REPORT ON THE WATER-POWER

OF THE

MISSISSIPPI RIVER AND SOME OF ITS TRIBUTARIES.

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The gulf of Mexico extends far into the southern part of North America, almost washing the base of the Mexican ranges of the Cordillera. Its drainage area in the United States is about 57 per cent. of the whole area of the country. The drainage of very nearly three-quarters of this area, of about 1,725,980 square miles, tributary to the Gulf, is monopolized by the great river which is the subject of this report.

To say that the Mississippi drainage system is exceeded in extent by only two other rivers on the globe, does not convey much significance to those unaccustomed to the comparison of water-courses; but when we are told that over one-third of the entire area of the United States pours its tribute into this stream; that its mouth is at the southern shore-line of our country while its northern branches extend across the boundary into the British possessions; that the sun has been shining two hours and twenty minutes upon its waters in the east before it appears above the mountain peaks in which the far western branches rise; and that each year it carries to the sea 159 cubic miles of water—then it is that we form some idea of the vastness of a stream which can exceed the Mississippi.

There is something impressive in the fact, as you stand upon one of the bluffs overlooking the river, that there, before you, gathered in a single channel 3,000 feet wide, the melted snow and ice of the far north and the Rocky mountains mingle with the rains of the Alleghanies. The semi-tropical swamps, and the region lying far away toward the north, the mountains of the east and west, and the great rolling prairie, are all represented in this vast volume of water, rushing on with noiseless swiftness toward the sea.

As a matter of interest, a few facts such as can be gathered from the limited resources at hand regarding the large rivers of the globe are inserted:

Amazon river.—The Amazon is the greatest in every respect in the world, and has a drainage area of at least 2,264,000 square miles. It is from 3,500 to 4,000 miles long, and has 10,000 miles of navigation for large boats; 1,000 miles from the sea it is 4 miles wide; its average depth is 42 feet in the upper portion, and at the mouth it is 312 feet deep. The usual current is 3 miles per hour. The flood-rise is from 42 to 48 feet above the lowest level. The elevation, at a distance of 3,000 miles from the mouth, is only 210 feet above the sea, and the tide is observable 400 miles above the mouth. The average discharge has been estimated by Jean Jacques Élisée Reclus to be 2,458,026 cubic feet per second. (See *Van Nostrand's Magazine*, vol. 24, page 66.) Another estimate gives a discharge of 500,000 cubic feet per second at a point above the entrance of two large tributaries each over 800 miles long. It is impossible that both these estimates should be right. Because of the heavy rainfall in the tropics, the first amount is more likely to be correct.

Mississippi river.—The Mississippi has a drainage area estimated to be 1,261,000 square miles. Its length to the sources of the upper Mississippi is 2,616 miles. The distance by water from the sources of its great tributary, the Missouri, to the gulf of Mexico is 4,194 miles. The length of navigable waters is estimated to be 15,000 miles, but a large portion of this is closed during low stages of water. The average width in the lower half of its course is from one-half to three-quarters of a mile. The maximum depth of channel averages about 60 feet in the lower half of its river, increasing to 125 feet near the mouth. The maximum flood-level is about 52 feet above low water on the lower half of the river, diminishing to 15 feet near the mouth. The source of the Mississippi is 1,680 feet above the sea-level. The tidal influence is not noticeable 300 miles from the mouth. The range of spring tide in the Gulf is 1.7 foot. The total discharge from the basin averages 675,000 cubic feet per second.

Rivers of Asia.—There are in Asia several rivers of grand dimensions, and the largest, the Obi, flowing north through Siberia, has a drainage area estimated to be 1,250,000 square miles.

The Yenesei, adjoining on the east, drains 1,041,000 square miles; and the Lena, just east of that, drains 787,000 square miles. Of the three rivers just mentioned, the Obi is the only one which is navigable for any distance.

The Yangtse Kiang drains from 550,000 to 750,000 square miles, and has an average flow of 770,397 cubic feet per second. The Hoang Ho and the Amoor each drain over 500,000 square miles, and the average discharge of the former is 116,000 cubic feet per second. (See *Van Nostrand's Magazine*, vol. 24, p. 63.) The Yangtse Kiang is the longest river of Asia, about 3,300 miles. The Yenesei is about 3,200 miles long, and the rest range from 1,500 to 3,000 miles in length.

The Ganges and Brahmapootra, in India, connect at their mouths, and together they drain an area of about 500,000 square miles. The Ganges, at 500 miles from the sea, has an average flow of 233,000 cubic feet per second. The length of the Ganges is about 1,500 miles. In the first 160 miles it falls 12,000 feet, and is then 1,024 feet above sea-level. The average discharge of the Ganges at Ghazapoor has been estimated at 203,485 cubic feet per second.

Rivers of Europe.—The Volga, which is the largest river of Europe, adjoins the Obi on the west. It has a drainage area of about 500,000 square miles, and is 2,500 miles long.

The Danube, the second river of Europe, has a drainage area of 300,000 square miles. The average flow is about 200,000 cubic feet per second.

Rivers of Africa.—The Nile and Congo are the largest rivers of Africa, and their sources are in the unexplored region in the interior of that continent. The drainage area of the Nile is said to be not less than 500,000 square miles, and 800,000 square miles are claimed by one authority for the Congo. The Nile is probably not less than 4,000 miles long, and its average discharge has been estimated at 130,032 cubic feet per second.

In comparing these few data concerning the great rivers of the globe, it must be remembered that hydrographic comparisons and hydrological comparisons are very different in their nature. Two rivers having equal drainage areas may be very unequal in their volumes, owing to differences in climate, rainfall, etc., as will presently be illustrated to a marked degree when mentioning the tributaries of the Mississippi itself. The Mississippi is probably the second river of the world in extent of drainage basin, being exceeded only by the Amazon. In volume of discharge, as in extent of area drained, the Amazon is truly an immense river, and there seems no reason to doubt the large estimate of flow given for it. Relatively to extent of basin, it is exceeded by some of the smaller rivers of the Mississippi basin.

Although no actual measurements of the discharge of the Obi are obtainable, there is every reason to believe that, in its region, where every thing is frozen solid most of the year, the precipitation and the volume of flow bear no comparison to the like factors of the Mississippi basin.

The two rivers which, after the Amazon (if the estimates made concerning them can be relied upon), exceed the Mississippi in volume although not in drainage area, are the Congo and the Yangtse Kiang. The amount of 1,800,000 cubic feet per second for the Congo was apparently an exceedingly rough approximation, based on assumed factors. The estimates for the Yangtse Kiang were made with more care, and the estimate of 770,000 cubic feet per second is probably of some value. This exceeds the average flow of the Mississippi by nearly 100,000 cubic feet per second, while the drainage area of the river is hardly more than one-half the area of the Mississippi basin.

THE BASIN OF THE MISSISSIPPI.

The sources of the Mississippi proper are between latitudes 47° and 48° north, and almost exactly in the center of the continent on an east-and-west line. Its general course is southward. The mouth is in latitude 29° north.

Form and location.—The basin, very irregular in outline, can best be described as an oblong, with the major axis 1,700 miles in length, running southeast from the northwestern portion of Montana, through Dakota, Nebraska, Missouri, and Tennessee, into the northwestern corner of the state of Alabama. On each side of this line the basin spreads out from 300 to 500 miles, while at the east there is a large protuberance from the general outline, extending to the Alleghany mountains. The total area of this basin is 1,240,030 square miles. This immense area includes, wholly or in part, 25 states and 5 territories, besides a small area in the British possessions. All the states and territories between the Alleghanies and the Rocky mountains contribute to the volume of the Mississippi. The eastern outline of the basin conforms roughly to the Atlantic coast; its mean distance from it being about 250 miles. The eastern and western outlines are determined by the two great systems of mountains, the Appalachian and the Cordilleras, which, from the physical laws attending their formation, coincide more or less closely with the coast-lines of the continent.

Hydrographical division of the basin.—The Mississippi is popularly considered to rise in Minnesota, and, for geographical purposes, this is a sufficient distinction; but in considering the Mississippi and its branches with regard to the areas drained, and the actual volume of the streams, some further distinction is necessary. This will be made apparent by a glance at the map, and a comparison of the following data concerning the chief rivers of the basin.

The entire area may be divided into these four grand sections, in the following order of size: The Missouri basin, on the west; the basins of the Arkansas and Red rivers, on the west; the Ohio basin, on the east; the basin of the upper Mississippi.

The upper Mississippi is considered to extend to the mouth of the Missouri, and below that the river is called the lower Mississippi. Humphreys and Abbot, in beginning their report, state that the true Mississippi begins at the mouth of the Missouri—with what grounds we will be better enabled to judge after examining the data of the rivers.

In Humphreys and Abbot's report, which is considered the authority on the subject, is found this division of the basin:

Name of basin.	Area drained.	Average flow per second.	Annual discharge.
	Square miles.	*Cubic feet.*	*Cubic feet.*
Missouri	518,000	120,000	3,780,000,000,000
Ohio	214,000	158,000	5,000,000,000,000
Arkansas	189,000	63,000	2,000,000,000,000
Upper Mississippi	169,000	105,000	3,300,000,000,000
Red	97,000	57,000	1,800,000,000,000
Yazoo	13,850	43,000	1,350,000,000,000
Saint Francis	10,500	31,000	990,000,000,000
Small, direct tributaries	32,400	....	....

Relations of the upper Mississippi and the Missouri.—From this table it is seen that the Ohio river has the largest volume of flow; then comes the Missouri, and next the upper Mississippi. The question as to the continuation of the main drainage trunk lies evidently between the Missouri and the upper Mississippi. As regards extent of territory the Missouri can undoubtedly claim the prestige, for its basin is well-nigh half the entire drainage area, and it determines the form of the Mississippi basin, the major axis, already alluded to, lying nearly in the general course of the Missouri. But, considering the actual sizes of the two streams, the Missouri loses ground; the discharge of the upper Mississippi is 87.5 per cent. of that of the Missouri, while its basin is only 32.6 per cent. of the Missouri basin. At this rate it would require only an addition of 9,320 square miles, or 5.5 per cent., to the drainage basin of the upper Mississippi to make its average flow exceed that of the Missouri. To some extent the upper Mississippi has a claim to distinction as being the continuation north of the general course of the river. The Missouri is a turbulent, rushing stream of muddy water, and with its swift current, carrying with it many logs and trees, presents a strong contrast to the quiet and placid upper Mississippi. Below the junction the united currents flow in a channel even narrower than that of the upper Mississippi, and consequently the stream assumes a character in which the preponderating influence attributed to the Missouri may be more apparent than real. It would seem that the situation is briefly this: If area drained and length of water-course are to be considered, the Missouri should be called the Mississippi; if consideration is to be taken of the volume of flow, together with the general course of the stream, the true Mississippi should be considered, as it is, to rise in Minnesota. It is also apparent that, for hydrological purposes, the rational method is to divide the river into the upper and lower Mississippi, and this distinction will be carried throughout this report.

In comparing the large rivers of the world, allusion was made to the great difference existing between the hydrographic and hydrological relations of rivers. This is brought out very plainly by the data for the rivers of the Mississippi basin, as indeed might be inferred from the great extent of country covered, and the climatic differences of different parts. The facts just mentioned, concerning the upper Mississippi and the Missouri, illustrate it; the dry, arid region, of which a large part of the Missouri basin consists, nearly gives the precedence to the upper Mississippi in point of flow, although the latter drains less than one-third the area included by the former. In like manner, the Ohio, with its basin of only 214,000 square miles, exceeds the discharge of the Missouri by 38,000 cubic feet per second. Again, the figures given show that the average flow per second per square mile of drainage area in the well-watered Yazoo basin is 3.1 cubic feet, while for the Missouri the average flow is only 0.23 cubic foot per second.

TOPOGRAPHICAL FEATURES OF THE BASIN.

As regards topography, the country included within the Mississippi system presents all varieties. Mountain and prairie, arid plain, and alluvial bottom teeming with vegetation, are all represented within its limits. The great extent, however, is very uniform in contour, and presents none of the grand features of a mountainous country. The Mississippi occupies the great basin lying between the two great mountain chains of North America. On the east, the sources of the only large tributary, the Ohio, take their rise among the ranges of the Appalachian system. On the west, the headwaters of the Missouri and the Arkansas are among the massive peaks of the Rocky mountains. At the north, the sources of the upper Mississippi and the northern tributaries of the Missouri and the Ohio are limited by an indefinite line separating the basin from the regions of the great lakes and the Red river of the North; but no range of mountains forms the water-shed, and, in fact, some swamps and lakes drain indiscriminately in both directions.

West of the river.—The region lying between the foot-hills of the Rocky mountains and the Mississippi river may best be described as an immense undulating plain, sloping toward the south and east. Its elevation is from 4,000 to 6,000 feet above the sea at the base of the mountains, diminishing to less than 1,000 feet near the Mississippi. This area constitutes the great plains and the western portion of the prairie region.

East of the river.—East of the Mississippi the topography is not so distinctly prairie, especially south of the Ohio river, but is, nevertheless, not mountainous, except near the eastern water-shed of the basin. In Illinois, northern Indiana, and southern Michigan and Wisconsin are large extents of prairie; but eastward the country is much broken up by the streams, and southward, in eastern Kentucky and Tennessee, occur the Cumberland plateau and other table-lands, making a great diversity in the nature of the surface. Through Indiana and Ohio the soil is fertile and excellent for farming; but south and east of the Ohio river there is not that uniform richness of the land that is so remarkable in Illinois and the prairies of the west and northwest.

The average elevation above the sea is from 500 feet in southern Illinois and Indiana, rising to 800 feet in the northern portion of those states. The average elevation of the undulating surface of Ohio is about 1,000 feet. The surface in Tennessee and Kentucky varies from 300 feet above the sea near the Mississippi, to from 600 to 1,000 feet in the central portions. On the Cumberland plateau the height above sea-level averages about 3,000 feet. In the East Tennessee valley the elevation ranges from 600 to 2,000 feet.

Near the sources.—The country about the extreme sources of the Mississippi, far away in Minnesota and Wisconsin, is from 1,200 to 1,500 feet above the sea. As is already described in the "General Remarks upon the Water-power of the Northwest", there is one point where the water-shed of the Mississippi basin crosses the end of the lake Superior trough, which is only slightly elevated above that lake, or about 610 feet above the sea. This is lower than the altitude reached by the line of water-shed even in part of the state of Mississippi, adjoining the gulf of Mexico.

Staple products.—The Mississippi basin is the agricultural region of the United States, and its population of 21,821,254 is directly dependent upon the cultivation of the ground for its support. The mines of the West do very little to increase the wealth of the country in comparison with the products of the soil. According to the statistics of the Census of 1880, the value of the mineral product of the entire country but slightly exceeded the value of the agricultural products of the state of Illinois alone. The staple products of the land are wheat, Indian corn, tobacco, cotton, and sugar; in the western portion of the basin, and to some extent in the east, grazing is carried on extensively. In considering the distribution of these staples, the Mississippi valley may be roughly divided into zones belonging to the several crops, although they merge one into the other. The wheat belt extends from the vast prairie of the British possessions down into Illinois, the winter wheat not extending above southern Minnesota. Then comes the corn belt, more or less confused with the wheat region, and extending down about to Mississippi, although large quantities are raised in Texas. In southern Tennessee begins the cotton belt, which continues south to the Gulf coast. Along the delta of the Mississippi, in Louisiana, are sugar-cane plantations.

The Mississippi basin has rapidly increased in population within recent years, owing largely to the settlement of the western prairies. In 1870 the number of inhabitants was 16,431,855, and in 1880 it had increased to 21,821,254.

Navigation.—This rapid settlement has been at once the outgrowth and the cause of the great systems of railroads which cross the basin from east to west and are the principal channels of freightage for the products of the soil. The great river itself, with the larger branches, furnishes a grand system of internal navigation of great value to the country. The Mississippi basin is stated by one estimate to have 15,000 miles of navigable waters, of which the Missouri has 3,500 miles, and the Ohio has 5,000 miles. Over large portions of these distances, however, as already stated, navigation is impracticable in low stages of water. The route from Pittsburgh down the Ohio to the Mississippi is of great value, and at high stages the river is alive with "stern-wheelers", barges, and tow-boats, which carry the coal, oil, and iron of the east, to the states reached by the Mississippi. The trade down the river to New Orleans, and especially to Saint Louis, is large and of increasing importance. The navigation of the Missouri is very difficult, owing to the uncertainty of the channel; and the upper portion of the stream is now used to only a small extent for trade.

DISCOVERY AND EARLY EXPLORATIONS OF THE MISSISSIPPI RIVER.

The first explorers of our continent were the Spaniards and the French; and it was fitting that the river which ranks first among its water-courses, whose very name signifies the "Father of Waters", should be discovered and its course explored by these earliest invaders of the New World.

SPANIARDS, 1541.—De Soto and his following of Spanish cavaliers started from the southern Atlantic coast in their fruitless search for the "El Dorado", and after tedious wanderings through the Gulf states, passing northwest through Alabama and Mississippi, they came out at last on the crest of the bluffs which form the east shore of the

Mississippi, near where Memphis now stands. It is thought that these men, as they stood above the broad flood of the Mississippi on that day in June, 1541, were the first Europeans to gaze upon its waters. De Soto and his men were, of course, sadly disappointed in their hopes concerning the discovery of an El Dorado. Instead of plenty and peace, they found unending hardships; their visions of a fountain of life (conjectured to be caused by Indian rumors concerning the hot springs of Arkansas, toward which they were journeying) ended as visions always do; and after burying their leader beneath the waters of the stream, they fled down its rapid current, glad of the means it offered for escape.

THE FRENCH.—The discoveries of the Spaniards were in great part abandoned, and not until a century later was the region of the Mississippi again invaded. Then it was that the French explorations began, which, including the interests of domain, barter, and religious zeal, left a permanent impress upon the country, strongly apparent at the present time. In Mr. Francis Parkman's *History of the Great West* is an exceedingly interesting account of the early French possession, from which the following facts are gleaned:

Nicollet.—Jean Nicollet, a French interpreter, approached the Mississippi from the north. He heard of an Indian tribe to the westward, which traded with a tribe of men with smooth faces and no hair. Europe was endeavoring to find a western passage to the east, and what more natural than for him to suppose that these beardless men were the Chinese. He heard from the Indians that there was water communication to the west, and a great river; this, he concluded, must be the long-sought western passage, and he determined to find it. Accordingly he set out on the great lakes, ascended the Fox river, made the portage to the Wisconsin, and descended that wide stream to near the mouth. Nothing doubting that this led to the Pacific ocean, he returned.

Marquette, 1672.—On May 17, 1672, Marquette and Joliet started from Point Saint Ignace, on the straits of Michillimackinac, pursued Nicollet's route down the Wisconsin, and on June 17 entered the Mississippi, the first white men to reach its northern waters. Down its placid course they floated, until greatly terrified by the boiling, surging water of the Missouri river, which at that time was probably in flood from the melted snow of the Rocky mountains. Marquette wrote: "I never saw anything more terrific." Along the now turbulent stream their canoe was hurried, and they reached the mouth of the Arkansas river, where they stopped; and on July 17 began their return journey, confident that this great stream entered the gulf of Mexico. At the foot of the La Chine rapids of the Saint Lawrence, within sight of their final destination, Montreal, after months of arduous labor and many miles of travel, their canoe upset, and all their notes and maps were lost. Glad was Marquette, who wrote an account of the trip, to escape with his life.

Hennepin, 1680.—Father Hennepin, in 1680, was sent to explore the Mississippi; and, being taken captive by the Sioux Indians, was carried away by them in the very direction he wished to follow. He spent the winter in their lodges about Mille Lacs, on the upper Mississippi, and the following year was allowed to return. Hennepin was the first man to explore the Mississippi above the mouth of the Wisconsin, and to him is due the earliest description of Saint Anthony's Falls, the Owah-Menah, or the "Falling Water" of the Sioux.

La Salle, 1682.—La Salle next explored the Mississippi. Pursuing the course taken by Marquette and Joliet on their return trip, he started down the Illinois river; and on February 6, 1682, entered the great river. After waiting for the floating ice to disappear, this party too floated down the current, landed at the Arkansas, as their predecessors had done, and then, continuing their course, reached the gulf of Mexico. On a dry piece of ground near the mouth they planted a column bearing the French coat of arms, and on April 9, 1682, La Salle took formal possession, for Louis XIV, of the entire basin of the Mississippi and the region adjoining the Gulf, giving it the name of Louisiana.

Transfers of territory.—The French soon controlled this region by means of a line of frontier posts. Subsequently the part east of the Mississippi was ceded to Great Britain, and fell into the hands of the United States at the close of the Revolution. The western part went into the hands of Spain, then was returned to France and was sold by it to the United States in 1803.

Traces of the old-time rule and the Indians.—All along the course of the Mississippi the traces of the old-time rule are to be seen. On the lower part of the stream are to be noticed the influences of Spanish life, and all along its course are scattered the traces of French occupancy. The names of La Salle, Joliet, and Hennepin, of Nicollet, Dubuque, Duluth, and good old Père Marquette are familiar. Even the Saints are represented: Saint Paul, Saint Peter, Saint Louis, etc., are well-known names. The country about the extreme upper waters of the Mississippi was occupied by the fur-traders of the Northwest Company, and the Hudson Bay Company had many a quarrel with them about disputed territory. This was ended by the formation of the United States. The region of the upper Mississippi has been, until comparatively recent years, the scene of many bloody fights between the Sioux and the Chippewa Indians. Their boundary line ran through the state of Minnesota, cutting its eastern border on the lower Saint Croix. They, too, have left their mark in the present nomenclature. The beautiful names in which the state abounds are due to them. Minnesota, sky-tinted water; Minneopa; the famed falls of Minnehaha, Minnetonka, Owah-Menah, the falling water; and many other melodious terms are due to the Sioux. The wilder names to the northward, as Pokegama, Totogatic, etc., were given by the Chippewas, who yet exist there in considerable numbers. Their language abounds in names like Suskenobekouse, a small rapid; Tongamink, a slack-water; Kakawbekouls, etc. Their name for the present Mille Lacs was Missi-saugaigan, or Great Lake.

Names of the Mississippi.—The name Mississippi appears to be derived from the Algonquin language, which originated in the eastern part of the continent. It is found spelled in various ways, Messasipi, Messipi, Michisipi, etc., but according to Schoolcraft, the present name is a corruption, through French and then English handling, of the name Missi Sepe, meaning Great River, a word, as he remarks, much softer and more beautiful than the modern ending, *sippi*. Various names were given to the river by the early explorers, as Rivière de Buade, Rivière Colbert, and Rivière de la Conception; but all have finally given way, as they should, to the old Indian name.

GENERAL DESCRIPTION OF THE COURSE OF THE MISSISSIPPI.

In describing the basin of the Mississippi, the uniform, undulating surface of the basin was found to continue northward, unbroken by any mountain chain. Hence the river can not be considered a mountain stream. Its utmost sources are not more than 1,680 feet above the sea, although 2,616 miles distant from it. The Hauteur des Terres, a low range of sandy ridges of glacial origin in northern Minnesota, contains the birthplace of the Mississippi.

The source.—It springs from a sheet of water, one of the innumerable sparkling lakes which dot the surface of that region, called by Schoolcraft, who visited it on July 13, 1832, Itasca lake. The Chippewa name was Omoshkosh Sagaigon, and the French traders called it Lac la Biche. The length is about 4 miles, and the breadth exceeds nowhere half a mile. It is fed by trickling streamlets, none of which are over 2 miles in length. The surrounding country consists of low ridges of light sandy soil, largely covered with pine and intervening tamarack and cedar swamps. Mr. Schoolcraft, in his account of his trip, describes the voyage down the river from lake Itasca. From his account the following description is abstracted:

The outlet.—The outlet is about 10 or 12 feet wide, and from 12 to 18 inches deep. From the outlet the force of the current increases, and for 12 miles the stream is rapid and the turns are very abrupt. Next comes a savannah-like valley for 8 or 9 miles, in which the stream has a gentle current. Beyond this, the river is narrow and very rapid, over a rough bowlder bed, after which comes a second plateau, perhaps 9 miles long, succeeded by some easy rapids. Then come more savannahs, with a wide, winding channel; then short rapids, which, writes Schoolcraft, bring the river out of what may be called the Alpine passes. Then the stream takes a size easily navigated by canoes, and thus lake Bemidji is reached. Four miles above this lake the east branch comes in from the southward. This heads in lake Ossowa, only 6 miles from Itasca lake. Schoolcraft describes the east branch as "a thread wound along the savannah valley." Well up its course are rapids, aggregating perhaps 48 feet in descent.

Between lake Bemidji and Cass lake there are strong rapids, among which Schoolcraft counted ten principal ones. In this distance of about 145 miles, from the utmost sources to the outlet of Cass lake, the total fall is about 380 feet. The descent from lake Bemidji is 42 feet. From Cass lake to the outlet of Leech lake there is a good current, the total descent being about 44 feet, and the average width about 60 feet. Leech Lake river is nearly as large as the main river, and below it the width averages 100 feet. Below Leech Lake river to the falls of Pokegama the course of the river is exceedingly tortuous, in a prairie averaging 3 miles wide, bounded by low sand ridges, covered with yellow pine. The current is sluggish. Thus far the bed of the stream is entirely in glacial drift. The most prominent features are the low sand ridges with their covering of pine; the tamarack and cedar swamps; in places forests of elm, maple, and ash; and along the shallow valley, the rushes, wild rice, and rank grass. At Pokegama falls is met the first rock in place. Below Pokegama falls the current is good, with many rapids of small extent. The stream averages 300 feet wide down to the Crow Wing river (formerly called Rivière de Corbeau), and is less winding. The clay banks, at first 4 to 10 feet in height, gradually become higher. There are forests of elm, maple, birch, oak, and ash. We have now followed the river through fully the 180 degrees of a semicircle, which it has described from its source. The mouth of the Crow Wing, which enters from the west, is only 75 miles from Itasca lake, while the distance along the river from the sources is 450 miles. From this point the general course of the Mississippi is southeast for 475 miles. The Crow Wing is an important tributary, and increases the size of the stream materially. The average width down to Saint Anthony falls is stated by Schoolcraft to be 750 feet. There are several rapids, the chief being Little falls and Sauk rapids, formerly called Big falls. Many timbered islands occur; the banks are abrupt, of clay or sandy loam, and lead to natural meadows, 60 feet above the river. These contain a rank growth of grass interspersed with scrub oak, and were the favorite feeding-grounds of the buffalo.

Saint Anthony falls.—At Saint Anthony falls occurs a sudden break in the nature of the river. It pitches down a vertical fall and rapid, amounting to 75 feet in a half-mile, and, in so doing, leaves the prairie and clay banks for a channel between rocky bluffs of limestone and sandstone. These bluffs continue for many miles down the river, increasing to even 500 feet in height as the bed sinks below the general prairie level, and they give great variety and beauty to the scenery. Their sides are not vertical bare surfaces of rock, but the easily-eroded stone and drift have formed slopes well wooded or covered with grasses. Ten miles below Saint Anthony falls, the Minnesota river, formerly called the Saint Peter's river, enters from the west. It is the largest tributary thus far encountered, and below it the breadth of the stream is about 1,000 feet.

Below the Minnesota river.—From this point down to the mouth of the Missouri the general characteristics are the same—a broad, placid stream, with innumerable islands, which make the entire width occupied by the river average about one mile; varied scenery of the bluffs, now rugged and steep, now sloping away in beautifully wooded hills, several hundred feet high, to the prairie surface. In many places, especially where the tributaries enter, there are fertile flats between the river and the bluffs. Fifty-five miles below the Minnesota river is lake Pepin, an expansion of the river apparently caused by the immense quantities of sand brought down by the Chippewa river. It is 27 miles long and 2 or 3 miles wide.

The large tributaries are the Saint Croix, Chippewa, Wisconsin, Rock, and Illinois, on the east; and below the Minnesota river on the west, the Iowa and the Des Moines. Two exceptions occur to the otherwise placid character of the river. At Rock Island, 384 miles from Saint Paul, there are rapids over a succession of rocky chains extending across the river, and the descent is 20.4 feet in a distance of 12 miles. Again at Keokuk, 509 miles from Saint Paul, is the foot of the Des Moines rapids, where, in a distance of 11 miles, the river falls 21.85 feet over a rocky bed. These two rapids and those above Saint Anthony falls will be more fully described when the water-powers are considered.

This brings us to the end of what is known as the upper Mississippi, at a distance from the source estimated to be 1,204 miles.

THE LOWER MISSISSIPPI.

The Missouri now enters, the great tributary of the basin; and from this point down to the Gulf the river, now called the lower Mississippi, possesses the character of a great river. The combined currents flow in a channel scarcely over a half-mile wide, and make a turbulent stream, especially during high-water periods. The water is muddy, and snags and floating trees, washed from the banks, are more numerous than on the quieter current of the upper Mississippi. The bluffs continue, with a bottom upon one side. From the Missouri, for a distance of about 185 miles, down to Cape Girardeau, the bottoms are almost entirely upon the east side of the river, and are very fertile, including the celebrated American bottom. They are from 3 to 8 miles wide. Many islands occur. Along the bottoms the banks are low, and have to be protected from floods by levees. Scattered through the bottoms are numerous sloughs and crescent-shaped lakes, marking the old courses pursued by the river; cut-offs occur, or the smaller channels are gradually choked with *débris* of fallen trees and snags; sand and mud silt in; and, in time, the old channel is left a slender, curved lake, perhaps several miles away from the river. Below Cape Girardeau, for about 6 miles, the bluffs rise close to the river on each side, and then leave it—on the east passing up the valley of the Ohio, which enters about 30 miles below; on the west disappearing in the Great swamp, caused by the subsidence of the ground in the early part of the present century.

Alluvial region.—At Commerce, where the river passes from the bluffs, may be said to commence the alluvial section of the basin. It continues clear to the Gulf, the land being low, and, indeed, beneath the flood level of the river. The natural surface is highest immediately at the river bank and slopes back for from 1 to 3 miles to the swamps. The soil is of great fertility, and has been largely reclaimed by levees thrown up along the river banks; but these are continually giving way, allowing the river to inundate the country. It was estimated that during the floods of the fall of 1881, when at places the river was higher than it had before been since the flood of 1858, the damage resulting below Saint Louis amounted to $3,300,000. As above the Ohio river, so also in this portion, the banks are constantly changing, and many lakes, sloughs, and swamps are the result. The course of the river is very winding. From the mouth of the Ohio to the Gulf, by the river channel, the distance is 1,097 miles, while in a straight line it is only 497 miles. Sometimes in rounding a great bend, the erosion will take place on both sides of the neck, until finally a channel is worn through and a cut-off is produced. This has occurred in a great many instances, whereby the channel is apparently much shortened and the velocity increased. The bluffs approach the river only at Helena, on the west, but at several places the river runs close under the eastern bluffs, from 200 to 400 feet high. The points of contact below the Ohio river are at Hickman, at the first, second, and third Chickasaw bluffs, and next at Memphis, Tennessee, where is the fourth Chickasaw bluff. Below Memphis is the wide Yazoo bottom, and the next place at which the bluffs strike the river is at Vicksburg, Mississippi. Then the line of bluffs is near to the river down to Baton Rouge, and touches it at nine points between those places. At Baton Rouge the last of the bluffs is seen. They there leave the river's course and veer to the eastward, in the direction of the Gulf coast. The alluvial region has an average width of 30 to 40 miles from the Ohio down to Baton Rouge, and at the Yazoo bottom is not less than 80 miles across.

The Delta.—A few miles below Baton Rouge may be said to commence the delta of the Mississippi. There the highland turns eastward as already described, and strikes the Gulf about 100 miles east. On the west the line of highland runs along the shore-line of the Gulf at an average distance from it of 20 or 30 miles, and marks the limit of the alluvial soil. The features of the alluvial region are the characteristics which distinguish the lower Mississippi: Low shores, with occasionally the appearance of a bluff; great sweeping curves of the river; in the lower part, particularly, swamps and bayous. The growth of cottonwood, willow, sycamore, ash, and elm gradually changes toward the south; the cypress appears in the swamps, and becomes more abundant; sweet-gum and the tupelo are noticed; the palmetto is seen, and Spanish moss festoons the trees. In lower Louisiana the live-oak is met with. About the mouth of the river the ground and vegetation gradually fades away into the Gulf, as is the case with delta-forming rivers. The climate and the vegetation are semi-tropical. We have thus followed the river from its cold springs in northern Minnesota to where it is lost in the warm waters of the gulf of Mexico.

The bed of the river.—The bed of the river consists of stiff clay, mud, sand, and gravel. Toward the mouth, where even what land there is has been built up by the river itself, the shores and bed are soft, and the land marshy, except where reclaimed; and generally below high-water level. Large quantities of sediment are yearly carried down to the Gulf, and the building out of the delta is constantly going on. The estimate has been made that enough solid matter is carried down to the Gulf each year, either in suspension, or else pushed along the bed of the river, to cover one square mile to the depth of 268 feet. This mud is spread out on the bed of the Gulf for miles; and the shores, if such they can be called, immediately at the mouth, are hardly more than a morass.

The mouth.—The river divides into five radiating arms, called passes, at the mouth, and it is very difficult to maintain even a ship-channel through their uncertain beds. Captain Eads' system of training-walls, and the constant agitation of the beds by dredges, are successful with the Southwest pass. A singular phenomenon is that of the "mud lumps", which will rise suddenly to the water surface like a small volcano, with a salt-water spring at the top. They are not satisfactorily accounted for, some attributing them to artesian action, others to the generation of carburetted-hydrogen gas from buried vegetable matter; but, at all events, they occur in unlooked-for places, and often interfere with navigation.

