR R.
TOLEDO
LAKE ERIE
ERIE
BUFFALO
LAKE ONTARIO
ST. LAWRENCE R.
CAPE VINCENT
OSWEGO
ALBANY
NEW YORK STATE BARGE CANAL
LAKE CHAMPLAIN
VERMONT
NEW HAMPSHIRE
AUGUSTA
PORTLAND
BANGOR
PORTSMOUTH
BOSTON
MASSACHUSETTS
CAPE COD CANAL
NEWPORT
HUDSON R.
DELAWARE R.
NEW YORK
NEW JERSEY
PENNSYLVANIA
CLEVELAND
SANDUSKY
CHICAGO
GRAND CALUMET
LAKE CALUMET
DES MOINES
PITTSBURGH
WHEELING
PHILADELPHIA
BALTIMORE
WASHINGTON
DEL.
MIAMI CANAL
CINCINNATI
ILLINOIS
ILLINOIS R.
WEST VIRGINIA
CHARLESTON
KANAWHA R.
RICHMOND
JAMES
NORFOLK
KANSAS CITY
MISSOURI
ST. LOUIS
WABASH R.
OHIO R.
LOUISVILLE
KENTUCKY R.
CAIRO
CUMBERLAND R.
TENNESSEE
ROANOKE
RALEIGH
NORTH CAROLINA
NEUSE R.
CAPE FEAR
WILMINGTON
WHITE R.
ST. FRANCIS R.
ARKANSAS R.
MEMPHIS
TENNESSEE R.
COLUMBIA
SOUTH CAROLINA
ATLANTA
SAVANNAH R.
SANTEE R.
CHARLESTON
ARKANSAS
OUACHITA
SALINE R.
YAZOO R.
GEORGIA
SAVANNAH
ALTAMAHA
SHREVEPORT
VICKSBURG
TOMBIGBEE R.
ALABAMA R.
MONTGOMERY
FLINT R.
PEARL R.
MOBILE
PENSACOLA
JACKSONVILLE
BATON ROUGE
NEW ORLEANS
TRINITY R.
GALVESTON
TAMPA
INDIAN R.
GULF OF MEXICO
KEY WEST
ATLANTIC OCEAN
Scale
100 0 100 200 300 400 500 600 Miles
DRAWN BY V. SOURNIN

tons. Thames River, Connecticut, is a tidal estuary from 400 to 4,000 feet wide, extending from Long Island Sound to Norwich, a distance of 15 miles. Its channel is 200 feet wide and from 20 feet deep to Allyn Point and 14 feet deep from there to Norwich, with wharves at New London and Norwich. The tonnage on that river in 1917 was 328,188 tons. The Housatonic River has an improved channel from 100 to 200 feet wide and seven feet deep to Derby and Shelton, a distance of 13 miles from its outlet. Its tonnage in 1917 was 300,047 tons.

Bridgeport has several improved channels from Long Island Sound leading up to the port to accommodate coastwise vessels. Its tonnage in 1917 was 1,588,056 tons.

There are several other harbors along the south coast of Connecticut that have been improved, all of which show the increasing interest in waterways improvement.

Long Island Sound is 75 miles long and 20 miles wide. It is a great waterway for several superb steamboat lines plying between New York and towns and cities on its northern shore. The Connecticut River at one time was navigated by a number of river boats and had considerable commerce. A line of boats ran between Wells River, Vt., and Hartford. The boats were flat boats and did not draw much water. The *Barnet* was the first steamer for Connecticut River service. It drew 22 inches of water. On its first trip from Hartford to Vermont it had in tow a barge filled with people. Other steamers were built for river service, in which they were engaged for many years. This river was a great natural highway for the transportation of produce to market. The rapids in the river were overcome by canals at South Hadley Falls, at Turner Falls and at Bellows Falls.

New York.— The waterways of New York comprise that portion of the Atlantic Ocean washing Long Island on the south, and that part of Long Island Sound washing Long Island on the north, and also the upper and lower New York and Jamaica bays, and a portion of Staten Island Sound and all of the East, Harlem and Hudson rivers. They also include the Mohawk, Seneca, Chemung, Black, Oswego and parts of the Delaware, Susquehanna, Genesee, Allegheny, Niagara, Saint Lawrence and other rivers, interior lakes and parts of Lakes Erie, Ontario and Champlain and others.

In and about the port of New York are many inflowing streams and contiguous harbors. Some of these are Port Chester, Mamaroneck, Echo Bay, Westchester, Bronx River, Flushing Bay, Hempstead, Huntington, Port Jefferson, Mattituck, Great South Bay, Brown's Creek, Jamaica Bay, Sheepshead Bay, East River, Wallabout Channel, Newtown Creek, Harlem River, Hudson River, New York Bay and the various improved channels therein. All such waterways have been improved and are navigable by coastwise vessels, and many of them by the ocean-going vessels.

New York is the largest commercial port in the world, having wrested first place from London recently. The total tonnage of the port of New York for the year 1917 was 65,176,983 short tons. That was during the World War, when war supplies were being shipped in great quantities. Its unique position at the confluence of the East and Hudson rivers overlooking one of the finest harbors in the world, has added to its other commercial advantages and is destined to continue it as the emporium of the western hemisphere. On the north flows the picturesque Hudson, discovered in September 1609, and navigable by steam vessels 150 miles to the city of Troy, and by canal barges to Waterford. It has been improved, its many harbors also improved and the river has been canalized from Waterford to Fort Edward. It receives on the west the waters of the Mohawk, formerly navigable about 95 miles, to Little Falls, which is also canalized from the Hudson nearly to the city of Rome. The canalized Hudson and Mohawk form a part of the improved canal system of the State of New York, constructed pursuant to the provisions of the Canal Referendum Law, which law provided for the issue and sale of the bonds of the State, amounting to $101,000,000, for the construction of a system of barge canals, having a bottom width of 75 feet and a depth of 12 feet, from the waters of the Hudson to those of Lake Champlain, Lake Ontario and Lake Erie, adequate for barges carrying 2,000 or more tons. That was followed by the Cayuga and Seneca canal referendum of 1909, authorizing a bond issue of $7,000,000 to improve the Cayuga and Seneca Canal, which was approved. That was also followed by the Barge Canal Terminal referendum measure of 1911, authorizing a further bond issue of $19,800,000 to construct Barge Canal terminals and was approved, and that was followed by the canal referendum of 1915, authorizing a further bond issue of $27,000,000, thus making aggregate bond issues for canals and terminals of $154,800,000. An additional bond issue of $25,000,000 will be required to complete the system.

The Cayuga and Seneca Canal has been enlarged to Barge Canal dimensions and connects Cayuga and Seneca lakes with the Erie Barge Canal. The New York Barge canals have standard locks 328 feet long, 45 feet wide with 12 feet of water over mitre sills. These will admit of the passage of barges carrying 2,000 or more tons. See Barge Canal.

These are the largest canal improvement projects ever undertaken by one of the American States. West of the city of Rome is Oneida Lake, into which flows Wood Creek, which is canalized and connected with the Mohawk. Oneida Lake, Oneida River and Oswego River are all canalized, as well as the Seneca River from the Three River point to the outlet of Onondaga Lake, and thence southwesterly nearly to Seneca Lake. New York contains several beautiful bodies of water, such as Lake George, part of Lake Champlain, part of Lake Ontario, part of Lake Erie, Onondaga, Skaneateles, Cayuga, Seneca, Keuka, Canandaigua and Chautauqua lakes. All of these lakes are navigated by passenger steamers during the summer.

New Jersey.— The waterways of New Jersey comprise a portion of the lower Hudson, upper New York Bay, Newark Bay, Staten Island Sound, Raritan Bay, the Atlantic Ocean and several arms of the ocean indenting the eastern coast of New Jersey, and Delaware Bay on the south and the Delaware River on the west, and other rivers intersecting it.

New Jersey and Pennsylvania.— Newark Bay is navigable for six miles and Passaic

River in New Jersey for 16 miles. Hackensack River has been made navigable for 15 miles from its mouth. Staten Island Sound, 17 miles long, connects New York and Raritan bays.

Commerce on Raritan Bay, Arthur Kill and Passaic River in 1906 amounted to 25,584,273 tons.

The Raritan Bay, seven miles long, and Raritan River to New Brunswick, a distance of 12 miles, are being improved. The Raritan River is navigable from Raritan Bay to New Brunswick, and from that point along the bed of the Raritan and Millstone rivers to Trenton is a canal, thus joining the waters of lower New York Bay with those of the Delaware. The total length of the Susquehanna River, including tributaries, is over 400 miles, and it is only partially navigable.

In some portions of its course the Susquehanna has been canalized to overcome rocks and vegetable matter, which obstructed its navigation. It flows into the Chesapeake Bay, which is 120 miles long and 50 miles wide. It has been improved to a depth of 15 feet with a width of 200 feet from Chesapeake Bay to Havre de Grace. It is proposed to render it navigable to Harrisburg. A bill authorizing an appropriation for this work was passed in 1919.

Pennsylvania has suffered its extensive canal system to pass from its control.

The Schuylkill River is being improved for six and one-half miles up from the Delaware River to a depth of 22 feet and 200 feet wide.

Delaware River is about 315 miles long and empties into Delaware Bay, which is 50 miles long. The river has been improved as far as Trenton, N. J., to a depth of 12 feet and to a width of 200 feet which is to be increased to 400 feet. Its channel from Delaware Bay to Philadelphia is 35 feet deep at low water and has a width of 800 feet, and in the city of Philadelphia it is 1,000 to 1,200 feet wide. The tonnage at Trenton in 1917 was 2,439,044 tons.

Philadelphia has extensive modern terminal facilities and its water-borne tonnage, coastwise and foreign, for the year 1917 was 26,282,734 short tons. The total arrival of vessels for the year was 51,206 and the departures were 58,838. This shows the enormous waterway activities of that port. Other ocean ports were more or less active.

Middle Atlantic States.— Wilmington Harbor on the Delaware River, at the mouth of Christiana River, includes sections of those two rivers and is well provided with wharves and terminals. Its tonnage in 1917 was 414,987 tons.

Several rivers, creeks and harbors in New Jersey, Delaware and Maryland have been improved. The Wilmington district includes 26 rivers, creeks and harbors that are being improved, the largest being Wilmington Harbor, including the Christiana River, navigable for 15 miles, and a tidal canal between Rehoboth and Delaware bays.

The Appoquinemink, the Smyrna, the Leipsic, Little Saint Johns, Murderkill, Mispillion and Broadkill rivers, all in Delaware, are small streams that have been improved in their lower reaches. A waterway six feet deep and 50 feet wide extends from Rehoboth Bay and Delaware Bay whose tonnage in 1917 was 15,275 tons.

The inland waterway from Delaware Bay to Chincoteague Bay, Virginia, which is six feet deep and 70 feet wide, had a tonnage in 1917 of 22,520 tons.

The Chesapeake and Delaware Canal has been purchased by the United States government and is to be enlarged and made a sea-level canal, 12 feet deep at mean low water with 90 feet bottom width. It extends from the Delaware River to Black Creek at Elk River, a distance of 18.9 miles and becomes a part of the Intercoastal Waterway from Maine to Key West.

The Baltimore district includes 26 rivers and harbors undergoing improvement. The principal harbor is Baltimore. That includes Curtis Bay and Patapsco River and tributaries and is 11 miles above Chesapeake Bay. It has several channels of 35-feet depth and of variable widths from 400 to 1,000 feet with wharves, terminal facilities and a belt line railway connecting the waterfront terminals with the trunk line railways. Its tonnage in 1917 was 14,055,885 tons.

The Washington district comprises 11 rivers and harbors, including a part of the Chesapeake Bay and the streams emptying into it.

The harbor of Washington is on the Potomac River, 110 miles from its outlet into Chesapeake Bay. The average depth of water in its channel is 20 feet.

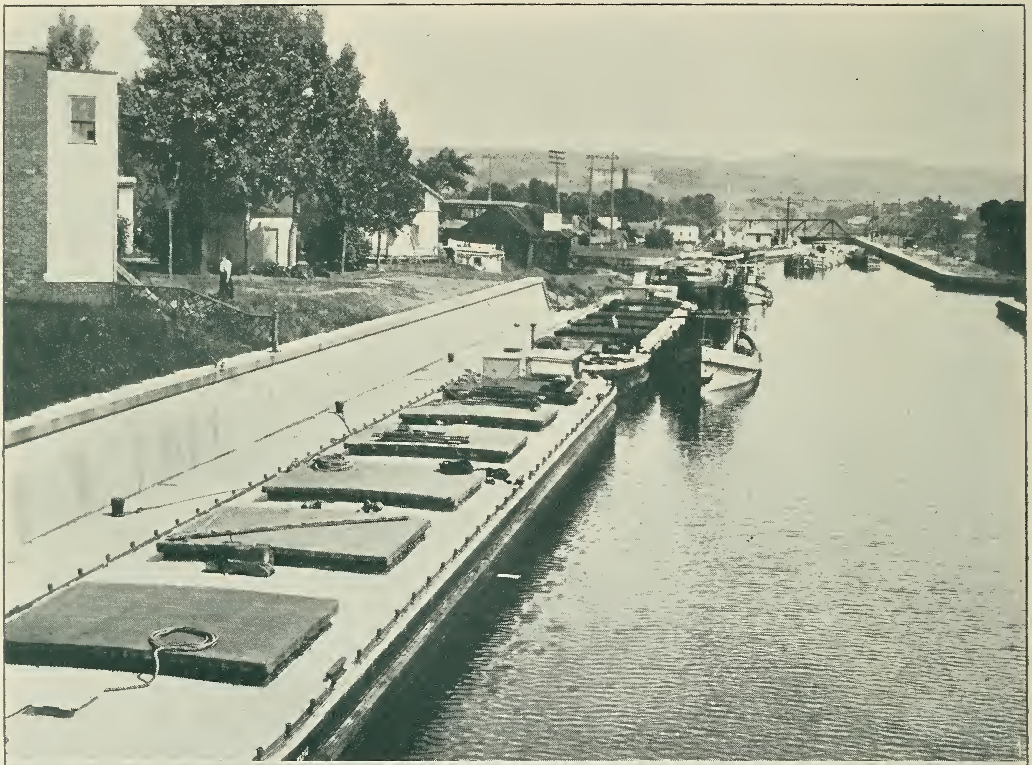
The Washington Harbor is two miles in length and 950 feet in width. It has 44 wharves, eight of which are municipal and eight are open to the public on equal terms. Vessels of 30 feet draft may moor at the docks extending 11,000 feet along the waterfront. In 1917, the tonnage was 837,221 tons. Above Washington is the Chesapeake and Ohio Canal of six feet depth of prism paralleling the Potomac for 175 miles to Cumberland, Md.

In 1906 its tonnage was 225,142 tons. The Anacosta River is 20 miles long, flowing into the Potomac at Washington. It has been improved and has 15 terminals. Its tonnage in 1917 was 226,911 tons. Several ports have been improved on the Potomac, such as Georgetown, Alexandria and Lower Cedar Point. The Potomac River is about 400 miles long and navigable 110 miles for large vessels. It flows into Chesapeake Bay from the northwest. It receives from the south the waters of the Shenandoah. The Rappahannock River is over 200 miles long and navigable by vessels of 10-feet draft to Fredericksburg, a distance of 110 miles.

The James River is 320 miles long and is being improved to Richmond, a distance of 103.8 miles. Its channel will be 22 feet deep at mean low water and have a width of 200 to 400 feet. The river is equipped with terminals at various points connecting with railroads. It has extensive wharves and docks at Richmond, some of which are free for public use. In 1917 the tonnage was 715,255 tons.

Norfolk Harbor, Va., has a channel 40 feet deep at mean low water and 750 feet wide from Hampton Roads to the mouth of the southern branch of the Elizabeth River, and thence 450 feet wide up that branch, a distance of 11¾ miles, except in front of the navy yard where the channel is 35 feet and from 600 to 800 feet wide. There are other channels in the harbor of various dimensions. Its wharves, piers and terminals number 165. In 1917 its tonnage was 31,870,321 tons.

1 New York State Barge Canal lock and dam in the canalized Hudson river. Lock on the farther bank, Taintor gate regulating section of the dam in the foreground
2 Dam at the foot of Mohawk river navigation — 1,922 feet long, of gravity type, with circular trace of 700 feet radius
3 Lockport locks, where the Barge canal descends the Niagara escarpment. Two new locks have replaced one tier of five old locks



1 Steel barges built for Federal Governmental use on the New York State Barge Canal and put in service in 1919
2 Fleet of concrete barges on Barge Canal — built and used by Federal Government

The harbor at Newport News, 10 miles west of Norfolk, has a channel 600 feet wide, 35 feet draft and three and one-quarter miles long. It has extensive shipbuilding, railway and other facilities. Its tonnage in 1917 was 6,259,774 tons. The lower reaches of the Appomattox, 137 miles long, a tributary of the James River, are being improved to a depth of 12 feet and with a diversion channel two and one-half miles long, and from 200 to 400 feet wide below Petersburg. Its tonnage in 1917 was 335,947 tons. The Pagan and Nansemond rivers and Cape Charles City Harbor, Va., are being improved. The Congress of the United States has made appropriations in part for the construction of an intracoastal waterway with a prism having a bottom width of 90 to 300 feet and a depth of 12 feet at mean low water, paralleling the Atlantic Coast from Norfolk, Va., to Beaufort, N. C., a distance of 186 miles. It will comprise natural watercourses except through four land cuts to connect such watercourses.