The bayous.—The delta is intersected by numerous bayous, or water-channels, running irregularly through it, and often connected with each other. Three of these, the Atchafalaya bayou, the bayou La Fourche, and the Plaquemine, are of interest, in connection with the Mississippi. The Atchafalaya starts from the mouth of the Red river, and flows thence to the Gulf, with a length of 133 miles, while by the Mississippi the distance is 326 miles. During floods on the Red river that stream feeds the Atchafalaya chiefly; but high water in the Mississippi pours a great flood down the bayou, and threatens to make it the main stream. In 1839 persons could cross at the head of the Atchafalaya in low water on foot. In 1850 it was 50 feet deep at the head in high water, and 730 feet wide. On December 29, 1873, the discharge was 122,000 cubic feet per second into the Atchafalaya. In 1879 it was 85 feet deep at the head during extreme low-water, and 900 feet wide.

Bayou La Fourche has been closed up. In 1860-'61 it had a maximum discharge at the head of about 11,500 cubic feet per second. Bayou Plaquemine had then a maximum drainage from the Mississippi of 35,000 cubic feet per second. The many bayous intersecting the delta are very valuable for the navigation they allow; and Major C. W. Howell, corps of engineers, U. S. army, who is stationed at New Orleans, is clearing them, the chief obstructions being driftwood and snags. Cotton, sugar, and lumber, chiefly southern pine and live-oak, are the principal shipments.

Gulf tides.—The average spring tides on the Gulf are about 1.7 feet, and their effects are not observable to any great extent upon the Mississippi; but probably delicate measurements would show oscillations due to them as far up as the mouth of the Red river, 316 miles from the mouth. The effects of strong winds, however, are much more prominent, and continue for days at a time. The Gulf level is raised 3 or 4 feet, and by hurricanes has in one instance been raised even 7 feet; and an oscillation of 1.5 foot from this cause has been noticed at Red River Landing.

Dimensions of the river.—The following data concerning the river are inserted to give a general idea of its dimensions; elevations, discharge, etc., will be noticed further on. From the Missouri to the Ohio river the width varies from 2,500 feet to a mile; and in some of the bends where islands occur, this increases to even 3 miles between extreme shores. The average slope in this distanc is nearly 6 inches per mile. From the Ohio to the Arkansas the average width is 4,000 feet; depth, in low water, 49 feet; and low-water slope, for most of the distance, about 0.4 foot per mile. From the Arkansas to the Red river the corresponding figures are 3,600 feet, 56 feet, and the low-water slope, 0.158 foot for the lower half of the distance. From Red river to bayou La Fourche the figures are 2,900 feet, 78 feet, and from 0.034 to 0.025 foot. From bayou La Fourche to the mouth, 2,350 feet, 114 feet; and the slope is first 0.008 foot per mile, then 0.004 foot, then increases to 0.036 foot, and at the mouth is about 0.03 foot per mile. The above figures are gathered from Humphreys and Abbot's report, published in 1861.

The maximum flood-rise above low-water level is as follows: At New Orleans, between 14 and 15 feet; from there it increases until it attains an extent of from 50 to 52 feet at Natchez, Vicksburg, and Cairo. At Saint Louis, where the channel is narrow, the highest rise was about 40 feet above low-water. On the upper Mississippi the maximum flood-rise varies from 10 to 20 and even 30 feet.

NAVIGATION AND RIVER IMPROVEMENT.

The navigation of the Mississippi is a matter of great importance, not only to the immediately adjoining states but to the country at large; and as the river requires constant attention to maintain it in a navigable condition, it gives rise to one of the largest works undertaken by the government. The Mississippi River commission, which includes some of the most prominent engineers of the country, deals with the problem of maintaining and improving the navigation of the entire river. At different places along the river are stationed officers of the engineer corps of the army, constantly employed in benefiting navigation. Their interesting reports are embodied in the annual reports of the chief of engineers. The upper Mississippi is thus divided: The engineer's office at Saint Paul, Minnesota, has charge of the entire river down to that place. From Saint Paul down to the mouth of the Illinois river the channel is in charge of the office at Rock Island, Illinois, with the exception of the Des Moines rapids at Keokuk, which are in charge of a separate office at that place. From the Illinois to the Missouri river the upper Mississippi is under the charge of United States engineers stationed at Saint Louis.

The main features of the work upon the river from the mouth up are the maintaining of a navigable and certain channel (rendered more or less difficult by the mobile character of the bed and banks), and the removal of snags, driftwood, etc. The preservation of a channel at the mouth has been very difficult, and stirring of the soft bed, dredging, the building of training-walls, the closing of most of the passes, and a ship-canal have all been proposed. As has already been mentioned, the combination of the methods of training-walls and stirring the bottom, the outgoing current carrying off the mud, is successful upon the Southwest pass. Upon the river above, dredging is done where necessary; wing-walls are built of brush and gravel to direct or confine the current, and dams are thrown across the heads of sloughs (the minor channels around islands) to concentrate the low-water flow in the main channel. This is necessary, not only on the lower but also on the upper Mississippi, where, although the wearing of the banks is not so great, the bed is largely composed of shifting sand-bars, difficult to control. Above the mouth of the Chippewa river in Wisconsin the difficulty from sand is not so great. In past years navigation was dangerous from the snags and "sawyers" which abounded, especially below the Missouri; now the government boats are careful to remove these, and they are no longer sources of danger. By the caving of banks trees are thrown into the current; finally they sink or become lodged in a bar; a branch rises above the water, or within only a few feet of the surface; this limb is called a "snag". It may be that a tree will float down-stream until its loaded roots sink to the bottom, where they lodge, while the broken end will float, swaying with the current; such an anchored log is called a "sawyer"; a boat passing down stream will run over this, merely depressing it, but when going against the current, the stiff trunk, braced against the bed, may break a hole in the bow.

In the upper portion of the upper Mississippi the low-water navigation is especially difficult. Saint Paul is considered its limit; and Saint Anthony falls, of course, oppose a barrier, only to be surmounted by a canal and locks. Above the falls it is practicable to make the river navigable for small vessels even to Pokegama falls, by dredging, slack-water dams and locks, and the methods usually pursued with the smaller streams.

THE "RESERVOIR SYSTEM".

A scheme for regulating the flow of the upper Mississippi and thus improving the low-water navigation, which has received much attention of late, is the reservoir system. A glance at the map will show that about the upper waters of the main river, the Saint Croix, Chippewa, and Wisconsin rivers, are a great number of lakes and extensive marshes. These, and the generally level surface of the entire basin of the upper Mississippi, make its flow rather more uniform than that of the other streams; but the aim is to increase this beneficial influence upon the river by an extensive system of artificial reservoirs upon the streams mentioned. The reservoir system has not yet been definitely decided upon, but for several years past Major Charles J. Allen, captain of engineers, in charge of the United States engineer's office at Saint Paul, has been making observations and surveys upon which to base calculations of the probable effects of the proposed plan upon the navigation of the river. The topography is so favorable that many extensive reservoirs can be practically constructed. There were, when Major Allen's report of December 12, 1880, was made, seven available sites that had been examined on the Mississippi and its tributaries above Saint Anthony falls, fourteen upon the Saint Croix, twelve on the Chippewa, and six upon the Wisconsin. The entire cost of the proposed improvements was estimated at $1,500,000.

By careful estimates it is found to be practicable to increase the discharge of the several streams mentioned by the following amounts, for a period of ninety days, if the above reservoir sites are improved. The natural low-water discharges at the mouth are also given. The figures are taken from the engineer's reports:

River.	Natural low-water discharge per second.	Extra supply per second from reservoirs during ninety days.
	Cubic feet.	*Cubic feet.*
Upper Mississippi at Saint Paul	5,800	7,100
Saint Croix	2,800	4,400
Chippewa	2,600	2,800
Wisconsin	4,700	2,300

The calculations are made with liberal allowances for loss from evaporation, etc., and no reason appears why, with the above additions to the low-water flow, the tributaries, at least, shall not be very greatly benefited. How would it be with the main stream? From Major Allen's report to the chief of engineers, dated December 12, 1879, the following figures are obtained: For 100 days a discharge of 12,200 cubic feet per second could be depended upon at Saint Paul, during the low water of summer and fall. The discharge during the very low stage is now 5,800 cubic feet. Below the mouth of the Saint Croix the discharge for 100 days of low water would be about 18,000 cubic feet per second, while the discharge during the very low stage is now about 8,600 cubic feet. Below the Chippewa river the discharge for 100 days of low water would be, in round numbers, 24,000 cubic feet per second, while the extreme low-water flow is now 11,000 cubic feet. Below the Wisconsin the discharge for 100 days of low water would be about 36,000 cubic feet per second, while the extreme low-water discharge is now 17,000 cubic feet.

Thus the low-water discharge would be more than doubled and navigation greatly benefited. That the effects would be felt for a great distance down the river can hardly be doubted. The adding of 16,600 cubic feet per second during three months of the year to the low-water volume is not to be disregarded: 16,600 cubic feet per second is 87 per cent. of the extreme low-water flow at Rock Island, 55 per cent. of that above the mouth of the Illinois river, and about 30 per cent. of that at Saint Louis, below the mouth of the Missouri.

The adoption of the reservoir system would also be of very great value to the water-power interests along the river, but that will be considered later.

GEOLOGY OF THE MISSISSIPPI BASIN.

In the "General Remarks" prefacing the Report of the Water-power of the Northwest, allusion was made to the base, or rib of Archæan rock, extending west through Canada and the northern part of the United States into Minnesota, upon which, as a shore, the successive strata were deposited toward the south. The Paleozoic seas, breaking at the base of this line of Archæan mountains, deposited their sediments, as they advanced and receded, in strata of successive outcrop, with a general slope south and west in the central portion of the modern continent.

Then came the Glacial period, covering everything in the north with a blanket of drift, and, with the subsequent modifications, changing the entire topographical character of that region.

These are only the prominent facts which stand out in the geological history of the Mississippi basin; there were many minor changes of great influence in determining our country as we see it.

The Mississippi in its course southward crosses all the successive strata just mentioned. The sources are underlaid, after the covering of drift is removed, directly by the Archæan rock; the mouth is surrounded by the soft marshes of its own delta now forming; between these two extremes all ages are represented.

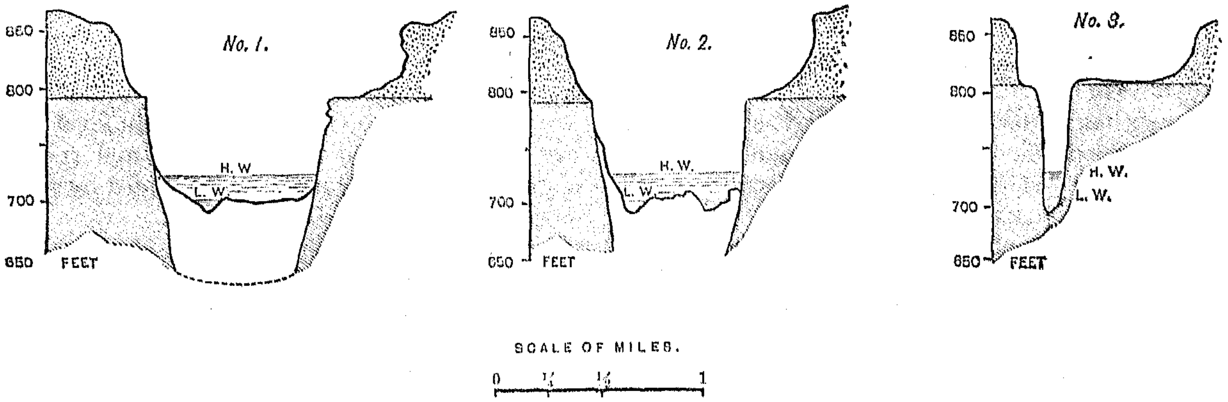
Modern action of the river.—At the close of the Quaternary age the Mississippi was striving to clear from its bed the accumulation of the Drift period, a process still in progress. This is a slow operation, with its comparatively small volume and diminished slope. Its bed is yet 100 feet above the rocky bottom of the ancient trough, nearly as far north as the junction of the Minnesota river, and at the mouth several hundred feet of transported drift material lie between. In only two places below the mouth of the Minnesota does the river run over a rock bed, viz., at the Rock Island and at the Des Moines rapids. It was suggested by Dr. J. S. Newberry, and subsequently ascertained by General G. K. Warren, of the corps of engineers, U. S. army, that in these two cases the river had forsaken its ancient channel and was running across the country, wearing a new passage in the rock.

Significance of the modern features.—We can now see the true significance of the present physical aspect of the Mississippi river. The rocky bluffs that limit the trough of the upper river are the old cliffs which confined the ancient stream. The finely-divided soil which crowns their summits, and in many places rounds their outlines, is the *Bluff* formation, the Loess, which has been washed out of the trough by the modern river. The prairies and bottoms which skirt the river between the bluffs are built out of the modified drift and Loess with which the ancient trough was filled, covered in places with the alluvium of the modern river. The bluffs of stratified clay, gravel, sand, etc., along the lower river have been carved out of the ancient deposits brought down to the sea by the river itself. Lastly, the delta is the modern representative of that ancient process which gradually filled the lower trough of the river, except that the latter was the filling up of an arm of the sea, while the modern creation is a true delta formation, throwing its arms far out into the gulf of Mexico. During past ages the mouth of the Mississippi has passed north and south several times, and more than twice has it visited every point along a line of 1,000 miles.

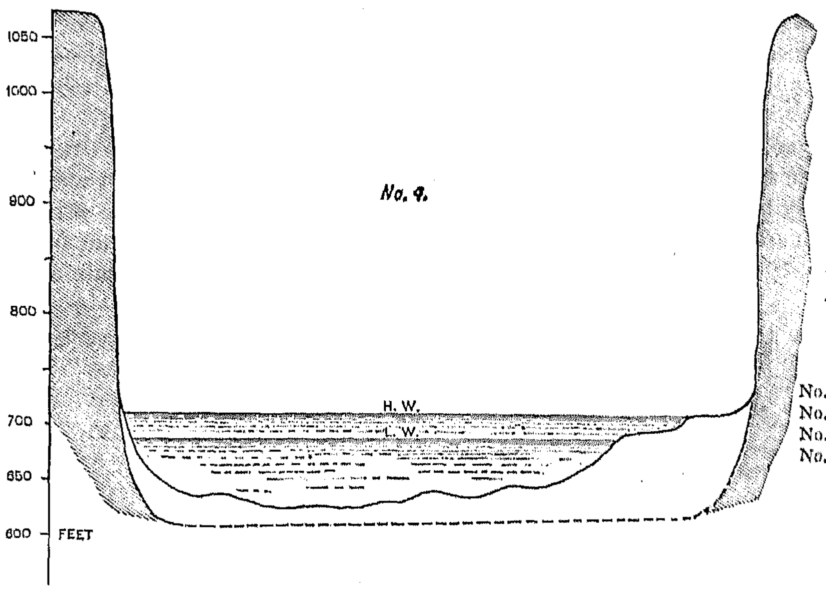
There are a few points to be noted in the geological history of the *headwaters* of the Mississippi.

Ancient course of the upper Mississippi.—During and subsequent to the Glacial period the representatives of lake Michigan and lake Erie overflowed into the Mississippi from the east, and to the north the vast drainage basin of lake Winnipeg, in British America, added its tribute to the Mississippi. In the report on the Red river of the North, attention has been called to the evidence in favor of the theory that the Minnesota valley was once the channel whereby the large drainage of the lake Winnipeg region passed south to the Mississippi. Now, the real continuation of the old Mississippi trough above Saint Paul is this valley of the Minnesota, as the accompanying sections and map show, and the truth seems to be that in days before lake Winnipeg changed its allegiance the Minnesota river was the true upper Mississippi, and the modern stream which bears that name, although probably much larger than now, was a comparatively insignificant tributary from the area to the eastward, entering the great river at some point of the Minnesota valley a few miles above the present junction.

Saint Anthony falls.—In the case of the Mississippi river above the junction of the Minnesota we find a condition similar to that existing at the Rock Island and the Des Moines rapids. The river has deserted its ancient bed a short distance above Saint Anthony falls, and is now excavating a new channel through the rock. The peculiar character of the strata there—Trenton limestone underlaid by the soft Saint Peter's sandstone—has made the falls possible. Hence Saint Anthony falls are recent.



Vertical scales show heights above sea-level.



SECTIONS
OF THE
MISSISSIPPI AND MINNESOTA VALLEYS,
Copied from Geological Report of Minnesota, 1880.

No. 1, Section of Minnesota valley above mouth.
No. 2, Section of Mississippi valley below mouth of Minnesota river.
No. 3, Section of Mississippi valley above mouth of Minnesota river.
No. 4, Section of Mississippi valley at lake Pepin.

One point to be noticed is, that in approaching the sources of the river we have been leaving behind us one outcrop after another of the different layers of rock, and are nearing the primitive metamorphic rock of the Archæan base of the continent. It is true that the rock is usually covered, except where the rivers run, by the blanket of drift, but the evidence is plain that we are nearing the northern coast-line of the old Paleozoic sea. Ascending the Minnesota valley, the bed after a time runs out upon the hard granites and syenites of the primitive formation, and on the upper Mississippi a trip of 78 miles above Saint Anthony falls brings us to rapids where the water dashes over the unyielding Archæan rock. Because of the resisting nature of these earliest formations the ancient streams carved out their channels slowly, and hence no deep troughs are to be seen, such as mark their passage through the softer sedimentary rock lying farther south; the only bluffs of any prominence due to erosion consist of drift. Thus the troughs of the Minnesota and of the extreme upper Mississippi have been worn through the drift blanket, in many places to the hard granitic bed; the bluffs are composed of drift entirely, but as the sources are neared, where the river has made comparatively little impression even upon the soft material of the drift, the bluffs sink into low banks, and the bed is entirely in clay, sand, and gravel, while accumulations of bowlders form the only rapids.

Effect of the metamorphic rock upon the water-power.—The presence of the primitive rock in this region of the Mississippi basin has a most important bearing upon the water-power of this portion of the northwest, as the resistance to erosion preserves the falls and rapids, whereas in a more uniform and softer material the descent would have been distributed along the entire course of the river.

Sketch of the probable past history of the water-power.—There is no evidence that the Mississippi existed previous to the close of the Carboniferous age. Each one of the changes down to the present day has wrought its corresponding change upon the water-power, which is dependent upon the two factors—volume of flow and fall of stream.

Each change of level would have its effect upon the *theoretical* water-power of the streams. It is, of course, impossible to ascertain the amount of rain which descended in those ancient days, or the volume of the streams, but we know that in the ages from the Carboniferous to the Glacial period there were fluctuations in level which must have increased and diminished the amount of water-power, as the slope of the streams altered and the confines of the ocean changed. We also know that a large part of the western half of the basin was occupied by the sea until the middle Tertiary age.

As the continent rose, preceding the Glacial period, the extent of drainage basin and the slope of the streams gradually increased, and hence the water-power developed. But by degrees the climate became more severe, the low-water stage of winter lasted longer into the spring, and as the chilling ice-sheet came creeping down toward the south, we may imagine the branches of the Mississippi congealed and absorbed in the great frozen mass above. Certainly all water-power was locked fast where the ice-cap came, and as it reached south to near the latitude of the mouth of the Missouri, all the drainage of the region north was cut off. The southern and western tributaries of the Missouri and the southern part of the Ohio basin were free, and as the lower rim of the ice-cap was constantly melting, this tribute swelled the streams to large size. The water-power must then have been confined to that portion of the basin not covered by the ice. As the ice-sheet receded, the volume of water from its melting increased.

When it had retreated into northern Minnesota, the northern part of the continent was elevated many hundred feet above its present level, and for hundreds of miles east and west the great barrier of the retreating glacier was pouring its floods of water and mud down the rapid slope of the Mississippi basin to the sea. What must have been the power of these torrents, with the heavy fall and the volume of flow is hardly to be conceived. Never since has it been approached; for after the glacier receded the land sank, the slope to the south diminished, and the ocean ascended the valley of the Mississippi, until finally it united with the great inland, fresh-water sea. The Mississippi as a river was gone.

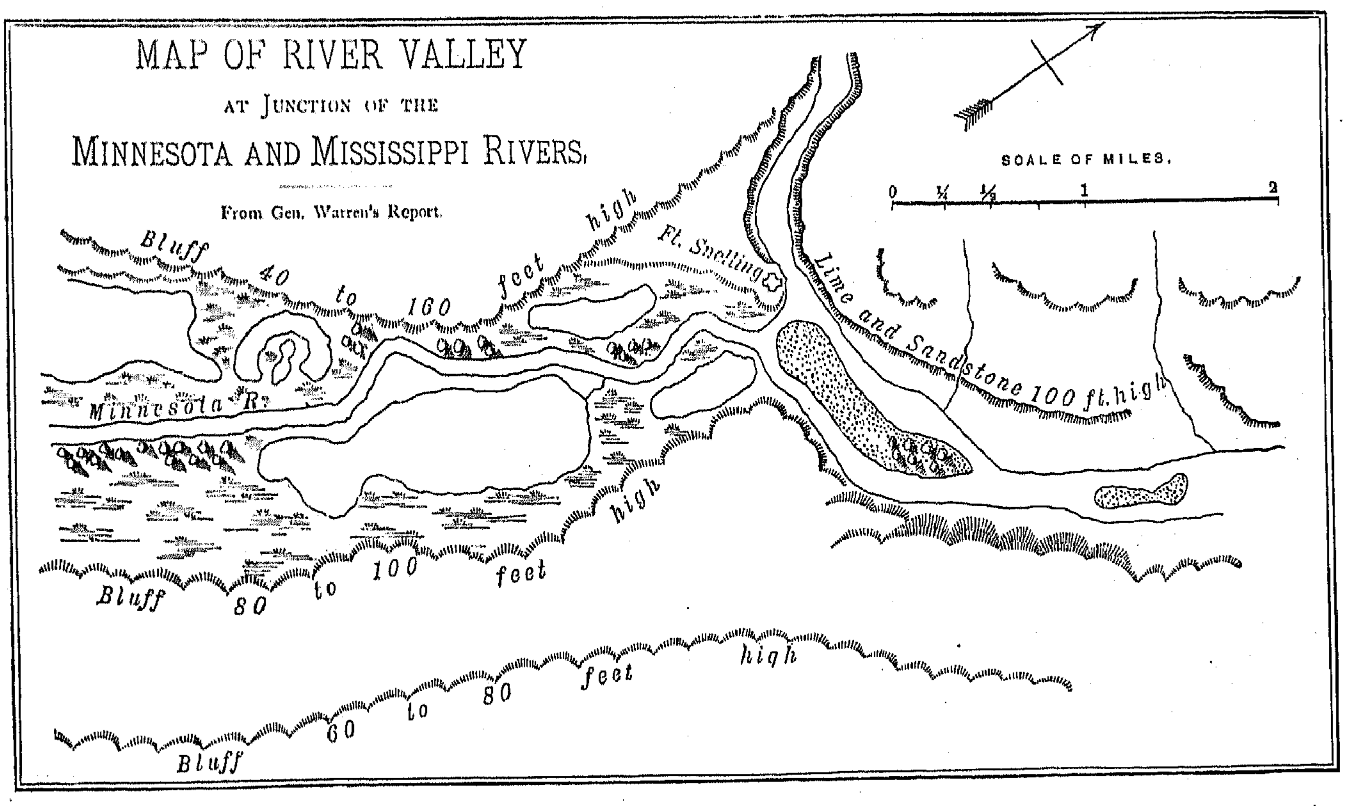
Finally, the period of submergence approached its end; the land began to rise; the inland sea was drained; the arm of the ocean which had occupied the valley of the lower Mississippi receded toward the Gulf, and the basin of the Mississippi became once more dry land. With the rising of the land above the waters the streams reappeared, and as the slope of their beds increased, the water-power grew in amount. From that time to the present the same condition of affairs has existed, with perhaps slight variations due to changes in rainfall or elevation of the land.

During the early part of the modern age the drainage of the basin was probably greatly augmented by the discharge from lake Winnipeg and by overflow from the great lakes, the remnants of the great inland sea.

HYDROLOGY OF THE MISSISSIPPI BASIN.

Enough has already been said regarding the topographical character of the Mississippi basin to make it evident that the streams cannot have any great fall. There are, however, numerous water-powers, moderate in extent; and the distribution of these, with the physical conditions affecting them, now claim our attention.

Elevation of the water-shed line.—The elevations of the line of water-shed limiting the basin of the Mississippi are as follows: Starting from the gulf of Mexico and running northeast, it soon rises, among the hills of central Mississippi, to a height of 500 and 700 feet; bending eastward across northern Alabama its elevation is from 1,100 to 1,160 feet. Then it strikes the Appalachian system of mountains, and, gradually rising, crosses western North Carolina at an elevation varying from 2,200 to 5,000 feet. Through Virginia and West Virginia the crest-line sinks to an altitude of 2,500 or 3,000 feet, and then, in crossing Pennsylvania, to 2,000 to 2,500 feet. In Ohio the height is 1,200 feet, falling to 700 feet. Passing around the southern end of lake Michigan at an elevation, near Chicago, of 610 feet, the boundary line rises in passing north into Wisconsin. The course through the latter state and Minnesota has already been given in the "General Remarks on the Water-power of the Northwest". Suffice it to say here that the line assumes successively in Wisconsin the following typical levels: 980 feet, 910 (at Portage City), 1,530 feet, 1,600 feet, and 1,200 feet. Passing into Minnesota, it dips to 650 feet in crossing the western end of the lake Superior trough, then rapidly rises to 1,400 feet, attaining an elevation of about 1,680 feet at the source of the Mississippi, and then falls to 995 feet where it enters Dakota.



Through Dakota it extends in a northwest direction, rising from 1,000 to 2,000 feet, and attaining a greater altitude in British America. When it re-enters the United States in Montana we find it at an elevation of 6,000 or 7,000 feet above the sea; it has entered the Rocky mountains, and from there through Wyoming and Colorado the elevation ranges from 6,000 to 14,000 feet. In crossing the Llano Estacado in New Mexico the line of water-shed falls to an elevation of about 4,500 feet, then descends in Texas, crosses Louisiana at an altitude of from 200 to 300 feet, and finally drops once more to the waters of the Gulf. The hypsometric map prepared by Mr. Henry Gannett, and published in Volume I (Population) of the quarto series of the Tenth Census reports, illustrates the elevations of the Mississippi basin.

It will be noticed from the preceding figures that the highest elevations are attained on the west and east, 14,000 and 5,000 feet, respectively. On the north the line is comparatively low, probably not exceeding 1,700 or 1,800 feet in height, except in western Dakota and Montana, and in this low region are the sources of the upper Mississippi. Where the line passes the western end of lake Superior, not more than 130 miles from the extreme headwaters, the elevation above the sea is less than in the state of Mississippi.

Comparison of the large streams.—To use a homely illustration, the surface of the Mississippi basin may be compared to the wide brim of a soft hat, with the sides rolled up where the eastern and western mountain chains are, and the front and back low. Through the center, from front to rear, runs the main stream, with a comparatively gentle slope; from the high, upturned edges on the west and east come the large tributaries with rapid fall, especially at their headwaters, while between them are the smaller branches of the main river, moderate in their descent, and in this respect resembling the Mississippi itself.

Hence, we would not look to the main stream above the junction of the large tributaries for the greatest exhibition of water-power (using the term in a strictly theoretical sense). Its total fall from source to mouth is only 1,680 feet, which is much exceeded by most of the large streams.

The following table shows the entire descent from source to mouth of the main rivers of the basin:

River.	Average flow per second.	Length.	Fall.	Slope per mile.
	Cubic feet.	*Miles.*	*Feet.*	*Feet.*
Ohio	203, 800	1, 204	1, 390	1. 15
Missouri	121, 000	2, 908	(?)6, 400	2. 20
Upper Mississippi	118, 600	1, 265	1, 287	1. 02
Arkansas	63, 000	1, 514	9, 900	6. 55
Red	50, 000	1, 200	2, 240	1. 87

The table is arranged in the order of amount of average discharge, and serves to give a rough idea of the relative hydraulic power of the streams, with this consideration: that, in the cases of the Arkansas and Missouri by far the greater portion of the descent occurs before they have left the mountains and before the volume of water has attained anything like the amounts at their mouths. With the other rivers of the table the distribution of the fall is somewhat more uniform along the entire course.

It is correct to infer that the Ohio basin represents the greatest actual theoretical horse-power, and the upper Mississippi cannot claim the leadership in this respect.

Power of the smaller tributaries.—As regards the smaller tributaries of the Mississippi, many of them take their rise at an altitude fully equal to that of the sources of Itasca lake, and have rapids in their courses. This is especially true of the branches of the upper Mississippi; but the streams which enter the lower Mississippi are by no means lacking in sufficiently rapid descent to give evidence of power. Rivers like the Saint Francis of Arkansas and the Yazoo of Mississippi flow through vast swamps at their mouths, but before they leave the hill country the waters have power sufficient to turn many a wheel.

This brings us to the consideration of the distribution of the *available* water-power of the Mississippi basin, and in this respect the drainage basin of the upper Mississippi may well dispute position with any of the other divisions of the main drainage system.

Distinction between theoretical and available water-power.—There is a sharp distinction to be made between *theoretical* and actually *available* water-power; it is the difference between the mere presence of power and its presence in such a form and under such conditions as will admit of its utilization with profit on the investment. For example: the Mississippi as it flows past New Orleans gives an exhibition of tremendous force, and by damming it up to a head of 10 feet a power of nearly 700,000 horse-power would result, but the river would be flooded back for 300 miles, and the plan is therefore impracticable.

Away up near the headwaters, where the river is but a brook in comparison, there is a natural fall of 75 feet in half a mile, and by the slightest effort of man over 100,000 horse-power is immediately available.

For the capitalist the term *available water-power* can hardly be applied to any power, unless its location with reference to the centers of supply and demand is such as to make its improvement profitable. It appears to be the province of the capitalist to decide whether a power can be made to pay after improvement, and of the engineer to decide whether it can be improved within a certain limit of expense, and to do it. Both classes sometimes do double duty, often at a loss in the case of those who understand the management of finances better than engineering.

In this report the adjective *available* is applied to those water-powers concerning which there is no physical obstacle to development with what, in ordinary cases, would be a reasonable expense, and the consideration of whether a woolen mill can be made to pay in one place or whether a cotton factory is profitable in another is left to others. It is hoped, however, that sufficient is said in the general descriptions of the various regions regarding the nature of the country, crops, facilities of transportation, etc., to convey some general ideas upon the financial aspects of the subject.

Centers of available power.—Having given the above definition of *available water-power*, we reiterate the statement that, as regards *available* power, the upper Mississippi basin may well dispute position with any of the other divisions of the main drainage system; and for this reason, mainly: the available power of the side-streams is, as a rule, greater than that of the branches of the Missouri at least, while on the main stream itself exist available powers of large dimensions. On the Ohio, at Louisville, is a large power, and when the scheme of slack-water navigation is carried out, it is possible that others will be available, but two of its largest tributaries enter very near its mouth, below all available power, and back-water is a very serious drawback to improvement. On the Missouri there is no available power until away up toward the mountains of the west, where the stream is small and the country sparsely settled; and the Arkansas and Red rivers offer no powers on a grand scale.

All these are eclipsed by the famous power at Saint Anthony falls, and the Rock Island and the Des Moines rapids, by a heavy outlay, can be made to yield water-powers of large size. These are all upon the upper Mississippi, and the last two are the only available powers on the river below Saint Anthony falls. Above Minneapolis, on the upper Mississippi, are several rapids where from 5,000 to 10,000 theoretical horse-power is available, while a number of the tributaries present powers of equal magnitude.

In considering the large tributaries, the fact must not be lost sight of that there is a widespread distribution of available powers of moderate size throughout this central drainage system of the continent, and of great value are they to the country. Alike, among the sandy hills of Mississippi and Louisiana, on the wide prairies of the West, and among the mountains, are many powers, some of which already yield rich returns to industry. The greatest utilization of the power is on the upper Mississippi and its tributaries and the northern branches of the Ohio river, but other water-powers are fast coming into use, as the country to the westward is settled.

Centers of power employed.—The chief centers of actual use of power, exclusive of the Ohio basin, which has not been visited at the writing of this report, are Saint Anthony falls, in Minnesota, on the upper Mississippi, and the region lying in Illinois, southwest of Chicago, within a distance of 50 or 60 miles of that place. There are no large manufacturing centers using water-power elsewhere, either because it does not exist or because there is no demand for it if it does. In the lower part of the Missouri basin there is a fine power, though of comparatively small size, at Sioux falls, which has lately been improved to some extent, as described in the report of Mr. Dwight Porter, to whom the Missouri river was assigned. It may be remarked here that Mr. Porter has also reported upon the Arkansas, the Red river, and most of the western tributaries of the Mississippi, as well as upon the Ohio and its tributaries.