The tidal waterway along the coast of Virginia, including Cat River and Bogues Bay, with a channel four feet deep and 25 feet wide, had a tonnage in 1917 of 109,024 tons.

Four routes were surveyed for that intracoastal canal and the route via the Albemarle and Chesapeake Canal was recommended. It follows the existing waterway, via Neuse River, Adams Creek, Adams Creek Canal, Core Creek and Newport River. Several rivers which flow into the Atlantic Ocean and into the bays connected by this intracoastal canal are being improved for some distance up from their outlets and wharves and terminal facilities are being installed along their navigable waters. Roanoke River is 198 miles long, and from Weldon to its mouth, a distance of 129 miles, it is being improved to secure a channel 50 feet in width and six feet in depth. In 1917 its commerce was 78,736 tons. The Roanoke flows into Albemarle Sound, which is about 50 miles long and from five to eight miles wide, and it communicates through Croaton Sound with Pamlico Sound, which is 75 miles long and about 20 miles wide. These sounds will be connected with the Chesapeake by the intracoastal canal, having a depth of 12 feet and destined to do an active business.

The Wilmington, N. C., district comprises 25 rivers and harbors, including Beaufort Harbor, N. C., and several inland waterways and Cape Fear River. Most of the sounds are shallow and communicate with the Atlantic Ocean. Into Pamlico Sound flows the Pamlico and the River Neuse. The Cape Fear, Black and East Cape Fear rivers have been improved. Most of the other rivers and harbors of the Wilmington, N. C., district will be improved and brought into navigable communication with the coastal canal.

South Atlantic States.— The Charleston, S. C., district includes 11 rivers and harbors. The Waccamaw River is to be improved its entire length of 147 miles. The Little Peedee, South Carolina, is to be improved 113 miles above its outlet into the Great Peedee River, so as to have a four-foot channel. The Santee River is to be improved and a canal constructed between Estherville and Minim Creek, six feet deep and 70 feet wide for river steamers. Wateree River is to have a four-foot navigable channel from Camden to its mouth, a distance of 67 miles.

The Congaree River is to have a four-foot navigable channel for 49 miles above its mouth. The creeks, sounds, rivers and bays between Charleston Harbor and Alligator Creek for a distance of 47½ miles are being connected by a channel 100 feet wide and six feet deep at mean low water, and another channel seven feet deep has been recommended from Winyah Bay to Charleston, via Estherville-Minim Creek Canal. Charleston Harbor has an area of six square miles and is to be improved by the construction of a channel 30 feet deep and 500 feet wide from the sea up to the navy yard, and 1,000 feet wide out to seaward. The North Jetty is 15,443 feet long and the South Jetty is 19,104 feet long and the passageway between them is 2,900 feet wide. The eastern waterfront of Charleston Harbor has three-quarters of a mile of piers and the same length of marginal wharves. On the western front there is one small public wharf. The tonnage of the port in 1917 was 766,026 tons. The harbor is formed at the confluence of the Ashley and Cooper rivers. The Ashley River is being improved by constructing a channel 24 feet deep at mean low water and 300 feet wide from the mouth of the river up to the Standard wharf, a distance of seven and one-half miles and of eight feet depth above that to Lambs. Ashley River also has 12 phosphate wharves. Cooper River has been improved to a depth of 32 feet for six miles and a marginal wharf and warehouses have been built along it.

Savannah, Ga., district comprises 16 rivers and harbors. Savannah Harbor is being improved by a channel 30 feet deep and 500 feet wide to Quarantine, thence 26 feet deep and from 400 to 500 feet wide to the city waterworks, a distance of 16 miles, and thence 21 feet deep and 300 feet wide, one and one-half miles to King's Island, making the entire length of the improvement 27½ miles. The turning basin at West Broad and Barnard streets is 26 feet deep and 600 feet wide with a basin at Fort Oglethorp 26 feet deep and 900 feet wide. It has a wharf frontage of five miles, comprising municipal, private and railway terminals. Its tonnage in 1917 was 2,429,288 tons. From Savannah, 17 miles from the sea to Augusta, 218 miles from the sea, the Savannah River has a navigable channel of five feet depth, and along its course on many landings and at Augusta are private wharves with a total frontage of 1,450 feet. It also has a municipal wharf and warehouse with an electrically equipped elevator and locomotive crane. From Augusta to Petersburg, a distance of 53 miles, a channel is being maintained from 12 to 25 feet wide for vessels with a draft of one and three-tenths feet. A waterway 53 miles long with a depth of seven feet is being constructed along Ramshorn Creek, Wright and Mud rivers from Savannah to Beaufort, S. C. Another waterway is being constructed from Beaufort, S. C., to Saint John's River, Florida. Still another project provides for a channel seven feet deep and 150 feet wide from Savannah, Ga., to Fernandina, Fla., through Skidway and Creighton Narrows, Little Mud River, Frederica and Jekyl creeks and Cumberland River, a distance of 147 miles. Auxiliary channels through Three Mile Cut, near Darien, around Saint Simon's and Saint Andrew's Sound and along Club and Plantation Creek with supplemental routes, altogether measuring 183 miles. These improved natural channels made navigation safer and reduced freight rates. An improved waterway, 29 miles long, seven feet deep and 100 feet wide, connects Saint John's River, Florida, six miles from its mouth, with Cumberland Sound, Georgia. Other waterways and harbors in that region are being improved.

Satilla River, Georgia, 350 miles long, is being improved so as to afford steamboat navigation 93 miles up-stream. The channel of Saint Mary's River for 12½ miles above its mouth is 17 feet deep and 200 feet wide and for 24½ miles still further up-stream the channel is being cleared.

The Altamaha River is being improved its entire length of 137 miles. It will have a channel 60 to 100 feet wide and four feet deep. Its tonnage in 1917 was 37,625 tons. The River Oconee for 145 miles and Ocmulgee for 205 miles, whose confluence forms the Altamaha, are being improved in the same manner as the last-named river. The inner and outer harbors of Brunswick, Ga., are to be dredged to a depth of 30 feet at mean low water and equipped with terminal facilities. Fernandina Harbor, Florida, and Cumberland Sound, Georgia and Florida, are also being improved.

The Jacksonville, Fla., district includes 26 rivers and harbors undergoing improvement to various navigable depths.

Saint John's River is to have a channel from 300 to 600 feet wide and a depth of 24 to 30 feet from Jacksonville to the ocean, a distance of 28 miles, and a channel 200 feet wide and 13 feet deep from Jacksonville to Palatka, a distance of 55 miles, and a channel 100 feet wide and eight feet deep from Palatka to Sanford and five feet deep from Sanford to Lake Harney, the two last improvements extending up the river 115 miles above Palatka. Lake Crescent, 14 miles long and one to three miles wide, is in touch with Saint John's River through Dunn's Creek, eight and one-half miles long, with a channel 100 feet wide and eight feet deep.

In 1917, the total number of arrivals and departure of steamers, motor boats, sail boats, lighters and rafts on the Saint John's River was 10,098. The freight traffic was 174,609 tons. A waterway, known as the East Coast Canal, extends from Saint John's River to Key West, Fla.

The channel of the Oklamaha River, Florida, a tributary of Saint John's River, is being cleared to a depth of six feet from its mouth to Silver Springs Run, a distance of 62 miles. Indian River has a channel 75 feet wide and five feet deep for 77 miles; Lucie Inlet with a channel 200 feet wide and 18 feet deep connects Indian River with the ocean, 235 miles south of Saint John's River. The Miami Harbor has an entrance channel 300 feet wide and 20 feet deep. It embraces artificial basins and dredged channels through to the ocean with parallel projecting stone jetties. It has wharves and piers, some of which are public. Its water-borne tonnage in 1917 was 244,380 tons.

The harbor at Key West has a channel 300 feet wide and 30 feet deep. The channel opposite the wharves is 26 feet deep and 800 feet wide. It is an important harbor affording shelter for vessels exposed to hurricanes. It had a tonnage in 1917 of 745,056 tons.

Gulf Coast.— The Kissimmee River is being cleared and is to have a channel 30 feet wide and three feet deep for 99½ miles, connecting several interior lakes, including Kissimmee, Tohopekaliga and Okeechobee, connected many years ago by canals with Lake Hicpochee. The lowering of the water in Lake Okeechobee for drainage purposes has interfered with the navigation of the upper Kissimmee River, which was navigable for 137 miles. The Caloosahatchee River has a channel 200 feet wide and 12 feet deep to Puntarasa and thence a channel 100 feet wide and 10 feet deep to Fort Myers, where there is a turning basin and a channel from two to four feet deep to Fort Thompson. Fort Myers is 20 miles from Charlotte Bay and Fort Thompson is 43 miles from Fort Myers. A drainage canal connects Fort Thompson through Lake Hicpochee with Lake Okeechobee. That is to be improved and made navigable so there will be a navigable channel through from Charlotte Harbor to Lake Tohopekaliga. The Orange River, a tributary of the Caloosahatchee, is also being dredged so as to have a navigable depth of four feet for a distance of six miles. Charlotte Harbor is from five to 11 miles wide and 11 miles long and is to have a channel 300 feet wide and 24 feet deep to Boca Grande, and 10 feet deep to Punta Gorda and six or seven feet in Pine Island Sound. There is now a channel 12 feet deep up Peace River to Punta Gorda, 200 feet wide in the bay and 120 feet wide in Peace River. In 1917 the tonnage was 304,095 tons.

Sarasota Bay is to be brought into navigable communication with Tampa Bay on the north by a proposed channel 100 feet wide and five feet deep. Little Sarasota Bay has a channel 75 feet wide and three feet deep to Venice. Tampa Bay is a large body of water 25 miles long to Gadsend Peninsula where it divides into Hillsboro Bay and Old Western Tampa Bay. It is from seven to ten miles wide. It has a channel from its entrance to Port Tampa 200 feet wide and 26 feet deep. Its tonnage in 1917 was 1,181,076 tons.

The connecting bays and inflowing rivers are being provided with navigable channels of 200, 300 and 500 feet in width. Hillsboro Bay and river and Manatee River are navigable for several miles. Saint Petersburg is on the west shore of Tampa Bay eight and three-quarters miles from Port Tampa. That part of the bay is called Bayboro Harbor connected by a channel 200 feet wide and 10 feet deep with the wide waters of Tampa Bay. Its tonnage in 1917 was 22,151 tons. Clearwater Harbor eight miles long and from one-half to one and three-quarters miles wide and Boca Ceiga Bay are shallow sounds but navigated by small vessels. The lower reaches of Anclote crystal, Withlocoochee and Suwannee rivers are navigable for small vessels. The latter has been improved up to Ellaville, 135 miles above its mouth, and has a channel 150 feet wide and five feet deep for the first 75 miles, and one 60 feet wide and four feet deep for the remaining 60 miles.

Alabama.— The Montgomery, Ala., district includes 18 rivers and harbors. Carrabelle Harbor, Apalachicola Bay and river, the lower and upper Chipola, Flint and Chattahoochee rivers, the canal 36½ miles long connecting Apalachicola River, which is a large stream, and Saint Andrew's Bay and the entrance to Saint Joseph's Bay are all navigable waterways with channels of different widths and depths. They are being improved. Choctawhatchee Bay, 20 or more miles long, is navigable. Choctawhatchee River has a navigable channel from its mouth up to Geneva, Ala., a distance of 96 miles. Its tributary, the Holmes River, is to be made navigable from its mouth up to Vernon, a distance of 25 miles. Blackwater River will have a channel 100 feet wide and nine feet deep up to Milton, a distance of 10 miles. Escambia River, 65½ miles long in Florida, and Conecuh, 235 miles long in Alabama, is the same river and is to have a navigable channel from its mouth to Patsaliga Creek, a distance of 147 miles, unless the present project be modified.

Pensacola Harbor is 13 miles long and is five miles wide. It joins Escambia, East and Blackwater bays and Santo Rosa Sound on the southeast. Pensacola Harbor has a channel 500 feet wide from the Gulf of Mexico and 28 feet deep. It is equipped with several wharves, a terminal railway and warehouses. Its tonnage in 1917 was 524,058 tons. The Alabama River formed by the confluence of the Coosa and Tallapoosa rivers, 22½ miles above Montgomery, unites with the Tombigbee River, 44 miles above Mobile, to form the Mobile River. The Alabama, whose width is from 400 to 700 feet, and Coosa rivers are being improved so as to have a continuous channel four feet deep up to Wetumpa on the Coosa, a distance of 321.6 miles. Vessels of three feet draft may now navigate the river all the year as far as Montgomery where there are some terminal facilities and whose port tonnage in 1917 was 94,356 tons. The Coosa River, formed by the Oostanaula and Etowah rivers, is being improved by the construction of a channel 100 feet wide and four feet deep and of seven dams and seven locks 40 to 52 feet wide and 176 to 280 feet long at various points, rendering the river navigable for 165½ miles above its mouth, 22½ miles above Montgomery. Its tonnage in 1917 was 15,744 tons.

The Mobile, Ala., district includes 14 rivers and harbors. Into Mobile Harbor flows Mobile River. A channel 300 feet wide and 27 feet deep has been constructed from the ocean up Mobile Bay for 33½ miles to the river and thence up Mobile River in front of the city of Mobile for five miles to Chickasaw Creek. In the bay it is 200 feet wide and in the river 300 feet wide. Wharves and piers line the west shore of Mobile River for two and one-fourth miles. The city owns a wharf and pier in the upper end of the bay 8,300 feet long and 300 feet wide. Mobile tonnage in 1917 was 1,816,284 tons. Black Warrior River, a tributary of the Alabama River, has been dredged, and 17 dams and 18 locks have been constructed to afford slackwater navigation for 332½ miles from its mouth to Sanders Ferry on the Mulberry Fork of the Black Warrior River and to Nichols Shoals on the Locust Fork of the same river. The entire length of the section to be improved is 443½ miles to Sanders Ferry and 423½ miles to Nichols Shoals. The channel is 100 feet wide and six feet deep. The locks are 52 feet wide, about 282 feet long with a depth of six and one-half feet of water over mitre sills. The tonnage on that part of the improved waterway in use in 1917 was 580,728 tons. The Tombigbee River is shallow, having a channel two feet in depth, though in some sections it is six feet deep and all the way 100 feet wide from Demopolis to its mouth, a distance of 185 miles. In 1917 the tonnage thereon was 445,458 tons. From Demopolis, Ala., to Columbus, 149 miles, which is 230 miles from its mouth, the Tombigbee is to have a channel six feet deep by dredging and by the construction of dams and locks. From Columbus to Walkers Bridge, 169 miles, it is to have a high-water channel, which is more or less hazardous.

Mississippi and Louisiana.— Pascagoula Harbor and Gulfport Harbor have both been improved, the former having a channel 300 decreasing to 153 feet in width and a depth of 25, decreasing to 22 feet in depth four miles up Dog River. It had a tonnage in 1917 of 199,817 tons and the latter (Gulfport Harbor) has a channel 26 feet deep and 300 feet wide made through Slip Island Pass and one 19 feet deep and 1,320 feet wide for an anchorage basin one-half mile long. It had a tonnage in 1917 of 345,688 tons. Both ports have limited terminal facilities. Leaf and Chickasahay rivers have been cleared of obstructions and are navigable, the former for low water navigation 78 miles above its mouth and the latter for rafts 75 miles above the outlet. Those two rivers unite to form the Pascagoula River flowing into Mississippi Sound. That river has a channel of seven feet depth from the mouth of Dog River to Dead Lake, 32 miles, and of three feet depth above that point for 50 miles. Biloxi Harbor, Saint Louis Bay, Wolf, Jordan, East Pearl, including Lake Borgne, and Pearl rivers near the Gulf of Mexico have been dredged and are navigable for vessels of small, but different draft for limited distances. Pearl River is to have a navigable depth of two feet from its mouth to Rockport, a distance of 246 miles.

The New Orleans district includes 25 rivers, harbors and lakes. These include the South and Southwest Passes up into the Mississippi River. The latter is 1,000 feet wide between bulkheads and in the ideal area 2,400 feet wide and 35 feet deep, completed for seven miles with protecting jetties, the east one four and one-half miles and the west three and one-half miles long. Through the South Pass the channel is at least 39 feet deep between parallel dikes 700 feet apart. It is 14 miles via the South Pass from the gulf to the head of passes, 91 miles below New Orleans. The improvement of the several mouths of the Mississippi is the work of years and has involved all the skill of the Engineers of the United States army. Dikes, submerged sills with mattresses placed on the sills at the head of Pass à Loutre, through which 45.7 per cent of the waters of the river flow, and levees have been constructed at various places below New Orleans. The harbor at that city, which is about 104 miles from the Gulf, possesses the advantages of a seaport. It is from 1,500 to 3,000 feet wide and 40 feet deep and has extensive wharves and other modern terminal facilities. It accommodates ocean-going vessels. Its domestic and foreign commerce in 1917 totaled 8,026,283 tons. Its river commerce is increasing.

Lake Pontchartrain, 40 miles long and 24 miles wide, has a central depth of 16 feet. The principal channel is seven feet deep except through the dredged channel of eight feet in depth to Lake Borgne, which is in navigable communication with Mississippi Sound. The new Basin Canal, seven miles long, brings it into communication with New Orleans. The channels of Chefuncte, which flows into the lake, and Bogue Falia, its tributary, 10½ miles above Lake Pontchartrain, are improved to Covington, a distance of 14½ miles. The tonnage of those waterways in 1917 was 288,630 tons. Pass Manchac, rising in Lake Maurepas and flowing into Lake Pontchartrain, seven miles long, is to have a channel seven feet deep and 100 feet wide and will pass vessels plying the Amite River, Bayou Manchac and Tickfaw River to and from New Orleans.

Tickfaw River flows into Lake Maurepas. It receives the Natalbany River two miles above its mouth and the Blood River seven miles above its mouth. Its channel is dredged to seven feet for 10 miles and to six feet from the 10th to the 26th mile above its mouth. Blood River is to be similarly dredged for four miles and Natalbany River and its tributary Ponchatoula, together, are improved for 15½ miles. The Amite River is to be cleared of obstructions for 110 miles above its mouth and its channel deepened and widened for 44 miles. Bayou Manchac is to be improved for 11¼ miles above its mouth. Other bayous in Louisiana are being improved. An intercoastal waterway of five feet depth and of 40 feet wide on the bottom is being constructed from Bayou Teche near Franklin to the Mermenteau River, a distance of 45 miles. It extends through several lakes and through the Hanson Canal, purchased by the United States, for a distance of 4.2 miles. A dam across Schooner Bayou and a lock are to be constructed. It also includes Schooner Bayou Canal 12 miles long, crosses White Lake 13½ miles and includes the canals, connecting Turtle, Alligator and Collicon lakes and extends to Grand Lake 12 miles wide. That waterway is navigable throughout the year. Another connecting intercoastal waterway extends from Mermenteau River, Louisiana, to Sabine River, a distance of 62 miles. It includes the Lake Misere Canal and passes south of Sweet Lake and then to Calcasieu River. It has a prism five feet deep and 40 feet wide and is to be seven feet deep and 75 feet wide from Mermenteau to Calcasieu River. It is open throughout the year. Bayou Lafourche, once one of the outlets of the Mississippi, has a lock at its head and a channel five feet deep and a bottom width of 75 feet through its entire length of 107 miles. Its tonnage in 1917 was 766,203 tons. Bayou Terrebonne is 53 miles long and empties into a bay of the same name. It has a channel six feet deep from its mouth to Houma, a distance of 24.11 miles. In 1917 its tonnage was 188,411 tons. Bayou Plaquemine is 112 miles from New Orleans via Mississippi, with which river it is connected by Plaquemine lock. Vessels passing through that lock in 1917 varied in draft from three and one-half to seven feet and the tonnage was 205,741 tons. It forms 10.6 miles of the waterway to Morgan City, La. That waterway also includes 19.4 miles of the Grand River, Bayou Natchez for six miles, Little and Big Goddel for six miles, Belle River for nine miles, Bayou Long for seven and three-tenths miles, Flat Lake and Drews Pass to Berwick Bay three and two-tenths miles and thence by Atchafalaya River three and two-tenths miles to Morgan City. Pigeon bayou connects Grand River with Grand Lake. The entire waterway is 64 miles long. The lock is 298 feet 7 inches long and 55 feet wide with 10 feet of water over the mitre sills. The tonnage over that waterway in 1917 was 776,781 tons. The boats were of four to seven feet draft. Bayou Grossetete, a tributary of the Bayou Plaquemine, is being improved from its mouth eight miles below Plauqemine lock to above Maringouin, La., a distance of 29 miles. It will have a channel five feet deep and 60 feet wide. Its tonnage in 1917 was 237,947 tons. Bayou Teche is 125 miles long and joins the Atchafalaya River 10½ miles above Morgan City. It is to have a channel six feet deep and 50 feet wide from its mouth to Arnaudville, La., a distance of 106½ miles. It is to have a dam and lock at Keystone Plantation 72½ miles above its mouth and other regulating works. In 1917 its tonnage was 693,622 tons, but that passing Keystone lock was only 10,172 tons. The Atchafalaya River, an outlet of both the Mississippi and the Red River, was provided with a channel from a point 17½ miles below Morgan City to its mouth in Atchafalaya Bay, from 1,500 to 3,000 feet in width and from 20 to 140 feet in depth. The last improvement was from the 20-foot contour four miles below its mouth to the 20-foot contour in the Gulf of Mexico, a distance of 15¾ miles to give it a ship channel 20 feet deep and 200 feet wide The channel from Morgan City down will have a minimum depth of 14 feet and a width of 200 feet. The tonnage at Morgan City in 1917 was 814,713 tons and was carried in vessels of not exceeding 11 feet draft. Vermillion River is to have a channel five feet in depth and 40 feet on the bottom from Vermillion Bay to Lafayette, La., a distance of 51 miles. Its tonnage in 1917 was 32,810 tons. Mermenteau River is 71½ miles long and is being improved its entire length and through Lake Arthur six miles, as also are 25 miles of Bayou Nezpique, its tributary, and Mud Lake, all in Louisiana, which has a score of navigable waterways. The lower reaches of the Bayou Queue de Tortue, also a tributary of the Mermenteau, is being improved for a distance of 14 miles above its mouth. The lower section of the Bayou Plauqemine Brule, another tributary of the Mermenteau, is being improved for a distance of 19 miles so as to have a channel six feet deep and 60 feet wide. Calcasieu River widens out and forms a lake of the same name 25 miles north of the Gulf of Mexico. The lake is 18 miles long and shallow. The river, including the lake, is provided with a channel for 72 miles, which is the head of boat navigation of not less than six feet in depth. This improvement is carried through Lake Charles and West Lake, where there are several wharves and boathouses. The mouth of the bayou is also protected by two converging jetties one and one-half miles long projecting out into the Gulf and there is a channel between them 200 feet wide and 12 feet deep up to the entrance into the river. The channel from that point to a point above Calcasieu Lake is 80 feet wide and eight feet deep. The tonnage over that waterway in 1917 was 763,619 tons.

Texas.— The Galveston, Tex., district includes 25 rivers and harbors. The entrance to Galveston Harbor is protected by two rubblestone jetties extending from Galveston Island, which is 28 miles long, and Bolivar Peninsula out into the Gulf. The former is six and three-fourths miles and the latter is four and three-fourths miles long, their outer ends being 1,000 feet apart. The channel is 30 feet deep and 800 feet wide. Galveston channel is 30 feet deep and 1,200 feet wide from the outer end more than four miles westward to 51st street in Galveston, which is to be extended, but at the reduced width of 1,000 feet to 57th street. The seawall five miles long protecting the entrance to the harbor is to be extended. The terminal facilities include a wharf system adequate to accommodate 63 or more ocean vessels, several miles of piers, grain elevators, transfer carriers and warehouses. The tonnage of the port of Galveston in 1917 was 2,965,937 tons and the number of vessels entering and departing from the port during the year was 1,539. A channel 200 feet wide and 30 feet deep and four miles long connects Galveston Harbor with Port Bolivar at the end of the Bolivar Peninsula, where there is a turning basin 1,000 feet square. The port is equipped with slips, piers, wharves and warehouses. Its tonnage in 1917 was 109,227 tons. The Houston Ship Canal, 25 feet deep and 150 feet wide on the bottom, extends from Galveston Harbor across Galveston Bay, with a bottom width, up the Jacinto River and Buffalo Bayou to a turning basin 600 feet in diameter at Long Beach and thence by a channel eight feet deep and 40 feet wide through Buffalo Bayou to Houston, Tex. The entire length of the improved waterway is 50 miles. It is protected through upper Galveston Bay by a dike nearly five miles long. There are docks, warehouses, terminals, railway tracks and other terminal facilities at Houston and a regular line of steamships between Houston and New York City. The tonnage of Houston in 1917 was 1,161,424 tons. Some other bayous and streams entering Galveston Bay have been improved for short distances under various river and harbor acts of Congress, authorizing the improvement of West Galveston Bay channel, Double Bayou and the mouths of adjacent streams. In 1851–53 the West Galveston Bay and Brazos River Canal was constructed paralleling the coast but from one to four miles therefrom. It was 10 miles long and had a depth of six feet and a width of 100 feet. It was purchased by the United States government in 1892 at a cost of $30,000. A new waterway with a channel five feet deep and 40 feet wide on the bottom is being constructed from West Galveston Bay, through Oyster Bay and along the route of the Galveston and Brazos River Canal to Brazos River. Chocolate and Bastrop bayous and Oyster Creek are commercially tributary to that waterway. The channel between Brazos River and Matagorda Bay, a distance of 32 miles, is to be five feet deep and 40 feet wide on the bottom. At the mouth of Brazos River and at Matagorda are wharves, docks and fish and oyster houses. That forms a part of the 202 miles of inland waterway extending from Galveston to Corpus Christi. The Guadalupe River is to have a channel five feet deep and 40 feet wide on the bottom for 52 miles to Victoria from San Antonio Bay, which is 16 miles across, also to be dredged to similar dimensions to the main line of the inland waterway.

The channel from Pass Cavallo to Port Lavaca, Tex., a distance of eight miles, is to have a depth of seven feet and a width of 80 feet. The channel from Pass Cavallo, the west end of Matagorda Bay, to Aransas Pass, extends through Espiritu Santo, San Antonio Mesquite and Aransas bays and is 63 miles long. It is also to have a depth of five feet and a width of 40 feet. It is equipped with wharves on Aransas Bay and at some other places. From Aransas Pass it follows Turtle Cove and passes through Corpus Christi Bay. That section of the inland waterway is 21½ miles long. Freeport Harbor is at the mouth of Brazos River and is protected by parallel north and south jetties a mile more or less in length, and is being improved for six and one-half miles to Velasco, the channel being 18 feet deep and 150 feet wide. There are some wharves there open to the public and regular sailings of vessels therefrom to New York. The tonnage of the port in 1917 was 334,693 tons.

The Brazos River is 950 miles long and is navigable to Bolivar Landing. It had a depth of four to 20 feet above that point to Old Washington, 254 miles from its mouth, and that section is to be cleared. There is but little traffic on that river. It has been proposed to improve its channel to a depth of four feet as far as Waco by the construction of locks and dams and by dredging the open channel for 103 miles. Aransas is to be protected by two rubblestone jetties, the north two and three-fourths and the south one and three-fourths miles long, and by a dike on Saint Joseph Island, three and three-fourths miles long, connecting with the north jetty.

The channel up to the town of Port Aransas is 100 feet wide and 17 feet deep, but down toward the Gulf it is 400 feet wide and 25 feet deep and still farther out it is 1,200 feet wide and 25 feet deep out between the jetties, where the dredged channel is to be 600 feet wide. The Harbor Island Basin will be thus extended. Other channels have been dredged leading from Harbor Island Basin.

The Dallas district includes 11 rivers and harbors. Port Arthur Canal, seven miles long, extends from Sabine Pass to Port Arthur docks near Taylors Bayou. Sabine Pass, seven miles in length with a width varying from 1,700 to 5,000 feet, connects Sabine Lake with the Gulf of Mexico. Its entrance is protected by jetties extending out four miles, between which is a channel 26 feet deep and 200 feet wide. The channel through Port Arthur Canal is to be 26 feet deep and 150 feet wide to Fort Arthur, where there are two turning basins 25 feet deep, one 600 feet by 1,700 feet and the other 420 feet by 1,800 feet. At Sabine are wharves and other facilities. In 1917 the tonnage on the Port Arthur Canal was 6,984,286 tons.

That canal cost $1,029,982 and was transferred to the United States government without charge. The Sabine River, 550 miles long and 700 feet wide, enters Sabine Lake through three passes. Neches River, 300 miles long and 650 feet wide, flows into the same lake. A new waterway starting from Port Arthur Canal has a channel 25 feet deep and 90 feet wide through the land and 115 feet wide in the open lake and 150 feet wide in the open rivers and extends through the Sabine-Neches Canal and Neches River to Orange on the Sabine River and from the mouth of Neches River to Beaumont on that river, terminating in a turning basin 500 feet by 1,500 feet on each stream. There are some terminal facilities at Beaumont in touch with ocean-going vessels. The tonnage over the Sabine-Neches Canal in 1917 was 1,437,489 tons and on the Sabine River 215,605 tons and on the Neches River was 1,066,310 tons. Trinity River, Texas, 760 miles long and discharging into Galveston Bay, is being improved by the construction of dams and locks and by dredging. Thirty-seven locks and dams were recommended by the Engineers of the United States army. Those locks have chambers 140 feet long, 50 feet wide and a navigable depth of six feet over the mitre sills. In 1917 only nine locks were completed and navigation was practicable as far as Liberty, 41½ miles above the mouth of Trinity River. To completely canalize the river to Dallas Tex., 512 miles above its mouth and 370 feet above the tide water, is the present project partially completed. The city of Dallas is bearing part of the expense.

Other Gulf-State Waterways Development.—Red River is 1,275 miles long and from its mouth in Louisiana to Fulton, Ark., the distance is 482 miles. It is under improvement. From Fulton to Shreveport, La., there is a minimum depth of five feet and from Shreveport to its mouth there is a minimum depth of seven feet from December to June when the water is high and the river within its improved sections may be navigated, but not at other times. At high stages of water light draft vessels have and may still ascend as far as Denison, 763 miles above its mouth and 11 miles below the outlet of the Washita. At Denison there is in some months a depth of five feet in the channel. Lanesport, 75 miles above Fulton, formerly was at the head of navigation, though boats occasionally ascended to the mouth of the Kiamichi, 158 miles above Fulton, Ark. Some clearings of the channel and dredging has been done in the lower 51 miles of the Sulphur River, and during high water in the Red River there is a backwater flow into Sulphur River for 50 miles which render the lower reaches of the latter navigable for light draft steamboats for a distance of 17 miles for rather irregular and short periods of time. The channel of the lower part of Cypress Bayou for 66 miles is being dredged and straightened from Red River at Shreveport, La., to Jefferson, Tex. A dam has been constructed without a lock at the foot of Caddo Lake, which is 17 miles across. That dam creates a pool extending 43 miles to Jefferson City, Tex., which insures a navigable waterway four feet deep.

The Vicksburg, Miss., district comprises 16 rivers and harbors, some of which have already been described. The Ouachita River, Arkansas, is being improved by the construction of eight locks and dams and by clearing the channel so as to afford a navigable depth of six and one-half feet of water from the mouth of Black River, Louisiana, to a point 10 miles above Camden, Ark., a distance of 360 miles. The lock chambers are 55 feet wide and 268 feet long and have lifts of five and one-half to 14¾ feet. In 1917 the tonnage over that waterway was 178,136 tons. The Tensas, which has its source in Lake Providence and is 235 miles long, joins the Ouachita and Little rivers to form the Black River, Louisiana. The Tensas receives, as a tributary, Bayou Mason, which is 270 miles long. The channels of both of those streams are being cleared and improved to make the Tensas navigable from Westwood Place, 81 miles above its mouth, and Bayou Macon from Floyd, 112 miles above its mouth, so as to afford a navigable depth of six feet from January until June. At high stages those channels are 150 feet wide and eight feet deep. The traffic on the two streams in 1917 was 8,344 tons on the sections improved. Boeuf River, Bayou Bartholomew, Saline River, Bayous D'Arbonne and Coney are navigable for light draft vessels in their lower reaches during the months of high water. The Yazoo River, a tributary of the Mississippi, has a channel four feet deep and 500 feet wide its entire length of 178 miles. Loaded boats thereon draw four feet of water. The tonnage of that river in 1917 was 102,418 tons. The lower 115 miles of the Tallahatchie and the lower 40 miles of the Coldwater rivers have been made navigable for vessels of three feet draft. Big Sunflower River, a tributary of the Yazoo River, is 216 miles long and is to have a navigable depth of four and one-half feet and a navigable width of 100 feet for 171 miles above its mouth. In 1917 its tonnage was 61,017 tons. Several other smaller streams in that district have been improved.