Table giving the elevation, drainage area, rain-fall, flow,

Station.	Number of station.	Distance below preceding station.	Distance below source of the river.	Elevation of ordinary low water above the sea-level.	Fall from preceding station.	Average slope, per mile, to preceding station.	Average slope, per mile, to source of river.	Drainage area above station.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Square miles.*
Utmost source of the Mississippi	1	......	......	1, 680. 00	......	......	......	......
Head of lake Itasca	2	6. 00	6. 00	1, 575. 00	105. 00	17. 500	17. 500	......
Outlet of lake Itasca	3	4. 00	10. 00	1, 575. 00	0. 00	0. 000	10. 500	78±
Above mouth of the Pinniddiwin	4	24. 00	34. 00	1, 375. 00	200. 00	8. 308	8. 941	233
Mouth of Pinniddiwin river	5	0. 00	34. 00	1, 375. 00	0. 00	0. 000	8. 941	384
Mouth of east branch of the Mississippi	6	19. 00	53. 00	1, 356. 00	19. 00	1. 000	6. 113	543
Head of lake Bemidji	7	2. 5	55. 5	1, 353. 46	2. 54	1. 016	5. 883	543
Outlet of lake Bemidji	8	2. 5	58. 00	1, 353. 46	0. 00	0. 000	5. 630	583
Head of Cass lake	9	17. 00	75. 00	1, 299. 46	54. 00	3. 176	5. 074	604
Mouth of Turtle river and outlet of Cass lake	10	7. 5	82. 5	1, 299. 46	0. 00	0. 000	4. 615	1, 073
Head of lake Winnibigoshish	11	20. 00	102. 5	1, 289. 36	10. 10	0. 505	3. 815	1, 114
Outlet of lake Winnibigoshish	12	13. 00	115. 5	1, 289. 36	0. 00	0. 000	3. 382	1, 406
Mouth of Leech Lake river	13	23. 5	139. 00	1, 278. 56	10. 80	0. 450	2. 888	2, 554
White Oak point	14	16. 5	155. 5	1, 274. 96	3. 60	0. 218	2. 605	2, 719
Head of Pokegama falls	15	30. 00	185. 5	1, 266. 06	8. 90	0. 297	2. 231	2, 952
Foot of Pokegama falls	16	0. 1	185. 6	1, 251. 96	14. 10	141. 000	2. 306	2, 952
Head of Grand rapids	17	3. 5	189. 1	1, 249. 06	2. 90	0. 829	2. 273	2, 966
Foot of Grand rapids	18	0. 3	189. 4	1, 244. 06	5. 00	16. 667	2. 240	2, 966
Mouth of Prairie river	19	2. 6	191. 0	1, 242. 96	1. 10	0. 430	2. 241	3, 457
Bend in the river to the southeast	20	20. 00	212. 00	1, 234. 19	8. 77	0. 439	2. 103	3, 554
Mouth of Swan river	21	19. 00	230. 9	1, 225. 85	8. 34	0. 439	1. 534	3, 928
Mouth of Sandy Lake outlet	22	41. 00	271. 9	1, 207. 86	17. 99	0. 439	1. 762	4, 457
Mouth of the Willow and White Elk rivers	23	30. 00	301. 9	1, 198. 26	9. 60	0. 322	1. 596	5, 149
Mouth of Rice river	24	17. 00	318. 9	1, 192. 72	5. 48	0. 322	1. 528	5, 350
Mouth of Pine river	25	37. 00	355. 9	1, 171. 31	21. 41	0. 570	1. 120	6, 705
Brainerd	26	22. 00	377. 9	1, 151. 76	19. 55	0. 934	1. 398	6, 997
Mouth of Crow Wing river	27	10. 00	387. 9	1, 145. 06	6. 70	0. 670	1. 121	10, 573
Head of Little falls	28	21. 00	408. 9	1, 089. 86	55. 20	2. 629	1. 444	11, 084
Foot of Little falls	29	0. 4	409. 3	1, 082. 56	7. 30	18. 250	1. 460	11, 084
Watab	30	24. 6	433. 9	1, 000. 16	82. 40	2. 350	1. 567	12, 120
Head of Sauk rapids and mouth of Sauk river	31	6. 00	439. 9	987. 66	12. 50	2. 083	1. 347	13, 242
Foot of Sauk rapids	32	0. 8	440. 7	976. 36	11. 30	14. 125	1. 597	13, 242
Saint Augusta	33	8. 3	449. 00	945. 86	30. 50	3. 675	1. 635	13, 327
Clearwater	34	8. 8	457. 8	935. 36	10. 50	1. 193	1. 627	13, 582
Monticello	35	14. 3	472. 1	890. 26	45. 10	3. 154	1. 673	13, 688
Mouth of Elk river	36	12. 00	484. 1	850. 26	40. 00	3. 333	1. 716	14, 300
Mouth of Crow river	37	5. 00	489. 1	841. 06	9. 20	1. 840	1. 715	17, 457
Mouth of Rum river	38	8. 2	497. 3	825. 96	15. 10	1. 846	1. 717	19, 016
Minneapolis, at Saint Anthony falls	39	17. 3	514. 6	793. 36	32. 60	1. 890	1. 723	19, 585
Mouth of Minnesota river	40	9. 00	523. 6	683. 52	109. 84	12. 900	1. 521	35, 819
Saint Paul bridge	41	4. 00	527. 6	681. 36	2. 16	0. 540	1. 893	35, 824
Mouth of Saint Croix river	42	29. 00	556. 6	666. 49	14. 87	0. 513	1. 821	43, 872
Mouth of Cannon river	43	21. 25	577. 85	661. 41	5. 08	0. 238	1. 763	45, 646
Mouth of Chippewa river	44	33. 00	610. 85	659. 56	1. 85	0. 056	1. 670	55, 876
Mouth of Zumbro river	45	7. 00	617. 85	655. 87	3. 69	0. 527	1. 658	57, 222
Mouth of Buffalo river	46	4. 75	622. 6	653. 04	2. 83	0. 596	1. 641	57, 690
Fountain City	47	22. 25	644. 85	640. 67	12. 37	0. 556	1. 596	58, 491
Mouth of Trempealeau river	48	13. 25	658. 1	633. 29	7. 38	0. 556	1. 590	59, 256
Trempealeau	49	7. 00	665. 1	630. 36	2. 93	0. 419	1. 578	59, 335
Mouth of Black river	50	17. 5	682. 6	624. 77	5. 59	0. 319	1. 547	61, 059
Mouth of Root river	51	4. 00	686. 6	622. 81	1. 96	0. 490	1. 540	63, 900
Mouth of upper Iowa river	52	29. 5	716. 1	611. 51	11. 30	0. 383	1. 492	65, 484
Lynxville	53	22. 75	738. 85	605. 02	6. 49	0. 285	1. 455	65, 844
Mouth of Wisconsin river	54	18. 77	757. 62	600. 11	4. 91	0. 262	1. 425	78, 565
Mouth of Turkey river	55	21. 71	779. 33	593. 30	6. 81	0. 314	1. 393	80, 407
Dubuque	56	32. 78	812. 11	581. 48	11. 82	0. 361	1. 353	81, 322
Mouth of Fever river	57	5. 98	828. 09	579. 59	1. 89	0. 316	1. 329	81, 689
Mouth of Maquoketa river	58	12. 67	840. 76	572. 36	4. 17	0. 329	1. 318	83, 772
Fulton	59	32. 95	873. 71	563. 00	9. 36	0. 284	1. 278	84, 857
Mouth of Wapsipinicon river	60	15. 62	889. 33	558. 25	4. 75	0. 304	1. 261	87, 558

power, etc., for various points on the Mississippi river.

Average annual precipitation above station.	Average annual precipitation, per second, on area above station.	Flow, per second, past station. Ordinary low flow.	Flow, per second, past station. Average flow.	Flow, per second, past station, per square mile of drainage area. Ordinary low flow.	Flow, per second, past station, per square mile of drainage area. Average flow.	Ratio of average flow to average precipitation above station.	Ratio of ordinary low flow to average flow.	Theoretical horse-power at station, under an assumed head of 10 feet. Ordinary low flow.	Theoretical horse-power at station, under an assumed head of 10 feet. Average flow.	Number of station.
Inches.	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*		*Horse-power.*	*Horse-power.*	
....	....	....	....	....	....	....	....	....	....	1
....	....	....	....	....	....	....	....	....	....	2
....	144	26	56	0.33	0.716	38.9	0.464	29	64	3
25.00	429	77	167	0.33	0.716	38.9	0.461	87	189	4
25.00	707	127	275	0.33	0.716	38.9	0.462	144	312	5
25.00	1,000	180	389	0.331	0.716	38.9	0.463	204	441	6
....	1,000	180	389	0.331	0.716	38.9	0.463	204	441	7
....	1,076	194	418	0.333	0.717	38.8	0.464	220	474	8
....	1,280	232	496	0.334	0.715	38.7	0.468	263	563	9
25.00	1,979	361	783	0.336	0.729	39.5	0.468	410	888	10
....	2,048	374	809	0.336	0.726	39.6	0.462	424	918	11
....	2,589	474	1,015	0.337	0.722	39.2	0.467	538	1,152	12
25.00	4,707	896	1,903	0.351	0.746	40.4	0.471	1,017	2,159	13
....	5,011	952	2,019	0.351	0.743	40.2	0.472	1,080	2,291	14
....	5,443	1,031	2,183	0.343	0.739	40.1	0.472	1,170	2,477	15
....	5,443	1,031	2,183	0.349	0.739	40.1	0.472	1,170	2,477	16
....	5,466	1,036	2,192	0.349	0.739	40.1	0.473	1,175	2,487	17
....	5,466	1,036	2,192	0.349	0.739	40.1	0.473	1,175	2,487	18
25.00	6,370	1,183	2,572	0.342	0.744	40.3	0.460	1,342	2,918	19
....	6,555	1,216	2,642	0.342	0.743	40.3	0.460	1,380	2,997	20
25.06	7,257	1,330	2,935	0.338	0.747	40.4	0.453	1,509	3,330	21
25.11	8,251	1,498	3,344	0.336	0.748	40.4	0.448	1,699	3,794	22
25.16	9,364	1,672	3,787	0.331	0.750	40.4	0.442	1,897	4,296	23
25.18	9,946	1,766	4,019	0.329	0.750	40.4	0.439	2,004	4,560	24
25.21	12,456	2,167	4,953	0.323	0.739	39.7	0.438	2,458	5,619	25
....	12,948	2,246	5,101	0.323	0.732	39.4	0.440	2,548	5,787	26
25.30	19,723	3,328	7,602	0.315	0.719	38.5	0.438	3,776	8,624	27
....	20,713	3,483	7,899	0.314	0.713	38.1	0.441	3,951	8,960	28
....	20,713	3,483	7,899	0.314	0.713	38.1	0.441	3,951	5,960	29
....	22,686	3,793	8,493	0.313	0.701	37.4	0.447	4,303	9,635	30
25.45	24,834	4,123	9,174	0.312	0.693	36.9	0.449	4,678	10,408	31
....	28,434	4,123	9,174	0.312	0.694	36.9	0.449	4,678	10,408	32
....	24,997	4,152	9,223	0.312	0.692	36.8	0.450	4,710	10,463	33
....	25,484	4,239	9,369	0.312	0.690	36.7	0.452	4,809	10,629	34
....	25,687	4,275	9,430	0.312	0.689	36.7	0.453	4,850	10,698	35
25.49	26,974	4,402	9,816	0.311	0.684	36.3	0.450	5,002	11,136	36
26.02	33,577	5,391	11,924	0.309	0.683	35.5	0.452	6,116	13,528	37
26.18	36,082	5,859	12,855	0.308	0.676	35.6	0.456	6,647	14,584	38
....	38,033	6,017	13,193	0.307	0.674	34.7	0.457	6,826	14,967	39
27.07	71,456	8,576	20,922	0.239	0.584	29.2	0.410	9,729	23,736	40
....	71,467	8,577	20,925	0.239	0.584	29.2	0.410	9,731	23,738	41
27.63	90,324	11,500	27,398	0.262	0.624	30.3	0.420	13,047	31,083	42
27.70	93,160	12,006	28,453	0.263	0.623	30.5	0.422	13,621	33,380	43
28.10	118,687	15,710	37,712	0.281	0.674	31.7	0.417	17,833	42,784	44
28.83	121,563	16,096	38,460	0.281	0.672	31.6	0.419	18,261	43,633	45
28.86	122,701	16,227	38,756	0.281	0.672	31.5	0.419	18,410	43,969	46
....	124,807	16,435	39,283	0.281	0.671	31.4	0.418	18,646	44,567	47
28.99	126,571	16,648	39,799	0.276	0.671	31.4	0.419	18,887	45,155	48
....	126,768	16,669	39,815	0.281	0.671	31.4	0.419	18,911	45,170	49
29.18	132,590	17,433	41,840	0.283	0.670	31.5	0.417	19,778	47,467	50
29.25	137,729	18,004	43,162	0.283	0.675	31.3	0.419	20,404	48,967	51
29.38	141,737	18,705	44,186	0.286	0.675	31.1	0.423	21,228	50,120	52
....	142,666	18,799	44,418	0.286	0.675	31.1	0.423	21,327	50,392	53
30.31	175,465	23,704	56,101	0.314	0.742	31.9	0.423	26,892	63,647	54
30.35	179,988	24,233	57,272	0.301	0.711	31.8	0.423	27,492	64,975	55
....	182,281	24,455	57,845	0.301	0.711	31.6	0.423	27,744	65,625	56
30.45	183,264	24,550	58,091	0.301	0.711	31.6	0.423	27,852	65,904	57
30.58	188,789	25,111	59,518	0.312	0.710	31.5	0.422	28,488	67,523	58
....	191,746	25,393	60,228	0.299	0.710	31.4	0.422	28,808	68,329	59
30.85	199,109	26,095	62,139	0.298	0.711	31.2	0.420	29,604	70,497	60

Table giving the elevation, drainage area, rain-fall, flow, power,

Station.	Number of station.	Distance below preceding station.	Distance below source of the river.	Elevation of ordinary low water above the sea-level.	Fall from preceding station.	Average slope, per mile, to preceding station.	Average slope, per mile, to source of river.	Drainage area above station.
		Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Square miles.*
Head of Rock Island rapids, at Le Claire	61	7.13	896.40	557.43	0.82	0.115	1.252	87,703
Foot of Rock Island rapids, at Rock island	62	14.75	911.21	537.03	20.40	1.383	1.254	87,842
Mouth of Rock river	63	2.12	913.33	536.37	0.66	0.311	1.252	98,821
Muscatine	64	29.89	943.22	526.86	9.51	0.318	1.223	99,100
Mouth of Iowa river	65	20.50	963.72	521.22	5.64	0.275	1.202	111,845
Mouth of Henderson river	66	25.12	988.84	510.86	10.36	0.412	1.183	113,276
Burlington	67	6.40	995.24	508.36	2.50	0.391	1.177	113,495
Mouth of Skunk river	68	4.09	999.33	506.58	1.78	0.435	1.174	118,141
Head of Des Moines rapids, at Montrose	69	25.98	1,025.31	497.76	8.82	0.339	1.251	118,513
Foot of Des Moines rapids, at Keokuk	70	11.12	1,036.43	475.59	22.17	1.994	1.162	118,705
Mouth of Des Moines river	71	2.90	1,039.33	473.64	1.95	0.672	1.161	133,395
Mouth of Fox river	72	3.14	1,042.47	471.97	1.67	0.532	1.159	133,905
Mouth of Wyaconda river	73	20.02	1,062.49	460.69	11.28	0.564	1.147	135,115
Mouth of Fabius river	74	13.21	1,075.70	455.03	5.66	0.428	1.139	137,220
Hannibal	75	15.31	1,091.01	448.21	6.82	0.445	1.136	137,460
Mouth of Salt river	76	26.62	1,117.63	434.97	13.24	0.497	1.114	140,791
Falmouth	77	29.55	1,147.18	420.90	14.07	0.476	1.098	141,794
Mouth of Cuivre river	78	17.92	1,165.10	412.34	8.56	0.478	1.088	143,000
Mouth of Illinois river	79	15.23	1,180.33	404.70	7.64	0.505	1.080	172,229
Above mouth of Missouri river	80	24.00	1,204.33	392.70	12.00	0.500	1.069	172,525
Mouth of Missouri river	81	0.00	1,204.33	392.70	0.00	....	1.069	700,197
Saint Louis	82	17.00	1,221.33	379.18	13.52	0.795	1.065	700,603
Mouth of Meramec river	83	18.20	1,239.53	364.70	14.48	0.795	1.061	705,075
Mouth of Kaskaskia river	84	52.30	1,291.83	330.00	35.00	0.666	1.122	711,935
Mouth of Big Muddy river	85	34.60	1,326.43	307.00	23.00	0.666	1.035	715,116
Commerce	86	34.10	1,360.53	284.00	23.00	0.666	1.026	715,555
Mouth of Ohio river, at Cairo	87	32.80	1,393.33	262.00	22.00	0.666	1.018	929,914
Columbus	88	21.00	1,414.33	254.00	8.00	0.381	1.008	930,540
Mouth of Reel Foot river	89	102.70	1,517.03	213.00	41.00	0.399	0.967	932,418
Mouth of Forked Deer river	90	20.00	1,537.03	205.00	8.00	0.400	0.960	936,804
Mouth of Big Hatchee river	91	27.10	1,564.13	194.00	11.00	0.400	0.950	939,827
Mouth of Wolf river	92	52.20	1,616.33	173.00	21.00	0.400	0.957	941,559
Memphis	93	2.00	1,618.33	172.20	0.80	0.400	0.932	941,559
Mouth of Saint Francis river	94	70.20	1,688.53	144.00	28.00	0.400	0.900	950,443
Mouth of Arkansas river, at White river	95	102.30	1,790.83	107.00	37.00	0.362	0.879	1,140,246
Gaine's Landing	96	52.50	1,843.33	89.90	17.10	0.328	0.863	1,140,632
Lake Providence	97	89.25	1,932.58	65.29	24.61	0.276	0.778	1,141,403
Mouth of Yazoo river	98	60.25	1,992.83	49.29	16.00	0.266	0.818	1,154,583
Vicksburg	99	10.50	2,003.33	46.67	2.62	0.250	0.815	1,154,607
Mouth of Big Black river	100	49.25	2,052.58	35.63	11.04	0.224	0.801	1,158,469
Mouth of Big Pierre river	101	10.25	2,062.83	33.37	2.26	0.220	0.798	1,159,555
Natchez	102	49.50	2,112.33	23.97	9.40	0.190	0.784	1,160,249
Mouth of Homochitto river	103	42.75	2,155.08	16.70	7.27	0.170	0.772	1,161,747
Above mouth of Red river	104	19.25	2,174.33	13.70	3.00	0.156	0.766	1,162,209
Mouth of Red river, at Red River Landing	105	0.00	2,174.33	13.70	0.00	....	0.766	1,259,209
Baton Rouge	106	71.00	2,245.33	7.37	6.33	0.089	0.745	1,260,261
Plaquemine, at mouth of bayou Plaquemine	107	22.75	2,268.08	5.66	1.71	0.075	0.738	1,260,346
Donaldsonville	108	29.25	2,297.33	4.01	1.65	0.056	0.729	1,260,547
New Orleans	109	79.00	2,376.33	2.35	1.66	0.021	0.710	1,261,084
Fort Saint Philip	110	77.00	2,453.33	1.55	0.80	0.010	0.684	1,261,416
Head of the passes	111	20.00	2,473.33	1.29	0.26	0.013	0.679	1,261,432
Mouth of the Mississippi	112	17.00	2,490.33	0.00	1.29	0.076	0.675	....

etc., for various points on the Mississippi river—Continued.

Average annual precipitation above station.	Average annual precipitation, per second, on area above station.	Flow, per second, past station.		Flow, per second, past station, per square mile of drainage area.		Ratio of average flow to average precipitation above station.	Ratio of ordinary low flow to average flow.	Theoretical horse-power at station, under an assumed head of 10 feet.		Number of station.
		Ordinary low flow.	Average flow.	Ordinary low flow.	Average flow.			Ordinary low flow.	Average flow.	
Inches.	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Cubic feet.*	*Per cent.*		*Horse-power.*	*Horse-power.*	
....	199, 504	26, 130	62, 234	0. 298	0. 710	31. 1	0. 420	29, 644	70, 604	61
....	199, 883	26, 163	62, 321	0. 298	0. 709	31. 1	0. 420	29, 682	70, 704	62
31. 39	228, 596	30, 064	72, 269	0. 304	0. 731	31. 6	0. 416	34, 108	81, 989	63
....	229, 356	30, 125	72, 436	0. 304	0. 731	31. 5	0. 416	34, 177	82, 179	64
32. 27	265, 033	33, 303	81, 199	0. 291	0. 720	30. 5	0. 411	37, 782	92, 120	65
32. 31	269, 683	33, 630	82, 050	0. 297	0. 724	30. 4	0. 410	38, 152	93, 093	66
....	270, 264	33, 700	82, 184	0. 297	0. 724	30. 4	0. 410	38, 233	93, 238	67
32. 50	282, 912	34, 832	85, 208	0. 295	0. 721	30. 1	0. 409	39, 517	96, 578	68
....	283, 890	34, 914	85, 425	0. 295	0. 721	30. 0	0. 409	39, 610	96, 915	69
....	284, 408	34, 956	85, 537	0. 294	0. 721	30. 0	0. 409	39, 658	97, 042	70
32. 12	325, 532	37, 804	93, 762	0. 284	0. 702	28. 8	0. 404	42, 900	106, 373	71
32. 13	327, 123	38, 032	94, 112	0. 283	0. 702	28. 7	0. 404	43, 147	106, 770	72
33. 16	330, 904	38, 283	94, 765	0. 283	0. 700	28. 7	0. 404	43, 432	107, 511	73
33. 25	335, 702	38, 707	95, 998	0. 282	0. 700	28. 5	0. 404	43, 981	108, 910	74
....	336, 306	38, 818	96, 131	0. 282	0. 699	28. 5	0. 404	44, 039	109, 061	75
33. 22	344, 670	39, 550	97, 972	0. 281	0. 696	28. 4	0. 404	44, 869	111, 149	76
....	347, 478	39, 771	98, 590	0. 280	0. 695	28. 3	0. 403	45, 120	111, 850	77
33. 30	350, 854	40, 048	99, 333	0. 280	0. 695	28. 3	0. 403	45, 434	112, 693	78
33. 93	430, 542	42, 096	118, 440	0. 265	0. 688	27. 5	0. 355	47, 758	134, 377	79
....	431, 340	42, 161	118, 624	0. 265	0. 688	27. 5	0. 355	47, 832	134, 590	80
23. 13	1, 193, 271	....	240, 532	....	0. 344	20. 1	....	....	272, 884	81
....	1, 194, 626	....	240, 857	....	0. 344	20. 1	....	....	273, 252	82
23. 23	1, 206, 077	....	244, 000	....	0. 346	20. 2	....	....	276, 880	83
23. 38	1, 226, 402	....	249, 084	....	0. 348	20. 3	....	....	282, 586	84
23. 45	1, 235, 598	....	251, 453	....	0. 352	20. 3	....	....	285, 273	85
....	1, 236, 659	....	251, 730	....	0. 352	20. 3	....	....	285, 598	86
27. 98	1, 917, 370	....	455, 805	....	0. 490	23. 7	....	....	517, 213	87
....	1, 919, 216	....	456, 538	....	0. 491	23. 7	....	....	517, 912	88
28. 01	1, 924, 727	....	459, 018	....	0. 492	23. 8	....	....	520, 756	89
28. 11	1, 940, 225	....	466, 006	....	0. 498	24. 0	....	....	528, 684	90
28. 18	1, 950, 871	....	470, 847	....	0. 501	24. 1	....	....	533, 176	91
28. 21	1, 956, 995	....	473, 603	....	0. 503	24. 2	....	....	537, 370	92
....	1, 956, 995	....	473, 603	....	0. 503	24. 2	....	....	537, 370	93
28. 34	1, 984, 467	....	492, 580	....	0. 518	24. 8	....	....	558, 831	94
28. 35	2, 381, 444	....	557, 048	....	0. 489	23. 4	....	....	632, 043	95
....	2, 382, 078	....	557, 918	....	0. 489	23. 3	....	....	632, 958	96
....	2, 389, 047	....	560, 066	....	0. 491	23. 4	....	....	635, 395	97
28. 66	2, 437, 819	....	590, 807	....	0. 516	24. 4	....	....	670, 510	98
....	2, 437, 916	....	596, 375	....	0. 516	24. 4	....	....	676, 587	99
28. 75	2, 454, 142	....	605, 577	....	0. 523	24. 6	....	....	687, 027	100
28. 78	2, 458, 670	....	608, 114	....	0. 524	24. 7	....	....	689, 905	101
....	2, 461, 400	....	609, 801	....	0. 526	24. 7	....	....	691, 820	102
28. 83	2, 467, 721	....	613, 288	....	0. 527	24. 8	....	....	695, 775	103
....	2, 469, 605	....	614, 472	....	0. 529	24. 8	....	....	697, 118	104
29. 57	2, 743, 386	....	664, 544	....	0. 528	24. 2	....	....	753, 928	105
....	....	....	....	....	....	....	....	....	....	106
....	....	....	....	....	....	....	....	....	....	107
....	....	....	....	....	....	....	....	....	....	108
....	....	....	....	....	....	....	....	....	....	109
....	....	....	....	....	....	....	....	....	....	110
....	....	....	....	....	....	....	....	....	....	111
....	....	....	....	....	....	....	....	....	....	112

Table giving the drainage area, rainfall, discharge, power, etc., of the tributaries of the Mississippi river.

Stream.	Number of river.	Distance of mouth from source of the Mississippi.	Length.	Area of basin.	Average annual precipitation on the basin in rain and melted snow.					Average annual precipitation per second on the entire basin.	Discharge of river per second.		Discharge per second per square mile of drainage area.		Ratio of average discharge, to average annual precipitation on the basin.	Theoretical horse-power at mouth of river under an assumed head of 10 feet.	
					Spring.	Summer.	Autumn.	Winter.	Year.		Ordinary low flow.	Average flow.	Ordinary low flow.	Average flow.		Ordinary low flow.	Average flow.
		Miles.	*Miles.*	*Sq. M.*	*In.*	*In.*	*In.*	*In.*	*In.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*P. ct.*	*H. P.*	*H. P.*
Mississippi above the Pinniddiwin river	1	....	23	233	6.84	9.25	6.27	2.64	25.00	429	77	167	0.33	0.717	39	87	189
Pinniddiwin	2	33.8	17	151	6.84	9.25	6.27	2.64	25.00	278	50	108	0.33	0.715	39	57	123
East branch of the Mississippi	3	52.5	26	133	6.84	9.25	6.27	2.64	25.00	245	44	96	0.33	0.722	39	50	109
Turtle	4	80.5	40	300	6.84	9.25	6.27	2.64	25.00	552	102	232	0.34	0.773	42	116	263
Leech Lake	5	139.0	50	1,105	6.84	9.25	6.27	2.64	25.00	2,035	400	856	0.37	0.775	42	464	971
Prairie	6	191.9	19	491	6.84	9.25	6.27	2.64	28.00	904	147	380	0.30	0.774	42	167	431
Swan	7	230.9	40	349	6.84	9.75	6.27	2.64	25.50	656	105	276	0.30	0.791	42	119	313
Sandy Lake	8	271.9	......	421	6.84	9.75	6.27	2.64	25.50	791	131	332	0.31	0.789	42	149	377
Willow and White Elk rivers	9	301.3	......	547	6.84	9.75	6.27	2.64	25.50	1,028	159	411	0.29	0.751	40	180	466
Rice	10	318.9	24	293	6.84	9.75	6.27	2.64	25.50	550	88	220	0.30	0.751	40	100	250
Pine	11	355.9	140	961	6.84	9.75	6.27	2.64	25.50	1,805	288	722	0.30	0.750	40	327	819
Crow Wing	12	387.9	105	3,560	6.84	9.75	6.27	2.64	25.50	6,688	1,068	2,475	0.30	0.695	37	1,212	2,808
Sauk	13	430.9	82	968	6.55	11.38	5.40	2.58	26.00	1,854	290	593	0.30	0.613	32	329	673
Elk	14	464.1	100	687	6.55	11.38	5.40	2.58	26.00	1,124	158	337	0.27	0.591	30	179	382
Crow	15	480.1	141	3,085	6.18	12.30	6.81	2.71	28.00	6,364	926	2,036	0.30	0.660	32	1,051	2,310
Rum	16	497.3	136	1,539	6.23	11.58	6.61	2.58	27.00	3,061	462	918	0.30	0.596	30	524	1,041
Minnesota	17	523.6	256	16,027	7.03	11.75	6.60	2.62	28.00	33,060	2,500	7,604	0.156	0.474	23	2,836	8,627
Saint Croix	18	556.8	168	7,576	7.81	12.14	7.09	2.96	30.00	16,744	2,706	6,195	0.37	0.818	37	3,172	7,028
Cannon	19	577.8	90	1,492	7.21	12.04	6.84	2.91	29.00	3,188	433	893	0.29	0.599	28	491	1,013
Chippewa	20	610.8	105	9,573	8.39	13.87	7.94	3.80	34.00	23,978	3,542	8,872	0.37	0.927	37	4,018	10,065
Zumbro	21	617.8	80	1,346	7.21	12.04	6.84	2.91	29.00	2,876	377	748	0.28	0.556	26	428	849
Buffalo	22	622.6	50	468	8.12	13.57	7.03	3.68	33.00	1,138	131	296	0.28	0.632	26	149	336
Trempealeau	23	658.1	73	723	8.12	13.57	7.03	3.68	33.00	1,768	202	456	0.28	0.631	26	229	517
Black	24	682.6	166	2,272	8.39	13.87	7.88	3.86	34.00	5,691	750	1,992	0.33	0.877	35	851	2,260
Root	25	686.6	95	1,600	6.08	11.60	8.22	4.10	30.00	3,556	467	926	0.28	0.576	26	530	1,051
Upper Iowa	26	710.1	110	952	7.21	11.03	8.66	4.10	31.00	2,174	451	565	0.28	0.593	26	512	641
Wisconsin	27	757.6	407	12,280	8.57	12.70	8.21	5.43	35.00	31,663	4,790	11,399	0.39	0.928	36	5,434	12,932
Turkey	28	779.3	115	1,725	7.41	11.53	8.76	4.30	32.00	4,067	483	1,057	0.28	0.613	26	548	1,199
Maquoketa	29	840.7	116	1,904	9.51	11.72	8.90	5.87	36.00	5,050	514	1,313	0.27	0.690	26	583	1,490
Wapsipinicon	30	880.3	205	2,644	9.82	13.23	8.90	5.05	37.00	7,207	687	1,874	0.26	0.709	26	779	2,126
Rock	31	913.3	386	10,973	9.68	11.55	8.90	5.28	35.50	28,697	3,900	9,944	0.36	0.906	35	4,419	11,281
Iowa	32	963.7	326	12,466	8.03	10.63	9.33	5.01	30.00	35,816	3,117	8,596	0.25	0.690	24	3,536	9,752
Henderson	33	988.8	54	612	8.53	12.98	8.09	5.40	35.00	1,578	147	379	0.24	0.619	24	167	430
Skunk	34	999.3	243	4,427	9.88	13.23	8.84	5.05	37.00	12,067	1,062	2,896	0.24	0.654	24	1,205	3,286
Des Moines	35	1,030.3	402	14,000	9.88	14.31	9.60	4.21	38.00	41,124	2,938	8,225	0.20	0.560	20	3,333	9,331
Fox	36	1,042.5	62	600	10.34	11.08	8.45	6.13	36.00	1,591	138	350	0.23	0.583	22	157	397
Wyaconda	37	1,062.5	85	501	10.34	11.08	8.45	6.13	36.00	1,329	115	292	0.23	0.583	22	130	331
Fabius	38	1,075.7	98	1,987	10.34	11.08	8.45	6.13	36.00	5,270	457	1,159	0.23	0.583	22	518	1,315
Salt	39	1,117.6	185	3,044	9.34	10.58	8.10	5.98	34.00	7,625	669	1,678	0.22	0.551	22	759	1,904
Cuivre	40	1,165.1	99	1,100	10.54	11.88	8.45	7.13	38.00	3,348	275	737	0.23	0.610	22	312	836
Illinois	41	1,180.3	307	29,013	10.31	11.79	8.51	6.39	37.00	79,063	2,000	18,980	0.07	0.654	24	2,269	21,533
Missouri	42	1,204.3	2,908	527,072	6.10	6.40	4.40	2.70	19.60	761,922	....	121,908	......	0.231	16	....	138,305
Meramec	43	1,239.5	217	4,098	11.67	11.13	8.54	6.66	38.00	11,472	....	2,983	......	0.728	26	....	3,384
Kaskaskia	44	1,291.8	280	5,876	11.87	11.38	8.54	7.21	39.00	16,743	....	4,353	......	0.741	26	....	4,938
Big Muddy	45	1,320.4	127	2,374	11.97	11.48	8.94	7.61	40.00	6,996	....	1,819	......	0.766	26	....	2,064
Ohio	46	1,393.3	1,265	214,000	11.90	11.80	8.50	10.90	43.10	679,488	....	203,846	......	0.953	30	....	231,263
Forked Deer	47	1,537.6	92	4,306	16.91	11.33	8.24	11.52	48.00	15,227	....	6,852	......	1.591	45	....	7,774
Big Hatchee	48	1,564.1	128	2,726	16.91	11.33	8.24	11.52	48.00	9,640	....	4,338	......	1.591	45	....	4,921
Wolf	49	1,610.3	72	1,392	16.91	11.33	8.24	11.52	48.00	4,922	....	2,215	......	1.591	45	....	2,513
Saint Francis	50	1,688.5	380	7,989	12.40	10.20	8.60	10.30	41.30	24,307	....	17,015	......	2.130	70	....	19,304
Arkansas	51	1,790.3	1,514	189,000	8.55	9.33	6.33	4.08	28.30	304,019	....	63,000	......	0.333	16	....	71,075
Yazoo	52	1,902.8	500	12,794	17.79	10.94	8.90	15.67	53.30	50,237	....	35,166	......	2.749	70	....	39,896
Big Black	53	2,052.6	444	3,406	18.30	12.20	10.30	16.50	57.30	14,378	....	7,908	......	2.322	55	....	8,962
Big Pierre	54	2,062.8	100	1,018	17.00	12.30	10.30	16.30	56.80	4,261	....	3,344	......	2.303	55	....	2,650
Homochitto	55	2,155.0	106	1,201	17.90	12.30	10.30	16.30	56.80	5,027	....	2,765	......	2.301	55	....	3,137
Red	56	2,174.3	1,200	97,000	11.51	10.22	8.44	8.15	38.30	273,691	....	50,000	......	0.515	22	....	56,725

EXPLANATION AND DISCUSSION OF THE TABLES OF FLOW, RAINFALL, ETC.