The mouth of the Yazoo River is opened up through Lake Centennial to the Mississippi for a distance of nine and three-tenths miles with a bottom width of 98½ feet and a depth of six and one-half feet. The canal is navigable all the year. In 1917 its traffic was 61,657 tons.

The lock and dam in the Big Sunflower River at Little Callao Landing, Miss., create a pool of varying depth of one to 22 feet for 61.8 miles up stream and render the river navigable to Pentecost, Miss., 124½ miles above its mouth. The Little Rock, Ark., district comprises five rivers and the locks and dams on the upper White River. The Arkansas River, 1,460 miles long, a tributary of the Mississippi, is to be improved from its mouth to Neosho (Grand) River, 461 miles. The Grand is navigable to Fort Gibson two miles from its mouth. Under ordinary conditions from February to July the Arkansas has a navigable depth of four feet from its mouth to Little Rock, 174 miles, and some years it has a navigable depth of three feet as far as Fort Smith, 369 miles above the mouth. In 1917 steamboats ascended the river to Littles, 202 miles above its mouth, and gasolene boats ascended to Dardanelle, 261 miles above its mouth. Steamboats with barges of three to four feet draft operated as far as Little Rock for four and one-half months in 1917. The tonnage on that river in 1917 was 38,659 tons. The White River, 690 miles long, a tributary of the Mississippi, is being improved from its mouth to Batesville, a distance of 301 miles, by the construction of works, dredging, etc. A lock and dam has been constructed one mile below Batesville, a second lock and dam seven and eight-tenths miles above Batesville and a third lock and dam nine and seven-tenths miles above Batesville, thereby affording all-year slack-water navigation for vessels of three feet draft from the first dam to Guion, a distance of 33 miles farther up stream. The locks are 147 feet long, 35 feet wide, and have six feet of water over the mitre sills. At low water in 1917, its controlling channel depth was three and one-half feet from its mouth to Grand Glaize, a distance of 241 miles, and three feet from Grand Glaize to Jacksonport, a distance of 123 miles, and 14 to 16 inches from the latter port to Batesville. Forsyth, Mo., 505 miles above the mouth of the White River, was at the head of steamboat navigation. For seven and one-half months in 1917 a channel depth of six feet obtained from the mouth to Devall Bluff, a distance of 124 miles. In 1917 the tonnage on the White River was 205,198 tons and that through the three locks was 16,014 tons.

The Arkansas and White rivers enter the Mississippi River through a common inlet. The Black River in Kansas and Missouri is 300 miles long and flows into the White River at Jacksonport. It is being dredged and being made navigable from its mouth to Poplar Bluff, Mo., a distance of 239 miles, by boats of 18 inches draft and by boats of two and one-half feet to the mouth of Current River, a distance of 116 miles. In 1917 boats of three and one-half to five feet draft operated below Current River and boats of two feet draft above Current River two months. The Black River tonnage in 1917 was 154,281 tons. The Current River is 200 miles long and is being cleared of snags from its mouth to Van Buren, Mo., a distance of 94 miles, so that flatboats may ascend that far and have ascended 33 miles farther up the river to Jack's Fork. In high water steamboats ascend from the Black River as far as Pitman's Landing, 41 miles above the mouth of Current River. In 1917 the controlling channel depths were to Duff's Ferry, 32 miles above the mouth, three and one-half feet; to Doniphan, 53 miles up stream, 14 inches, and to Van Buren, from 10 to 12 inches. The tonnage in 1917 was 16,762 tons.

Some work has been done toward clearing the lower reaches of the Saint Francis River, 460 miles long, the L'Anguille River and the Blackfish Bayou to render the same navigable for boats of four-foot draft at medium and high stages of water from January until August, but the controlling depths in L'Anguille River and in Blackfish Bayou are due to the backwater stages of the Mississippi River. In 1917 a steamboat of three-foot draft operated as a weekly packet in the Helena- (on the Mississippi) Marianna- (on the Saint Francis) Blackfish commerce. The Saint Francis River to Marked Tree, the Blackfish Bayou to Fifteen Mile Bayou and the L'Anguille to Marianna are navigable by boats of four-foot draft at medium or high water. The aggregate tonnage on the three streams in 1917 was 344,278 tons.

The Mississippi System.— The Mississippi River has a total length of 2,471 miles. Its channel has a depth of 35 feet from the Head of Passes to New Orleans about 104 miles from the Gulf of Mexico and a depth of 30 feet up to a point 227 miles above the Head of Passes, which is 13 miles from the mouth of the South Pass. It has a width of 250 feet. Thence for 833 miles to the mouth of the Ohio River its channel has a depth of nine feet and a width of 250 feet and thence to Saint Louis, a distance of 188 miles, its channel has a minimum depth of eight feet and a width of 250 feet, and thence to the mouth of the Missouri, a distance of 17 miles, its channel has a depth of six feet at low water and a width of 250 feet. From the mouth of the Missouri River to the Twin City Lock and Dam, it is 664 miles and to Washington Avenue Bridge at Minneapolis, the head of navigation, it is 669 miles, that being 1,955 miles from the mouth of the Mississippi. In that section of the Mississippi River the channel is to have a depth of six feet and a width of 300 to 1,400 feet, to be obtained by means of contracting works consisting of wing and spur dams for narrowing the main channel of the river. In 1918 the depth of water at Rock Island Rapids at the lowest stages was only four feet. From Cape Girardeau, Mo., to Rock Island, Ill., a distance of 452 miles, the Mississippi for most of the way is protected by levees as it is for 1,503 miles below Cape Girardeau. The channel has been improved at various places below Cairo. At Keokuk, Iowa, 496 miles below the head of navigation and 173 miles above the outlet of the Missouri River, is a power dam of 41 feet crest with a lock 400 feet long, 110 feet wide with six feet of water over mitre sills. There is also a dry dock there 380 feet long, 140 feet wide with entrance gates 110 feet wide. During the 252 days of navigation in 1917, steamboats to the number of 489 and launches to the number of 233 passed through that lock. That replaces the old Des Moines Rapids Canal.

The Moline Lock and Dam at the foot of Rock Island Rapids, 366 miles below the head of navigation, has a length of 350 feet, a width of 80 feet and a depth of six feet of water over the mitre sills. One hundred and fifty-four steamboats, 74 barges and 270 launches passed through it during the 265 days of navigation in 1918. That lock overcomes the swiftest part of the Rock Island Rapids. Le Claire Canal has been proposed 360 miles below the head of navigation of the same dimensions as those of the Moline Canal.

Provision has been made for the construction of a power dam with a lock 350 feet long, 298 feet wide and having a lift at low water of 33½ feet between Minneapolis and Saint Paul. That will make it possible for vessels to transport grain from the elevators and flour from the mills at Minneapolis to the Gulf of Mexico or to ocean carriers without transshipment. The depth of water over the mitre sills varies from seven to 10½ feet. The upper Mississippi, from Saint Paul to Brainard, a distance of 170 miles, is navigable for light draft vessels, and from Brainard to Grand Rapids, a distance of 180 miles, it is to have a channel 60 feet wide and three and one-half feet deep at mean low water. A similar improvement has been made in the river between Aitkin and Grand Rapids, a distance of 125 miles and three and one-half feet depth has been secured. The large natural reservoirs at the head-waters of the Mississippi River, in addition to Itasca Lake, its source, and Cass Lake, 283 miles above Brainard, the head of navigation, include Winnibigoshish Lake, Leech Lake, Pokegama Lake, Sandy Lake, Pine River and Gull Lake, having an aggregate capacity of 97¼ billions cubic feet. Their discharge is regulated by dams and controlling works at their several outlets and their waters keep up a uniform flow in the Mississippi as far down as Lake Pepin, 52 miles below Saint Paul. The waters of Winnibigoshish and Leech Lakes reservoirs flow into Pokegama reservoir and thence into the Mississippi. The Leech River has been dredged and improved for 27 miles and has a channel 100 feet wide and eight feet deep and the channel of the Mississippi was made eight feet deep and 100 feet wide above the Leech River and 125 feet wide below that river, that entire section of the Mississippi improved being 65 miles in length. New Orleans has five miles of wharves, of which three and one-half miles are covered with steel sheds. Natchez has some wharves and old landings. The harbor at Memphis is subject to thick deposits and requires much dredging as do many other harbors along the Mississippi.

The Saint Croix River flowing through Lake Saint Croix, which is 25⅓ miles long, and into the Mississippi, 26.9 miles below Saint Paul, is being improved to obtain a channel three feet in depth from its mouth to Taylor's Falls, a distance of 52.3 miles.

The Minnesota River, 450 miles long, is to have an open channel to accommodate vessels of four-foot draft from its mouth at Saint Paul to Shakopee, a distance of 25.6 miles.

Lake Traverse, one of the sources of the Red River of the North, is 25 miles long and through its narrows is to have a channel 50 feet wide and four feet deep.

The Red River of the North flows northerly between Minnesota and North Dakota about 350 miles and thence along the International boundary and thence into Lake Winnipeg. From Breckenridge to Moorhead, a distance of 97 miles, it is to have a navigable channel during high and medium stages of water; from Moorhead to Grand Forks, a distance of 155 miles, it is to have a channel 50 feet wide and three feet deep, and from Grand Forks to the International Boundary, a distance of 143½ miles, it is to have a channel 60 feet wide and four feet deep at low water. Red Lake River between Thief River Falls and Red Lake, a distance of 71 miles, is to have a channel of three feet depth. Regulating works are being constructed at the outlet of that lake to control its discharge and the flow of the river in the interest of navigation. Warroad Harbor and Warroad River are southwest of the Lake of the Woods. The harbor has a wharf open to the public and the river, 26 miles long, connecting the harbor with the lake, has a depth of eight feet. In 1917 the tonnage of the harbor was 8,500 tons. A harbor of refuge has been constructed in Zippel Bay on the south shore of the Lake of the Woods.

The Missouri River from its mouth to Kansas City, a distance of 398 miles, is to have a permanent channel six feet deep and 1,200 feet wide, though in 1917 the draft of steamers was three and one-half feet and that of barges from four to four and one-half feet, but in low water it was from three to three and one-half feet. From Kansas City to Sioux City, Iowa, a distance of 409 miles, in 1917, it had a channel four feet deep, though the loaded draft of boats did not exceed two and one-half feet. From Sioux City to Fort Benton, Mont., the head of navigation, a distance of 671 miles, loaded vessels had an average draft of two feet in the upper reaches of that section of the river. The lower reaches of the Osage River from its outlet into the Missouri up to Linn Creek, a distance of 109 miles, are to have an open channel 80 feet wide and three feet deep. A lock 220 feet long and 42 feet wide with an available depth of nine feet of water over the mitre sills and with a lift of 16 feet has been constructed seven miles above its mouth. That has made the lower 109-mile section navigable for light draft vessels. In 1917 its commerce was 28,171 tons. The Gasconade River is being cleared of obstructions from its mouth to Gascondy, a distance of 61.4 miles. It had in 1917 a channel of only nine inches navigable depth in some sections and two feet in others. It had a score of small warehouses in the lower 39½ miles of its course and a tonnage in 1917 of 24,523 tons.

The Cumberland River in Tennessee and Kentucky has been improved from Burnside, the head of navigation, to its mouth, a distance of 418.7 miles. That has been done by dredging and by the construction of locks and dams in its several sections. The average width between Burnside and Nashville, 326.1 miles below, is 300 feet and from Nashville to its outlet into the Ohio River, a distance of 192.6 miles, it has a width of 400 to 500 feet. The channel between Burnside and Nashville is 150 feet wide and six feet deep at low water. There are six locks and dams in that section of the river below Nashville. Locks A, B and C are 280 feet long by 52 feet wide, with six feet of water over the mitre sills, and have lifts of 12 feet. Locks D, E and F are 310 feet long and 52 feet wide with six and one-half feet of water over the mitre sills and have lifts of 10 to 13.3 feet. These have made the lower Cumberland navigable to Nashville and its tonnage in 1917 was 131,325 tons. In the section above Nashville, the river is navigable for light draft vessels for four or five months in the year during high water. Above Nashville are locks 1, 2, 3, 4, 5, 6, 7 and 21 (locks 8 to 20 and 22 proposed in the original plans having been eliminated), each 280 feet long and 52 feet wide with six and one-half feet of water over the mitre sills and with lifts of six to 14 feet. These structures set the water back so that a navigable depth of six feet will be provided within four miles of Burnside and over that distance a navigable channel of four feet depth will be obtained. The total water-borne commerce at Nashville in 1917 was 267,091 tons. That will undoubtedly materially increase after the improvement has been completed and boat lines are established. The Board of Engineers of the United States army have recommended the construction of 10 additional locks, namely eight to 17 as originally planned, provided that the

States, counties and local agencies will save the United States harmless from claims for damages due to overflowing lands along that section of the river. The total commerce passing through all the locks in 1917 was 683,529 tons.

Tennessee.— The Tennessee, 652 miles long and formed by the junction of the French Broad and Holston rivers, four and one-half miles above Knoxville, Tenn., flows southwesterly into Alabama and westerly across the northern part of that State and thence northerly into and across Tennessee and northwesterly into and across Kentucky into the Ohio River about 36 miles above the outlet of the latter into the Mississippi. Above Chattanooga it is 700 feet wide, but below it is 1,000 feet wide and at Muscle and Colbert Shoals it is more than 1,000 feet wide. From its head to Chattanooga, a distance of 188 miles, it is to have a channel 150 feet wide and three feet deep. A concrete dam and lock 265 feet long and 60 feet wide with six and one-half feet of water over mitre sills and with a lift of 25.7 feet is at the foot of Caney Creek Shoals, which sets the water back for 24.6 miles, making a navigable depth of six feet. That 188-mile section is navigable for boats of three-feet draft, however, only when the water is at high stages from January to June. For short periods boats of four-feet draft may navigate parts of that section, but boats of only one foot draft can navigate that section all the year. Both Knoxville and Chattanooga have a wharf with a warehouse equipment with conveyors. The shoals in the upper reaches of the Tennessee are being dredged. The total river tonnage above Chattanooga for the year 1917 was 613,243 tons. Chattanooga is 464 miles above the mouth of the Tennessee. At Hale's Bar, 33 miles below Chattanooga and 431 miles above the mouth of the Tennessee, is another concrete dam and lock, 267 feet long and 60 feet wide, with six and one-half feet of water over the mitre sills and with a lift of 37½ feet. That sets the water in the river back and affords a navigable depth of six feet as far as Chattanooga. The tonnage through that lock in 1917 was 15,681 tons. Concrete dams and locks are to be constructed at Widow's Bar, 56.1 miles below Chattanooga and Bellefonte Island, 72.1 miles below Chattanooga, or one concrete dam 17.9 feet high and a lock at the latter place to provide a navigable channel of six feet depth. The locks are to be 265 feet long and 60 feet wide with six feet of water over the mitre sills. The project announced by the War Department in 1917 provides for an open channel, 150 feet wide and five feet deep at extreme low water between Hale's Bar and Brown's Island, that section being 138 miles long, except in those parts of that section that may be canalized. The Muscle Shoals Canal opened in 1890 and comprises two sections, aggregating about 18 miles in length. It had 11 locks from 275 to 283 feet in length and all 57 feet in width with different lifts, ranging from three and nine-tenths to 13.1 feet and having from two and two-tenths to seven and five-tenths feet of water over the mitre sills. The locks in the 36.6 miles of rapids above Florence overcome 134 feet of fall in the river. The existing project provides for the construction by the United States government of new locks, dams and a power-house, securing nine and one-half feet of water for 14.7 miles and a depth of five feet of water in the canals at extreme low water. The construction of dam No. 2 was approved in 1918. It is two and seven-tenths miles above Florence with locks 300 feet long, 60 feet wide and total lift of 90 feet. When the new project is completed, old locks Nos. 3 to 9, inclusive, will be submerged, but old locks Nos. 1 and 2 and locks A and B on the Elk River Shoals section will remain in service. This improvement not only provided for the navigation of the Muscle Shoals section of the Tennessee, but also for the generation of electric power for the production of some of the nitrates used during the World War. A bill is now pending in Congress for the nationalization of that nitrate plant.

From Florence, 208 miles below Chattanooga and 256.5 above the mouth of the river to Colbert Shoals, the available depth of channel at extreme low water is five feet throughout the year. In that section is the Colbert Shoals Canal on the left bank of the river and nearly eight miles long with a depth of six feet over mitre sills. Its width is 140 feet. Its single lock is 350 feet long and 80 feet wide with a lift of 26 feet. The river tonnage between Chattanooga and Florence in 1917, was 170,968 tons and through that canal was 38,286 tons.

The Tennessee from Riverton to its mouth, a distance of 226.5 miles, is to have a channel 150 feet wide and six feet deep at ordinary stages of water and at five feet deep at extreme low stages. The draft of boats in that section of the river varies from two to six feet. The tonnage below Florence in 1917 was 416,304 tons. The French Broad River has been made navigable for steamboats of two-feet draft up to Dandridge, 46½ miles above its mouth, and at stages of high water as far as Leadvale, 69½ miles above its mouth. The tonnage thereon in 1917 was 129,201 tons.

Clinch River, a tributary of the Tennessee 103½ miles above Chattanooga, is being provided with a navigable channel two feet deep from its mouth to Clinton, Tenn., a distance of 60 miles, and a channel one and one-half feet deep from Clinton to Walker's Ferry, a distance of 66 miles. The usual draft of boats varies from 15 inches to three feet, but during periods of low water there is little or no navigation of parts of the river. Its tonnage in 1917 was 8,983 tons. The United States Engineers have recommended that no further moneys be expended in its improvement. The Hiawassee River rises in northern Georgia and empties into the Tennessee, 36½ miles above Chattanooga. Its channel is being improved for 35 miles above its mouth and is to have a width of 154 feet and a depth of three feet in the centre and two and one-half feet the entire width of the channel. It has been navigated as far as Savannah Ford, though its present steamboat traffic does not extend above Charleston, Tenn., 19 miles above its mouth. Its tonnage in 1917 was 2,152 tons.

North Middle States.—The next great waterway of the United States is the Ohio River, which is formed by the junction of the Allegheny and Monongahela rivers at Pittsburgh, Pa. Thence it flows southwesterly 968½ miles into the Mississippi River at Cairo. The section between Pittsburgh and Steubenville, Ohio, a distance of 65.7 miles, has dams Nos. 1 to 10, the section from Steubenville to a point two miles below Huntington, W. Va., a distance of 245.2 miles, has dams Nos. 11 to 28 and the section from the last-named place to a point two miles above Madison, Ind., a distance of 242.7 miles, has dams Nos. 29 to 40 and the section extends from the last-named place to Mound City, Ill., a distance of 408 miles, and has dams Nos. 41 to 54, inclusive. The Louisville and Portland Canal was completed in 1830 by a Kentucky corporation to overcome the falls in that part of the river. It had three combined lift locks, each of eight and two-thirds feet lift, a width of 50 feet and a length of 200 feet. That has been enlarged and under the existing project it is to be again enlarged. The improvement of the Ohio involves the construction of locks and movable dams so as to provide a minimum channel of nine feet of water in the pools formed thereby and the widening of the Louisville-Portland Canal from 90 to 200 feet. Shoals form in the river and annual dredging is necessary to keep the channel cleared of obstruction and deposits. There are to be 53 locks which are to have usable dimensions of 600 feet in length and 110 feet in width, and having varying lifts from three and one-tenth to 29 feet, most of them having seven and three-tenths to nine feet lifts. Down to 30 June 1918 the total expenditures under the existing adopted project aggregated $28,578,032.38 on new work and the amount expended on all projects in the improvement of the Ohio for new work aggregated $46,235,306.16. The tonnage on the Ohio River including that over ferries for 1916 was 7,917,112.61 short tons, and for 1917 was 6,149,213.32 short tons.

Pennsylvania.— The Monongahela River is to be made navigable for 130 miles above its mouth by the construction of 15 locks and dams to afford slack-water navigation from Pittsburgh, Pa., to a point four miles above Fairmont, W. Va. The locks have a width of 50 to 56 feet and lengths of 159 to 360 feet, and lifts of four and four-tenths to 12.8 feet and with five to nine and four-tenths feet of water over the mitre sills. The tonnage on the Monongahela in 1917, was 16,000,153 tons.

The Allegheny River is 325 miles long and joins the Monongahela to form the Ohio at Pittsburgh, Pa. It is designed that it have an open channel from its mouth to the New York State line, a distance of 214 miles. Formerly it was the route for the pioneer and traders passing between New York and southern Ohio. Locks 286 to 360 feet long and 55 to 56 feet wide with seven to 11 feet of water over their mitre sills and having lifts of seven to 12 feet are being constructed above Pittsburgh and three have been completed affording slack-water navigation up to Natrona, Pa., a distance of 24 miles with a controlling depth of six and one-half feet. Slack-water navigation is to be extended to Riverton, Pa., a distance of 37 miles. Its tonnage in 1917 was 2,300,143 tons. The harbor at Pittsburgh comprises sections of the Ohio, Monongahela and Allegheny rivers and these are 27.2 miles in length. The channels are from 300 to 800 feet wide and seven to 10 feet deep. Terminal facilities include wharves, docks, hoists of various types and other equipment. The commerce of Pittsburgh for the year 1917 was 14,639,496 tons.

The Youghiogheny River, Pennsylvania, a tributary of the Monongahela, is being improved by dredging and the construction of three locks, 360 feet long and 56 feet wide, with eight feet of water over the mitre sills and dams between its mouth and West Newton, 19½ miles up-stream, which will afford slack-water navigation to West Newton. The tonnage on that river in 1917 was 85,585 tons.

Virginia, West Virginia, Ohio and Indiana.— The Little Kanawha, a tributary of the Ohio, has been improved for a distance of 48 miles from its mouth to Creston by the construction of locks and dams, thereby affording a navigable depth of four feet to Creston. The locks are 125 feet long, 23 feet wide and have a depth of four to 10.2 feet over the mitre sills and lifts of six and four-tenths to 12.4 feet. The tonnage over that river in 1917 was 40,849 tons. The States of Virginia and West Virginia, improved sections of the Kanawha River, also a tributary of the Ohio, and packets and barges ascended the river for a distance of 90 miles at high-water stages. It is 97 miles long. Ten locks, 271 to 313 feet long, 50 to 55 feet wide, with six and five-tenths to 11.35 feet of water over the mitre sills and having five and sixty-five hundredths to 13.67 feet lifts, are being constructed at various sections of the river. All the dams are of the movable type except two. That will afford a navigable channel of six feet depth for 90 miles above its mouth. The tonnage on that river in 1917 was 1,605,495 tons. Sixteen steamboats and 265 other craft navigated the river in 1917. The Wabash River, 517 miles long, flows northwesterly from Ohio across Indiana and southerly between that State and Illinois into the Ohio, 121 miles above the mouth of the latter river. The Wabash in its original condition was 450 to 1,300 feet wide and was navigable at periods of high water, when boats ascended as far as Peru, Ind., 366 miles above its mouth. It has been made navigable in separate sections and at different periods. A lock, 214 feet long and 52 feet wide, and dam at Grand Rapids, 97.1 miles above the mouth, provide slack-water navigation for 12 miles. Through navigation is impracticable on account of the rapids and shallows in some parts of the river. The New Harmony Cutoff, 41½ miles above the mouth, where there is a fall of six and one-half feet, is to be closed and the river dredged to afford a navigable channel of three and one-half feet at low water from the mouth of the river to Terre Haute, 214 miles from the mouth, but boats drawing three feet can make that distance for less than four months of the year. Boats of 20-inches draft can pass from Mount Carmel, 96 miles above the mouth, to Vincennes, 32 miles farther up-stream, at all stages of water, but cannot pass down-stream to the mouth of the river only at very high water. In 1917 about 800 boats passed through the locks at Grand Rapids. One of the principal tributaries of the Wabash River is the White River, formed by the confluence of the East and West Forks about 50 miles above its entrance into the Wabash. It is navigable in its lower reaches for light-draft boats. The Scioto, Maumee and Miami rivers formerly were navigable and the latter two are in the route of the projected Miami and Erie Canal across Ohio.

Kentucky and Ohio.— The Green and Barren rivers in Kentucky are being improved by the construction of six locks and fixed dams in the former, a tributary of the Ohio, and one lock and dam in the latter, a tributary of the Green River. The locks are 138 to 142 feet long and 35 to 35.6 feet wide, with six to eight feet of water over the mitre sills and having lifts of 11 to 20 feet. That improvement renders the Green River navigable for boats of five-feet draft all the year from lock No. 1 at Spottsville to Mammoth Cave, Kentucky, a distance of 187½ miles, or to Bowling Green, Ky., on Barren River, a distance of 171 miles from lock No. 1 on the Green River. The tonnage in 1917 was 252,841 tons. Rough River, Kentucky, 125 miles long, another tributary of the Green River at Livermore, has been cleared of obstructions and a lock and dam have been built near Livermore, Ky. The lock is 125 feet long and 27 feet wide, with four and nine-tenths feet of water over the lower mitre sills, and having a lift of nine and four-tenths feet. That structure sets the water back and affords slack-water navigation to Hartford, Ky., 29½ miles from the mouth for boats of four-feet draft. Its tonnage in 1917 was 12,701 tons.

The Muskingum River is being improved from its outlet into the Ohio River at Marietta up to Dresden, a distance of 91 miles, by the construction of 11 locks and dams and four short lateral canals, affording a minimum depth of five and one-half feet. All the locks are 35½ feet wide and 160 feet in length with the exception of lock No. 10 which is 159 feet long, and lock No. 1 which is 55½ feet wide and 360 feet long. The depth of water over the mitre sills is six feet or more and the lifts vary from four and eight-tenths feet to 15.1 feet. There are several warehouses along the river and its tonnage in 1917 was 92,426 tons. The improvement may be extended through the valley of the Cuyahoga to form the Ohio and Erie Canal. The Big Sandy River, on the boundary between Kentucky and West Virginia, formed by the junction of the Levisa and Tug Forks, flows north 27 miles and empties into the Ohio 10 miles below Huntington. Its improvement involves the construction of three locks and dams. Two locks and dams are being constructed on each of the Levisa and Tug forks. The locks are about 158 feet long and 54½ feet wide. The improvement has rendered the Big Sandy River navigable by vessels of six-feet draft 27 miles to Levisa and the Levisa Fork navigable for 18 miles, and the Tug Fork navigable for 12 miles by vessels of six-feet draft. The tonnage on those rivers in 1917 was 88,344 tons.

Kentucky.— The Kentucky River, formed by the North, Middle and South forks, is 255 miles long and empties into the Ohio at Carrollton, Ky. It is being improved by the construction of 14 locks and fixed dams.

That affords slack-water navigation for vessels of six-feet draft to points on the three forks above Beattyville, Ky., a distance of 280 miles. The lower five locks are 145 feet long and 37 to 38 feet wide, with six and one-tenth to six and eight-tenths feet of water over the mitre sills and having lifts of 12½ to 17 feet; these afford slack-water navigation for 88 miles. The remaining nine locks are 146 feet long and 52 feet wide, with six to seven feet of water over the mitre sills, and lifts from 14.4 to 18 feet. Slack-water depth of five feet has been obtained for 260 miles up from the mouth of the river and the additional foot will be obtained as soon as the dredging is completed. In 1917 the tonnage was 148,981 tons. Some years ago, the Licking River was improved from its mouth into the Ohio 125 miles up to West Liberty.

Great Lakes System.— The Fox River, 176 miles long, in Wisconsin, is divided into the upper and lower Fox by Winnebago Lake. It has a depth of six feet from Depere to Montello, a distance of 125 miles, and a depth of four feet from Montello to Portage, a distance of 31 miles, and a width from Lake Winnebago to Montello of 100 feet. The lower Fox is from 300 to 3,000 feet wide and 39 miles long. In its course it has 27 locks and 16 dams. The locks are from 136.4 to 148.6 feet long and from 34.3 to 40 feet wide, the water over the mitre sills varies from one and two-tenths to 14 feet. The Wolf River, which flows into it 10 miles above Oshkosh, is being improved from its mouth to New London, a distance of 47 miles, to afford navigation for vessels of four-feet draft.

The head of navigation on the Upper Fox is Portage, except that during high water in the Wisconsin River, boats can proceed from Portage into Wisconsin River and thence down into the Mississippi. The tonnage on the river in 1917 was 161,060 tons. The further improvement of the Wisconsin River has been chiefly that of clearing the channel of obstructions. Formerly the Wisconsin River, a tributary of the Mississippi, 600 miles long, and the Fox River, 200 miles long, with a connecting canal, formed a continuous waterway from the Mississippi to Lake Michigan. It was declared by the courts a public highway. Grand River, Michigan, has also been declared a public highway. It has an improved channel, 100 feet wide and six feet deep, from Grand Haven, Mich., to Grand Rapids, a distance of 38 miles.

A ship canal connects Sturgeon Bay with Lake Michigan. It is 7,200 feet long, varying from 160 to 250 feet wide, and the channel is being continued into Sturgeon Bay, a distance of four miles, having a width of 200 feet and a depth of 19 feet at low water datum. In 1917 the tonnage through that canal was 720,803 tons and the harbor afforded shelter for more than 100 vessels.

The Chicago River, formed by the junction of the North and South branches, discharges into the Sanitary Canal and is only seven-tenths of a mile long. It has a channel 21 feet below low water datum in Lake Michigan. The head of navigation is Belmont avenue, five and five-fourteenths miles on the North Branch, and Ashland, four and eight-hundredths miles on the South Branch. In the Chicago River are numerous slips, docks and other terminal facilities. The Calumet River is seven and eighty-three-hundredths miles long and empties into Lake Michigan 12½ miles south of Chicago. It is formed by Little Calumet River, 60 miles long, and Grand Calumet River, which is a lagoon 18 miles long. The entrance to Calumet River is to be 200 feet wide and 21 feet deep, and the improvement is to be extended upstream five and forty-seven-hundredths miles to "The Forks," with turning basins located at intermediate points.

The river is navigable by vessels of four-feet draft from The Forks to Indiana Harbor

Canal, and by vessels of six-feet draft to Riverdale on the Little Calumet, a distance of 12 miles from the mouth of the river. The entrance to the harbor is protected by parallel breakwaters. The tonnage of the river and harbor in 1917 was 10,269,304 tons. The Illinois River, formed by the junction of the Kankakee and Des Plaines rivers, empties into the Mississippi 36 miles above Saint Louis. It is 273 miles long. Years ago it was navigable by Mississippi boats from its mouth as far as Utica, a distance of 230 miles. It is now being improved to secure a seven-foot depth at low water from La Salle, the head of navigation, to its mouth, a distance of 223 miles, by lock and dam construction and dredging. The locks are 325 feet long and 73 feet wide, with seven and seven-tenths feet of water over the mitre sills and with seven-feet lifts. The State of Illinois is co-operating with the United States government in that improvement. The tonnage over the improved sections of the river in 1917 was 284,970 tons and the number of passengers transported was 32,574. When improved, the Illinois River will form a part of a continuous waterway from the Mississippi to Lake Michigan, the other connecting sections being the Illinois and Michigan Canal, 63 miles long, extending from La Salle to Joliet and the Chicago Sanitary or Drainage Canal extending from Joliet to Lake Michigan. The Illinois and Michigan Canal, when constructed was 96 miles long and extended to the South Branch of the Chicago River at Chicago. It had a bottom width of 40 feet, a surface width of 60 feet and a depth of six feet, and 11 locks, which were 103 feet long and 17 feet wide, and had five to six feet of water over the mitre sills. That canal has been repaired and restored to a navigable condition. Another waterway connecting Lake Michigan and the Mississippi River is the Illinois and the Mississippi Canal, proceeding from the Illinois River at a point one and three-quarters miles above Hennepin, via the Bureau Creek Valley and over the summit to Rock River, and down that river to the Mississippi. It has a surface width of 80 feet, a depth of seven feet and 33 locks 150 feet long and 35 feet wide. The main canal is 75 miles long and has a navigable feeder extending from Rock Falls on Rock River to the summit level. Some improvements have been made in that canal, which were completed in 1918. Its tonnage in 1917 was 15,662 tons and 32,377 passengers were transported. The Keweenaw waterway, partly natural and partly artificial, 25 miles in length, extends across Keweenaw Point in Michigan. It is a navigable channel 20 feet deep with a bottom width of 120 feet, along which there are 32 privately owned docks. It affords access to a harbor of refuge for Lake Superior vessels. The tonnage passing through it in 1917 was 558,456 tons.

Saint Joseph River in Michigan and Indiana was at one time navigable as far as South Bend, a distance of 50 miles. It now has a channel from 30 to 50 feet wide and from two to three feet deep, at low water, from its mouth into Lake Michigan at Saint Joseph up to Berrien, a distance of 22 miles. The harbor at the outlet including the outlet of the Pawpaw River and the Benton Harbor Canal is two and one-tenth miles long, with a channel 18 feet deep and 150 feet wide, two-thirds of a mile long, a turning basin and a canal 15 feet deep and 100 feet wide to Benton Harbor. The tonnage of that port in 1917 was 115,138 tons. Saginaw River in Michigan has been improved and has a channel, 200 feet wide and 18½ feet deep, from Saginaw Bay to the mouth of the river three and one-quarter miles and thence 16½ feet deep to its source, a distance of 22 miles. There are several thousand feet in length of docks in and between Bay City and Saginaw, which are situated on that waterway. The lower three and one-quarter miles of the channel of Black River in Michigan has been dredged to a depth of 17 feet and the width of 160 decreasing to 75 feet. Boats of small draft ascend the river five miles beyond the improvement. There are docks on both sides of the river for a thousand feet or more, all of which are privately owned. In 1917 the tonnage was 80,006 tons.