A report upon the water-power of the Mississippi basin is not complete without some consideration of the meteorological and topographical conditions which so greatly affect it. The valley of the Mississippi, including as it does the entire central portion of the United States, embraces every variety of climate from the semi-tropical to one of almost arctic winters, the rainfall varying from that of the arid desert to the heavy down-pour of a torrid clime; and it contains within its extensive boundary the rugged mountain range, the forest, the broad treeless plain, the cultivated farming land, and the wild southern swamp, thus explaining the wide differences in the character of the rivers.

The original aim was to collect well-certified facts, and from them to deduce results. To a great extent, and so far as possible, this has been carried out; but further investigation showed the utter impracticability of relying on this method in every case, because sometimes absolutely no data could be obtained. In such cases resort was had to comparison, and just here was another difficulty: There are few if any places in the west where long-continued and frequent gaugings of the streams have been made, and the conditions there are so different from those usual in the eastern states that the results obtained from the one cannot be applied with any certainty to the other. However, the endeavor was made to do the best possible under the circumstances, and in describing the tables it will be shown how, to a certain extent, a test is applied to the calculations, checking the results. Enough actual data were available and were used, to inspire the confidence that, at least for general results, the conclusions reached may be relied upon; and in order that those who are sufficiently interested to take the pains may satisfy themselves in the matter, the methods and facts made use of are described where practicable.

No one, unless he has undertaken a task of a similar character, can understand the difficulty of reaching conclusions from the mass of apparently conflicting testimony; and especially is this true in the west, where until within recent years most of the few measurements that have been made of the streams have been inaccurate, and are of no avail because insufficiently described. A few years more will probably see a great increase in the amount and value of the data regarding stage and flow, at least for the Mississippi and the Missouri, for the Mississippi River commission and the government engineers in charge are now engaged in systematic gaugings at various points.

It is a pleasure to acknowledge the invariable courtesy of the United States engineers connected with the river improvement, without whose kind assistance in furnishing material the preparation of these tables would have been impossible.

A set of calculations has been made for the tributaries of the Mississippi, and embodied in the second table. From those are deduced the results for the main river, which are given in the first table. Data furnished from the United States engineers' offices and government reports, where obtainable, have been given credence above all others. The method of arriving at the amounts placed under the various headings will now be described.

In making the list of tributaries, each one having a drainage area of 500 square miles or over has been included, and several, at the upper waters, of smaller size. The total number taken is 56. In selecting stations upon the main river, the mouths of all the above-mentioned tributaries have been included, and also such other points as, from their position with reference to the physical features of the river, or their relation to surveys and river gaugings, will be of value. The total number of stations is 112.

Distances.—Distances along the river course were thus obtained: A table of distances from Saint Paul up to Cass lake was furnished by Major Charles J. Allen, stationed at Saint Paul; the report for 1880 of Captain A. Mackenzie, stationed at Rock Island, contains a table of distances from Saint Paul to the mouth of the Illinois river, which was used; below that the distances were taken partly from Humphreys and Abbot's report, partly from the various reports of the chief of engineers. Above Cass lake the only published distances, so far as known, are those estimated by Nicollet, and also by Schoolcraft. The estimates of the former are used by Humphreys and Abbot, but, as is mentioned by them, are undoubtedly too great. No meanderings have been made above Cass lake; and, in their absence, it was concluded best to measure the course of the stream as closely as possible from the map of the state of Minnesota, made on a scale of 6 miles to the inch. This places the outlet of lake Itasca 65 miles above the head of Cass lake, while, according to Nicollet, the distance is 135 miles. It is probable that 65 miles is somewhat less than the true amount. In order to obtain the distance of any station in the tables from the source of the river according to Nicollet's estimates, it is only necessary to add 70 miles to the distance given. The length of the river would then appear as 2,560 miles, instead of 2,490.

Below Cass lake the distances can lay claim to greater accuracy. The plan pursued was to take the positions of all points mentioned in the several surveys and insert most of them in the tables. Intermediate stations were determined by taking the surveyed distances and dividing them in proportion to the distances as measured, either upon the United States engineer's survey maps or upon the maps of the United States land office. It must be remembered that the course of the river is changing and cut-offs are occurring, which may have slightly altered its length since the surveys of Humphreys and Abbot were made. The lengths of the tributaries have been taken, where possible, from the reports of the United States engineers. All others were measured from large state maps or from the United States land office maps. Judging from tests made, the latter estimates are somewhat less than the true amounts.

Elevations.—Considerable difficulty is experienced in tabulating a complete series of levels for the Mississippi. No complete survey has ever been made of the entire stream, and the detached surveys do not agree with each other. This is not much to be wondered at. The surface of the upper river is usually connected with the levels of the great lakes by means of railroad levels, and the levels of the lower river are mainly carried upward from the Gulf. The variation in the height of the water-surface is 10 or 12 feet near the mouth, as much as 50 feet about the Ohio river, and from 10 to 20 feet upon the upper river. Apparently there has not been much concerted action, until recent years, in the use of the river-gauges, and it is hard to decide from the records to just what stage any series of levels is referred, while a comparatively small fluctuation in the river will have a considerable effect upon the level of the water-surface. We are prepared, then, to find a discrepancy of several feet between two independent surveys.

Our aim is to give a complete series of elevations from the source to the mouth at an *ordinary low* stage of the river. The levels available divide the river into four sections: 1, from the source to Cass lake; 2, from Cass lake to Saint Paul; 3, from Saint Paul to Grafton, at the mouth of the Illinois; 4, from the mouth of the Missouri to the Gulf.

The best levels obtainable for the first section are those taken by Nicollet with a barometer in 1836; they are those used by Humphreys and Abbot. Major Allen supplies a list of levels for section 2, presumably at ordinary low water of an average year. Captain Mackenzie gives in his report a table of elevations for section 3, reduced to the low water of 1864 (an extremely low year). For section 4 "precise levels" are furnished by the Mississippi River commission for five points. They must nearly represent an ordinary low stage of the river. No levels were found connecting the Missouri and the Illinois rivers. The first set places Cass lake 1,402 feet above the sea; the second set places Cass lake 1,300.1 feet above the sea, and Saint Paul 682 feet above the sea; while the third set places Saint Paul 678 feet above the sea; the fourth set places the mouth of the Missouri 392.7 feet above the sea; while the third set, by prolonging the slope of the upper Mississippi below the mouth of the Illinois, would place the mouth of the Missouri 387.32 feet above the sea-level.

The relative levels of the different stations of the same survey are undoubtedly nearly correct, and the only course seems to be to take one set of levels as a starting point, and reduce the other series to accord with it, preserving their individual relations. Accordingly the levels obtained from the Mississippi River commission have been selected, and the others reduced so as to agree with them.

The only levels of the commission in my possession are those for the mouths of the Red, Arkansas, Saint Francis, and Missouri rivers. For intervening points the low-water slopes, as determined by Humphreys and Abbot for the years 1851 and 1855 are employed, increasing or diminishing them proportionately, as the case may require.

The distance from the Missouri to the Illinois river is 24 miles, and from the two surveys the difference in elevation, 6.74 feet, or 0.26 foot per mile, is very small. The slope above the mouth of the Illinois is 0.515 foot per mile, or approximately 0.5 foot per mile, to the Missouri river, this would make the elevation of the mouth of the Illinois 404.7 feet, or 5.26 feet more than that given by the survey of section 3. The water was at an *exceedingly* low stage and the elevation at an *ordinary* low stage would be greater. To each of the elevations of survey No. 3, 5.26 feet are added. This makes Saint Paul 1.26 feet higher than the elevation given in survey No. 2; hence 1.26 foot are added to each of the elevations of that survey. Above Cass lake the elevations are approximate. Nicollet's estimates for the source of the river and lake Itasca agree well with elevations taken in the basin of the Red river of the North and are adopted. The slope from Cass lake to the mouth of the Pinniddiwin is assumed from Schoolcraft's description of the river's course to be about 12 inches per mile. Major Allen's estimate of 1,300.1 feet+126 feet, is assumed as the elevation of Cass lake. The difference of about 100 feet between Nicollet's estimate of the level of Cass lake and Major Allen's survey is assumed to be included in the fall from lake Itasca to the Pinniddiwin river, which, from Schoolcraft's description of the severe rapids, does not seem at all improbable.

It is evident that to carry the difference of 5.26 feet unchanged from Grafton to Saint Paul, and of 1.26 foot from Saint Paul to Cass lake, cannot possibly give absolutely correct elevations, but it is the best that can be done, and is certainly within the limits of fluctuation of the water-surface. The slope as given in the surveys is retained, which is the chief point, and it is only necessary to subtract either 1.26 foot, or 5.26 feet, as the case may be, from the amounts in the column of elevations to get the figures of the surveys. For points intermediate of the stations of the surveys the elevations were found approximately by distributing the difference in level proportionately to the distances.

The columns giving the slope of the water-surface in feet per mile are obtained from the preceding ones.

Drainage areas.—The drainage areas of the tributaries and of the main river were measured expressly for this report, with the exception of those of the Missouri, Ohio, Arkansas, and Red River basins. In the case of the Missouri, the estimate made by Major Suter, corps of engineers, U. S. army, was used. Major Suter is stationed at Saint Louis, and is engaged upon a very complete report on the Missouri; and his estimate for the Missouri basin, 527,672 square miles, is probably more nearly correct than that of 518,000 square miles, made for the report of Humphreys and Abbot twenty years earlier.

The drainage areas of the Ohio, Arkansas, and Red rivers are taken from Humphreys and Abbot's report; and the chief of engineers at Washington states that he has no more reliable data on these rivers in his possession.

All the other areas, as stated above, were measured. For this purpose an accurate planimeter, reading to hundredths of a square inch, was used. The areas were taken from the United States land-office maps, made on scales varying from 12 to 18 miles to the inch. The only exception was in the case of the small streams entering the Mississippi from Kentucky and Tennessee. The land-office has not published maps of those states, and a map on a scale of 12 miles to the inch, accompanying J. D. Killebrew's report on the resources of Tennessee, was used for that state; while, for Kentucky, a map on a scale of 26½ miles per inch, prepared for the *Eclectic Geographies*, was employed.

In drawing the lines of water-shed they were made to meet at the mouth of each river. Where large tracts occur, as is frequently the case in flat countries, with no well-defined limits of drainage, the area was divided as nearly as possible proportionately between the neighboring streams. From the mouth of one tributary to the next there is frequently a large tract draining by small brooks directly into the Mississippi. These areas, which we may call *brook areas*, are not included in the drainage basins of the tributaries, and were measured separately. By a proper comparison of the two tables their amounts can be ascertained. There are 17,673 square miles of this brook area tributary to the upper Mississippi; and the entire amount tributary to the Mississippi, as calculated for this report, is 31,710 square miles. The column giving the drainage area above stations on the main river was obtained by adding these brook areas to the drainage areas of the tributaries.

The planimeter was several times tested on accurately known areas, all large measurements of over 3,000 or 4,000 square miles were duplicated, and the amounts given are thought to be very closely correct for the areas as given on the land-office maps.

The total area of the Mississippi basin is estimated to be, in round numbers, 1,261,400 square miles. The report of Humphreys and Abbot states it to be 1,244,000 square miles, 1.38 per cent. less, about one-half of this difference occurring in the Missouri basin estimates. The calculations give 3,525 square miles more drainage area to the upper Mississippi than is recorded by Humphreys and Abbot.

RAINFALL, ETC.

The tables published by the Smithsonian Institution, of Washington, in May, 1881, have been used in estimating the *average* annual precipitation in rain and melted snow upon the Mississippi basin. The course pursued was to plot upon the land-office maps, in its proper place, the amount of annual precipitation for each station as given in the rain tables, and the number of years of observation. By careful comparison of the figures plotted within each river basin, taking account of the number of years of observation, and by comparing these figures with the rain charts in the book, the average precipitation upon the basin of each tributary of the Mississippi was estimated. For the Missouri, Ohio, Arkansas, and Red River basins, the figures were plotted upon a small map of the United States, and the different basins were divided into sections of equal area and nearly similar rainfall. The average precipitation was ascertained for each of these sections, and then for the entire basin. The distribution of the precipitation according to the seasons was estimated by comparing the rainfall charts for each of the four seasons, and also the tabulated rain gaugings. The most elaborate discussion of the rainfall of the Mississippi basin in relation to the systems of drainage, so far as known, is that of Humphreys and Abbot. They pursued much the same course as that mentioned above, but the data at their command were not nearly so complete as those furnished in the publications of the Smithsonian Institution. Their results and those obtained for this report agree substantially, with the exception of the estimates for the Yazoo basin. They state its average precipitation to be 46.3 inches per annum, while it is here considered to be about 53.3 inches. The reason of this difference is apparent: Humphreys and Abbot had at their disposal the records of only three stations, Memphis, Vicksburg, and Jackson, of which Memphis had a precipitation of only 41.8 inches. This, in averaging the records, gave too low a result, as plainly indicated by the Smithsonian Institution publications.

Discussion of geographical variations of the rainfall.—A comparison of the table of tributaries shows a somewhat uniform increase in the amount of precipitation from the source to the mouth of the Mississippi in the vicinity of its immediate valley. Starting with barely 25 inches at the source, it increases to nearly 60 inches at the Gulf. If, however, we include in the comparison the large tributaries great variations occur; and this is plainly shown by the average precipitation column of the table of the main river, as also by the curve plotted on the curve-sheet. The average on the basin of the Mississippi above the Missouri gradually increases to 33.93 inches; the Missouri, with its precipitation of only 19.6 inches, lowers it to 23.13 inches. The Ohio, with its precipitation of 43.1 inches, raises the average to 27.98 inches. The Arkansas, with its precipitation of 28.3 inches, just maintains the average above its mouth, although much below the rainfall at its mouth. The Red river, which has an annual precipitation of 38.3 inches, is also below the rainfall at its mouth, but nevertheless raises the average of the entire basin from 28.83 to 29.57 inches.

Variation due to the seasons.—The above are the prominent features of the yearly precipitation. The changes in the distribution of the precipitation through the four seasons as we pass through the Mississippi basin are very unlike. The *average* precipitation for the different seasons on that portion of the basin above the successive stations on the main river has not been given, because of the time required to determine more than a very rough approximation. For the basins of the various tributaries, however, it is given in the second table, and a general idea can be obtained from it for the entire Mississippi basin. In the same way as for the total precipitation, a comparison of the distribution for the smaller tributaries shows a rather uniform change from the source to the mouth, while the large tributaries appear in the columns, with variations from the surrounding figures more or less pronounced.

Variation along the main river.—Considering the smaller tributary basins only, and dividing the length of the main river into four equal sections, we have the following *approximate* results for the distribution of the precipitation:

Region.	Average precipitation of rain and melted snow.				
	Spring.	Summer.	Autumn.	Winter.	Year.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Source	6.84	9.25	6.27	2.64	25.00
First quarter	7.21	12.04	6.84	*2.91	29.00
Second quarter	9.93	13.23	8.84	5.50	37.50
Third quarter	13.37	11.36	8.54	9.30	42.57
Fourth quarter	16.00	10.93	9.10	14.10	50.13
Mouth	18.30	12.20	10.30	16.50	57.30

This shows that toward the mouth the winter and spring precipitation is immensely greater, relatively to the summer and autumn rains, than near the source, and this change takes place along the entire course of the river. In the first quarter, the summer and autumn precipitation is 18.88 inches; the winter and spring precipitation is 10.12 inches. In the fourth quarter, the summer and autumn precipitation is 20.03 inches; the winter and spring precipitation is 34.80 inches.

Variation in the large tributary basins.—Turning, now, to the four large tributaries, we find these results:

River.	Annual precipitation of rain and melted snow.				
	Spring.	Summer.	Autumn.	Winter.	Year.
	Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*
Missouri	6.10	6.40	4.40	2.70	19.60
Arkansas	8.55	9.33	6.33	4.08	28.30
Red	11.51	10.22	8.44	8.15	38.30
Ohio	11.90	11.80	8.50	10.90	43.10

The distribution on the Missouri basin, so far as the four seasons are concerned, is very similar to that at the sources of the Mississippi. The distribution on the Arkansas basin is of much the same character. For the Red River basin the winter and spring precipitation exceeds that of summer and autumn by one inch in depth, and the distribution partakes more of the nature of that at the mouth of the main river. In the Ohio basin the distribution is more like that existing at the mouth of the main river than is the case with any of the other rivers mentioned, the winter and spring precipitation exceeding the summer and autumn rainfall by 2.5 inches. There is apparently a tendency for the lower of the large tributaries to have a greater precipitation in winter than in summer, while this tendency is not so strong toward the north. In this respect they resemble the immediate Mississippi valley.

Summary of facts.—Summing up all the evidence, we have this result: A light precipitation at the sources of the river, gradually increasing toward the south; a very light precipitation on the western portion of the basin, about the upper waters of the Missouri, the Arkansas, and the Red rivers; very little change in the amount of precipitation on passing eastward through the Ohio basin. As regards the distribution of this annual precipitation according to the seasons, there is a preponderating summer precipitation at the sources, but a gradual increase in the winter precipitation relatively to that of the summer toward the south, until at the mouth the winter precipitation is much the greater of the two: A greater summer than winter precipitation at the west, upon the basins of the Missouri and Arkansas especially, while nearly equal proportions prevail within the Red River basin; a greater precipitation in winter and spring than in summer and autumn on the basin of the Ohio.

Physical causes of the above facts.—The causes of these peculiarities are readily traced. The ocean is the great reservoir from which is drawn the moisture that waters the earth. The warm Pacific current, accompanied by moisture-bearing winds, strikes the western coast of the United States and British America and forms one source of supply; the Atlantic also, to some extent, feeds the air with vapor which falls on the United States; but the gulf of Mexico, lying under a semi-tropical sun, is the great evaporating surface from which are obtained the rains of our country. The saturated southerly and southwesterly winds blow up the valley of the Mississippi, and meeting no abrupt changes in the contour of the country, deposit their moisture in a broad sheet, extending beyond the northern confines of the United States, and to some extent westward over the plains east of the Rocky mountains; but as the anti-trades, of which these winds are a part, are essentially southwest winds, the prevailing tendency is for the line of maximum precipitation due to them to take a northeast direction across the Ohio basin and into the Atlantic states.

The moisture-bearing winds from the Pacific are largely deprived of their moisture by the chilling contact of the western ranges of mountains, and after passing these and entering the warmer region eastward their capacity for retaining moisture is increased, so that very little rain or snow falls from them upon the dry regions of the western portion of the Mississippi basin.

To this influence of the barrier of the western ranges of mountains, in checking the flow of vapor from the Pacific ocean, is due the light annual precipitation of from 6 to 14 inches about the headwaters of the Missouri, Arkansas, and Red rivers. To the action of the moist winds from the Gulf is due the precipitation of the Mississippi basin, which gradually diminishes toward the north as the south winds become drier, and more rapidly toward the west, where the rainfall mentioned is largely due to it.

The variation in the distribution of this precipitation, which has already been described, is due to the passage of the sun to the southern hemisphere, or *vice versa*. There are two contending forces in the temperate zone—these warm moisture-bearing winds just described, and the cold, dry winds from the north. When they meet, the result is the condensation of the moisture of the southern winds, and rain or snow, as the case may be. When the sun is far up in the north and summer prevails in the northern hemisphere, then the moist winds encroach upon those from the north, and the result is that the larger part of their moisture is carried beyond the southern part of the Mississippi basin and precipitated farther north. As the sun sinks lower in the southern horizon and winter sets in, the cold winds gain the ascendency, and the result is that comparatively little precipitation occurs in the northern portion of the Mississippi basin, while on the other hand the southern part of the basin is receiving the bulk of its annual rainfall, and thus this belt of heaviest precipitation swings north and south, season after season, following the sun in its changes of declination. The winter precipitation on the Ohio basin almost exceeds that of summer. On the large western tributaries, however, the cold winds easily gain the mastery, and at their upper waters the winter precipitation is consequently very light.

FLOW OF THE STREAMS.

In studying this branch of the hydrology of the Mississippi basin the two tables have been necessarily considered together. The principle has been to collect all the actual gaugings obtainable of the main river and its branches at various points, and from these to determine as nearly as possible the flow of each tributary, and of the main river at each of the stations given in the table. Comparisons have then been made with the rainfall, etc., and ratios deduced. Only two stages of flow have been selected, viz., the ordinary low flow and the average flow. There are several reasons for this—the gaugings in the west are so few as to make great detail of discussion an impossibility, and the two stages selected are the only two of prime importance to the interests of water-power. No division of the subject into monthly flow and comparison with the monthly rainfall has been attempted, because, while such a course is possible for many eastern streams, where long series of measurements have been made, it is impracticable for the streams under discussion.

Definitions of ordinary low flow and average flow.—The ordinary low flow is intended to represent the average flow during a period of twenty or thirty days in the late summer or fall, when the river is lowest. A record of monthly stages for five years at Rock Island shows the month of lowest stage to have been September. At Saint Paul and above it is probable that the lowest stages occur in midwinter; but no gaugings have been made of the flow at that time, and it must be understood that *the calculations given for the ordinary low flow in that region are not applied to the winter months*, although, as moderate estimates are used, it is probable that they are not greatly in excess even for that period.

In making calculations at the engineer's office at Saint Paul the average flow of the Mississippi at Minneapolis for the 134 days from November 17 to April 1 was taken at 5,000 cubic feet per second. The tables give the ordinary low flow at Minneapolis as 6,017 cubic feet per second. The ordinary low flow of the main river has not been carried in the tables below the Missouri river, as below that point the large tributaries come from such far-distant sources that, while one is at low stage, another may be running with overflowed banks, and there is no certainty of an ordinary low stage existing throughout the drainage system at any one time. With the average flow, however, the case is different. That represents the stage of the river if we presume it to remain constant from one day to another all the year through, and is practically the actual condition that would exist if a perfect and uniform system of reservoirs was applied throughout the entire Mississippi basin, so that the floods could be held back and distributed during the low-water seasons. Whether such a system of reservoirs is practicable, is another matter. To a certain extent it is, and this makes the average flow of great importance in the consideration of the water-power.

The recorded gaugings at Saint Paul and above were made under the direction of Major Charles J. Allen, with the exception of those for the Minnesota river. Those for the main river, from Saint Paul to the mouth of the Illinois, were furnished by Captain Alex. Mackenzie, stationed at Rock Island. The gaugings of the main river below the Missouri are taken from the elaborate report of Humphreys and Abbot.

ORDINARY LOW FLOW.

Flow of main river above the Minnesota.—Above the mouth of the Minnesota river all the gaugings employed were made on the main river itself. The first below the source was made at Grand Rapids. A gauging made there October 13, 1880, reduced to a mean low stage, gave 1,058.5 cubic feet per second. Three gaugings made October 15, 1879, at 0.4 of a foot below mean low-water, gave an average of 969 cubic feet per second, from which we estimate the mean low flow to be 1,065 cubic feet per second. The table gives an ordinary low flow at Grand Rapids of 1,036 cubic feet per second. Four gaugings made at Aitken, below the mouth of Rice river, October 20, 1879, at a stage 0.2 of a foot below mean low water, give an average flow of 1,743 cubic feet per second, from which we estimate the mean low flow to be 1,863 cubic feet per second. The table indicates an ordinary low flow past Aitken of almost precisely the same amount. Daily gaugings were made at Brainerd, Sauk Rapids, and Fridley's bar just above Minneapolis, through the spring, summer, and fall of 1875. The lowest stage at Brainerd was in August, when for eleven days the flow varied between 3,000 and 2,700 cubic feet per second. At Sauk Rapids the low stage ran for sixteen days from 4,327 cubic feet to 4,753 cubic feet per second. At Minneapolis the low stage varied for twenty-eight days between the limits of 5,640 cubic feet and 7,177 cubic feet per second, with an average of about 6,600 cubic feet per second. The table gives an ordinary low flow per second past these stations of 2,246, 4,123, and 6,017 cubic feet, respectively. The results given in the table for the first two places are probably low estimates of the ordinary low flow; they certainly are such for the year 1875, which was not far from being an average year as regards rainfall. For Minneapolis the amount given in the table is somewhat nearer the gaugings for 1875.

"High-flow" and "low-flow" streams.—The United States engineers' reports state the average low flow of the Saint Croix river to be 2,796 cubic feet per second, giving a flow per square mile of 0.369 cubic foot per second; and of the Wisconsin 4,790 cubic feet per second, giving a flow per square mile of 0.39 cubic foot per second. We will be on the safe side if we assume these figures for the *ordinary low flow*, as previously defined.

The Rock river has been gauged near its mouth for the purposes of water-power, and its ordinary low flow determined to be 3,900 cubic feet per second, or 0.355 cubic foot per second per square mile of drainage area.

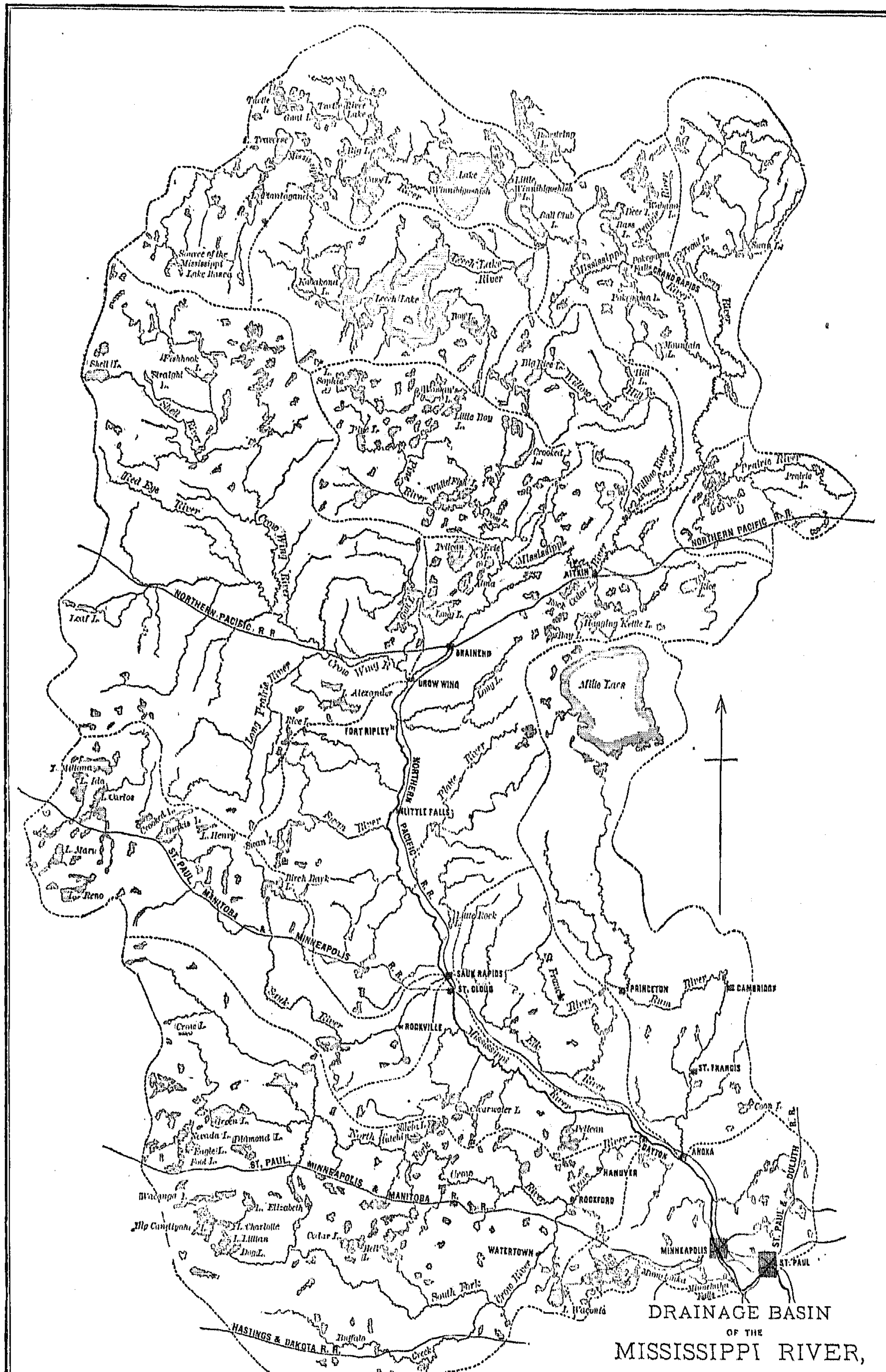
The Minnesota river is a very variable stream, and while its discharge rises to 60,000 cubic feet per second, it sometimes falls as low as 800 cubic feet per second; but from the gaugings made under General G. K. Warren it is concluded to call the ordinary low flow 2,500 cubic feet per second, or 0.156 cubic foot per second for each square mile of drainage area.

There are two classes under which, for convenience, we can range the tributaries of the upper Mississippi, with, of course, some intermediate cases. These are what may be called high-flow streams, like the Saint Croix, etc., flowing from a swampy and wooded region, giving an ordinary low flow of over 0.3 cubic foot per second per square mile; and low-flow streams, like the Minnesota, draining a prairie country and giving an ordinary low flow of less than 0.3 cubic foot per second per square mile.

The Chippewa basin has features similar to those of the basins of the Saint Croix and Wisconsin rivers; and, considering the rainfall, etc., the flow has been estimated at 0.37 cubic foot per second per square mile, which certain gaugings indicate to be approximately correct. The basin of the Black river is likewise considered, from similar reasons, to give an ordinary low flow of 0.33 cubic foot per second per square mile. These two rivers are included among the high-flow streams.

Flow of the upper Mississippi below the Minnesota.—The following data concerning the volume of flow and corresponding stage of the Mississippi at points between Saint Paul and the Illinois river are collected from material furnished by Captain Mackenzie. The adopted low-water volumes represent an extreme low flow, not an ordinary low flow in the sense in which we use the term:

Locality.	First tributary above station.	Stage.	Width.	Flow per second.	Adopted low-water flow per second.
		Feet.	*Feet.*	*Cubic feet.*	*Cubic feet.*
Frenchman's bar	Minnesota	5.8	....	20,091	5,000
Wabasha	Chippewa	3.6	1,500	21,212	10,000
Johnsonport		1.0	1,570	16,473	14,000
Below mouth of Wisconsin river	Wisconsin	0.96	1,237	20,527	17,000
Lyons	Maquoketa	3.10	1,736	37,512	18,500
Princeton	Wapsipinicon	1.1	2,087	27,743	19,000
Rock Island	do	2.1	2,444	30,313	19,000
		18.4	2,737	251,348	10,000
Burlington	Henderson	7.2	2,406	103,536	22,000
		0.7	2,333	27,020	22,000
Canton	Fox	5.2	2,339	61,445	26,000
Hannibal	Fabius	1.5	1,100	38,741	30,000


DRAINAGE BASIN
OF THE
MISSISSIPPI RIVER,
ABOVE ST. PAUL, MINNESOTA.
SCALE OF MILES.
0 5 10 15 20 25 30
NORTHERN PACIFIC R.R.
ST. PAUL, MINNEAPOLIS & MANITOBA R.R.
HASTINGS & DAKOTA R.R.
ST. PAUL & DULUTH R.R.
BRAINERD
CROW WING
FORT RIPLEY
LITTLE FALLS
SAUK RAPIDS
ST. CLOUD
ROCKVILLE
PRINCETON
CAMBRIDGE
ST. FRANCIS
ANOKA
DAYTON
HANOVER
ROCKFORD
WATERTOWN
MINNEAPOLIS
ST. PAUL
AITKIN
GRAND RAPIDS
Mille Lacs
Leech Lake
Lake Winnibigoshish
Source of the Mississippi Lake Itasca
Red Eye River
Crow Wing River
Long Prairie River
Sauk River
Rum River
Elk River
Crow River
Prairie River
Willow River
Mississippi River

In order to determine the ordinary low flow we will have to resort to approximation, by making use of measurements of the water-level.. Of course the amount of flow does not bear a simple proportion to the stage of the river; yet while it would not be permissible to consider the average flow to equal that at the average stage, the employment of this method to determine the ordinary low flow may be reasonably expected to yield a somewhat close approximation. As a test, we may apply the method to the daily records of flow and stage made at Fridley's bar, under Major Allen's direction, during August, 1875. The average flow for August was 6,695 cubic feet per second, and the average stage 0.661 foot above low water. The flow corresponding to the stage is about 6,635 cubic feet per second, giving a difference of only 60 cubic feet per second.