The Clinton River in Michigan, 60 miles long, has a channel eight feet deep and 60 feet wide at its mouth, which narrows down to 50 feet up the stream. The improvement extends for about eight miles up the river and vessels of light draft ascend two miles farther. The lower portion of the Rouge River in Michigan has been widened and deepened for three miles or more from its outlet into the Detroit River up to Wabash Bridge or farther. Its tonnage in 1917 was 1,954,470 tons.

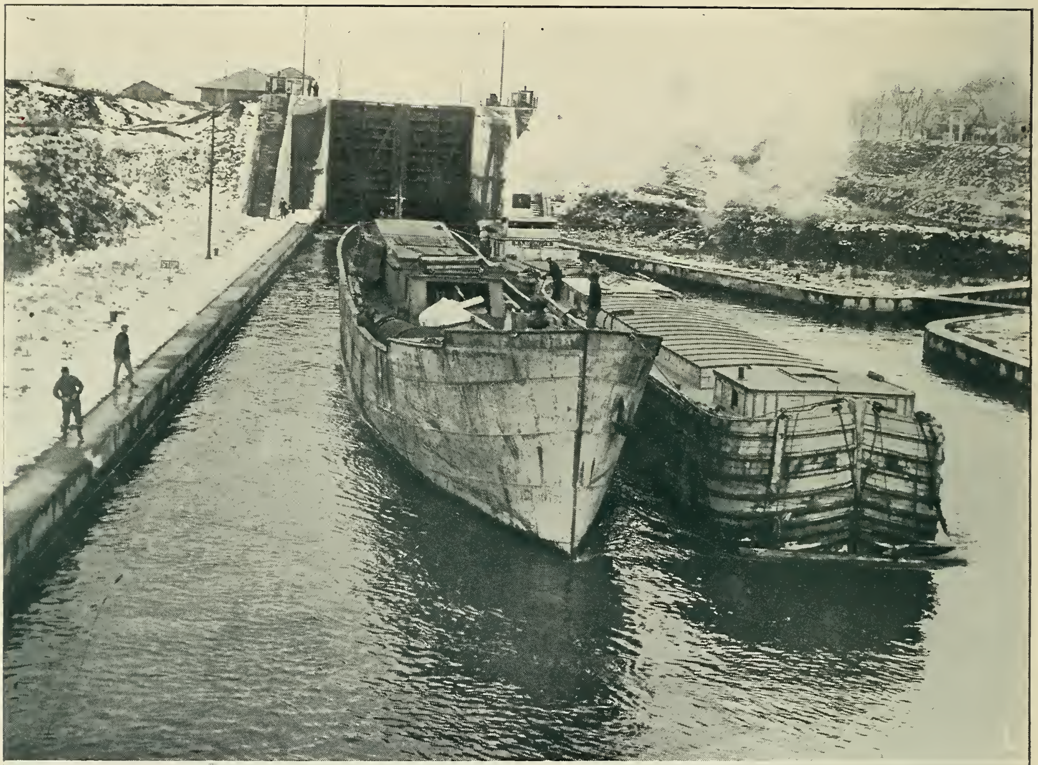
The Great Lakes and Connecting Waterways.— Saint Mary's River is the outlet of Lake Superior and flows from Point Iroquois, 63 miles southeasterly, to the Detour Passage into the northern end of Lake Huron. It has a total fall of 18 to 21 feet. Its improved one-way channels are 300 feet wide and 21 feet deep and its bothway or upbound and downbound single channel is 600 feet wide and 21 feet deep. There are four large locks in the Saint Mary's River located at Sault Sainte Marie, Michigan. The Weitzel Lock is 515 feet long and 80 feet wide with a lift of 20½ feet. The Poe Lock is 800 feet long and 100 feet wide with a lift of 20½ feet. The third lock is 1,350 feet long and 80 feet wide with a lift of 20½ feet. A fourth lock is 1,350 feet long and 80 feet wide with a lift of 20½ feet, nearing completion. The Weitzel Lock has a depth of 12 6/10 feet of water on the lower breast wall, the Poe Lock has a depth of water of 18 feet on the lower breast wall, and the third and fourth locks have each a depth of water of 24½ feet on the lower breast walls.

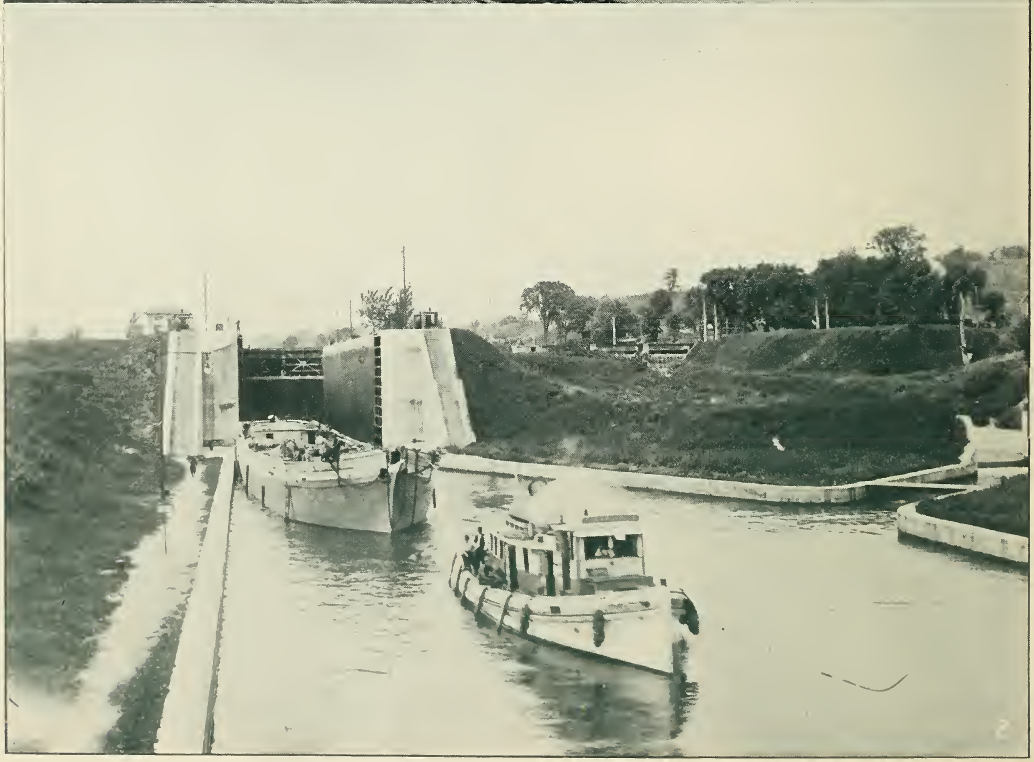
The Saint Clair River connects Lake Huron and Lake Saint Clair. It is 40 miles long. Its channel is from 20 to 22 feet deep and has a width of 400 to 2,400 feet. A channel has been dredged through the Saint Clair Flats, 300 feet wide and 20 feet deep. The distance through Lake Saint Clair traversed by Great Lake vessels is 18 miles, although the lake is 30 miles wide. The outlet of Lake Saint Clair is the Detroit River which is 28 miles long and flows into Lake Erie. It has several channels. Its Fighting Island Channel, four and one-half miles long, is 800 feet wide and 22 feet deep. Its Amherstburg Channel is 12 miles long, 600 feet wide and from 20 to 22 feet deep. Its Livingstone Channel is nine and one-half miles long and has a width of from 300 to 800 feet, and a depth of 22 feet. These are connecting waterways between the Great Lakes. Both the

WATERWAYS

1 Saint Marys Falls Canal. Upper approach to locks
2 Saint Marys Falls Canal. Lower entrance Weitzel and Poe Locks

WATERWAYS





1 Steam trawler, built at a Great Lakes shipyard, passing through the New York State Barge Canal for use on the ocean
2 Great Lakes vessel, partially dismantled, passing through the Barge Canal for ocean use during war emergency

United States and Canadian canals are open to the vessels of either country.

The Great Lakes with their spacious bays and in-flowing tributaries are partly within the jurisdiction of the United States and partly within the Dominion of Canada. Such parts of them as are within the United States comprise some of its most important waterways. Their waters wash the shores of Minnesota, Wisconsin, Michigan, Indiana, Illinois, Ohio, Pennsylvania and New York. Other States also are brought in touch with their manifold and extensive commerce. Their score or more spacious and improved harbors with the channels of 19 to 23 feet in depth are frequented by the largest grain, ore and lumber fleets in the world, and the volume of their aggregate tonnage approaches, if it does not exceed, 100,000,000 tons annually. They are equipped with all modern appliances for loading and unloading the large lake vessels, some of whose cargo capacities exceed 14,000 gross tons. In 1917, the tonnage at the port of Duluth was 52,411,824 tons, that being the largest tonnage of any inland port in the world.

In 1917 there passed through the United States canals at Saint Mary's Falls, 10,469 lockages of vessels carrying 74,361,850 tons of freight, and 11,990 passengers, and there passed through the Canadian Saint Mary's Falls Canal 5,349 vessels carrying 15,452,048 tons of freight and 26,349 passengers, making an aggregate tonnage passing through the two Saint Mary's Falls canals of 89,813,898 tons of freight and 38,339 passengers. In addition to these were the vessels with their cargoes and passengers passing through other Great Lake ports, but not through Sault Sainte Marie canals. The lake tonnage of the port of Buffalo in 1917 was 18,925,179 tons. Such other lake ports as Superior, Chicago, Milwaukee. Detroit, Toledo, Cleveland, Ashtabula, Conneaut, Erie, Tonawanda, Oswego and Ogdensburg had in the aggregate millions of tons of waterborne freights and in addition thousands of passengers. The commerce of the Great Lakes and connecting waters justifies the expenditure of millions of dollars annually to keep their harbors adequate to accommodate the several hundred lake vessels in the service. The Niagara River along its eastern margin has a ship channel 200 feet wide and 23 feet deep from Buffalo Harbor down five miles through the ship lock 650 feet long and 68 feet wide with 22 feet of water over the mitre sills into the deep waters of the river. The navigable channel at Tonawanda has been improved. Tonawanda Creek is also improved to make it navigable for lake vessels. The harbors and connecting channels of the Great Lakes are from 19 to 23 feet deep at mean lake levels.

Lake Ontario ports include Charlotte Harbor, with a channel, 200 feet wide and 20 feet deep up to the mouth of the Genesee River; Great Sodus Bay and Little Sodus Bay, which have been improved, each having an entrance channel 150 feet wide and 15½ feet deep, protected by lengthy parallel piers; Oswego Harbor with an entrance channel 16 feet deep and 600 feet wide up to the mouth of the Oswego River and Cape Vincent Harbor and the harbor at Ogdensburg. The latter is provided with an upper entrance channel 19 feet deep and from 300 to 450 feet wide, and also for a channel 19 feet deep and from 200 to 350 feet wide along the city water front, and also for a lower entrance channel and basin 19 feet deep and from 1,600 to 2,100 feet wide along the lower wharf frontage. Ogdensburg is the principal Saint Lawrence River Harbor in the United States, and its tonnage in 1917 was 1,029,427 tons. The Saint Lawrence is the outlet of the Great Lakes and flows wholly through Canadian territory below its Long Sault Rapids a few miles north of Ogdensburg.

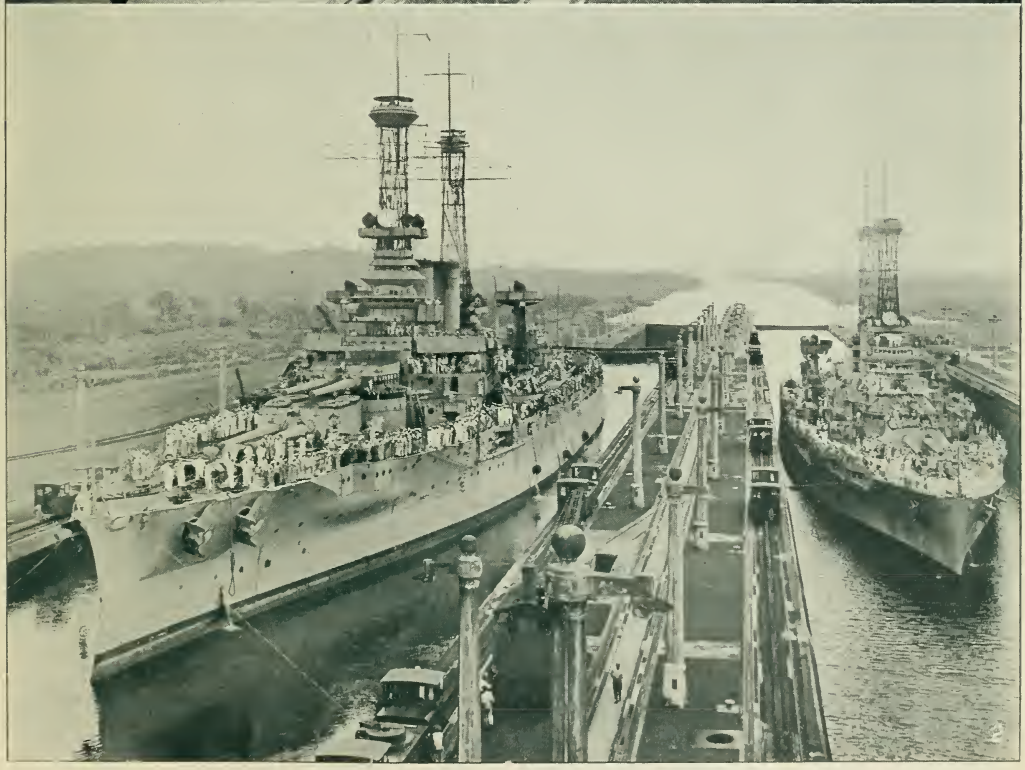
Pacific Coast. *California.*— The Colorado River is navigable between the Laguna Dam and Fort Mohawk, a distance of 280 miles, by boats of 20 to 22 inches draft nearly all the year, provided channels be maintained through shifting bars of sand. San Diego and Los Angeles harbors have each been dredged and have entrance channels 35 feet deep and from 400 to 500 feet in width, which channels increase in width landward to turning basins. The tonnage in San Diego Harbor in 1917 was 33,092 tons, and that for 1917 in Los Angeles Harbor was 288,917 tons.

San Francisco has the largest harbor on the Pacific Coast. It is 40 miles long and from three to 10 miles wide and its depths of water vary from 40 to 90 feet. It is a landlocked harbor. It has 50 or more piers averaging 700 feet in length. Its piers for handling bulk freight are equipped with freight-handling devices. The State of California owns the entire water front of San Francisco and its terminal facilities are publicly owned and are open to the public upon reasonable terms. Its tonnage in 1917 was 9,294,366 tons. Into San Francisco Bay flows Redwood Creek which has a channel 150 feet wide and five feet deep for three and one-quarter miles up stream. Along it are several wharves. The commerce of that waterway in 1917 was 24,271 tons. Oakland Harbor is but a part of San Francisco Bay and has a channel 500 feet wide and 30 feet deep at low water through Oakland Estuary to Brooklyn Basin, a distance of four and three-quarters miles and thence it is but 300 feet wide and 25 feet deep around the basin, and 18 feet deep through Oakland Tidal Canal to San Leandro Bay, a further distance of four and three-eighths miles, making a total length of nine and one-eighth miles. Its tonnage in 1917 was 3,026,279 tons.

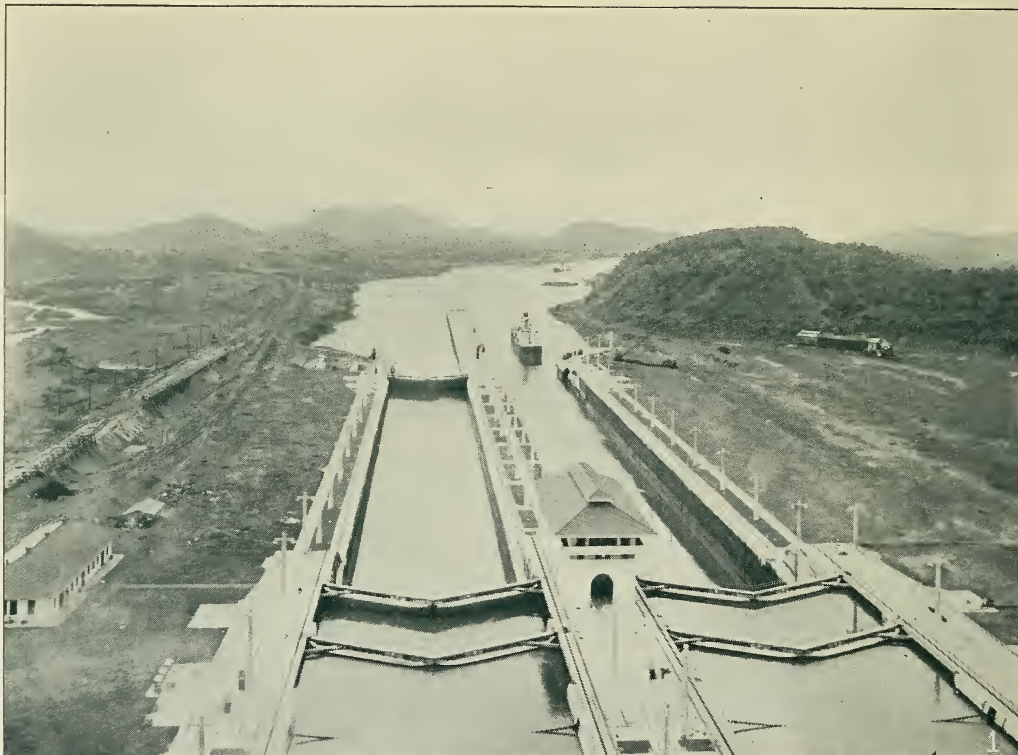
San Pablo Bay in California is a waterway 12 miles long and six miles wide, with a channel five miles long, 500 feet wide and 30 feet deep. It is provided with 20 privately owned wharves equipped with warehouses and other facilities. Its tonnage in 1917 was 11,531,518 tons. Suisun Channel, California, is a waterway 17 miles long with a channel 80 feet wide and six feet deep. In 1917 its tonnage was 62,842 tons. Napa River, California, is provided with a channel 75 feet wide and four feet deep, for a distance of 18 miles. It is a tidal estuary with a range of 6.92 feet at high water, giving it 11 feet of water at high tide. Steamers of five-feet draft, carrying fast freight, and sailing vessels of six-feet draft, carrying bulky freight navigate that river, whose tonnage in 1917 was 130,093 tons. Petaluma Creek, California, a stream 20 miles long emptying into San Pablo Bay, has a channel 600 feet wide in its lower section and 80 feet wide in its upper section, having a depth of eight feet of water and is navigable for 16 miles. In 1917 its tonnage was 284,423 tons. Montgomery Harbor in California in 1917 had a tonnage of 248,398 tons.

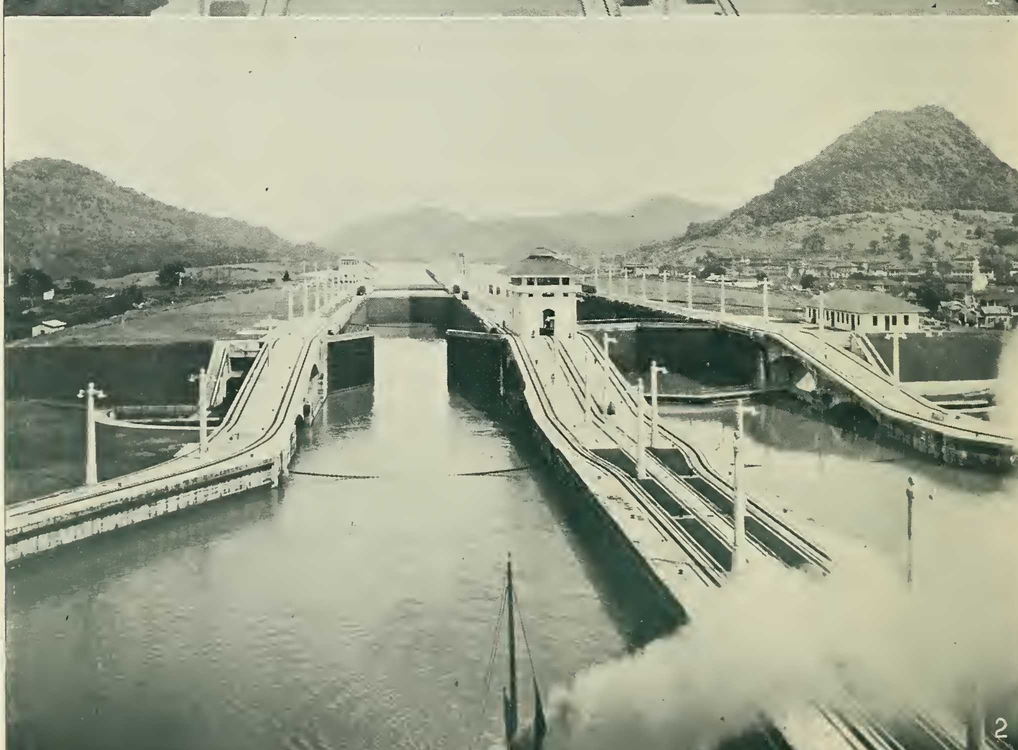
Humboldt Harbor and Bay, whose entrance is provided with protecting jetties, has a channel 300 feet wide and 18 feet deep. Its tonnage in 1917 was 463,901 tons. The San Joaquin River, California, has a channel nine feet deep and 200 feet wide from its outlet in Suisun Bay to Stockton Channel and through Stockton Channel to Stockton, a distance of 45 miles. That channel is to be extended at the same depth through Freemont Channel and McLeod Lake, which form part of the harbor of Stockton. Another channel, one and seven-tenths miles long, four feet deep and 80 feet wide, is being constructed from Stockton Channel to Centre street in the city of Stockton, known as Mormon Channel. There are several improvements along the river and some terminal facilities. Loaded vessels on that river do not ordinarily draw more than seven feet. The existing project for the improvement of that river provides for the diversion of the waters of Mormon Slough, through a canal, 150 feet wide, to the San Joaquin River. Its tonnage for 1917 was 1,890,856 tons. Mokelumne River, California, is 140 miles long and empties into the San Joaquin River, 20 miles above the mouth of latter. It has a navigable channel 50 feet wide and six feet deep from its mouth to Galt, New Hope Landing, a distance of 35 miles. Its tonnage in 1917 was 78,954 tons. Sacramento River, California, is to have a channel seven feet deep from its mouth at Collinsville in Suisun Bay up to Sacramento, a distance of 60.7 miles, thence a channel of four feet deep up to Colusa, a distance of 90 miles, and thence a channel three feet deep up to Chico Landing, a distance of 51.3 miles, and of such depths as are practicable up to Red Bluff, a distance of 52.4 miles. The latter place is at the head of navigation and 254.4 miles from the mouth of the river. The river points are provided with wharves, warehouses and other terminal facilities. Its tonnage in 1917 was 947,690 tons. Feather River, California, a tributary of the Sacramento, 20 miles above the city of Sacramento, has a cleared navigable depth of two and one-half feet from its mouth at Vernon up to Marysville, a distance of 28.3 miles.

Oregon, Washington and Montana.—The Coquille River, 100 miles long, has a controlling depth of five feet and a width of 100 feet from its mouth at Bandon to Coquille, a distance of 25 miles. There are wharves at Bandon and at various points up-stream. The outlet has a depth of 12 feet and the depth of channel decreases up-stream. In 1917 its tonnage was 40,050 tons. Coos Bay has an improved channel 18 feet deep and 200 feet wide up to Marshfield, a distance of 13 miles. Its tonnage in 1917 was 446,062 tons. The Coos River, Oregon, flowing into the bay, has a navigable length of 23 miles. Its tonnage in 1917 was 97,047 tons. Yaquina River, Oregon, has a channel 100 feet wide and 10 feet deep from its mouth to Toledo, eight and one-half miles, and above that town to the head of navigation, 22 miles from the mouth, the channel is 100 feet wide and two feet deep. Tillamook Bay, which is six miles long and three miles wide, has a navigable channel 16 feet deep and 200 feet wide, and at its entrance it is 22 feet deep. It is protected by a jetty a mile long on the north side. The channel from Bay City up to Tillamook City, 12 miles from the sea, is nine feet deep. The Columbia River is 1,200 miles long. Only 748 miles of its course is in the United States. It flows southwesterly through the State of Washington into the Pacific Ocean between that State and Oregon. It has such large tributaries as the Spokane, the Snake and the Willamette rivers. It has an entrance channel 42 feet deep and one-half mile in width, protected by jetties, the north one being two and one-half miles long and the southern one being seven miles long. The largest Pacific steamships may enter the harbor. The tonnage at the mouth of the Columbia River in 1917 was 2,357,863 tons. A channel 30 feet deep and 300 feet wide is maintained from its mouth up to the mouth of the Willamette River, a distance of 99 miles, and thence up the latter river to Portland, a distance of 14 miles. From the mouth of the Willamette River to Vancouver, Wash., a distance of four and one-half miles, it has an improved channel 150 feet wide and 20 feet deep. It also has a channel 10 feet deep and 300 feet wide in the vicinity of Cathlamet. At Portland on the Willamette are municipal and private docks, which include grain, lumber and other types. At Astoria on the Columbia River is a large municipal terminal and there are many private docks. In 1917 the tonnage was 2,357,863 tons carried on ocean-going vessels and 4,326,681 tons carried on inland river boats. The Cascade Rapids in the Columbia River, 140 miles above its mouth, are overcome by a canal 3,000 feet long with one lock consisting of two chambers, the lower being 469 feet long and the upper one 462 feet long, both of which and the canal have a width of 90 feet and lifts of from 18 to 24 feet, with eight feet of water over the mitre sills. The Dalles Rapids and the Celilo Falls, in a distance of nine and one-half miles, with a total fall of 81 feet, are overcome by the Dalles-Celilo Canal, 190 miles from the ocean, which canal has a depth of eight feet and a width of 65 feet at the bottom and five locks, each 265 feet long and 45 feet wide, with lifts of six and one-half to 70 feet. The canal is eight and one-half miles long. These canals render the Columbia River navigable as far as Priest Rapids, a distance of 397 miles, and also render navigation possible on Snake River to Pittsburgh Landing, which is 540 miles from the mouth of Columbia River. The maximum draft of boats on those sections of the Columbia River is four and one-half feet. The Columbia is to have a channel seven feet deep between Watchee and Kettle Falls, a distance of 242 miles. Pittsburgh Landing, Idaho, on the Snake River, is 216 miles from its mouth and is being improved to secure a channel five feet deep to Riparia, 68 miles above its outlet, and between Riparia and Lewiston, a distance of 72 miles, to secure a channel five feet deep and 60 feet wide, though for much of the distance the channel is from 240 to 700 feet wide. The tonnage through the Dalles-Celilo Canal in 1917 was 57,718 tons. The Willamette, a tributary of the Columbia,



1 Gatun Locks (Panama Canal). Looking south from west-wall Lighthouse
2 U. S. S. Arkansas (left) and U. S. S. Texas (right) in middle chambers of Gatun Locks (Panama Canal), 25 July 1919





1 Miraflores Locks (Panama Canal) (Sea-level section in distance)
2 Pedro Miguel Locks (Panama Canal) (Gaillard Cut in distance)

100 miles from the sea, is to have an improved channel six feet deep and 150 to 200 feet wide from Portland to Clackamas Rapids, 11½ miles, and thence a channel six feet deep and 100 feet wide to Oregon City, one and one-half miles, and thence a channel two and one-half to three and one-half feet deep to Corvallis, a distance of 106 miles. The Willamette Falls near Oregon City are overcome by a canal, four locks and a dam. The locks are 210 feet long and 40 feet wide, with six feet of water over mitre sills and having lifts of 10¼ feet. The tonnage through it in 1917 was 113,954 tons. The mouth of the Yamhill River, a tributary of the Willamette, 42 miles above Portland, was formerly the head of navigation, but loaded boats now ascend as far as Harrisburg on the Willamette, 33 miles above Corvallis. The Yamhill, eight miles above its mouth, has a lock 210 feet long and 40 feet wide, with four feet of water over the mitre sills and has a lift of 16 feet. That renders that river navigable to McMinnville, 18 miles above its mouth. Its tonnage in 1917 was 2,032 tons. Loaded boats below Oregon City are of five-feet draft and above that city they are of two-feet draft. The total traffic transported by 31 river boats in 1917 was 491,901 tons. The Lewis River, Washington, a tributary of the Columbia, 26 miles below Portland, divides three and three-quarters miles above its mouth into the North Fork, 106 miles long, and the East Fork, 36 miles long. It has a channel six feet deep and 50 feet wide to the forks. The East Fork has a channel four feet deep and 50 feet wide to La Centre, a distance of three miles, and the North Fork has a similar channel from its mouth to Woodland, a distance of three and one-half miles. Both La Centre and Woodland have terminals publicly owned. In 1917 the traffic on both forks was 25,262 tons, about one-half that of 1916.

The Cowlitz and Gray rivers, Washington, both tributaries of the Columbia River, have been improved in their lower reaches, the former as far as Toledo and the latter for eight miles above its mouth. In 1917 the tonnage on the former was 310,992 tons and on the latter 31,092 tons. Willapa Harbor is at the mouth of Willapa River, which is 30 miles long and is from 200 to 2,000 feet wide at the outlet of the harbor into the ocean. A channel 24 feet deep and 200 feet wide has been constructed from Willapa Bay to the forks of the river at Raymond, and thence up the South Fork, 150 feet wide, to the Cram lumber mill, and also from Raymond up the North Fork, 250 to 350 feet wide, to 12th street. The entire improvement extends 13½ miles. The harbor is equipped with city and railway wharves open to the public use. In 1917 its tonnage was 567,510 tons. Gray's Harbor at the mouth of the Chehalis River is 17 miles long and 14 miles wide and has a channel into it 500 feet wide and 24 feet deep, with projecting jetties, on the south three and one-half miles long and on the north three miles long. The tonnage at that port in 1917 was 455,957 tons. The Chehalis River has a channel 18 feet deep at low water and 200 feet wide from the bay to Cosmopolis, a distance of 15 miles, and thence a channel six feet deep and 150 feet wide to Montesano, a distance of eight and one-half miles. The traffic on that river in 1917 was 771,480 tons. Into Gray's Harbor also empties the Hoquiam River, whose channel is 100 feet wide and 18 feet deep for a distance of two miles. The commerce on that river is principally lumber.

Puget Sound is a large bay in the western part of the State of Washington opening out into the Strait of Juan de Fuca. It has many connecting arms and extensions, principally to the south and southwest deep waters. Into it flows the Skagit, Snohomish, Snoqualmie, Skykomish, Stilaguamish, Nooksak, Puyallup and Duwamish rivers and connecting navigable sloughs. The conditions are such that permanent results are not obtainable and continuous dredging is necessary. Large vessels may navigate the sound proper, but only vessels of six-feet draft can navigate its in-flowing streams.

At the south end of the sound is Budd Inlet. Upon this is Olympia Harbor, which has a channel 250 feet wide and 12 feet deep, with turning basins at the end of the improvement 20 feet deep. One of these is 400 feet wide and 800 feet long. The draft of vessels is limited to 10 feet. The tonnage of that port in 1917 was 283,472 tons. Another arm of Puget Sound is Commencement Bay, four miles long and two and one-half miles wide, constituting Tacoma Harbor. That has one channel 500 feet wide and 25 feet deep to 11th street bridge, and thence 18 feet deep to 14th street bridge, and thence from 500 to 200 feet wide and 15 feet deep to a point 8,500 feet from the entrance. The Puyallup waterway has a channel 500 feet wide and 28 feet deep for two-thirds of a mile. That is at the outlet of Puyallup River. The tonnage at Tacoma in 1917 was 2,912,530 tons. Lake Washington Canal extends from the lake through several bays, including Shilshole, Salmon, Lake Union and Union Bays to Puget Sound and is wholly within the city of Seattle. That canal has a double lock 760 feet long and 80 feet wide with 26 feet of water over the mitre sills and a fixed dam. Below the locks to deep water in Puget Sound, a distance of eight miles, the channel is 300 feet wide and 30 feet deep. Wharves and terminals are located on Salmon Bay, Union Bay and Lake Washington. The tonnage at Seattle in 1917 was 4,850,627 tons. Snohomish River has a channel 75 feet wide and eight feet deep for five and one-half miles above its mouth into the Puget Sound and its tonnage in 1917 was 1,038,477 tons. The channel of Skagit River, 150 miles long in the United States, is being improved nine and one-half miles above its mouth across Saratoga Passage. The draft of loaded boats is limited to three feet. Its tonnage in 1917 was 554,797 tons. Swinomish Slough, 11 miles long between Saratoga Passage and Padilla Bay, has a channel 100 feet wide and four feet deep. Its tonnage in 1917 was 54,347 tons. Bellingham Harbor, Washington, is an arm of Puget Sound. It is four miles long and two miles wide. Through its outlet is the Whatcom Creek waterway, 363 feet wide, two-thirds of a mile long and 26 feet deep at the outer end and 18 feet deep for the inner one-quarter mile of the improvement. The draft of loaded vessels was 10 feet. The tonnage of Bellingham Harbor in 1917 was 434,340 tons. The channel in Flathead Lake, Montana, is to have a channel 100 feet wide and six feet deep. Polson Bay at its southern end is a harbor six miles long and five miles wide. Loaded boats there were limited to six-feet draft.