Gauge-readings for five years at Rock Island, reduced to monthly averages, show the month of lowest stage for the year to have been September, during which the average was 1.44 foot above low water. It is thought that this can be safely assumed as the stage corresponding to the ordinary low flow. Unfortunately there are no records of gaugings of the flow at Rock Island during the stage of 1.44 foot, but we can turn to Princeton, just above. No large tributaries enter between these two places, and a rise of 1.44 foot at the one would probably, from the dimensions of the channel, be accompanied by a nearly equal rise at the other. A stage of 1.10 foot above low water at Princeton is reported to give a flow of 27,743 cubic feet per second.

A stage of 1.44 foot carried down to Burlington, gives a flow of about 35,000 cubic feet per second, according to the curve of discharges at that place contained in Captain Mackenzie's report of July 7, 1880.

A stage of 1.5 foot at Hannibal gave a flow of 38,741 cubic feet per second.

Although only approximations to the ordinary low flow, yet, because of the comparatively uniform nature of the upper Mississippi, the above amounts can be safely taken as being not far from the truth.

Flow of the tributaries.—We have now determined upon the ordinary low flow of the Mississippi at Minneapolis (the flow above will be considered later), Rock Island, Burlington, and Hannibal. The ordinary low flow of the high-flow tributaries, the Saint Croix, Chippewa, Black, Wisconsin, and Rock rivers, has been determined; also of the Minnesota among low-flow rivers. What remains to be done is to determine the ordinary low flow of the remaining rivers, which are all low-flow streams. So far as known, no gaugings by the United States engineers are obtainable for these streams; and most of the estimates made by those interested in water-powers are evidently too great, and are of little use for our purpose. However, the remarks made by practical millers and manufacturers, the observations upon the amount of power actually in use, and upon the nature of the drainage basins, permit a rational comparison of these rivers, and in this way:

If we take the increase in ordinary low flow of the main river, from Minneapolis down to Rock Island, and deduct the discharge of the rivers whose ordinary low flow is already fixed upon, the remainder will be the ordinary low flow from the remaining drainage area between those two places. In the same way can be determined the total flow of the streams between Rock Island, Burlington, and Hannibal. Going through this process we obtain the following figures for the flow per square mile. For convenience of comparison the results obtained from the tables are inserted beside those calculated from the flow as estimated from the United States engineers' reports, although they were deduced from them. The amounts of flow of the Minnesota, Saint Croix, Chippewa, Black, Wisconsin, and Rock rivers are already determined upon, and hence deducted:

Region considered.	Ordinary low flow per second per square mile.	
	U. S. reports.	Tables.
	Cubic feet.	*Cubic feet.*
Minneapolis to Rock Island..	0.358	0.281
Rock Island to Burlington...	0.229	0.248
Burlington to Hannibal......	0.150	0.214
Minneapolis to Rock Island..	0.358	0.281
Minneapolis to Burlington...	0.304	0.267
Minneapolis to Hannibal.....	0.244	0.245

From a knowledge of the nature of the country drained by the low-flow rivers involved in the above table, and from estimates given by those using their water-power, it seems hardly probable that there is so great a decrease in the flow per square mile toward the south as is indicated in the column headed "U. S. reports." Hence, in obtaining the amounts in the column headed "Tables," we take the average flow per square mile from Minneapolis to Hannibal (exclusive of the rivers named) and alter it for each river basin according to the characteristics of that basin, taking care that the total flow from the tributaries shall approximate to the ordinary low flow as determined for Rock Island, Burlington, and Hannibal. Due account is also taken of the flow from the "brook areas". (See remarks on drainage areas.) Thus, the Cannon river, for example, has a number of lakes in its basin, and, from the power used, is considered to have an ordinary low flow of 0 29 cubic foot per second. The Root, Zumbro, etc., are fed by many springs, and have many mills upon them; they are given 0.28 cubic foot. The Des Moines is an unsteady river like the Minnesota, and, according to the best figures we can obtain, is not entitled to more than 0.20 cubic foot.

The volumes of ordinary low flow at Rock Island, Burlington, and Hannibal, as obtained by this method, as also those estimated, as previously described, from the records of the United States engineers, are given in the following table:

Station.	Ordinary low flow per second.	
	U. S. reports.	Tables.
	Cubic feet.	*Cubic feet.*
Rock Island	27, 743	26, 163
Burlington	35, 000	33, 700
Hannibal	38, 741	38, 818

The differences are due to the course pursued in lessening the *variation* in the amount of flow per square mile, and the effect is shown in the table of flow per square mile just given. In the column headed "Tables" the extremes more nearly approach the mean than in the column headed "U. S. reports". The reasons why this is the true condition have been already set forth.

Thus we have settled upon the ordinary low flow of the tributaries from Minneapolis down to the Missouri river, with the single exception of the Illinois river. This stream, with its drainage area of over 29,000 square miles, might be expected to exert considerable influence upon the main river, but the fact is that, as regards the ordinary low flow, it is of comparatively small consequence. Major G. J. Lydecker, stationed at Chicago, who is in charge of the Illinois river, has very kindly communicated his views regarding its flow. He states that when the river is at its lowest stage in an average year the discharge is substantially 1,750 cubic feet per second. "During the general low-water season the stage of the river will fluctuate from week to week, rising after heavy rains and resuming its ordinary low stage after their effects have passed away." "The average flow during this season is probably about 2,000 cubic feet per second," or 0.069 cubic foot per second per square mile. This estimate, which seems an exceedingly low one, is apparently based on a gauging made at Spar island, 35 miles above the mouth, on September 16, 1879. The river was then at an extreme low stage, and gave a flow of 1,566 cubic feet per second.

The Illinois basin is, as Major Lydecker remarks in his letter, flat and mainly prairie, much reducing the ordinary low flow, but the estimate of the flow at a similar stage at the upper waters fully equals, if it does not exceed 2,000 cubic feet per second, and it seems hardly probable that the lower tributaries do no more than supply the evaporation. With due respect for Major Lydecker's estimate, it seems improbable that it is sufficiently large. It is employed, as stated by himself, only as an approximation.

Tributaries above the Minnesota.—Having gained an idea of the ordinary low flow per square mile from the several varieties of land to be found in the Upper Mississippi basin—from wooded, swampy country to dry prairie—we are in a condition to retrace our steps and estimate the ordinary low flow of the tributaries that enter above Minneapolis.

Taking the ordinary low flow past Minneapolis as 6,017 cubic feet per second, gives an average flow per square mile for the drainage area above of 0.307 cubic foot per second. The tributaries above Minneapolis are some of them prairie streams, some drain woodland, and many of them have a great number of swamps and lakes within their basins. The problem is much the same as before: to distribute the total flow of the river among the tributaries, according to the physical characteristics of their basins, checking the results by the gaugings at different points along the main stream. This has been done, and the results are given in the tables. As already stated, they are believed to be less than the true amounts rather than greater.

Effects of the lakes.—Those streams which drain prairie regions have many lakes tributary to them, and hence the flow per square mile is raised to 0.29 or 0.30 cubic foot per second. The other rivers are very similar in the characteristics of their basins to streams like the Saint Croix and Chippewa, and hence their flow per square mile is estimated to be from 0.33 to 0.37 cubic foot per second. In the Leech Lake basin especially there is great natural storage capacity, and it might be thought that the flow per square mile would be greater than for streams like the Saint Croix; but it must be remembered that the rainfall is only about 25 inches in the one case, while it is nearly 10 inches greater in the other. Also the low flow per square mile is usually larger, other things being equal, from a large than from a small drainage area.

The culminating point of effect from the remarkable system of natural reservoirs is at the mouth of the Leech Lake river, as shown by the following selections from the table. Below this the prairie influence gradually gains the ascendency. This is shown strikingly by the curve of ordinary low flow:

Station.	Ordinary low flow per second per square mile of drainage area above station.
	Cubic feet.
Head of Cass lake	0.334
Outlet of lake Winnibigoshish	0.337
Mouth of Leech Lake river	0.351
Grand Rapids	0.349
Brainerd	0.323
Sauk Rapids	0.312
Minneapolis	0.307

Table of flow per square mile for various kinds of country.—From the estimates we have been making in the preceding pages, and which are inserted in the two tables, the following conclusions are reached concerning the ordinary low flow (as previously defined) per square mile from the various kinds of topography met with in the upper Mississippi basin. The figures are derived from drainage areas of from 1,000 to about 15,000 square miles, and refer to the flow of all the months except from December through to March:

Nature of country.	Annual precipitation.	Ordinary low flow per second per square mile of drainage area.
	Inches.	*Cubic feet.*
Swamp and woodland with large lakes	25 to 35	0.37 to 0.40
Swamp and woodland		0.30 to 0.37
Prairie and lakes		0.28 to 0.34
Prairie and woodland		0.28 to 0.34
Rolling prairie with scattered groves and springs in the river bluffs.		0.20 to 0.30
True prairie streams		0.06 to 0.20

AVERAGE FLOW.

The term *average flow* has already been defined, and its importance to the water-power interests has been pointed out. It will be readily seen that it is very difficult, if not impossible, to determine the average discharge of a stream unless daily gaugings have been made. The subject is more uncertain than is the case with the ordinary low flow, because even the records of the stages of the river which can be relied upon to a certain extent in estimating the latter, cannot be considered to give a sufficiently close approximation for the former. On this account the estimates of average flow for the Mississippi basin are not so closely based upon actual records as are those of the ordinary low flow; enough daily gaugings are in our possession, however, to make an approximation possible. The same course is pursued as in determining the ordinary low flow. The gaugings upon the main streams are used to check the summation of the estimates for the tributaries, and these estimates are made in accordance with the physical conditions of the several drainage basins.

The report of Humphreys and Abbott gives valuable gaugings and calculations of flow for the lower river. Upon the upper portion of the river the only gaugings obtainable, at the time of making the calculations, which gave daily readings, were those made under the direction of Major Charles J. Allen at and above Saint Paul. We are enabled to ascertain the average stage at Rock Island and at one or two other points, but generally the average stage gives a very uncertain idea of the actual average flow, and cannot be relied upon. As far down as Minneapolis the results may be considered a rather close approximation, with data derived from the work done for the proposed "reservoir system". As the actual average flow is somewhat more dependent upon the amount of rain than is the ordinary low flow, it will be estimated in terms of that quantity, as so many per cent. of the annual precipitation, instead of in terms of the flow per square mile.

Minnesota river.—Let us first deal with the Minnesota river, and get an approximate idea for streams of that character. No long continued gaugings have been made upon it.

In 1867, which was a year of high rainfall, General G. K. Warren made a large number of gaugings, from which can be obtained the average flow from June 22 to November 18. From Major Allen's report of January 16, 1881, by comparing the records of the stations at Minneapolis and Saint Paul, can be obtained an approximation to the average flow of the Minnesota river from November 18 to April 9, 1875-'76; 1875 was a high-flow year for the Minnesota basin, judging from Major Allen's records. By combining the two we get 8,885 cubic feet per second; the average flow for a high rainfall year of about 32 inches. Assuming a direct proportion between the flow and the amount of annual precipitation, we get an average flow of 7,775 cubic feet per second for a year of average precipitation (28 inches). Hence the average flow is 23 per cent. of the annual precipitation. This, of course, can only be considered a rough approximation, but it agrees well with other results.

The river above the Minnesota.—Next we will consider the streams above Minneapolis. The daily gaugings of the flow made at Saint Paul, Minneapolis, Sauk Rapids, and Brainerd, have already been employed in estimating the ordinary low flow. They were conducted during the year 1875, mostly from March or April through the summer into November. At Minneapolis daily records of the stage were kept throughout the entire year. Fortunately for our purpose, 1875 was in this region a year of about average precipitation. To determine the average flow of the year it is necessary to know what it is during the three months, more or less, when no records were kept.

Mr. Joseph P. Frizell, Major Allen's chief assistant, is one of the most experienced engineers in his specialty in the country, and his careful study of the upper Mississippi makes his opinion concerning it of great value. In preparing the tables for Major Allen's report he estimates the average flow at the several stations during the winter season and inserts it.

The policy at Major Allen's office appears to have been throughout to make low estimates, and hence Mr. Frizell's figures probably err, if at all, on the safe side. For the period in question he assumes an average flow of 5,585 cubic feet per second at Saint Paul from November 18 to April 9; 5,000 cubic feet per second at Minneapolis from November 17 to April 1; 5,363 cubic feet per second at Sauk Rapids from November 1 to April 18; and 2,715 cubic feet per second at Brainerd from November 18 to April 6.

These figures we will assume as correct, and use the tables in Major Allen's report to determine the average flow of the year. The average flow of the year was: At Saint Paul, 25,145 cubic feet; at Minneapolis, 13,558 cubic feet; at Sauk Rapids, 9,797 cubic feet, and at Brainerd, 5,656 cubic feet per second. The flow at Saint Paul is evidently much in excess of what it would be for an average year, because of high water in the Minnesota river; hence it is discarded in our calculations. Comparison of the other estimates of flow with the average yearly precipitation gives these results:

(For convenience of comparison the results obtained from the two tables of the Mississippi are inserted beside those calculated from the flow as taken from Major Allen's report, although derived from them.)

Region considered.	Ratio of average flow to annual precipitation.	
	U. S. reports.	Tables.
	Per cent.	*Per cent.*
Minneapolis to Sauk Rapids	28.71	30.08
Sauk Rapids to Brainerd	34.84	34.27
Brainerd to source	43.61	39.40
Above Minneapolis	35.74	34.70
Above Sauk Rapids	39.46	36.90
Above Brainerd	43.61	39.40

In the same way as in the case of the ordinary low flow, the ratio gradually increases toward the source. This is undoubtedly due to the change in the nature of the country from prairie to tamarack and cedar swamps and woodland.

While the large number of lakes exerts the great effect already demonstrated upon the ordinary low flow, it cannot be considered to be so instrumental in increasing the ratio of average flow. The evaporation from their surfaces nearly, if not quite, equals the annual precipitation upon them. We are to look rather to the nature of the soil and growth for an explanation of the increase in ratio shown in the table.

The swampy, wooded character of the country about the sources of the Mississippi, and the sandy, "drift" nature of the soil are probably the chief causes of the high proportion the annual flow bears to the precipitation. In view of this fact it is thought proper to make the variation for the different river basins more gradual in the case of the average than of the ordinary low flow, as shown by a comparison of the two curves. On this account we will distribute the variation shown in the column headed "U. S. reports" more gradually between the source and Minneapolis.

As the result of a comparison of the nature of the several drainage basins, of the flow at the three stations upon the main river as given in Major Allen's report, and of the ratios of average flow to average precipitation deduced therefrom, we obtain the ratios given in the two tables of the Mississippi and the column headed "Tables" in the one just adduced. Their accuracy is not vouched for, and yet it is believed that they are not far from the truth. The probability is that they give less than the true amounts, rather than more.

For convenience of comparison the following table is inserted:

Station.	Average flow per second.	
	U. S. reports.	Tables.
	Cubic feet.	*Cubic feet.*
Brainerd	5,056	5,101
Sauk Rapids	9,797	9,174
Minneapolis	13,558	13,193

The average flow of the Minnesota river has been determined. This, taking account of the intervening "brook area" (see remarks on "drainage areas"), makes the average flow past Saint Paul 20,925 cubic feet per second. We have yet to consider the river below.

The river below the Minnesota—Statement of the nature of the problem.—In order to understand clearly the conditions, it is best to say at the outset that we have no actual gaugings upon the river to help us between Saint Paul and Columbus, below the mouth of the Ohio; neither do series of gaugings upon the side streams give us much clue to their actual average discharge. The best we can do is to apply our knowledge of the ratio of flow for various kinds of land surface to the drainage basins of these tributaries, and make the total foot up to the average flow of the Mississippi as ascertained at Columbus, Kentucky. In this we do not have to rely upon published ratios of flow to precipitation, deduced for other streams of perhaps far different character.

The ratios just determined for the tributaries above Saint Paul (see tables) can be safely used as approximations for streams draining country of a similar nature, and the estimates of Humphreys and Abbot for the average discharge give a clue to the value for low-ratio streams. Their estimate gives an average of 15.9 per cent. of the precipitation, entering the Mississippi from the Arkansas basin (including the White river). This is very nearly the general percentage assumed in the West for the low-ratio prairie streams of the Mississippi basin.

The ratios obtained for the Minnesota and the first three or four tributaries above, serve as guides in making estimates for streams draining country of an intermediate nature. The percentages found for the high-ratio rivers in the upper waters can be reasonably applied to the very similar basins of the Saint Croix, Chippewa, Wisconsin, and other streams.

Thus we are enabled by comparison to run through the complete list of tributaries down to the Ohio, with apparently reasonable claims of being approximately correct, especially as the sum total agrees with the gaugings made on the lower Mississippi. The effects of change in climate on passing south, if it has any effect upon the average flow, are unnoticeable compared with the uncertainties arising from scarcity of gaugings.

The basins of the Saint Croix, Chippewa, Black, and Wisconsin are wooded, and, particularly in the cases of the largest three, abound in tamarack and cedar swamps at their upper portions. Nearer the mouths of the rivers the basins are more open, especially on the Wisconsin; but, nevertheless, these streams stand high among the high-ratio rivers of the upper Mississippi. They are given ratios varying from 35 to 37 per cent.

The intervening streams drain largely prairie interspersed with groves, and as they are said to be fed by many bluff springs, they are given a ratio of from 26 to 28 per cent., falling to 24 per cent. for the Iowa river, which has considerable prairie land like that drained by the Minnesota.

For the Rock river a high ratio of 35 per cent. is used, because of the remarks of engineers regarding it and the swampy nature of much of the surface drained; it cannot be classed as a prairie stream. The Des Moines has a large amount of uncultivated prairie within its basin, giving a small return for the rain granted to it. It is not thought to have a ratio of not more than 20 per cent.

Considering the character of the large tributaries at the upper portion of the Illinois river, where one stream is much like the Rock river in nature, while another drains extensive swamp and woodland, 24 per cent. is thought to be not too high a ratio to assume for it, although extensive tracts of level prairie are tributary to its flow.

Missouri river.—For the Missouri nothing better can be done than to compare it with the Arkansas, the method used by Humphreys and Abbot.

Estimates (furnished to Mr. Dwight Porter by Major Suter, and kindly placed at my disposal) of the average monthly flow for 1879, give an average flow for that year of 74,047 cubic feet per second, but this, from an inspection of the monthly averages, was so evidently a year of low total discharge as to be of little value for our purpose.

The Missouri basin is very similar in character and in proportion of prairie and mountain to the basin of the Arkansas. The distribution of the rainfall is also much the same in character—light at the sources and increasing toward the mouth, although the average is higher for the Arkansas than for the Missouri. Hence we assume a ratio of 16 per cent. for the Missouri. This gives an average discharge of 121,900 cubic feet per second.

From the Missouri down to the Ohio the ratio is assumed to be 26 per cent. after a comparison with the country drained by the semi-prairie streams of the upper Mississippi.

Ohio river.—For the Ohio no gaugings exist, so far as known, which can aid us in determining the actual average discharge. The method used by Humphreys and Abbot was to assume the ratio of flow to precipitation equal in the cases of the Ohio and the upper Mississippi, because of a certain similarity in the physical characters of their basins. Hence they employed a ratio of 24 per cent. for the Ohio. If we made the same supposition we would use 27.5 per cent., the ratio estimated for the upper Mississippi. (See table of main river).

Now, from one-quarter to one-third of the Ohio basin is mountainous and clothed with timber; by far the greater portion of the remaining area, lying in Kentucky and Tennessee, is rolling, broken, or even hilly country, very largely covered with woods. To the north, in Ohio and Indiana, the country is mostly rolling land, with the river channels generally cut deep in the surface and considerable amounts of timber interspersed with prairie. Much of the land is also cultivated.

The ratio for mountain streams in the eastern states is found to range from 50 to 70 per cent., or even more in extreme cases. We have already found the ratio for regions in the Mississippi valley intermediate between prairie and wooded country to be from 25 to 30 per cent.

In view of these facts it is thought that 30 per cent. is a closer estimate for the Ohio basin than 24 per cent., and this is adopted. This ratio makes the average discharge 203,846 cubic feet per second.

The flow given in Humphreys and Abbot's report is 158,000 cubic feet. Their estimate of the average annual precipitation upon the basin is 41.5 inches. Using the Smithsonian publications, we estimate it to be 43.1 inches. The reason for using a higher ratio has just been shown, and, considering all the circumstances, it seems more nearly correct.

Average flow past Columbus—a check upon the calculations.—Thus the average flow from the Mississippi basin is estimated down to Columbus, and the table gives a flow past that place of 456,538 cubic feet per second.

Humphreys and Abbot estimate, by gaugings, the average discharge past Columbus for the year from December 1, 1857, to December 1, 1858, to have been 621,002 cubic feet per second.

The year of 1858 was one of almost universal heavy rainfall upon the Mississippi basin, and four great floods occurred, of which we get this description from Humphreys and Abbot's report:

The first, caused mainly by the Ohio, occurred in December, 1857; the rivers below were at a low stage.

The second occurred in March and April, 1858, and was caused by a general swelling of the lower tributaries of the Missouri, upper Mississippi, and Ohio. During this flood the rivers below the Ohio were high, especially the Arkansas.

The third flood was caused in the latter part of April, 1858, by heavy rains on the lower tributaries of the Ohio (the Tennessee river was unusually high), Missouri, and upper Mississippi. All the tributaries below the Ohio were then comparatively low.

The fourth, an almost unprecedented flood, took place in June, 1858. The Ohio, Missouri, and upper Mississippi were enormously swollen.

Quoting from Humphreys and Abbot: "With the Ohio and Mississippi both in full flood, the torrent which poured into the alluvial region by the river itself, and through the swamps above Columbus, was immensely greater than in any of the earlier rises of the year, and second to none of which we have records."

"The upland tributaries below the Ohio were all low during this rise" although heavy rains took place in the Saint Francis and the White River swamps.

On page 130 of their report (edition of 1876), Humphreys and Abbot state the total discharge of the Mississippi from November, 1857, to October, 1858, to have been 26,000,000,000,000 cubic feet, not including the discharge of the Red river. On the same page they give as the average for 33 years, 19,400,000,000,000 cubic feet. Hence the average is only 74.615 per cent. of the discharge above the mouth of the Red river during the year of 1858. As by far the greater part of the high floods of 1858 entered the river above Columbus, it is fair to suppose that this ratio between the average flow and the average flow for 1858 would hold good at that place, being, if anything, slightly diminished, because the floods of 1858 were relatively so much greater from the area above Columbus than from the total area above the Red river.

It has already been stated that the average discharge at Columbus from December, 1857, to December, 1858 was 621,002 cubic feet per second. Applying the ratio of 74.615 per cent. to this amount gives 463,361 cubic feet per second. The table of the main river, computed as has been described, from the best data at hand concerning the flow of the rivers above Columbus, gives an average flow past that place of 456,538 cubic feet per second, less than the amount just given by 6,823 cubic feet per second, and equal to 73.516 per cent. of the average flow for 1858. This is a reduction of 1.099 per cent. on the ratio just given, and, as previously stated, there probably should be a slight reduction of this kind, how much we do not know.

The above seems a pretty good indication that the estimates already presented are not far from the truth, in the aggregate at least. We have now to consider the Mississippi below Columbus.

The river below Columbus.—The chief tributaries below Columbus are the Arkansas and Red rivers, then the Saint Francis and Yazoo rivers, and finally streams like the Forked Deer, Big Hatchee, Big Black, and others.

Humphreys and Abbot found the total discharge of the Arkansas (including the White river) for 1858 to average 74,126 cubic feet per second. They take the average flow for an *average* year to be 63,000 cubic feet per second.

This agrees well with the results just deduced, as 63,000 is 85 per cent. of 74,126, and 85 per cent. is much greater than 74.6 per cent. The ratio should be greater than for the entire Mississippi basin, because the floods of 1858 were much less relatively upon the Arkansas than on the rivers above.

Red river.—Humphreys and Abbot estimated the average discharge of the Red river in the following manner.

It must be understood that at the time of writing their report there were three bayous tapping the Mississippi below the Red river. Of these the average flow in cubic feet per second was quite closely ascertained, as follows:

Atchafalaya bayou	50,000
Bayou Plaquemine	5,000
Bayou La Fourche	2,000
Total	57,000

This amount was abstracted from the Mississippi below the Red river.

The averages of 23 years of estimates at Natchez and of 10 years at Carrollton, near New Orleans, give a difference of only 31,000,000,000 cubic feet per year, or about 900 cubic feet per second in favor of the discharge past Natchez. Now, as the Red river enters between Natchez and Carrollton, and the bayous start between those places, the average discharge of the Red river must practically equal the average outflow through the bayous, viz., 57,000 cubic feet per second.

It will be noticed that in this calculation no account has been taken of the discharge from the Homochitto river and the "brook area", tributary to the Mississippi between Natchez and Carrollton. This can be assumed from the tables to be about 7,000 cubic feet per second. Deducting this, we take 50,000 cubic feet per second as the *approximate* average discharge of the Red river.

Yazoo, Saint Francis, etc.—We have now these results:

	Cubic feet per second.
Average flow above the Red river	615,167
Average flow past Columbus	456,538
Difference	158,629
Average discharge from Arkansas basin	63,000
Remainder	95,629

This remainder is the average flow from the Yazoo, Saint Francis, Forked Deer, and other streams, entering between Columbus and the Red river. The average precipitation upon the area represented by these streams is 156,460 cubic feet per second, and we are forced to the conclusion that the ratio of average flow to average precipitation for them is about 61.12 per cent. Humphreys and Abbot estimate the ratio to be 96 per cent., but they use throughout the data collected for 1858, instead of average amounts, and it hardly seems that their use would give as close average results as that of data for an average year.

Cause of the high ratio.—The reason for this high ratio of 61 per cent. lies apparently in the nature of the country. The region is very largely what is there called river-bottoms, consisting of immense tracts of swamp and low land, covered with an almost semi-tropical vegetation. The water soaks into the ground, stands in deep pools and lagoons, and is protected by the dense covering of foliage, so that the evaporation is comparatively small, although moisture is absorbed by the growth. On the uplands, which are rolling and broken, the tendency is, as stated by Humphreys and Abbot, for the rains to rapidly drain off and find the protection of the swamps.

Many of the ridges of the uplands are also sandy and gravelly in nature, and into them the rains quickly sink away from the effects of sun and vegetation, to appear as springs in the running brooks. Another point of importance is that most of the rainfall of the year occurs in winter, when the average temperature, according to the Smithsonian charts, is only from 40 to 50 degrees, while in summer it varies from 75 to 80 degrees.

Again, the evaporation, even of summer, can hardly be so great as might be supposed from the high temperature, as compared with that in more northern portions of the Mississippi basin, for this reason: Being near the Gulf coast, and traversed very largely by winds directly from that warm body of water, the tendency is for the air to be constantly near the saturation point for the existing temperature (this is indicated by the comparatively uniform distribution of rainfall through the season), and hence the evaporation goes on more slowly than if the atmosphere were dry.

From the report of Humphreys and Abbot (page 299, edition of 1876) are obtained the following figures:

Drainage basin.	AREA IN SQUARE MILES.	
	Bottom-lands.	Uplands.
Yazoo	7,110	6,740
Saint Francis	6,900	3,000
Area in Tennessee and Kentucky	750	9,500
Total	14,760	19,240

The bottoms are about 75 per cent. of the uplands in extent. The average ratio of flow to rainfall for the entire region is 61.12 per cent. The ratio for the upland region is thought to be, from comparison, not higher than 40 or 50 per cent., but no exact data can be obtained. If it is 40 per cent., then the ratio for the bottom-lands is 90 per cent.; if 50 per cent., then the ratio for the bottom-lands is 76 per cent.; if 45 per cent., then the ratio for the bottom-lands is 83 per cent.

The endeavor has been made to assign an average ratio for each river basin in accordance with its proportion of upland and bottom-land, and the probable ratio for its upland.

The Forked Deer, Big Hatchee, and Wolf River basins are given a ratio of 45 per cent. They are very largely highland. The Saint Francis and the Yazoo, with such a large proportion of lowland, are given a ratio of 70 per cent.; and so on, due account being taken of the flow from the intermediate small areas not included in the river basins.

Flow of the main river at the mouth of Red river.—After footing up the total amount we find the average flow of the Mississippi, above the mouth of the Red river, to be 614,472 cubic feet per second, only 695 cubic feet per second or 0.001 per cent. less than the average flow determined by Humphreys and Abbot from 33 years of river gaugings.

Table of average-flow ratios for various kinds of country.—From a comparison of the various physical characters of different portions of the Mississippi basin, with the ratios of average flow to average precipitation, as contained in the tables we have just deduced, can be obtained the following approximate ratios for the different kinds of topography and climate met with in the central portion of the United States.

Table of ratios of average flow to average precipitation.

Character of region drained.		Average temperature. Three summer months.	Average temperature. Three winter months.	Time of heaviest precipitation.	Ratio of average yearly flow to average annual precipitation.
		Degrees.	*Degrees.*		*Per cent.*
Rather level woodland, many wooded swamps, many lakes	1	60 to 64	4 to 12	Summer and spring	35 to 40
Sandy ridges, undulating woodland and prairie, a few swamps and lakes, largely clay soil	2	64 to 68	8 to 16	....do	30 to 40
Undulating woodland and prairie, largely uncultivated, few swamps, no lakes, largely clay soil	3	64 to 68	8 to 16	....do	27 to 35
Flat to rolling prairie, partly cultivated, scattered woodland, largely clay soil	4	60 to 70	12 to 20	....do	20 to 30
Flat to rolling prairie, very largely uncultivated	5	68 to 72	16 to 26	....do	15 to 20
Extreme cases of the last division	6	68 to 72	16 to 26	....do	10 or less (?)
Combination of six parts of rolling upland (clayey or sandy soil), with four parts of swampy, densely-grown bottom-land, met with on the lower Mississippi.	7	75 to 80	40 to 50	Winter and spring.	61
Average of the entire Mississippi basin	8	73	28	Summer and spring	24

It is out of the question to attempt to bring the ratios down to closer limits with the data at hand, but it is believed that the percentages just given include within their limits the correct amounts.

Average-flow ratio a complex problem.—However, such an immense number of influences bear upon this question of average-flow ratio as to make it an extremely uncertain one. Certainly, not until long-continued and precise records have been made of the flow of the streams, the rainfall, the direction of the winds, the temperature (*a*), the hygrometric state of the atmosphere, and the times of occurrence of these several conditions, can accurate ideas be formed of their effects upon the flow. That they have great influence is undoubted. The ratio for the same region will often vary many per cent. in successive years.

Then, in comparing different regions, the problem is immensely more complicated; there must be brought into consideration the nature of the country—whether the land is wooded or open, whether low and swampy or hilly and well drained, whether cultivated or not. If lakes occur, the effects of evaporation from their surfaces must be considered. The nature of the soil and underlying rock strata should also be taken into account; whether the surface is rocky or the soil is stiff, impervious clay, over which the water runs rapidly, or whether it consists of light sand and gravel, into which moisture rapidly sinks. If the water does find its way below the surface, is the condition of the underlying strata such that it is carried deep into the earth, to appear in some far distant artesian well, or does it merely spring out from the bases of the ridges to swell the neighboring streams?

It may be easily seen that to grasp the subject fully and master its details would require well nigh supernatural powers. No one can pretend to say what the precise flow of water from a given area will be.

All these various influences occur in the Mississippi basin—mountain and plain, woodland and prairie, lake, swamp and arid land, sandy soil, deep-seated drainage through rock strata, and the infinitude of meteorological conditions, all exist. Yet, in spite of them all, an approximation can be made, and this has been attempted on the preceding pages.

a In this connection it must be remembered that the amounts lost by direct evaporation and absorbed by vegetable growth do not have the same ratio for different years as the amounts of precipitation. The rainfall of one year may be double that of the preceding one, while the loss by evaporation may remain about the same.

Variation in ratios.—The following data are inserted as illustrating the immense variation in the ratio of flow to rainfall for various sections. The yearly variation for the same district cannot be better shown than in Mr. Joseph P. Frizell's paper, contained in Major Allen's valuable report to the chief of engineers, dated December 28, 1878. A portion of it is here quoted in full:

Observations have been made for some twenty-five years past at lake Cochituate, from which the city of Boston has, until recently, derived its supply of water, of the rainfall on and discharge from a district some 19 square miles in area. I am in possession of the results from 1852 to 1875, inclusive, a period of twenty-four years. The average flow is about 45 per cent. of the rainfall, which has averaged some 50 inches. To show the extreme uncertainty of these results, it may be mentioned that in 1857 the rainfall was 63.1 inches, 74 per cent. of which was represented by the discharge. In 1866 the rainfall was nearly the same, viz, 62.3 inches, only 25 per cent. of which appeared in the discharge. The latter was the lowest percentage shown during the twenty-four years. The highest was in 1859, being 78 per cent. on a rainfall of 49 inches. The highest rainfall of the period was 69 inches in 1863; the lowest, 35, in 1855. In other words, the variations in the rainfall are as 2 to 1. The variations in the discharge with the same rainfall are as 3 to 1. In 1857 the aggregate discharge was equivalent to 47 inches on the entire drainage-basin. In 1871 it was 15 inches.