Alaska.— Apoon Mouth is the most easterly outlet of the Yukon River and empties into Pastol Bay, 115 miles south of Nome Harbor. The Yukon is navigable for river boats of five and one-quarter-feet draft to the international boundary, a distance of 1,500 miles. Apoon Mouth has been improved for seven miles, having a channel from 150 feet wide and six feet deep through the bars at the mouth. Saint Michael Canal, Alaska, is a salt-water channel 18 miles long, 100 feet wide and six feet deep at the entrance of Saint Michael Harbor. That canal provides a sheltered passage for river boats plying between the port of Saint Michael and the mouth of the Yukon River. The tonnage thereon for the year 1910 was 24,622 tons. Nome Harbor on Norton Sound is the outlet of Snake River, a stream 20 miles long. The harbor is protected by concrete jetties 400 feet long. It has a basin 200 feet wide, 250 feet long and eight feet deep. Its tonnage in 1917 was 17,981 tons.

Hawaii and Porto Rico.— Hawaii has Honolulu Harbor, with an entrance channel 400 feet wide, 3,000 feet long and 35 feet deep at mean low water. Since the opening of the Panama Canal Honolulu has become a port of call for coal and fuel oil. It has 22 wharves and piers. Its tonnage in 1917 was 2,037,424 tons. Hawaii also has Kahului Harbor and Hilo Harbor, both improved to a depth of 35 feet. The tonnage of the former in 1917 was 228,853 tons, and that of the latter was 357,406 tons. San Juan Harbor in Porto Rico has an improved channel 600 feet wide and 30 feet deep with terminal facilities. Its tonnage in 1917 was 756,350 tons.

Cape Cod and Panama Canals.— The waterways of the United States also include many channels already described and also the Cape Cod and Panama canals. The former extends from Buzzard's Bay to Cape Cod Bay. It is from 100 to 300 feet wide on the bottom and was originally built by private parties, and may become a part of the Intercoastal Waterway from Maine to Key West. It is to be acquired by the United States and be given a prism 30 feet deep, with a minimum width of 200 feet. The largest of the government owned and operated canals is the Panama Ship Canal, approximately 40 miles long, extending from Limon Bay in the Atlantic to La Boca Bay in the Pacific. Its regulated summit level is between 82 and 87 feet above sea-level. The difference is due to the variation in the level of the Chagres River. That level is reached by a double lock, each lift being 45 feet, making a total lift of 90 feet at the Atlantic end of the canal and at the Pacific end there are double lift locks in the Pedro-Miguel section and a single lift lock below Lake Miraflores. Approximately one-half of its length is through Gatun Lake and Lake Miraflores, natural bodies of water, thereby materially reducing the original cost of that waterway. Its locks are 1,000 feet long and 110 feet wide. The canal has a minimum bottom width of 300 feet, but an average width of 649 feet, and it has a minimum depth of 41 feet.

The Waterways.— There are other waterways not mentioned in this article comprising interior lakes and unimproved rivers. The foregoing enumeration, however, of waterways and the description of their channels are sufficient to indicate their extensiveness the country over as well as their importance to the commerce of the nation. Those hereinbefore mentioned comprise thousands of miles of navigable channels. In their construction and maintenance, the government of the United States has expended hundreds of millions of dollars. Furthermore, some States and many communities have contributed large sums toward waterway improvements. The policy of co-operation between the general government and the States and communities may become a settled policy and that governmental aid may be extended only when localities advance some part of the expense of making waterway improvements. That policy has been adopted in some European countries and has been recommended by one or more commissions of the United States.

The data as to waterborne tonnage given in this article are chiefly from the official records for the year 1917. Over most waterways, it was not as voluminous as it was during the preceding four years, owing to the abnormal conditions prevailing the country over, in consequence of the Great War. Much of the commerce of the country was diverted from waterways to railways, which were under Federal control. The conditions in the year 1918 were still more unfavorable for water carriers and the waterborne tonnage, except ocean traffic, the greatest in the history of the country, was less over inland waterways than it was in 1917.

The end of the war and the return to normal industrial life will awaken an ever-increasing demand for greater facilities of transportation. The waterways of the country will furnish those facilities. The entire Atlantic, Gulf and Pacific coasts, the Great Lakes and the interior waterways of the country are equipped as shown in this article to do a volume of transportation unparalleled at any other period in the history of the world.

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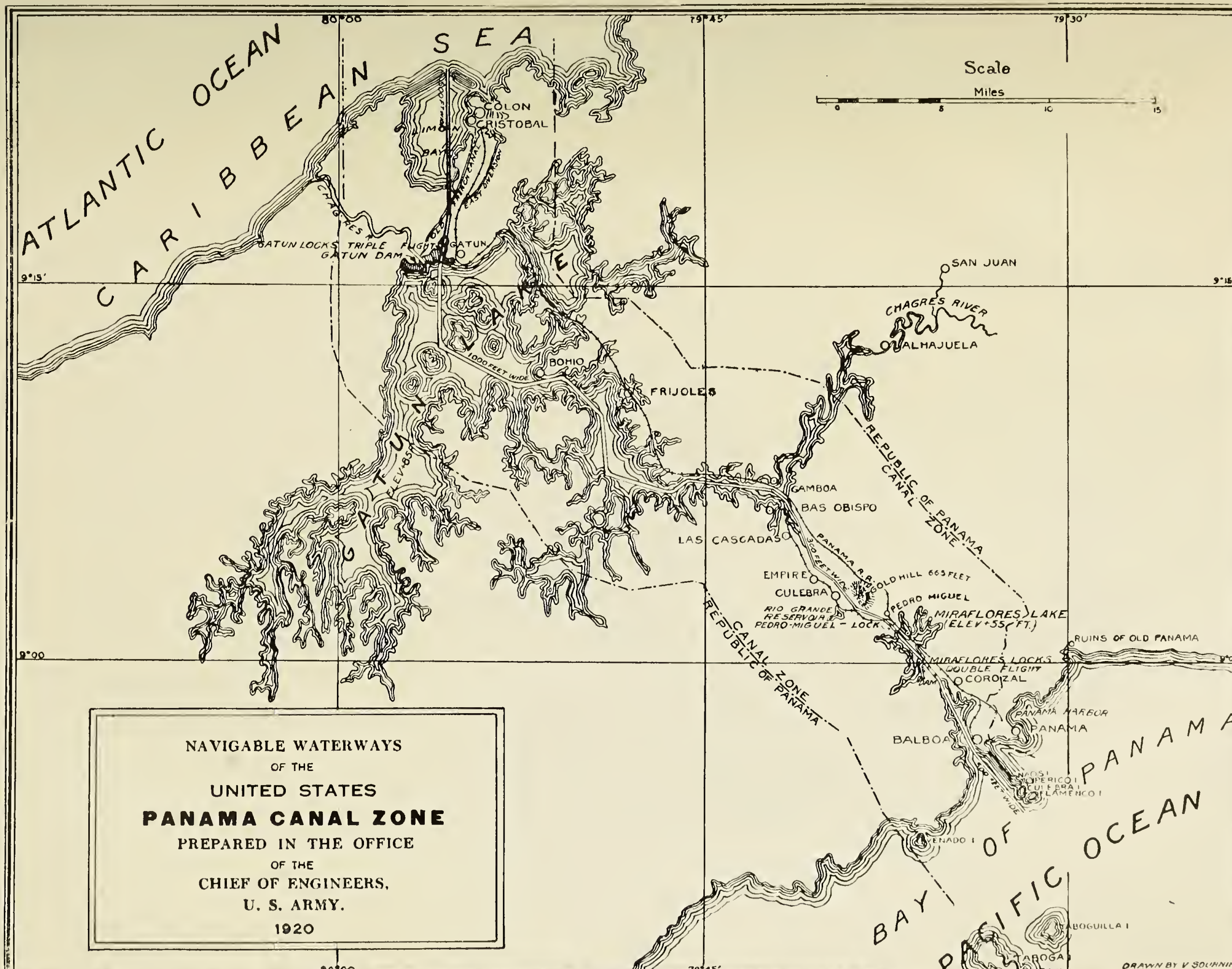
NAVIGABLE WATERWAYS
OF
THE UNITED STATES
ALASKA
PREPARED IN THE OFFICE OF THE CHIEF OF ENGINEERS,
U. S. ARMY.
1920
Scale
50 25 0 50 100 150 200 250 STAT MILES
DRAWN BY V. SOURNIN
ARCTIC OCEAN
BERING SEA
PACIFIC OCEAN
ASIA
EASTERN SIBERIA
RUSSIA
UNITED STATES
CANADA
ALASKA
BERING STRAIT
KOTZEBUE S.
ARCTIC CIRCLE
NOME
SNAKE R
ST. LAWRENCE I
NORTON S.
YUKON RIVER
INNOKO R.
IDITAROD R
KOYUKUK RIVER
TANANA RIVER
YUKON FLATS
FT YUKON
PORCUPINE R
CHATANIKA
FAIRBANKS
MT. McKINLEY 20,464 FT
MT. WRANGELL 17,500 FT
ESKA
CHICALOON
KENNECOTT
VALDEZ
CORDOVA
TYONEK
SEWARD
COOK INLET
PRINCE WILLIAM S.
YAKUTAT BAY
SKAGWAY
JUNEAU
STIKINE RIVER
SITKA
DIXON ENTRANCE
QUEEN CHARLOTTE I.
KUSKOKWIM RIVER
KUSKOKWIM BAY
NUNIVAK I
ST. MATTHEW I.
PRIBILOF IS
NUSHAGAK
KVICHAK R
ILIAMNA LAKE
BRISTOL BAY
KATMAI
SHELIKOF STRAIT
KODIAK I
ALASKA PENINSULA
ALEUTIAN ISLANDS
BARROW P.



NAVIGABLE WATERWAYS
OF THE
UNITED STATES
PANAMA CANAL ZONE
PREPARED IN THE OFFICE
OF THE
CHIEF OF ENGINEERS,
U. S. ARMY.
1920
ATLANTIC OCEAN
CARIBBEAN SEA
COLON
CRISTOBAL
GATUN LOCKS TRIPLE FLIGHT
GATUN DAM
GATUN
GATUN LAKE
BOHIO
FRIJOLES
SAN JUAN
CHAGRES RIVER
ALHAJUELA
GAMBOA
BAS OBISPO
LAS CASCADAS
EMPIRE
CULEBRA
GOLD HILL 665 FEET
PEDRO MIGUEL
RIO GRANDE RESERVOIR
PEDRO-MIGUEL - LOCK
MIRAFLORES LAKE
(ELEV+55 FT.)
MIRAFLORES LOCKS
DOUBLE FLIGHT
COROZAL
RUINS OF OLD PANAMA
PANAMA HARBOR
PANAMA
BALBOA
REPUBLIC OF PANAMA
CANAL ZONE
BAY OF PANAMA
PACIFIC OCEAN
TABOGUILLA I
TABOGA
Scale
Miles
0
5
10
15
80°00
79°45'
79°30'
9°15'
9°00
DRAWN BY V SOUHNIN

States; maps and charts of various sections of the United States; reports of Municipal Harbor Improvement Commissions, and many other records.

HENRY WAYLAND HILL,
President of the New York State Waterways Association, author of the articles on "Rainfall" and "Water Supply" in this Encyclopedia and of "Waterways and Canal Construction in New York."

WATERWORKS, systems of machinery and engineering structures, employed to supply water to individual manufacturing, mining and milling plants, and to municipalities, for domestic and industrial uses and for irrigation. Such systems existed during very early periods of history, and the waterworks of ancient Greece, Carthage and Rome may be readily traced and studied by the ruins of their reservoirs and masonry aqueducts. In these earlier systems, gravity was depended upon for the delivery of the water, but force pumps were introduced about the middle of the 16th century, and extended greatly the general installation and use of waterworks systems. The waterworks built at London Bridge by Peter Maurice 1562 appear to be the first on record. The plant consisted of 16 force pumps, each 17 inches in diameter, and 30 inches long, which were driven by a current wheel, and raised 311,000 gallons of water per day to a reservoir at an elevation of 120 feet above the pumps, and from which the water was delivered by gravity, through lead pipes to buildings in the immediate vicinity.

In the United States, the first pumping plant installed to provide water for municipal purposes was that at Bethlehem, Pa., about 1760. It consisted of a five-inch wooden force pump, which raised water to a height of 70 feet through pipes of bored hemlock logs. This was replaced in 1761 by three single-acting iron pumps, each four inches in diameter, and of 18-inch stroke, operated by an undershot water-wheel. The first municipal water-supply system built in America, however, was that of Boston, in 1652. It was built by the Water-Works Company, and consisted of a reservoir about 12 feet square, to which the water from springs in the vicinity was conveyed through wooden pipes. From 1652 up to the close of the year 1800, the waterworks plants in the United States numbered 16, and had been located and built at the following named cities: Boston, Mass., 1652; Bethlehem, Pa., 1754–61; Providence, R. I., 1772; Geneva, N. Y., 1787; Plymouth, Mass., 1796; Salem, Mass., 1795; Hartford, Conn., 1797; Portsmouth, N. H., 1798; Worcester, Mass., 1798; Albany, N. Y., 1798–99; Peabody, Mass., 1799; New York City, 1799; Morristown, N. J., 1799; Lynchburg, Va., 1799; Winchester, Va., 1799–1800; and Newark, N. J., 1800. With the exception of the plants at Winchester and Morristown, they were all built by private concerns, but passed into the ownership of the respective municipalities from time to time up to 1860. The works at Winchester were built by the municipality, and those at Morristown were built by a private concern and still remain in private ownership. Up to the present time (1919) the number of plants installed throughout the country amounts to nearly 4,000, of which four-fifths are under municipal control.

A clear and concise consideration of the subject of waterworks may be facilitated by arranging the various requirements under the four general headings — quality of the water; sources of supply; modes of distribution, and public policy.

Quality expresses the fitness of the water for the special purposes for which it may be required. A good quality of water is characterized by freedom from turbidity and color, unpleasant taste and odor, and undue sewage contamination.

Taste is the first quality to be satisfied in drinking water. Even a perfectly safe water may be rejected because of nauseating flavor. This may often be remedied by dosing with chlorine and then removing the chlorine taste with sodium sulphite.

Turbidity is a condition caused by clay and silt suspended in the water. When the source of supply is a river, this condition is liable to great variation according to the amount and character of the rainfall over the watershed. Heavy rains of short duration are drained off with great erosive effect, and introduce into the flowing rivers vast quantities of finely divided inorganic matter. Such impurity, however, is more offensive than harmful, unless taken into the system frequently or in large quantities. It is removed by the use of settling reservoirs where the water is allowed to rest and deposit the heavier particles, before it is passed through the filter-beds by which the smaller particles are removed. (See WATER SUPPLY). Color is a condition more offensive to the eye than harmful to the health. The apparent color due to turbidity disappears under the processes of sedimentation and filtration, but true color, generally due to infusion of vegetable organic matter, such as leaves, grass, etc., is much more difficult to remove.

Odor is a condition which, although less frequent, is much more objectionable than turbidity or color. As a rule it is due to the life processes of minute organisms, and is removable to a considerable degree by filtration. It may, however, persist at certain times in the year and has been known to produce, or be followed by bowel disturbances among small children.

Sewage contamination is the most harmful of all the various forms of impurities natural or artificial that a water supply may be subjected to, and is the direct cause of epidemics of typhoid fever and various troubles of the intestines, which by undermining the constitution reduces its power of resistance to other diseases. The water may be somewhat purified by filtration, but the proper remedy is to remove the source of pollution. Failing this, even a much polluted water may be made reasonably safe for drinking by sterilization with chlorine.

The quality of water is ascertained by various kinds of analyses, physical, chemical and bacteriological. Physical analyses consist merely of comparisons of the given samples with standard solutions, and afford data relative to temperature, turbidity, color and odor. Chemical analyses indicate the time of past contamination and the nature of its origin — animal or vegetable, and the content of mineral salts. Bacteriological analyses are principally used to ascertain the absence or presence of the growths which cause bad taste and odor. Such analyses are capable of showing the number and probable origin of the bacteria present, but in mat-