From measurements of the Sudbury river, Massachusetts, made for six years by Alphonse Fteley, and published in the *Transactions of the American Society of Civil Engineers* for July, 1881, are obtained these figures: The drainage area is 77.76 square miles; the variation in the annual rainfall was from 38 to 58 inches, and the ratio of discharge to rainfall from 32.71 to 57.90 per cent., the average being 47.56 per cent.

Regarding the variation for various sections, the following data are taken from Mr. J. T. Fanning's *Treatise on Water-Supply Engineering.*

Ratio of average flow to rainfall for average drainage areas:	Per cent.
Mountain slopes or steep, rocky hills	80 to 90
Wooded, swampy lands	60 to 80
Undulating pasture and woodland	50 to 70
Flat cultivated land and prairie	45 to 60

It does not seem possible from the results we have reached that Mr. Fanning's estimate for prairie can be applied to that character of land in the Mississippi basin. From his remarks it is inferred that the figures given above are for an average precipitation of about 40 inches per year, and, as before remarked, the variation in loss from evaporation, etc., does not have the same ratio as the variation in rainfall. To this, perhaps, is partly due the difference.

From several sources these percentages are collected:

	Per cent.
Connecticut River basin	63
Concord River basin, Massachusetts	41
Croton basin, New York	57.5
West branch of Croton basin	63
Lake Cochituate basin, Massachusetts	45

The last two basins are each about 20 square miles in extent.

From the report of Humphreys and Abbot (page 295, revised edition) is obtained the result, that for moorland, with 60 or 70 inches of annual precipitation, the ratio of average flow to precipitation for an area of from 2 to 7 square miles ranges from 60 to 80 per cent.

Horse-power.—The columns giving the theoretical horse-power under an assumed head of 10 feet are inserted because of the idea they will give of the power available on the different streams, supposing a fall of water to be available. Many of the tributaries have such fall available comparatively near their mouths, and there are a number of points on the upper waters of the main stream where power could easily be utilized. It is, of course, a simple matter to determine the power under any other head than 10 feet by the mere application of direct ratio. Although there is no available power on the lower river the columns have been filled out as a matter of interest merely.

Description of the curve sheet.—In order better to illustrate the prominent features of the hydrology of the Mississippi basin the accompanying diagram has been constructed from the data given in the table. A horizontal base line was drawn representing the channel of the main river, and the stations plotted upon it from source to mouth proportionally to their distances. From these stations were drawn vertical ordinates, and on these ordinates, starting from the base line as zero, were laid off the proper distances for the different curves ascertained from the table and the scale used. The points thus obtained were connected by straight lines and the curves constructed. The lengths of the ordinates to the curves from the different stations have the same ratios to each other as the rainfall, flow, percentages, etc., for the total areas above those stations.

Profile of river.—Glancing at the profile of the water-surface this is noticed: the rapid fall is all above the Minnesota river. In this region occur the rapids over hard granite which has resisted the tendency to wear down the bed to a uniform slope, and also the falls of Saint Anthony.

Below the latter, as described in the remarks on the geology, the river runs, with two exceptions, in a soft bed of drift, which has filled up its ancient channel. Consequently, in the distance from Saint Anthony falls to the mouth, the slope is comparatively uniform and obeys approximately the tendency to form a parabolic profile, as may be observed by a glance along the plane of the diagram. The principal exception to this is caused by the rock barriers at Rock Island and at the Des Moines rapids; they occasion a rise in the profile.

Curve of annual precipitation.—The curve of average annual precipitation above the different stations, called, for simplicity, the "rainfall curve", shows a gradual rise from a little above the Minnesota river to the Illinois, then a sudden fall of nearly 11 inches rainfall to the Missouri, a rise of about half that amount to the Ohio, and then a gradual rise to the mouth.

Curves of flow and percentage to rainfall.—The curves of ordinary low flow per square mile, average flow per square mile, and percentage of average flow to rainfall can best be discussed together. They naturally have a general similarity. Above the Minnesota river, where the amount of precipitation does not greatly change, the last two of these three curves correspond very closely.

The curve of ordinary low flow has its culminating point at the mouth of Leech Lake river, which represents the point of maximum storage capacity. Then it falls off gradually to the Minnesota river. The curve of average flow is likewise highest above the Minnesota river, but its culminating point is between the Willow River and Rice River stations, Nos. 23 and 24, although nearly as high opposite the mouth of Leech Lake river, No. 13.

As has been previously remarked, the average flow is not so dependent upon the amount of natural storage afforded by the lakes, and hence the difference from the ordinary low-flow curve. The ordinary low flow is from one-third to one-half the average flow for the entire length of the upper Mississippi.

All three curves take a sudden fall at the Minnesota river (a prairie stream) and then rise, owing to the Saint Croix, Chippewa, and Wisconsin rivers, all of them high-flow streams. The influence of each is shown.

The ordinary low-flow and average-flow curves have their culminating point, for the region below the Minnesota, at the Wisconsin river. From the Wisconsin river there is a general fall in both curves to the foot of the upper Mississippi. There the ordinary low-flow curve ceases, but the average flow and percentage curves fall very greatly, on account of the Missouri river. They then rise slightly to the Ohio river, whereupon they take a sudden leap upward, owing to that river. From the Ohio river the general direction is upward to the mouth of the Mississippi. The influence of the Arkansas river (a low-flow stream) is shown in the fall it causes in both curves. At the same time the influence of the high-flow streams like the Saint Francis, Yazoo, etc., with a ratio of flow to rainfall of 70 per cent., is shown. Notwithstanding their small drainage areas compared with the entire basin, they succeed in giving the upward tendency to the curves in this section below the Ohio river. Were it not for the Arkansas river their effect would be still more marked.

Curve of theoretical horse-power.—The curve of horse-power under an assumed head of 10 feet does not need any description. It shows the doubling of the power by the addition of the Missouri river, and then the great increase in power due to the Ohio river. The latter nearly doubles the theoretical power already existing previous to its entrance.

Deductions from diagram.—One cannot study the sheet without noticing the great influence exerted by the Missouri and the Ohio rivers.

The upper Mississippi flows along, preserving its characteristics, as indicated in the sheet. Then the Missouri enters, and for another section a new state of things prevails. The Missouri is a stream of low rainfall, low percentage, and hence low average flow. The result is a sudden and great fall in all the curves. The Ohio enters and inaugurates a new *régime* for the river down to its mouth.

The Ohio is in every respect the opposite of the Missouri; with a high rainfall, a comparatively high percentage, and hence a high average flow, it causes all the curves suddenly to rise again. Thus, there is a sharp depression in each of the curves between the ordinates representing the Missouri and the Ohio rivers.

Examining the curves between the Minnesota and the Chippewa rivers a very similar state of affairs is seen. The Minnesota bears the same relation to the Saint Croix and Chippewa that the Missouri does to the Ohio, and we find those streams carrying out in miniature the action of their larger relatives below.

DESCRIPTION OF THE WATER-POWER SITES OF THE MISSISSIPPI RIVER.

As Minnesota is a comparatively new state, and the northern part is yet almost in its native wildness, there has been no demand for water-power on the extreme headwaters of the Mississippi. The highest improved power is at Sauk Rapids, only 74 miles above Minneapolis. (*a*)

Power at the headwaters.—There are several available sites for water-powers of large magnitude, and probably near the sources a great many places where a mill might find power to turn a large amount of machinery, but no regular surveys have been made above Cass lake; and the early explorations of Schoolcraft and Nicollet did not have this subject in consideration. From their descriptions, however, and the elevations and volumes of flow given in the tables, some idea can be gained of the probable condition.

Schoolcraft describes how the river rushes down the rapids in the "Alpine passes" between lake Itasca and the mouth of the Pinniddiwin above lake Bemidji (called by him Lac Traverse). The descent averages nearly 9 feet per mile, and as there are several stretches of slack-water, the slope must be locally greater than this. The power under a head of 10 feet, at an ordinary low stage above the mouth of the Pinniddiwin river, we estimate to be 87 theoretical horse-power, enough to run a good-sized custom mill. Most of the year there would be double this power. Undoubtedly there are a number of available sites, such as are already used in the basin of the Red river of the North; whether there will ever be any demand for them is another question.

As mentioned on a previous page, these rapids, and all those down to Pokegama falls, are over accumulations of bowlders, which have prevented the river wearing its way rapidly through the drift.

From lake Bemidji to Cass lake there is a fall of about 54 feet, or 3 feet per mile; and, as Schoolcraft states that most of the descent is concentrated in the upper three-quarters of the distance in "strong rapids", there are very probably available sites there. The theoretical power under a head of 10 feet, with the ordinary low flow at the outlet of lake Bemidji, is 220 horse-power; with the average flow it is 474 horse-power. It is very probable, however, that during a high stage of the river back-water would very seriously diminish the head of water ordinarily available.

From Cass lake to Pokegama falls there is no power available; the river winds slowly along, with an average slope of 0.32 foot per mile, through a wide savanna covered with grass, wild rice, and rushes.

POKEGAMA FALLS.

These falls take their name from Pokegama lake, a body of water draining into the Mississippi about 3 miles above the falls. This lake acts as a reservoir, into which during high water the river overflows. These falls, and Grand rapids just below, are the only two rapids on the river between Cass lake and Little falls, 326 miles below, of any special importance for water-power.

Here is where the first rock in place is met. It is a red sandstone of a hard quality, dipping sharply to the southwest, and is stated by Professor N. H. Winchell to be probably the same formation that occurs at Fond du Lac, at the head of lake Superior. The latter he considers to be the most valuable for building purposes among the sandstones occurring in Minnesota. Immediately at the head of the falls, writes Schoolcraft, "is a small rocky island, covered with spruce and cedar, and dividing the channel nearly in its center."

The river rushes down a rocky channel. Above the falls it averages about 120 feet wide; at the falls it is contracted to 80 feet. The fall is 14 feet in a distance of about 500 feet, as surveyed under Major Allen. There is a good opportunity for erecting a dam at the head of the falls, and increasing the natural head of water at that point. This has been proposed in connection with the reservoir system.

On account of the level nature of the country above, a dam 30 feet high could be constructed, which would flood Pokegama lake and away back into Leech lake and lake Winnibigoshish, making an immense reservoir of that entire region. Such a plan would necessitate the building of extensive dikes along the eastern and southeastern sides of Pokegama lake, to prevent overflow into the Mississippi below, and is discouraged by those who have investigated the matter. It is possible, however, to erect such a dam at Pokegama falls. The surface of Pokegama lake is 2.6 feet above the water-surface just above the falls. A dam 7 feet high at the falls would flood an area of about 24 square miles to an average depth of 5.7 feet, without danger of breaking over the ridge to the southeast of the lake, and would give a head of 21 feet at the falls. Such a dam, in connection with several other dams above, is apparently the scheme approved of by the United States engineers.

a If the proposed reservoir system is carried out by the United States government upon the sources of the upper Mississippi, it is doubtful how much use of power for private purposes will be allowed upon the headwaters. The policy of the government would seem to be, from past experience upon the Mississippi itself, to keep aloof, so far as possible, from all business interests in common with private individuals or corporations. Where private rights already exist from prior usage or ownership they will be respected.

Power at Pokegama falls.—The tables indicate an ordinary low flow over Pokegama falls of 1,031 cubic feet per second, giving, under a head of 10 feet, 1,170 theoretical horse-power; and an average flow of 2,183 cubic feet per second, giving, under a head of 10 feet, 2,477 theoretical horse-power. Hence the following figures:

Head of water.	Theoretical horse-power.	
	Ordinary low flow.	Average flow.
14 feet	1,638	3,468
21 feet	2,457	5,202

From the best information obtainable it appears that the situation admits of the utilization of this power; and it is probable that for most of the year the power available would be nearly equal to that afforded by the average flow. If the reservoirs are constructed above Pokegama falls so as completely to store all surplus, they would be capable of giving the power represented by the average flow, day and night throughout the entire year. At these powers above Brainerd, however, the shutting down of the gates of the reservoirs might at times be a source of annoyance to manufacturing interests.

GRAND RAPIDS.

The Grand rapids proper begin 3.5 miles below the foot of Pokegama falls, and in the intervening distance there is a fall of 2.9 feet. At the rapids, which can be ascended in a canoe, there is in an ordinary low stage a fall of 5 feet in a distance of about 1,500 feet. No rock in place occurs at these rapids, and the fall is stated by the engineers to be available for power. A dam, however, could not be built raising the head more than 2 feet higher without setting back the river upon the tail-races at Pokegama falls, supposing that power to be improved.

The flow at Grand rapids is practically the same as at Pokegama falls. The power with the ordinary low flow, under a head of say 6 feet is 705 theoretical horse-power; while with the average flow it is 1,492 theoretical horse-power.

THE RIVER FROM GRAND RAPIDS TO LITTLE FALLS.

In all this distance of 220 miles there is no concentrated descent worthy of mention. The average slope is 0.702 foot per mile, though locally much greater. There are several places where in low water there will be a ripple over a bowlder bed, or swift water for a half-mile or so, but they are all covered during a high stage of the river, and small steamboats, carrying supplies to lumber camps, are able to ascend them. The slope is greater below the Pine river than above, and there are one or two rapids between it and Little falls which it might be feasible to utilize by throwing a dam across the river. This, indeed, it would be possible to do above Pine river, but a dam of any considerable height would flood a long distance up stream. There is no rock in place in the river from Pokegama falls to Olmsted's bar, about 10 miles above Little falls, and the rapids are over gravel or bowlder beds.

There are seven rapids distinguished in Major Farquhar's report of February 8, 1875, as situated between Grand rapids and Pine river. They average a fall of about half a foot in 500 or 600 feet, the extremes being 0.6 foot in 290 feet, and 0.44 foot in 1,586 feet.

From Pine river to Little falls the average slope is 1.54 foot per mile, and several rapids occur much more worthy of the name than those above.

Big Eddy rapids.—Nine miles below Pine river are Big Eddy rapids. There the river falls 2.58 feet in half a mile. The average slope above to Pine river is 0.80 foot per mile. The east bank is 12 feet, and the west bank 30 feet high. Supposing it feasible to raise a head of 9 feet at this place, there would be a power of about 2,200 theoretical horse-power with the ordinary low flow, and about 5,060 horse-power with the average flow.

French rapids.—About 4 miles above Brainerd, which is on the Northern Pacific railroad, are French rapids. In a distance of 4,100 feet there is a descent of 4.6 feet. The river is there "straight and narrow, flowing between high bluffs", and the flow is slightly greater than at Big Eddy rapids during the same stage.

Olmsted's bar.—Eleven and one-half miles below the Crow Wing river is Olmsted's bar. Here is seen the first outcrop of rock in place below Pokegama falls. It is a trap dike, running out from the west bank 300 feet into the river, which is here broad and shallow. For a distance of 4 miles below the head of Olmsted's bar the average slope is 4.14 feet per mile, making a total descent of 16.6 feet. The average slope above, to the Crow Wing river, is about 0.8 foot per mile. In this stretch of 4 miles are fifteen heavily-wooded islands, overflowed during high water. The theoretical power under a 10-foot head is, with the ordinary low flow, about 3,780 horse-power, and with the average flow, 8,630 horse-power.

Conradi's shoals.—Two and one-half miles below the above stretch of 4 miles, and at an elevation about 3 feet lower than its foot, begin Conradi's shoals. Here the river widens out over a coarse gravel bank, and falls 4.74 feet in a distance of 1,500 feet.

Elk rapids.—A short distance above Little falls are Elk rapids, where in a distance of 5,100 feet the river falls 7.2 feet. Below the rapids to Little falls the average slope is 3.17 feet per mile. The flow at a given stage is essentially the same as at the mouth of the Crow Wing river.

LITTLE FALLS.

This is a rapid which occurs in the river 21 miles below the mouth of the Crow Wing, and 106 miles by river above Minneapolis. The small village of Little Falls, with 508 inhabitants, is situated on the left or east bank, a few hundred feet back from the river. About half a mile east of the town runs the railroad connecting the Northern Pacific railroad at Brainerd with the cities of Minneapolis and Saint Paul. By railroad, Little Falls is about 30 miles below Brainerd and 90 miles from Minneapolis.

The falls, so called, are caused by the outcrop of the metamorphic rock belt which crosses this section of the state of Minnesota, and the obtrusion of a trap-dike has apparently increased the irregularity of the surface locally at this point. There is a natural descent of 7.3 feet in a distance of 2,100 feet from the head of the rapids.

Description of the falls.—The rock, which appears to be chiefly a variety of talcose slate, owing to a "system of joints" (Professor Winchell) has the appearance of dipping about 45 degrees down-stream.

A rib of this rock seems to cross the channel of the river at a slight angle down-stream, from the east to the west bank, and is the obstruction which forms the head of the falls. From one-third to one-half of the distance across from the east bank is a rocky island, starting at the head of the falls and running down-stream from 500 to 1,000 feet, called Mill island. It is, strictly speaking, an island only in high water, for the river, having worn the channel to the west of it more readily, has deserted the old channel on the eastern side, and except in full stages of the river the ridge of rock before mentioned extends across to the east bank in a line with the head of Mill island, dry or with only pools of water in the irregularities of the surface.

In ordinary stages the river practically flows through the narrow channel to the west of Mill island. This channel, which is about one-half the width of the river above the falls, is in the neighborhood of 300 feet wide. Both banks are about 15 feet high at the head of the falls, rising steeply from the river. On the west the land then runs back level into a rather swampy region; on the east it is slightly rolling, but yet constitutes a sandy, loamy plain, on which the village of Little Falls is laid out. These banks at the head of the falls are mainly the rugged projecting rock, slightly covered with earth. On the west side the trap referred to shows itself. Passing down from the head of the falls, the banks consist of sandy loam, underlaid by sand and gravel, then stiff clay, and finally by the solid rock. It does not seem probable that in the lower part of the falls the rock extends much above the level of the water-surface at the crest of the falls, although constituting the main portion of the bank at the crest. Passing down the falls, the water-surface soon descends to from 20 to 27 feet below the top of the banks.

Mill island presents an abrupt rocky face up-stream, its sides gradually becoming more earthy toward the lower end. It is of about the height of the surrounding land, and has a timber-growth upon its surface.

The river runs close to the west bank, but on the east the bank proper recedes from the crest of the falls, leaving a flood plain, considerably broken up by the action of the water, and partly occupied by the old channel, which runs close along the side of Mill island. The east bank approaches the river again at a point some 2,000 feet or more below the head of the falls. There is considerable timber on the east bank below the village, and the west bank of the river is also covered with timber, apparently consisting very largely of oak.

Present condition of the power.—A number of years ago there were some mills in operation at Little Falls, run by the water-power there, with a head of 8 feet. For some reason rather difficult to understand, the dam was constructed 200 feet above the head of Mill island instead of at the fine site afforded at the crest of the falls. It was carried away by the river, and now no use whatever is made of the power. The property is owned in the village, and it is said that this and all the interests connected with the power could be readily bought. Those undertaking its improvement would meet with every encouragement from the inhabitants of the town.

As the river is pronounced a navigable stream it is very probable that some arrangement would have to be made with the government before a dam could now be constructed. Perhaps, if the upper river is ever really improved for actual navigation, a lock will be required in any dam built at Little Falls. At all events, a sluice would be required for the passage of logs which are sent down the river in immense numbers during the spring and the June rises.

Regarding the use that could be made of the power, the first thought is employment for saw-mills; a considerable amount of the logs which now float down to the mills below might be caught and sawed into lumber at this place, and then shipped more directly to meet the prairie demand along the line of the Northern Pacific railroad. There is a road projected west from Little Falls, to be called the Little Falls and Dakota railroad, and if this is built there will then be direct communication with the immense wheat regions westward. There would then be every opportunity for the successful use of this power in the grinding of a part of the wheat which now finds its way to Minneapolis, or else passes in bulk to the sea-board. As it is, there would probably be enough wheat obtained in the surrounding region to give a moderate business to those seeking it. Other forms of manufacturing can be carried on advantageously at Little Falls as the country becomes more developed.

Plan of improvement.—It requires only a very short inspection to perceive the great natural advantages afforded at Little Falls for the improvement of its water-power. By far the best place for erecting a dam appears to be from each shore to Mill island, at the head of the falls. There is an excellent rock bed, with steep rocky abutments for the dam, both at each shore and at the island, while the length of dam required is comparatively small. A water-way and sluice-way for logs could be constructed in the west channel, and across the forsaken east channel a high dam could be built above high water. Mills might be stationed along the length of this east channel dam. Canals could be excavated from the dam along each bank to convey power. On the east side of the river mills built in the old flood-plain already described could be fed from such a canal, using the deserted east channel as a tail-race. This could be deepened and the head of water increased up to the dam.

The construction of a canal on either the west or the east bank would require considerable rock excavation at its head. It is the impression of those familiar with the locality that the west side canal could be more easily constructed than that on the east or village bank, as the rock lies at a lower level. The construction of a side-track from the railroad, which is half a mile to the east, is entirely feasible.

If saw-mills were erected it would be best to run the dam across the island and then up-stream some distance, and so across the river, in order to afford "boomage" room for the logs.

Power available.—The next point to consider is the actual power available. The following are the figures relating to the profile of the water-surface: From the crest of Elk rapids to the crest of Little falls, a distance of very nearly 3 miles, the fall is almost 13 feet. At Little falls the total descent at an ordinary low stage is 7.3 feet in a distance of 2,112 feet. Of this there is a fall of 0.67 foot in 100 foot, and in one place 1.59 foot in a distance of 30 feet. Below Little falls for a distance of 4.7 miles the average slope is 3.40 feet per mile.

It is stated that the water-level could be raised at least 10 feet at the crest of the falls without flooding land above to any great extent; this would flood out the most of Elk rapids. It is perfectly practicable to construct a dam at Little falls raising the water to this level, and probably a higher level could be maintained without any injury to property. A 10-foot dam would give a total head at Little falls of over 17 feet, say 16 feet for the average.

The table gives the ordinary low flow at Little falls as 3,483 cubic feet per second, affording, under a head of 10 feet, 3,951 theoretical horse-power; and the average flow as 7,899 cubic feet per second, giving, under a head of 10 feet, 8,969 theoretical horse-power. Hence, under the available head of 16 feet, there could be obtained at a low estimate, with the ordinary flow, 6,320 theoretical horse-power; and with the average flow, which represents the condition under a complete application of the reservoir system, 14,350 theoretical horse-power.

THE RIVER FROM LITTLE FALLS TO SAUK RAPIDS.

In this distance of 31 miles the descent of the river is rapid, the average slope being 3.1 feet per mile. The chief points of concentration of this descent are: Pike rapids, Cashe's rips, McDougal's rips, Blanchard's rips, and Watab rapids. The total fall is slight at these places, only amounting to 1 or 2 feet, but the intervening slope is great. Thus for the 4.7 miles from Little falls to Pike rapids it is 3.4 feet per mile; below Pike rapids for a distance of 6.7 miles it averages 5.43 feet per mile. Cashe's rips are nearly 3 miles below Pike rapids. The bed is there rock in place. Blanchard's rips are about 2(?) miles below Cashe's rips. There the bed is rock, and the fall 1.80 foot in 1,356 feet. Below Blanchard's rips for a distance of 1.7 mile the average slope is 3.97 feet per mile; then for 21 miles below this it averages only 1.5 foot per mile.

At Watab rapids the bed is rock, and the river falls 2 feet in 800 feet.

The large slope of the river in the upper part of this section gives a possibility of utilizing the power by constructing dams and backing the water up-stream without flooding very far back.

Proposed improvement.—It has been proposed to build dams, one at Cashe's island, with a head of 13 feet, and another at Blanchard's rips, with a head of 10 feet. The first would probably flood back to Pike rapids, and the second to about the foot of Cashe's rips. The flow of the river is essentially the same at these places as at Little falls. With the ordinary low flow the theoretical power would be, under a head of 13 feet, 5,136 horse-power; and under a head of 10 feet, 3,951 horse-power. With the average flow the theoretical power under the heads given would be, respectively, 11,660 and 8,969 horse-power.

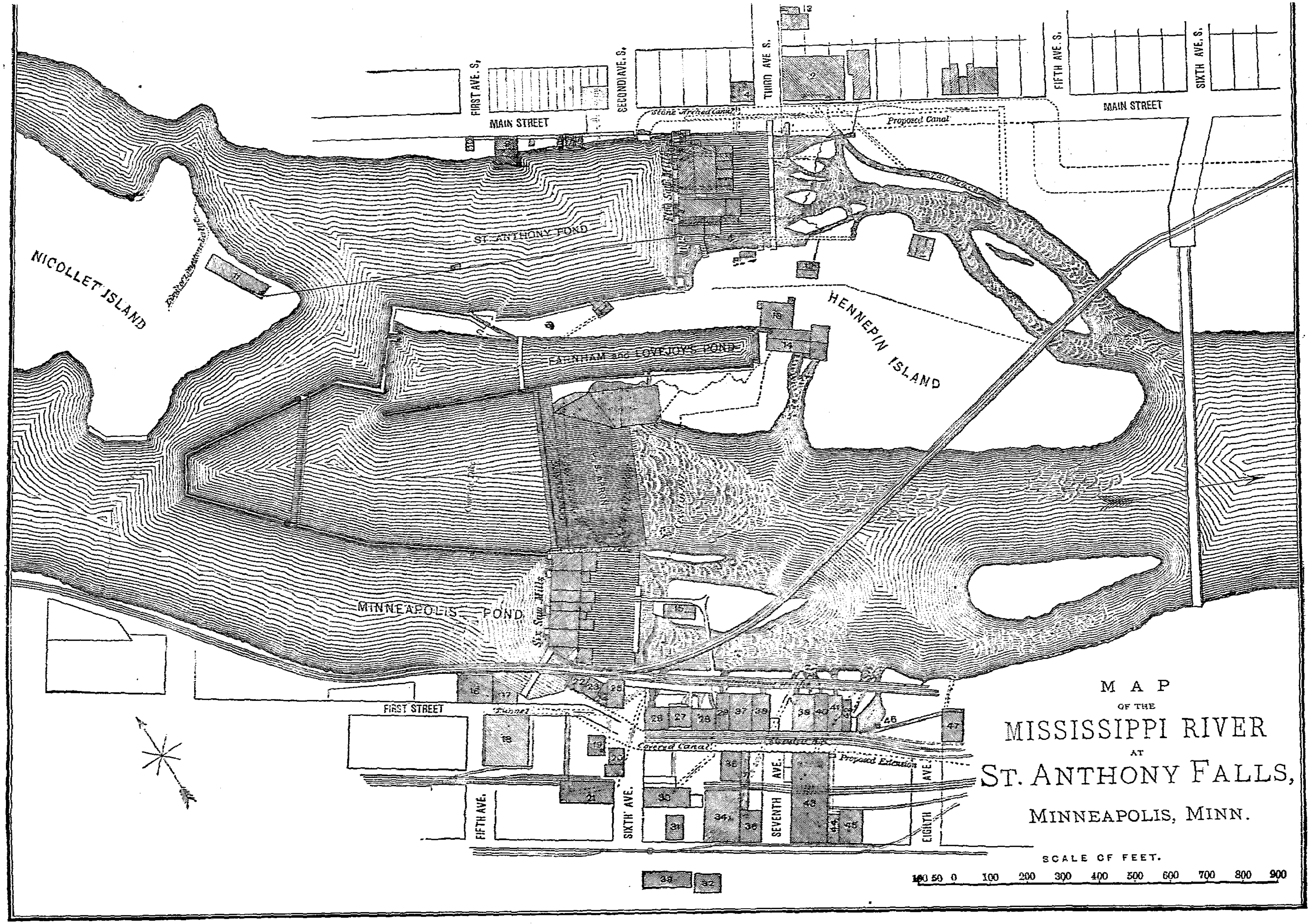
The total fall from the foot of Little falls to the head of Sauk rapids is 95 feet, and undoubtedly there are several places at which powers could be utilized, with what would be in the eastern states a reasonable outlay.

SAUK RAPIDS.

These are among the principal rapids above Saint Anthony falls. The descent, as given by Major Allen, is 11.3 feet in 4,224 feet. At a lower stage of water it has been estimated at 17 feet in 4,000 feet. The little village of Sauk Rapids is situated on the east bank. The Sauk river, draining 968 square miles, enters from the west at the head of the rapids.

Saint Cloud is about 2 miles down the river upon the west bank, where the Saint Paul, Minneapolis, and Manitoba railroad crosses. A branch of the Northern Pacific railroad passes through the village of Sauk Rapids. A highway bridge crosses the river at this place about 1,500 feet below the mouth of Sauk river. Although at Sauk rapids is the highest improved power upon the Mississippi, yet it is so little utilized as scarcely to deserve the name. One flouring-mill, of 250 barrels capacity, contains all the machinery run by an available power of over 5,000 horse-power in low water.

The river here flows over a hard rocky bed, consisting of gray granite, a part of the belt which passes west and southwest across the state. This Sauk Rapids granite consists very largely of quartz, and is a fine building-stone of great strength. It takes a fine polish, but is liable to contain spots of dark hornblende, which may disfigure the surface. This rock gives an excellent foundation for dams.



MAP
OF THE
MISSISSIPPI RIVER
AT
ST. ANTHONY FALLS,
MINNEAPOLIS, MINN.

The west bank is some 30 or 40 feet high, consisting chiefly of gravel and clay, underlaid by the granite. The east bank is much lower, and immediately at the dam it is solid granite, overlaid by a thin covering of earth. The dam starts from just above the bridge, at the east bank, runs out half way into the channel, which is here 600 or 700 feet wide, then runs up-stream 400 feet, and then across to the west bank. The dam is built of log crib work and stone. The granite has been extensively used in constructing it and the abutments. The immense number of logs which come down the river each spring pass over the dam near the west bank.

The flouring-mill is situated just below the bridge, at the east side of the river, about 2,500 feet above the foot of the rapids, and is fed by a short canal formed by building a retaining-wall a short distance out from the bank. The mill is built in the river channel, and a wing-wall passes some distance down-stream, keeping the flow of the river away from the wheel. The head obtained at the mill varies from 9 to 12 feet, according to the stage of the river; 100 horse-power is used. There is difficulty from back-water when the river is high, and once there was an ice-gorge below which flooded the rapids.

Between the mill and the bridge is an unoccupied building, originally intended as a railroad repair- and machine-shop. The abutments and masonry walls about the eastern end of the dam bear evidence of having been designed for extensive works, which have never been built.

History of the development.—The reason of the imperfect improvement of this fine power appears to be chiefly unfortunate management and conflict of interests. As nearly as can be ascertained, there was first incorporated the Sauk Rapids Water-Power Company, on the east side, which failed, and by foreclosure of the trust-deed the property passed into the hands of Mr. William F. Davidson, of Saint Louis, Missouri, who now owns the power on the east side, with the exception of the 100 horse-power used by the flouring-mill. On the west side of the river, where there is no improvement, the ownership of the power is disputed by Mr. William Dawson, of Saint Paul, and the Sauk Rapids Manufacturing Company.

It was the opinion of Mr. J. A. Stanton, the proprietor of the flouring-mill, from whom the above information was obtained, that there is no definite prospect for further improvement. The location is good, however, for manufacturing, being on the railroad, and only 75 miles by river from Minneapolis, and it is hardly probable that many years will elapse before legal difficulties will be settled and use will be made of the power.

It is possible to utilize the power upon both sides of the river, but the nature of the banks is such that the eastern one can be more readily improved, judging from the limited investigation permitted by the severe winter weather of 1880–'81. On that side the canal could readily be continued and a large number of mill-sites supplied. There are already some two or three available besides the one now in use. Under the head of 10 feet, which is the average in practical use now, there are, according to the table, 4,678 theoretical horse-power available in ordinary low water, and, with the average flow, 10,408 theoretical horse-power. By continuing the present canal it is probable that a head of very nearly if not quite 15 feet can be obtained, except in high water. There is a mill on Sauk river near its mouth, and the raising of the dam would flood the water back upon its wheel, but the owner of this mill has given full right of flowage, so the dam can be raised and the total head somewhat increased. Under a head of 15 feet the total theoretical power would be 7,000 horse-power with the ordinary low flow, and 15,600 horse-power with the average flow, or the flow obtainable under a complete application of storage-reservoirs.

THE RIVER FROM SAUK RAPIDS TO SAINT ANTHONY FALLS.

From Sauk rapids to Saint Anthony falls there are no rapids specially worthy of note. Still, in this distance of 74 miles, the river falls 183 feet, with an average slope of 2.47 feet per mile, making a rapid current. There are some eight small rapids, where for a short distance the slope is at the rate of from 4 to 10 feet per mile. Among the chief ones may be mentioned Smiler's rapids, Battle rapids, Houghton flats, and Coon rapids. At the latter the total fall is 6.9 feet in 3,600 feet, and the worst obstruction to navigation in the entire distance of 74 miles has here existed. The bed of the river at all the rapids appears from the engineering reports to be formed of bowlders and gravel.

It is very possible, and even probable, owing to the rapid fall, that practical sites exist in this distance for the construction of dams and the improvement of the power, but so far as could be ascertained no project of this kind has ever been entertained.

WATER-POWER OF SAINT ANTHONY FALLS, AT MINNEAPOLIS.

Above the junction of the Minnesota river the Mississippi has a general southeast direction. It has been flowing for more than 500 miles between banks mainly carved out of the drift which covers that region. Eight or 9 miles above the mouth of the Minnesota it suddenly cuts its way through the rock, and forms the "Owah-Menah", or "Falling Water", of the Sioux—the falls of Saint Anthony. At this place is the largest water-power of the northwest. On the right or western side of the falls is Minneapolis; on the east bank is Saint Anthony, now included in the former city as East Minneapolis. About the falls is collected a population of nearly 47,000 inhabitants. A yearly average of at least 790,000 cubic feet of water falls 75 feet every minute, and the result is 112,000 horse-power. The large business done by the city of Minneapolis is almost entirely in the line of manufacturing, as shown by the following figures, taken from the report of Mr. Charles W. Johnson, special agent of the Tenth Census. Practically all the power used in manufacturing is given by the falls.

Character and value of manufactures.—Sales during the census year in Minneapolis:

Total of all kinds	$39,526,200
Total of principal manufactures	27,171,200

The latter amount is thus distributed:

Flour	$20,364,200
Lumber, laths, and shingles	2,098,000
Feed and commission	1,934,000
Agricultural implements and machinery	1,500,000
Miscellaneous manufactures	1,275,000

Over two-thirds of the entire business of Minneapolis is manufacturing, and of this three-quarters is milling. The industry which ranks next to milling in value is the manufacture of lumber. About Saint Anthony falls is a group of flouring-mills which are said to give this point the second position as a milling center in the world, the only place outranking it being a town in Hungary. All this immense business has sprung into existence within the last quarter of a century. The growth of business has only kept pace with the rapid advance westward of the population, aided, of course, by the great advantages of the water-power. The character of the two chief industries, milling and lumbering, is the natural result of the character of the country and of the time. When the first enterprising settler began on a large scale to use the falls, it was to saw the pine lumber which grew in such quantities at the headwaters of the river. As the resources of the wheat-producing prairie-soil were realized, improved flouring-mills were built. The pine forests lying northward are being cut away at the rate of over 200,000,000 feet (board measure) per year, and the time will come when the saw-mills of Minneapolis will lose their occupation. The wheat-fields to the westward are, on the contrary, widening each year with marvelous rapidity, and the milling interests seem to have just entered upon a field of almost boundless scope, so far as the raw material is concerned. As the country becomes older, and the inhabitants accumulate more wealth, other branches of manufacturing will probably increase.

The peculiar advantages of Minneapolis for communication with the surrounding country have been already alluded to in the "General Remarks upon the Water-Power of the Northwest". Through-lines connect it with the eastern seaports and with the prairie region westward. It lies directly in the line of traffic between a large part of the west and the eastern coast.

Flouring and lumbering interests.—There were in operation here in the census year twenty eight flouring-mills, representing a capital of $3,816,000, with an annual production whose value has been already stated. There were also fourteen lumber-mills, with a capital of $1,945,000. The lumber-mills produced 158,555,000 feet (board measure) of lumber, 27,668,000 laths, and 37,940,000 shingles.

The flouring-mills produced 3,227,993 barrels of wheat-flour, or 10,313 barrels for each working day, using 16,807,186 bushels of wheat, or 53,697 bushels per day. Thus every day 10,000 barrels of flour left the mills, and 54,000 bushels of grain, requiring about nine trains of twelve cars each, were wheeled into them. At the time of collecting these statistics the largest of the mills had a capacity of 1,500 barrels per day. Since that time it has been enlarged to 3,000 barrels, as was also done with another mill, and a new mill has been built with a capacity of 5,000 barrels. Thus the total capacity per day was raised to about 18,000 barrels.(*a*)

The total power in use is in the neighborhood of 13,000 horse-power, hence the manufacturing might be increased to at least four times its present amount without taxing the ordinary low-water power of the falls, if properly utilized. The truth is, that even now there is a dearth of water in the low season, but, as will be shown later, this is due to waste in its utilization, and not to any lack of power if the situation were fully improved.

The following is a list of the manufacturing establishments in the city of Minneapolis, Minnesota, with a designation of the kind of mill or manufacture, and the names of certain of the mills. The figures indicate the location upon the map of each of the several establishments:

1.—Flouring-mill, "North Star."
2.—Flouring-mill, "Pillsbury A."
3.—Sashes and doors.
4.—Flouring-mill, "Phœnix."
5.—Iron-works, "Union Iron Works."
6.—Machinery.
7.—Machinery.
8.—Machinery.
9.—Eaves-troughs.
10.—Mattresses.
11.—Various industries.
12.—Furniture.
13.—Paper-mill.
14.—Saw-mill.
15.—Cotton-mill, "Minneapolis."
16.—Saw-mill.
17.—Water-works.
18.—Flouring-mill, "Crown Roller."
19.—Flouring-mill, "Model."
20.—Flouring-mill, "Dakota."
21.—Flouring-mill, "Standard."
22.—Flouring-mill, "Arctic."
23.—Flouring-mill, "Union."
24.—Flouring-mill, "Holly."
25.—Flouring-mill, "Cataract."
26.—Flouring-mill, "Empire."
27.—Flouring-mill, "Minneapolis."
28.—Flouring-mill, "Pillsbury."
29.—Flouring-mill, "Excelsior."
30.—Woolen-mill, "North Star."
31.—Flouring-mill, "Anchor."
32.—Machinery.
33.—Car-shop.
34.—Flouring-mill, "Washburn C."
35.—Elevators.
36.—Flouring-mill, "Washburn B."
37.—Paper-mill.
38.—Flouring-mill, "Northwestern."
39.—Flouring-mill, "Pettit."
40.—Flouring-mill, "Zenith."
41.—Flouring-mill, "Galaxy."
42.—Elevators.
43.—Flouring-mill, "Washburn A."
44.—Elevators.
45.—Flouring-mill, "Humboldt."
46.—Wheel for elevated railroad.
47.—Flouring-mill, "Palisade."

a On December 4, 1881, four of the medium-sized mills were burnt down.

GENERAL DESCRIPTION OF THE LOCALITY.

About three-quarters of a mile above the falls of Saint Anthony is a small island called Boom island, and just below this the head of Nicollet island. This extends down-stream some 3,000 feet or more, dividing the river into a west channel and an east channel, which latter is considerably the smaller of the two. At the lower third of the island a suspension bridge across the west channel connects the island with the main portion of the city of Minneapolis, while a stone arched bridge of several spans crosses the east channel into the other division of the city.

About 250 feet below the foot of Nicollet island is Hennepin island. This island, about 2,300 feet long, is narrow at the upper portion, widening out to over 500 feet at the lower end. The falls occur opposite Hennepin island. In the west channel their crest is about 700 feet below the foot of Nicollet island; in the east channel it is about 700 feet still farther down the river. Just above the crest in the west channel the total width of the river from bank to bank is 1,530 feet; the west channel proper being 960 feet and the east channel 450 feet wide. The banks of the river above the falls are from 15 to 30 feet high.

If the falls were left in their natural state they would show a vertical pitch of 20 or 30 feet, with rapids above and very strong rapids below them. The general level of the ground remains the same below the falls, but the banks become steep rocky bluffs, which rise above the bed of the river nearly 100 feet a short distance below. These bluffs bound the river on each side to Fort Snelling, where the Minnesota river enters the valley; there they separate, including between them the much larger valley of the river below.

Water-power companies.—The natural appearance of the falls is entirely obliterated by the means used for improving their power. There are three companies claiming the right to them—the Minneapolis Mill Company on the west side of the river, the Saint Anthony Falls Water-Power Company on the east bank, and the firm of Farnham & Lovejoy between the two, on Hennepin island. These concerns have constructed dams and training-walls, which divert the flow of the river almost entirely through their races in low water. On a line just above the crest of the falls a dam extends from the west bank out into the river 350 feet; then runs up-stream about 1,000 feet; then down and across to Hennepin island; then down Hennepin island and across the east channel to the east bank, about 400 feet above the crest of the east channel falls. There is a water-way of 450 feet left in the west channel between the dam of the Minneapolis Mill Company and Hennepin island. In this distance the falls have been covered by the United States government with an immense wooden apron, or chute, to protect them from the wear of the water. The water on the west and east sides is mainly carried around the falls and discharged from the bluffs below. Thus the falls of Saint Anthony would hardly be recognized by those who had visited them when nothing but the rock, the foaming water, and the trees were to be seen.

HISTORY OF THE FALLS AND OF THEIR IMPROVEMENT.

Early explorers.—The enforced journey of Father Hennepin up the Mississippi has been alluded to on a preceding page. He was probably the first white man to gaze upon the falls, which his Sioux captors called Owah-Menah. Visiting them in July of the year 1680, he probably found the river at a high stage, and was much impressed by their grandeur, stating that "it indeed of itself is terrible, and hath something very astonishing". He gave the falls the name of his patron saint, Saint Anthony of Padua. Hennepin describes them as being from 50 to 60 feet high (another translation gives from 40 to 50 feet). Since his time, Carver in 1778, Lieutenant Pike in 1805, Major Long in 1817, and after him several others have visited the falls, and written descriptions of them varying more or less; some evidently exaggerations, while with others the differences are no more than are due to the rapid changes which have taken place.

Government occupation.—The era marked by the entrance of pioneers and settlers in this new country hardly began with the close of the last century; it is true that the trappers and traders of the fur companies had bartered with the Indians along the line of the great lakes, but very little, if any, permanent settlement had been effected. The following facts relating to the improvement of the power at Saint Anthony falls are taken mainly from a series of articles written for the *Northwestern Miller*, by Mr. F. E. Hesler, formerly of the *Minneapolis Evening Journal*.

In 1819 the United States government began the erection of a military outpost on the bluff at the junction of the Minnesota with the Mississippi. This was called Fort Snelling, and is still occupied as a base of supplies for the frontier.

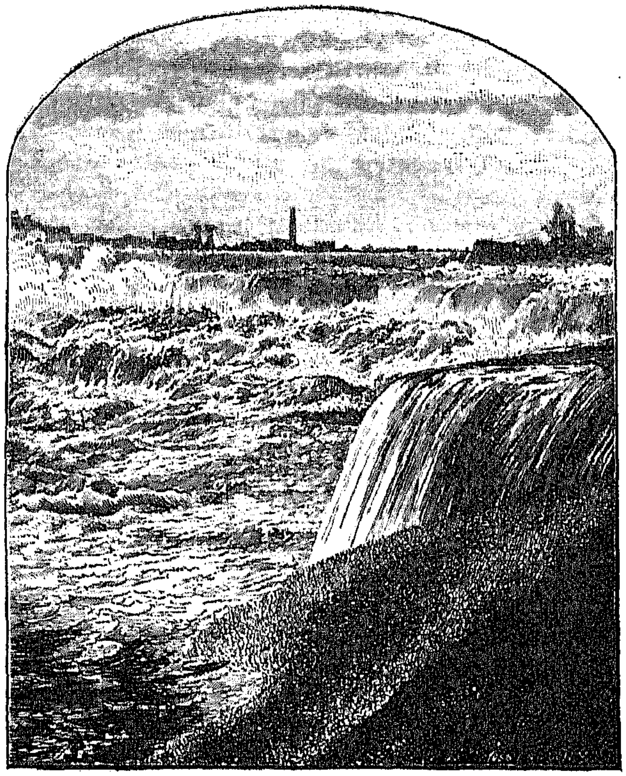
In 1825 the government built a saw- and grist-mill on the west bank of the river just below the brink of the falls. This, the first mill at Saint Anthony falls, was finally allowed to fall to ruin.

First extensive improvement.—In 1848 the first private improvement was inaugurated. Mr. F. Steele then built a dam across the east channel to Hennepin island, then up that island to the foot of Nicollet island, forming a pocket of the east channel. He erected four saw-mills, working under a head of 6 feet, and soon afterward built seven more. A Boston firm connected with Mr. Steele was desirous of relinquishing its right, and paid him $5,000 to allow it to retire. Mr. Steele made various sales and partnerships with several individuals, and finally in 1856 all those interested sold their rights to the Saint Anthony Falls Water-Power Company.

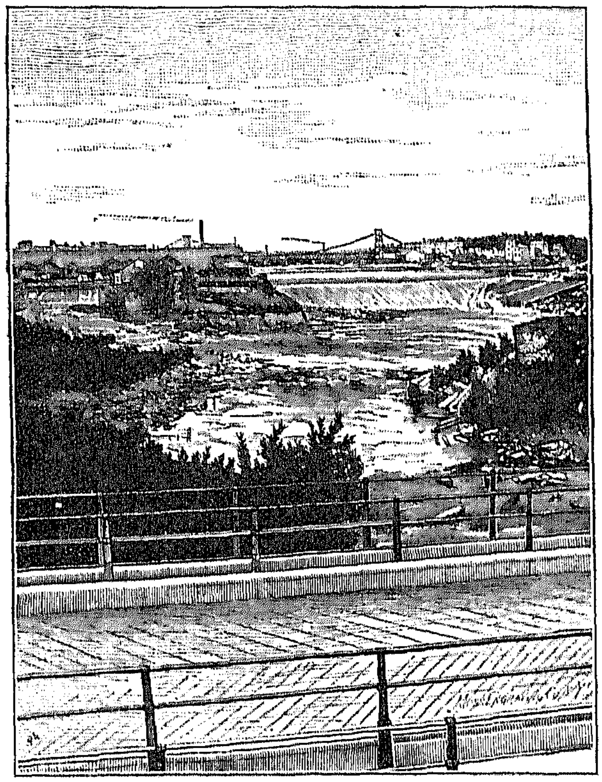
Organization of water-power companies.—This company was chartered by the territorial legislature on February 26, 1856, and on the next day the Minneapolis Mill Company received its charter, both of them perpetual.

Previously to the incorporation of these two companies the step had been taken which has resulted in the present immense milling business.

Development of the flouring interest.—The old government feed-mill built for the supply of Fort Snelling had long since disappeared, but in 1851 a Mr. Rogers roofed in a portable feed- and grist-mill on the east side; then, in 1852, in company with Mr. Steele, he extended it, erecting a one-story building and setting up two runs of stones. A thirty-two bushel grist, which came one day, was a wonder at that time. In 1854 the Island mill was started with three runs of stones, afterward increased to five. The country was then fast being settled, and although many thought this mill would not be a success, yet it paid for itself in two years. The first flour shipped out of the town was in 1858 by a farmer, a Mr. Getchell, who took that means of sending some money to his old home in New Hampshire. This soon resulted in an order to the mill for 100 barrels.



Saint Anthony falls as they were.



Saint Anthony falls as they are.

The mill was subsequently enlarged, but was destroyed by fire, as were also two others. A third mill shared the destruction caused by the break in the tunnel, which will be mentioned farther on.

In the mean time the Minneapolis Mill Company was not idle. No power had been used up to 1857, but then they began the construction of a dam and canal, and in 1858 the Cataract mill was built. After that came the City mill, the Union mill, the Arctic mill in 1866, and others in succession, until now there are altogether, upon both sides of the river, twenty-nine mills.

On May 2, 1878, occurred the great fire and explosion among the mills on the west side, when six large mills, representing eighty-eight runs of stones, were destroyed. A similar catastrophe on a much smaller scale occurred on December 4, 1881, when one cotton-mill and three flouring-mills were destroyed. These were merely interruptions, however, in the prosperity and development of the place.

The development of other manufacturing interests has been lost sight of in considering the great increase in the flour production at the falls; but various other industrial establishments, as machine-shops, woolen-, paper-, and cotton-mills, sash and door factories, etc., now take their power from the river.

Saint Anthony falls has not been exempt from the well-nigh universal litigation arising from conflicting water-power interests, but by recent adjustment of disputed interests the power seems now clear from all obstructions in the way of complete improvement.

GEOLOGICAL HISTORY OF THE FALLS.(*a*)

The immediate future of the falls is intimately connected with their geological character. It has already been mentioned that the river above the falls is bounded mainly by drift bluffs, but below them it sinks into a gorge about one-quarter of a mile wide, bounded by nearly vertical rock bluffs, which gorge continues to the junction

a Mainly gathered from Professor N. H. Winchell's report as state geologist.

with the Minnesota river. At the falls the river suddenly breaks through the rock strata, and flows along the lower level of the bottom of the gorge. In order to understand this a knowledge of the character of the strata is necessary.

Geological section.—At the falls it is as follows:

1. Drift, consisting of loam, clay, and gravel of varying thickness.

2. Trenton limestone, hard, compact, except for the many seams running through it, bluish in color, weathering to a buff color. It is generally as follows, in descending order: Impure limestone, from 9 to 12 feet; calcareous shale, from 4 to 6 feet; argillaceous limestone, 15 feet.

3. A layer 15 inches thick of hard, calcareous shale.

4. Saint Peter sandstone, 164 feet thick at the falls. This consists almost entirely of pure quartz sand, and is consequently white, except where stained by iron. There is so little lime that the grains are scarcely held together. The first 2 or 3 feet in depth are considerably impregnated with argillaceous matter, and are consequently quite hard. The rock can in any place be excavated with the pick, sometimes even with the hand. Where dripping water has had access to it the grains are more firmly cemented. It is very easily eroded by running water, disappearing almost like a lump of sugar.

5. Below the sandstone is the lower magnesian limestone.

The first four divisions are the only ones visible at the falls. The Trenton limestone there dips toward the southeast; at the iron bridge, which crosses the river some distance below the falls, the dip is very slight; at the falls it is 1 inch in 100 feet; a short distance above it is 3 or 4 inches in 100 feet; and on the east side, opposite the suspension bridge, it is 5 inches in 100 feet.

The bed of the river at the crest of the falls is in the Trenton limestone, of which there is a depth of about 16 feet between the bed of the river and the sandstone below. The bed below the falls is in the Saint Peter sandstone, but is strewn with fragments of all sizes of the Trenton limestone.

Causes producing the falls.—It is easy now to understand the cause of the existence of the falls. The water wears out the soft sandstone at the base, but is prevented by the hard cap of limestone from further action. The projecting limestone ledge, undermined by the wearing away of its support below, gradually breaks away, but always preserves a vertical face to the falls. Were it not for the stratum of limestone protecting the soft rock below, the river would long since have worn its bed to a uniform slope.

The above mentioned fact implies a gradual recession of the falls, and this is exactly what has taken place. In the same way as the gorge below Niagara falls has been carved out by the passage of the cataract up-stream, so have the falls of Saint Anthony passed upward from the valley of the Minnesota to their present position, cutting out the gorge we have already described.

The original position of the falls was never farther down the river than Fort Snelling, where the Minnesota enters. In this connection we may refer to the apparent fact that in the Glacial age the Minnesota was the real continuation of the main drainage trunk, and the stream represented by the present Mississippi above the junction was a comparatively small river tributary to it. Although small in comparison with the volume of the Minnesota at that time it was nevertheless much larger than at present.

Ancient channel of the Mississippi.—Instead of entering the ancient trough of the Minnesota where it now does, at Fort Snelling, the Mississippi left its present bed above Minneapolis, where Bassett's creek now flows into it, and running northwest of its present course entered the Minnesota valley at a point somewhere above Fort Snelling. This ancient course can be traced now. The river ran along the line of strike of the Trenton limestone, which probably formed a training-wall to the river, precisely as the hard lower magnesian limestone does now to the Wolf river in eastern Wisconsin.

The old bluffs, rounded off and partly concealed by the covering of drift, can yet be traced. The bed was cut over 100 feet deep in the Saint Peter sandstone, and there being no hard protecting cap of limestone there were no falls produced. Now the trough is nearly or entirely filled with the drift, and it was during the spreading of this in the Glacial age that the course of the river was changed to its present position. As the trough was filled up the river flooded back and the level rose, until, breaking across the limestone barrier, it for the first time fell down the face of the old river bluffs at Fort Snelling, and gave birth to Saint Anthony falls. Just how long the falls have taken to recede to their present position it is impossible to tell, but Professor Winchell, by comparing the descriptions given by the various travelers of the positions of the falls, fixes upon a rate of recession, and, with the hypothesis of uniformity of conditions in the past and present, calculates the length of time to have been from 8,000 to 12,000 years. Of course all such calculations must be taken with an understanding of their uncertainty.

Danger of the destruction of the falls.—A rather startling fact is apparent on an examination of the river-bed; the belt of outcrop of the Trenton limestone is not far to the north of this region, and, as the river-bed is worn somewhat into this bed of limestone above the falls, it happens that this hard, protecting layer, which is only 16 feet thick at the crest of the falls, thins out to a feather edge in the bed of the river and ceases entirely, just 1,200 feet above, in the west channel. If left to itself it would not be long before the last of the limestone would be gone, and the river would rapidly wear away the soft rock below, until nothing but a mass of foaming rapids would be left. This would be a very serious catastrophe to the water-power interests at Minneapolis, and there was imminent danger a few years ago of its actually taking place.

Rate of recession.—The rate of recession of the crest of the falls for at least the two centuries preceding their utilization was from 5 to 7 feet per year. When the improvements were commenced the recession became much more rapid. A high dam was thrown entirely across the east channel, another, 400 feet long, was thrown out from the west bank into the west channel, and the flood discharge of the river was practically restricted to the narrow passage, of 450 feet in width, between this dam and Hennepin island. This increased to a great extent the erosion at the base of the falls.

Then, again, the V-shaped dam above this water-way left in low water a large surface of the limestone bed of the river exposed to the action of frost in cold weather. This caused disintegration of the seamy limestone. The result has been that from the year 1857 up to 1876 the crest receded in the west channel 330 feet, or 17.2 feet per year. At this rate it would only require seventy years more for the falls to break away the last trace of the limestone.

Break in the limestone bed.—Then another cause of danger occurred in comparison with which the first was of slight importance. Some persons became possessed of the right to the use of a portion of the power on Nicollet island, and the idea was conceived of running a tunnel from the foot of the falls under the bed of the river to the foot of the island. There it was to be used as a tail-race by mills stationed upon the island. This was apparently an admirable plan, but it came near proving the destruction of the falls. Starting from the falls the tunnel was easily excavated in the soft sand-rock; everything was progressing finely, and a point had been reached about half way between Hennepin and Nicollet islands, when the water was found to be oozing through the roof and sides of the tunnel. Under the hydrostatic pressure of the river above it was finding its way below the upper edge of the limestone and was gradually wearing out the softer rock below. Finally, on October 4, 1869, the situation was very alarming, and suddenly, hardly giving the workmen time to escape, the water rushed into the tunnel, rapidly wore away the sandstone support, and, the limestone caving in, a great opening was made in the bed of the river, down which the water poured with ever-increasing violence. The cry rang through the city, "the Falls are going out!" as indeed was the case. Various methods were tried to stop the flow, and a raft of timbers, brush, etc., was floated over the opening, only to be broken in pieces. It was eventually checked by building a crib-work coffer-dam around the place. A second break soon occurred, just below, and was likewise closed. On the 5th of April a part of the coffer-dam about the second break was destroyed by the ice, the water entered the tunnel, and part of the lower portion of Hennepin island was washed away, including a number of mills. By this time considerable money had been spent by the city and private individuals.

Maintenance of the falls.—In July, 1870, Congress came to their aid with an appropriation of $50,000. The plan of the government engineers was to clean out the tunnel and fill it with puddle up to the limestone, then to build a masonry wall entirely around the breaks, filling the inclosed space to above high water with clay and gravel puddle, and then riprap the surface. Considerable work was done in accordance with this plan up to 1874, three minor breaks occurring. In 1874 a commission of engineers recommended the building of a solid dike of concrete extending entirely across the river, under the limestone ledge. This work was done in two years. It consists of a solid wall of concrete, 38 feet high and 4 feet thick, cemented to the lower side of the limestone strata, and extending down into the sandstone. It is, altogether, 1,870 feet long. Starting 325 feet above the dam on the west side, it runs across to Hennepin island, then diagonally down it, and then across the east channel, about 200 feet above the dam.

In addition to this work on the tunnel the crest of the falls has also been protected. In 1866, and again in 1869, the water-power companies attempted to protect the falls by a woooden apron, but their work was carried away by the high water. They were finally aided in this by the government. During the fiscal year ending 1877 the government also built the two spill-dams above the apron to keep the bed flooded and protected from the frost. During the next fiscal year the apron was remodeled.

The above facts are taken from Mr. J. P. Frizell's account in the report of the chief of engineers for 1879. Altogether there has been spent by the citizens of Minneapolis about $334,500 upon the preservation of the falls, and by the United States government $605,000 up to March 3, 1879. A description of the dike, apron, and dams will be found on a later page.

Advantage resulting from the character of the associated strata.—This soft layer of sand-rock, while it has been the cause of so great an expense, is, nevertheless, from its position, a very valuable feature in the improvement of the power, aside from its being partly the cause of the existence of the falls. Lying directly under the limestone, it is just in the position for the excavating of tunnels to act as tail-races to the mills on the banks above, and being so soft its excavation is a very easy matter. This peculiarity is very extensively taken advantage of. The solid layer of limestone serves admirably as a roof to the tunnels, which are driven just below it. They will be more minutely described farther on.

CHARACTER OF THE POWER.

The average flow of the river, given in the table for the main river, does not by any means represent the actual condition of affairs from day to day. Swollen by the spring rains or the melting snow and ice, the flow past Minneapolis may be over 50,000 cubic feet per second; while under the action of a dry summer and fall or the freezing winter it may dwindle down to even 4,000 cubic feet per second. From Major Allen's report are obtained the following average monthly conditions of stage and flow at Fridley's bar, just above Minneapolis, for the year 1875, which, as stated by him, was about an average year as regards the total flow for the year, although it may not have been in regard to distribution.

Table of monthly averages of flow, etc., at Minneapolis for 1875.

Month.	Average monthly stage above low water, in feet.	FLOW PER SECOND.			Theoretical horse-power under 75 feet head (average flow).	Effective horse-power under 75 feet head—efficiency of 75 per cent.—(average flow).
		Average for the month.	Maximum flow of the month.	Minimum flow of the month.		
		Cubic feet.	*Cubic feet.*	*Cubic feet.*		
March	2.00	....	....	....	....	....
April	8.10	36,132	53,496	19,155	307,400	230,600
May	6.15	27,642	32,070	22,983	235,200	176,400
June	6.76	29,927	40,066	18,245	254,600	191,000
July	1.97	10,530	16,876	7,177	89,600	67,200
August	0.66	6,695	8,535	5,640	57,000	42,700
September	2.16	11,122	12,355	9,172	94,600	71,000
October	2.30	11,623	11,980	10,883	98,900	74,200
November(*a*)	1.57	11,919	12,739	11,244	101,400	76,100
December	0.92	....	....	....	....	....
January	2.54	....	....	....	....	....
February	1.96	....	....	....	....	....

a Gaugings of the flow for November were taken only from the 1st to the 17th, inclusive.

Variation for the year 1875.—Starting with the 1st of March there was a gradual increase in the flow, caused by melting snow and ice and the rains, up to April 16, when the maximum of the year was reached, 53,496 cubic feet per second. The gauge then stood at 11.8 feet above low water. Then there was a gradual fall through May to the 29th, when the gauge stood at 5.2 feet, and the flow was 22,983 cubic feet per second. From the 29th of May the river began to feel the effect of the late spring and summer rains and rose until June 6, when it stood at 9.1 feet on the gauge, giving a flow of 40,066 cubic feet per second. It then fell continuously to August 16, when the gauge marked zero, and the flow up to the 19th was 5,640 cubic feet per second. From August 19 to September 7 the river rose to 2.5 feet on the gauge and a volume of flow of 12,355 cubic feet per second. From that time on to the 17th of November the river kept a pretty constant stage, not rising above 12,739 cubic feet per second, nor falling below 10,530 cubic feet per second. From November 18 to April 1 no record is given of the volume of flow.

Times of freshets.—The water-power owners state that there are ordinarily three annual rises in the river—the spring rise at the going out of the ice, usually in early April, generally not very great; the June rise, caused by heavy rains, which is generally the largest freshet of the year; and the fall rise, usually slight, caused by the fall rains. The average maximum rise for the year is between 6 and 8 feet.

The low water usually occurs from the latter part of July into the fall, and again in the winter months. It is generally considered that the lowest stages of flow occur in winter, especially if it is very severe, but the water-power companies do not base their calculations upon that flow. Mr. H. H. Douglass, agent of the Minneapolis Mill Company, states the average summer flow to be 15,000 and the average winter flow 10,000 cubic feet per second. Considering each of these seasons to include six months, the average flow of the year would be 12,500 cubic feet per second. As given in the table of the river it is 13,193 cubic feet per second. We take the estimate of 10,000 cubic feet per second for the average winter flow (there are many days when it is much less); and it is believed that the estimate given in the table of 6,000 cubic feet per second for the ordinary low flow, as defined in describing the tables, is on the safe side for the low season of summer, and may even be applied to the winter months, although, not having gaugings for that season, this cannot be positively asserted.

Power in use.—The total power used on the west side of the river is between 9,000 and 10,000 effective horse-power, with a head ranging from 12 to 48 feet, the average being, in the winter of 1880–'81, 23.6 feet.

The total power used on the east side, and on Hennepin island, is (including the large Pillsbury A mill) slightly more than 3,000 effective horse-power, with a head varying from 16 to 50 feet, averaging about 34 feet.

The total power in use is, hence, in round numbers, 13,000 effective horse-power, under an average head of about 25.5 feet, and assuming an efficiency of two-thirds, requiring a volume of flow of about 6,700 cubic feet per second.

Reasons for lack of water.—These figures serve to explain the fact that while the total theoretical power at an average stage of the river is over 100,000 horse-power, yet there is at times a scarcity of water, the mills drawing the level down nearly to the bed of the river, and the manufacturers are obliged to arrange for their mutua accommodation. Instead of making use of the total head of 75 feet, only about 30 feet is the average used. Then again, many of the arrangements are not the best possible for obtaining the maximum efficiency from the water and head used.

The improvement of the falls has not been from a comprehensive scheme, formulated at the commencement and completely carried out, but the first mills were built above the falls, using only the 12 or 16 feet of head afforded by the dam itself. Water was plenty, and there was no thought of want. Now tunnels are being driven, and the head is being increased for many of the mills. This will tend to reduce the difficulty from want of water, but cannot be relied upon entirely for that purpose. The expense is great, the work involving not only the excavation, but the putting in of a completely new set of wheels. Even supposing the head to be increased at all the mills, it is not probable that the average head used will be much over 50 feet for many years to come. About 70 feet is the head available, supposing canals to be carried down-stream for half a mile, and all the water taken to that point and then used, or supposing large tunnels to be started from that point and run up to the falls, using them as tail-races for all the mills. Such extensive improvements are theoretically possible, and perhaps at some future day will be put into a practical form, when the absolute necessity occurs for making available every horse-power; but at present they are not probable. Yet the two water-power companies upon the opposite sides of the river are endeavoring as much as possible to realize this ideal condition, and in the improvements now going on are pursuing the general plan just mentioned.

The constant tendency is to a better condition of affairs; but as more mills are built there will apparently be times, when the river is at its lowest, at which the supply of water will not be sufficient to meet the demands made upon it, just as at present. The proper way to meet this difficulty seems to be to continue making the utilization of the power more efficient, but also to strike at the root of the matter and endeavor to regulate the flow of the river.

Value of reservoirs to the water-power.—The upper Mississippi is far from being an unsteady stream, but during part of the year it may flow past Minneapolis at the rate of 35,000 cubic feet per second and then fall to 6,000 cubic feet; at one time barely affording enough water to supply all the mills now running, at another rushing over the apron at the falls, scarcely diminished by the amount taken by the mills. The proposed reservoir system has been already treated of. If this is carried out by the government upon the sources of the Mississippi, it will meet almost entirely this very requirement of the water-power interests. Of course it will be done, if at all, by the government, to improve the navigation of the river, and the flow would be regulated to further that interest; but at the same time it would act in favor of the water-power, because, so far as the flow is concerned, the interests of navigation and water-power are almost identical. The fact is that some of the chief opposition, especially in the state of Minnesota, to the application of the reservoir system by the government, arises from a feeling that it is being urged in the interests of the manufacturers of Minneapolis.

The physical peculiarities of the region above Saint Anthony falls have been already described on the pages relating to the deduction of the tables for the main river and its tributaries. It was shown that there was available for storage above Minneapolis an average yearly flow of slightly more than 13,000 cubic feet per second. The surveys conducted by Major Allen show that there is abundant storage capacity about the sources of the river, available at a practicable expense, for a very large amount of this average flow, and that, with the lowest estimates, a discharge of about 12,000 cubic feet per second past Minneapolis can be maintained during the low-water season of summer and fall.

Unless the autumn rains should fail, it is probable that the discharge could be maintained at nearly this amount during the winter months by a proper management of the reservoirs. The maintaining of a flow at all times of at least 12,000 cubic feet per second would be of immense value to the water-power of Minneapolis, doubling the power now obtainable at low stages of the river.

The manufacturers to construct the reservoirs.—Provided that the right could be obtained to the lands liable to overflow, which are of little value, and permission could be secured from the government, it appears highly to the future interests of the manufacturers of Minneapolis to carry out the reservoir plan themselves. The following calculation will not bear a rigid mathematical criticism, but is sufficient to illustrate the point:

The cost of construction of the seven dams proposed by the government is estimated at about $400,000. The extent of flowage of entered land was stated by Major Allen, in his report of January 15, 1878, to be probably not more than 2,500 acres, consisting, so far as could be ascertained, of hay meadows and wild rice-fields of small value. Setting the very high price upon this land of $10 per acre, the total would be $25,000. Suppose the cost of maintenance and attendance to be $20,000 per annum, certainly a large estimate, and we have this result:

Cost of construction	$400,000
Cost of flowage	25,000
Total	425,000
Interest at 6 per cent	25,500
Maintenance and attendance	20,000
Total per annum	45,500

With the present improvements, and an average head of about 25.5 feet used, there is obtained in round numbers 13,000 horse-power at the mills, and no more can be realized at a low stage of the river without increasing the average head. Suppose it to be increased to 50 feet, which is probably all that will be done for some time. Then assuming a simple proportion, there would be 22,000 horse-power obtained, and no more, without having difficulty in low water.

Supposing a flow of 12,000 cubic feet per second to be maintained throughout the year, at an average head of 50 feet, it would give, with an efficiency as low as 66.6 per cent., 45,000 effective horse-power. The difference, 23,000 horse-power, is the amount of power practically gained by the introduction of the storage system, supposing a head of 50 feet to be used. A horse-power is valued at $10 per year at Minneapolis. According to this estimate the value of the increase of power rendered available throughout the year would be $230,000 per annum. The yearly expense of the reservoirs, $45,500, is a small item in comparison.

The system of natural reservoirs takes to a great extent the place of the artificial ones proposed, and were it not for them the river would be like some of its tributaries, extremely low in severe winters and in drouths. There is no difficulty from backwater, the effect of high water in the river being to increase the head on the wheels.

Difficulty from ice.—Sometimes damage is caused to the dams in the breaking up of the ice, and at one time there was a jam in which the ice piled up 16 feet high and then came down over the falls. There is less danger to the dams when the ice goes out with a full stage of the river than when the water is low. Since the breaking away of a part of the dam, the water-power companies have united in the spring in cutting a channel through the ice about 100 feet wide and 2 or 3 miles long down to the falls. Through this channel the ice passes down without trouble. If the ice is soft at Minneapolis, and liable to pass out as soon there as above, then the channel is omitted. The cost of this work is $2,500 or $3,000.

DETAILED DESCRIPTION OF THE IMPROVEMENTS.

Rates of lease.—The water-power at Minneapolis has been estimated in terms of a unit called a "mill-power", which is equivalent to 75 effective horse-power. The rate of rental is the same with both of the water-power companies, viz., $750 per "mill-power" per annum, or $10 per horse-power. The usual method pursued with the Minneapolis Mill Company is for the manufacturer to buy the land and rent the power from the company.

The Saint Anthony Falls Water-Power Company fixes its rents according to the power used, and if the head is increased then the rent is increased proportionately. Of course some consideration must be taken of the efficiency of the wheels. Regarding the Minneapolis Mill Company, the statement was made that if a lessee increased the head of water at his mill the company would probably raise his rent for one-half the increase of power obtained.

The Minneapolis Mill Company leases its mill-powers for a "two-thirds run", that is, 16 hours out of the 24. During part of the year there is not sufficient water to supply all the mills with a two-thirds run, and the manufacturers have a right to demand a reduction in the rent in proportion to the reduction of the power below that leased. However, during a large part of the year there is more than sufficient water, and as the company allows the mills to run beyond the time stipulated in the lease the manufacturers consider that the one counterbalances the other, and they make no complaint during low water. They agree among themselves about running during low water. Several manufacturers using about equal amounts of power will arrange between them that certain ones shall run their mills during part of the 24 hours, the others taking the remaining time, and thus they divide the flow between them. Nothing of this kind has been done thus far upon the east side of the river, as it has not been fully developed.

The agent of the Minneapolis Mill Company is Mr. H. H. Douglass, of Minneapolis. The agent of the Saint Anthony Falls Water-Power Company is Mr. S. H. Chute, of Minneapolis, east district.

IMPROVEMENTS OF THE SAINT ANTHONY FALLS WATER-POWER COMPANY, ETC.

The dam runs across the east channel about 360 feet above the crest of the falls; then along the side of Hennepin island to its upper end; then diagonally up to the center of the west channel, where it is joined by the dam of the Minneapolis Mill Company on the west side of the river. Up to the head of Hennepin island it is a high dam, never overflowed by high water, and forms really a basin in the east channel from which the water is drawn to the mills. The head of water directly at the dam is from 16 to 20 feet, varying with the stage of the river. Main street runs along the east bank of the east channel. At the dam it is directly at the river-bank, which is here perhaps 20 feet high. Back of the street the bluff rises rapidly.

The mills supplied from the east channel are, with two exceptions, either at the dam or else facing on Main street. The exceptions are a furniture factory, on Hennepin island, and the Northwestern Fence Works, some distance back from Main street, on Third avenue south.

Methods of using the power.—There are two classes into which the various ways of taking the water might have been divided previous to the summer of 1881, when the canal was constructed. They are, (1) taking water directly from the dam; (2) taking it from below the dam, either by tunnels or by flumes in the channel of the river. The methods are shown on the map of the place.

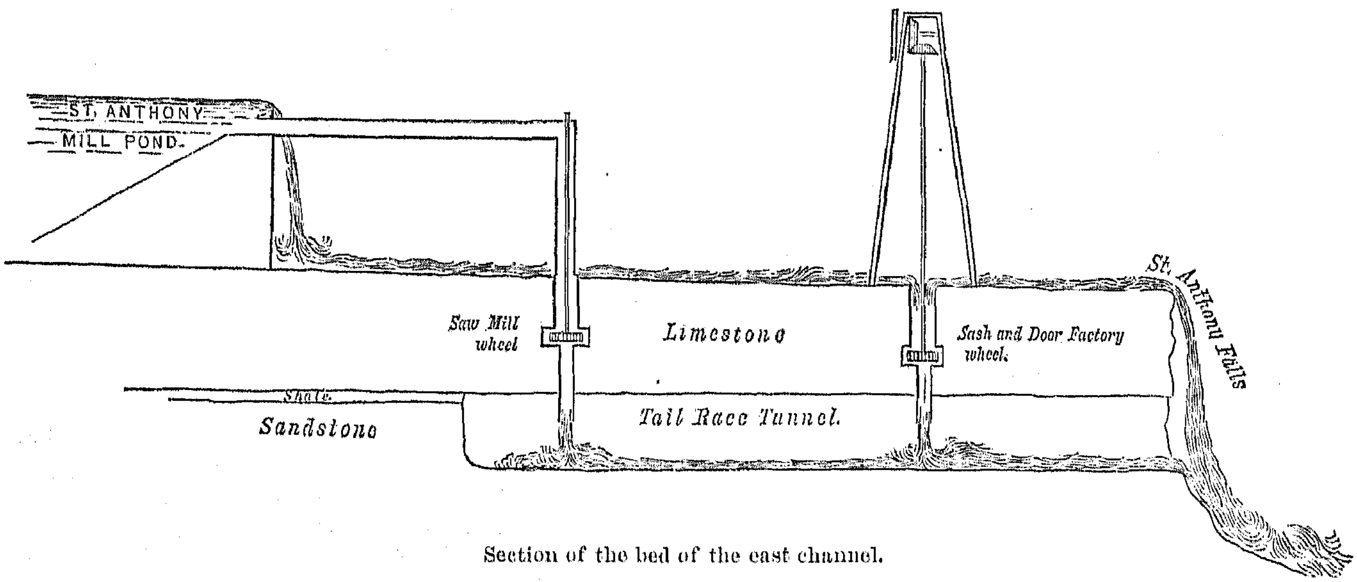
There are five saw-mills directly at the face of the dam, owned by three firms. To these firms there were scaled, during the sawing season of 1879, over 19,500,000 feet of logs. They use not only the head obtainable at the dam, but have run three parallel tunnels below the falls about 350 feet up to the dam, and then have sunk wheel-pits to the tunnels, using them as tail-races. By this means they get an average head of about 35 feet. The wheels are set only part way down in the pits, and draught-tubes are used to get the total effect of the head, as shown in the drawing. Each mill has one wheel, and one tunnel will suffice for two wheels (see map). These saw-mills use 200 horse-power each, and pay no rent to the Saint Anthony Falls Water-Power Company, as they own the power.

Stationed at the dam, and adjoining the saw-mills on the Hennepin island side, is the wheel-house of a set of manufacturing industries of various kinds, stationed at the foot of Nicollet island. It was for the power owned there that the tunnel was dug which came so near proving the destruction of the falls. The project of taking the power at Nicollet island was abandoned, and now it is conveyed by a wire rope of over 1,200 feet length, in two spans, from the wheel at the dam. This wheel discharges through a tunnel similar to those at the saw-mills; 400 horse-power is used, under a head of 35 feet, and no rent is paid to the Saint Anthony Falls Water-Power Company, as the power is owned on the island.

Between the saw-mills and Main street is a wheel, called the Union wheel, which, when visited in the winter of 1880–'81, ran with a head of only 16 feet, obtained at the dam. It gave 130 horse-power, applied to a line of shafting running 600 feet up Main street, and turning the machinery of three machine-shops, an eaves-trough factory, a mattress factory, and, by a branch shaft running across the street, the Union Iron Works. It was the expectation to extend this system in the coming summer so as to use 500 horse-power, probably by increasing the head, making use of the adjoining saw-mill tunnel.

On the east side of Hennepin island, just at the crest of the falls, is a wheel working under a head of about 25 feet, which, by a line of shafting some 150 feet long, connects with a furniture factory using 75 horse-power.

On the east bank of the river, about 100 feet below the crest of the falls, is a wheel, under a head of 25 feet, supplying 75 horse-power to the North Star flouring-mill, on the other side of Main street, by an underground shaft about 125 feet long. The water is carried to the wheel through a wooden flume leading from the bed of the river above the falls.



Section of the bed of the east channel.

Directly over the most eastern one of the three tunnels acting as tail-races for the saw-mills, and about 30 feet below the bridge leading to Hennepin island, is a wheel supplying power to industries on the river-bank. It is set in a very peculiar manner, illustrated in the section showing the discharge-tunnel. A pit was sunk through the limestone bed of the river, piercing the roof of the tunnel. Part way down in this the wheel is placed, with a draught-tube to the tunnel, into which the water is discharged. It enters the wheel through the bed of the river above. By this means a head of 20 feet is used and 75 horse-power obtained. This is transmitted by shafting about 90 feet to a tower on the river-bank, and from it, 320 feet up Third avenue south, to the Northwestern Fence Works by means of wire-rope. There is a small feed-mill in the tower, which is also run by this power.

On the northeast corner of Main street and Third avenue south, is the Phœnix flouring-mill. In the winter of 1880–'81 the wheel of this mill was supplied by a tunnel leading from the river, under Main street to the mill. There is, passing under Main street, an old tunnel which was originally intended for a tail-race to all the mills. From a point about opposite the dam it runs down 1,200 feet, and emerges in the cliff below. It is at a lower level than the supply-tunnel to the Phœnix mill, and is used by that mill for a tail-race. A bulkhead was built in the tunnel just above the North Star mill, and the water discharged through a short side tunnel into the river just at the falls. The water leaked around the edges of the bulkhead, wearing away the sandstone, and in December, 1880, a portion of Main street fell in, owing to the breaking of the limestone stratum. There is no serious damage anticipated from this however. The head of water used at the Phœnix mill is 25 feet, and 75 horse-power is obtained.

This brings us to the Pillsbury "A" mill, the latest and largest building not only on the east side, but also at the falls. Its erection marks a new era with the Saint Anthony Falls Water-Power Company in the improvement of its power. Activity has been renewed, and more attempts made to take advantage of the opportunities of the place.

The Pillsbury "A" mill has been already alluded to as the largest flouring-mill of this great milling center. Mr. J. K. Neftel, the special agent on milling, states that the mill has a capacity for turning out 5,000 barrels of flour per day. It stands at the southeast corner of Main street and Third avenue south; a blue limestone building, 115 by 175 feet, and 6 stories high above the street. Mr. C. J. A. Morris, the engineer of the Saint Anthony Falls Water-Power Company, stated that the intention was to make 3,000 or 4,000 barrels of flour per day. The mill engaged from the Saint Anthony Falls Water-Power Company 750 horse-power under 50 feet head of water, but it was thought probable that more would be required.

Hydraulic canal.—Up to this point nothing has been said about the water-power canal. This was being constructed when the place was visited in the winter, and again in the summer of 1881. It is part of a systematic plan of improvement now taken in hand for utilizing the power on the east bank.

The Saint Anthony Falls Water-Power Company owns a large amount of land along the river below the falls, extending as far down as Eleventh avenue south, and it is the intention to carry the water through this land by the canal, supplying mills, which can tunnel out through the cliff to the river for tail-races, much as is done on so large a scale at Niagara falls. The company also, in the winter of 1880–'81, excavated a tail race 800 or 900 feet long from the foot of the falls down the flat between the east channel and the cliff. By running their tunnels into this, mills can obtain a head of 50 feet, as has been done by the Pillsbury "A" mill. The tail-race is 15 or 20 feet wide, averages 10 feet depth, and was excavated out of earth and masses of limestone broken from the falls in past years and piled in every direction.

The plan proposed for the canal was to start from just above the dam and to carry it under Main street in two arched masonry conduits down to the company's land, and then as an open canal through it. This has been calculated with a width of 50 feet and a slope of 1 in 400. Mr. Morris states that a head of from 68 to 70 feet of water would be obtainable on the lower portion. One of the conduits was in process of construction in the summer of 1881, with a width of 14 feet, and was being built in apparently a very substantial and workmanlike manner. From this canal a short inlet was to lead to the two wheel-pits of the Pillsbury "A" mill, and from these two tunnels carry the discharge-water into the new tail-race, giving a head of 50 feet.

It is probable that the Phœnix mill, North Star mill, and others for which water has been let through the dam to the river below, will now change and take water from the new canal.

The following table gives, as nearly as could be ascertained, the power to which each manufactory on the east side is entitled, and the head used:

Power controlled by the Saint Anthony Falls Water-Power Company—Power used on east side.

Nature of manufacture.	Name of factory.	Number of horse-power to which entitled (effective).	Average head, in feet.
Flouring	Pillsbury "A" mill	*a*750	50
Five saw-mills		1,000	35
General manufactories on Nicollet island		400	35
Iron works Three machine-shops Eaves-trough factory Mattress factory	Union Iron Works	*a*180	16
Flouring	Phœnix mill	75	25
	North Star mill	75	25
Sash and door factory	Northwestern Fence Works	75	20
Furniture factory		75	25

a See description in text.

According to this table there is 2,580 effective horse-power in actual use on the east side of the river under an average head of 34 feet, but changes are continually being made. Assuming that 2,580 horse-power is used under the several heads given in the table, and that the efficiency is two-thirds, then a flow of 1,000 cubic feet per second is required. The fact probably is that much more than this is used, but the power might be obtained with this volume of water. If the Saint Anthony Falls Water-Power Company should secure the right to one-half the total flow of the river, then it would have at an ordinary low stage 2,000 cubic feet of water per second more than is now used from the east channel. This surplus, under a head of 50 feet, would give 11,345 theoretical horse-power. With the reservoir system applied, there would be throughout the year a surplus of 5,000 cubic feet per second, and, under a head of 50 feet, 28,363 theoretical horse-power, besides what is already in use from the east channel. If the head under which the present manufactories work is increased to 50 feet, then they will require less water for the same power, and hence the amount of water available for other mills will be increased.

With the large number of mill-sites owned by the Saint Anthony Falls Water-Power Company, the new canal conducting the water to them, and this surplus flow of the eastern part of the river, it is apparent that an immense development is in store for the water-power of east Minneapolis. It was proposed in the winter of 1880-'81 to run a short line of the Saint Paul, Minneapolis, and Manitoba railroad from Saint Paul which would pass by the land owned by the water-power company, and cross the river diagonally below Hennepin island (a). Side-tracks would undoubtedly be built to the mills, increasing very much the facilities of trade.

THE FARNHAM & LOVEJOY POWER. (b)

The relations of this to the other companies have been already described in treating of the legal conditions of the power. Only two establishments are run from their site. These are their own saw-mill, working under a head of 22 feet and using 300 horse-power, and a paper-mill, which has bought 250 horse-power from them, under a head of 25 feet. These mills are situated on the west side of Hennepin island, at the foot of the Farnham & Lovejoy mill-pond, which averages 150 feet in width, is 1,175 feet long, and is formed by a wing-dam running along the side of the island.

The mills discharge into the west channel below the falls. A canal could be run down the west side of the island on the property, giving a head of from 30 to 35 feet at the mills. All the water entering the mill-pond has to pass over or through the dams of the two water-power companies.

MINNEAPOLIS MILL COMPANY.

This company's dam starts from the west bank, half-way between Fifth and Sixth avenues, and runs straight out into the river 400 feet, to the head of the government apron; then it turns and runs up-stream, uniting with the Saint Anthony Falls Water-Power Company's dam in the center of the channel. The crest of this dam at the lower portion is above high-water mark, and a mill-pond is formed, connected by slack-water with the basin of the Saint Anthony Falls Water-Power Company. From this pond at the end of the dam a canal starts. It is 80 feet wide at the head, but soon narrows to 55 feet, its regular width. For a distance of 345 feet it runs at an angle of about 30 degrees with the river, but then bends and runs parallel with the river for 600 feet. The depth is greatest at the bend, diminishing toward each end, and averages about 12 feet. From this canal most of the manufactories are supplied with water.

Methods of using the power.—There are the following four methods in use of taking and disposing of the water:

1. Taking the water directly from the pond, and discharging directly into the bed of the river, as is done by the row of seven saw-mills situated at the dam.
2. Taking the water directly from the pond and discharging into a tunnel which leads below the falls, as is done by the city water-works and one saw-mill.
3. Taking water from the canal and discharging into the river either by an open cut or by a tunnel, according to the side of the canal from which the water is taken.
4. Taking the water directly from the river at the brink of the falls. This was done only by one cotton-mill upon Upton's island. By far the greater part of the power is obtained from the canal.

The head used varies from 12 to 48 feet, averaging about 30 feet. The only mills using a head of 12 feet are the seven saw-mills, which have taken only the head afforded by the dam; but in the winter of 1880-'81 a tunnel was being driven, similar to the tunnels on the other side of the river, from below the falls up to the dam, and three of the mills were to discharge into this, getting from 30 to 35 feet of head. It was the expectation to excavate another tunnel for the other mills. These saw-mills were bought out by the Minneapolis Mill Company, as they had too much control of the water. None of the other mills, except the cotton-mill, have less than 25 feet of head.

The situation is one of the best possible for the location of manufactories. Fifth, Sixth, Seventh, and Eighth avenues lead down to the mills, and with the streets running parallel with the river afford every facility for traffic. The system of railroad tracks is also very complete. Three side-tracks run between the mills and the river, on a trestle, and cars can be brought directly to the rear of the mills situated on that side of the canal. The canal itself is planked over, forming a street between the mills, and above this are three elevated railroad side-tracks, passing in front of the mills just mentioned. On the land side of the canal are numerous tracks, running to the remaining mills. Two of these tracks pass directly through the large Washburn "A" mill, the second in size at the falls.

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a A fine stone bridge for this line is now being built (August, 1882), as shown on the map.

b Since the writing of the report this power has been purchased by the Saint Anthony Falls Water-Power Company.

The depot and termination of the Minneapolis division of the Chicago, Milwaukee, and Saint Paul railroad is less than 2,000 feet distant. By means of these tracks there is every facility for the rapid handling of large amounts of material.

Power controlled by the Minneapolis Mill Company.—The following table gives the head of water and the power used in the winter of 1880–'81 by the different manufactories, as kindly stated by Mr. H. H. Douglass, the agent and engineer of the Minneapolis Mill Company:

Kind of mill.	Name of establishment.	Number of horse-power to which entitled (effective).	Average head, in feet.
Flouring	Washburn "C" mill	900	35
Do	Washburn "A" mill	700	37
Do	Crown Roller mill	525	27
Do	Pettit mill	450	37
Do	Standard mill	413	27
Do	Washburn "B" mill	375	35
Do	Northwestern mill	375	35
Do	Pillsbury mill	300	32
Do	Palisade mill	300	45
Do	Anchor mill	300	27
Do	Empire mill	263	30
Do	Excelsior mill	263	32
Do	Minneapolis mill	225	32
Do	Galaxy mill	225	37
Do	Humboldt mill	225	37
Do	Zenith mill	188	37
Do	Model mill	150	27
Do	Dakota mill	150	27
Do	Union mill	113	27
Do	Arctic mill	75	32
Do	Holly mill	75	28
Do	Cataract mill	75	28
Saw-mills	Minneapolis Mill Company's saw-mills. No. 1	300	12
	No. 2	300	12
	No. 3	300	12
	No. 4	225	12
	No. 5	375	12
	No. 6	300	12
Saw-mill		338	27
Paper-mill		225	35
Woolen-mill	North Star woolen-mill	150	27
Machine-shop		150	27
	City water-works	150	27
Wheel running the elevated railroad		75	32
Cotton-mill	Minneapolis cotton-mill	75	20

Four of the flouring-mills—the Excelsior, the Pillsbury, the Minneapolis, and the Empire—as also the Minneapolis cotton-mill, were destroyed by fire on December 4, 1881. The total number of horse-power given in the table is 9,628; and the average head, exclusive of the row of saw-mills, is 30 feet. Of this power Mr. Douglass states that about 1,875 horse-power is not owned by the Minneapolis Mill Company, they having been taken by the members in place of dividends before these were declared.

The Washburn "A" and the Crown Roller mills are the two largest manufactories on the west side of the river. The former had a capacity of 1,500 barrels per day, only using one-half of the building. In the spring of 1881 machinery was being placed to increase the production of this mill to 3,500 barrels, and the Crown Roller, which also used only one-half of the building, was expected to increase its capacity to 3,000 barrels per day.

Assuming an efficiency of two-thirds in the application of the power, then the 9,628 effective horse-power would require a volume of flow of 5,375 cubic feet per second, of which the row of saw-mills belonging to the Minneapolis Mill Company take 1,980 cubic feet per second. These saw-mills were bought by the company in order to control them in the use of water, and they will probably not be run to the detriment of the other establishments; hence, omitting them, the Minneapolis Mill Company requires for the complete satisfaction of all the other manufactories a flow of 3,395 cubic feet per second. This is about 300 cubic feet per second more than one-half the entire ordinary low-water flow of the river. It is evident from this that, unless the head is increased at the different mills, or the system of reservoirs is carried out, equalizing the flow of the river, the Minneapolis Mill Company can make very little further development except for a full stage of the river. If a flow of 12,000 cubic feet per second were maintained throughout the year, they would then have beside the power now in use (including the saw-mills) a surplus flow of about 600 cubic feet per second, and if the head at the saw-mills is increased to 30 feet this surplus will be somewhat increased. This is on the supposition that the company is entitled to half the entire flow of the river. A surplus of 1,000 cubic feet under a head of 50 feet would give 5,670 theoretical horse-power, and represents about all the surplus power which would be available for every day of the year, after the construction of reservoirs.

By an increase of head of the mills now working the surplus power could be very much increased in amount. The channel of the river below the falls could be excavated next to the west bank, as has been recently done at the east shore, and a head of 50 feet or more made available directly at the dam. It would be possible to start some distance down the river and run a large tunnel in the bank under the mill-sites, using it as a tail-race for all the mills. By this means a head of fully 70 feet could be obtained at all the locations. If the head were increased, then there would be surplus power to warrant the proposed extension of the canal. The Minneapolis Mill Company owns land for half a mile down the river, and the canal could readily be continued through this land. Assuming that the company has a title to one-half the entire flow of the river, and that a uniform head of 50 feet is used, then with an efficiency of two-thirds there would be a surplus power over what is now in use of 1,715 effective horse-power with the ordinary low flow, and of 13,055 effective horse-power with the average flow resulting from storage-reservoirs. If a uniform head of 70 feet were used, then the surplus power under the two conditions of flow would be, respectively, 6,255 and 22,140 effective horse-power.

It will be seen from these figures that there are yet opportunities on the west side of the river for considerable development, and it must not be overlooked that the figures apply to power obtainable every day of the year, while there are kinds of manufacturing which can afford to stop their wheels during low water, and hence these could be supplied beyond the low-water limit of the power. There are several unoccupied sites which could be supplied from the present canal.

DAMS AND OTHER ENGINEERING CONSTRUCTIONS.

The solid limestone bed of the river makes an excellent foundation for the building of dams. There is a total of about 5,650 linear feet of dam at Saint Anthony falls, of which some 800 feet belong to the government and the remainder is controlled in the interests of the water-power. A large part of this is of old crib-work construction. The entire length of the V-shaped dam, from the east bank to the west bank, is about 3,670 feet.

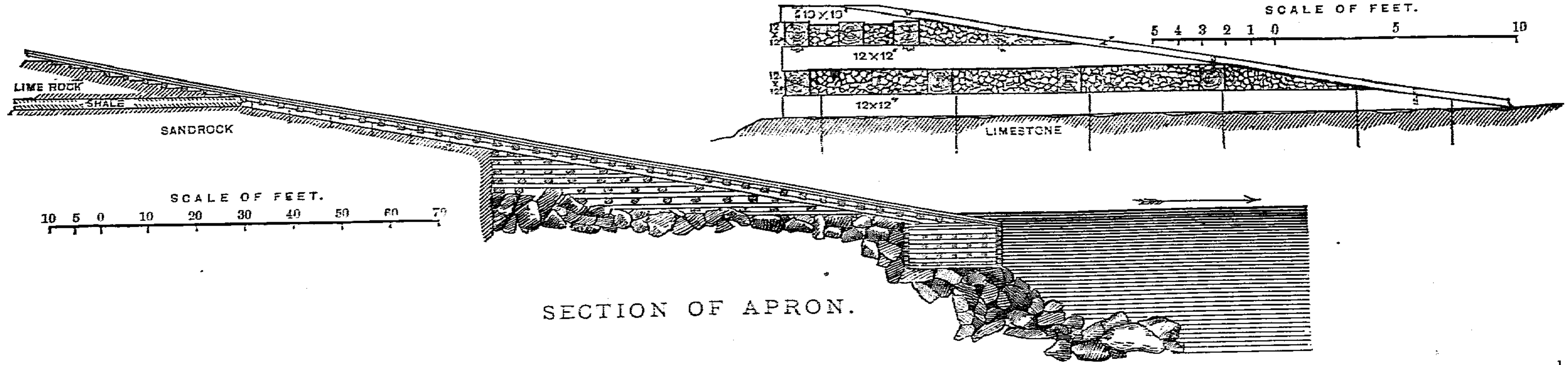
Dams on east side.—The portion crossing the east channel is 440 feet long, and is high enough to be above high-water level. It is constructed of triangular sets of squared timber, planked over on the face. There is no filling or planking on the back. The height varies from 15 to 20 feet.

From this point up to the apex of the dam in the middle of the west channel the construction is of timber crib-work. This was built in 1871, with an average height of 14 feet, at a cost of $25,000. It is about 50 feet broad at the base at the lower end, and from 16 to 20 feet at the upper end. Log cribs filled with stone, the lower timbers bolted 15 or 18 inches into the rock by iron bolts, were used. These cribs were planked over. Five hundred feet of the upper portion was once broken by the ice and carried away. This was rebuilt in a substantial manner of squared pine timbers, about 12 inches square throughout. The construction is a crib-work, with spaces of 2.5 feet, filled with stone. The sleepers were trimmed to fit the rock bed, which is quite even, and each one is fastened down by about six 1-inch iron bolts, let into the rock some 16 inches. The method taken to fasten the bolts was to drill holes in the rock one-half inch larger in diameter than the bolts themselves. These were filled with pine plugs, and then the iron bolts were driven hard into them. As the other dam failed owing to the ice wearing out the planking and then breaking up the unprotected crib-work, the new dam was made specially strong in this respect. The crest, 4 feet wide, is formed of pine timbers, 10 inches square, laid close together in the direction of the current. They are notched to fit the upper course of the crib-work, and are bolted to the timbers of that course. They are beveled at the upper ends to fit the inclined back of the dam, which is covered by 4-inch planking, tree-nailed to the timbers. The face of the dam is vertical and without an apron.

The dams from both sides of the river formerly met in a point very near the upper extremity of the limestone ledge, and there was apparent danger of its being undermined and the dam giving way. Accordingly a crib-work dam 100 feet long was built across below the point, and the latter was removed.

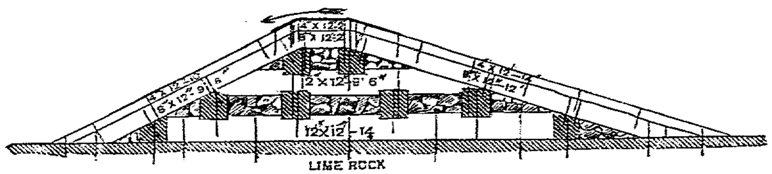
Dams on west side.—From the apex down to the west bank the dam is a log crib-work bolted to the bed of the river, and covered with 4-inch planking. It is about 60 feet wide at the base at the lower end, where the head of water is 12 or 15 feet, and narrows toward the apex as the head becomes less. The water never falls over the crest except at the upper portion, unless the river is extremely high.

Along the row of saw-mills the Minneapolis Mill Company was building in the winter of 1880–'81 a substantial stone dam behind the old crib-work dam. It is constructed of the Minneapolis limestone, rough-dressed, with regular coursing. The face is vertical; the back has a straight batter of about 0.37 in 1. The base is 10 feet wide, crest 3 feet across, and height 19 feet. A few iron bolts were let through the lower courses into the bed of the river as an extra precaution, although the dam is stable in itself. The structure was built in sections. The old dam leaked to some extent, and in order to exclude all water from the foundations a small coffer-dam was built around each section, about 2 feet distant from it. Small posts of scantling were set into the bed about 4 inches, and 2-by 4-inch scantlings spiked to them. Then against these were driven sheeting piles of 1-inch boards, beveled at the



Section of Dam at the
ST. ANTHONY MILL POND.

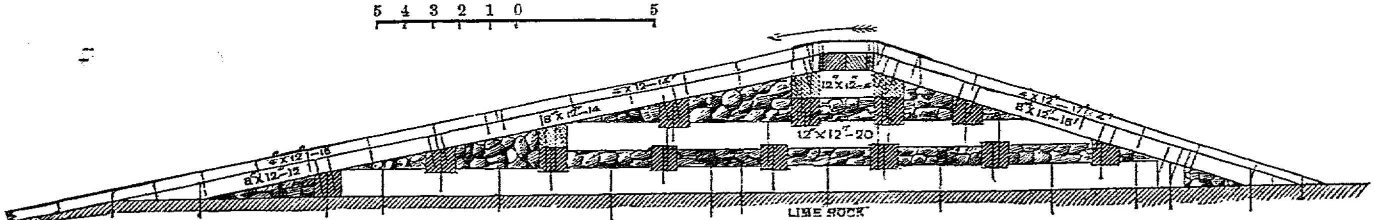
SECTION OF APRON.



SECTION OF UPPER ROLLING DAM.

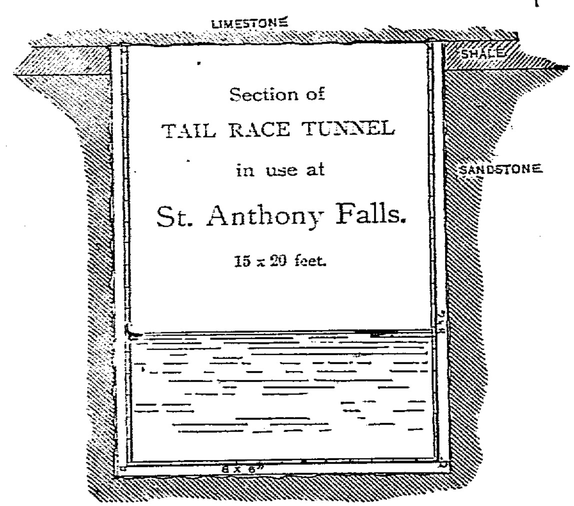
SCALE OF FEET.
5 4 3 2 1 0 5

Various
Engineering Constructions at
ST. ANTHONY FALLS,
Mississippi River.



SECTION OF LOWER ROLLING DAM.

SCALE OF FEET.
5 4 3 2 1 0 5 10



ends so that they would crush down and fit accurately to the bed-rock. About 1 foot inside of this was built another similar construction, and the intervening space was tightly packed with decayed horse-manure, which the engineer claimed was fully as good as, if not better than, earth for the purpose.

Roller-dams.—The two dams built by the government between the two sides of the V-shaped dam have been already alluded to. Their object is merely to keep a body of water over the river-bed above the falls to protect it from the frost, hence they are built low, as rolling-dams, allowing ice, logs, etc., to readily pass over their crests. The lower one, situated at the upper edge of the apron over the falls, is 450 feet long, about 44 feet wide at the base, and 5.5 feet high. The upper one, about 670 feet above, is 360 feet long, about 25 feet wide at the base, and 4.5 feet high. Both these dams are constructed of 12 by 12 and 8 by 12 inch timbers, bolted and notched together, as shown in the drawing. The crest is protected by a plate of iron bent over to fit the face and back, which are both inclined, and covered with 4-inch planking. The back of the lower dam has the same slope as the apron over the falls, and is in fact merely a continuation of its surface at the same angle.

Government apron.—The government apron is a very extensive construction built entirely over the falls in the west channel. The cause which led to building the apron has been already given. The main portion is 400 feet long, with an inclination of about 11.5 degrees from the horizontal, and is 245 feet wide in horizontal projection from the crest of the roller-dam to the foot. This makes the total fall 49.75 feet. At the end where the apron abuts on Hennepin island there is an additional apron 215 feet long, built in three planes, to protect the shore of the island. The construction is shown in the drawing.

The limestone ledge was stepped to receive stringers, and on these the timber facing was laid. When the sandstone was reached it was smoothed down, and sleepers were laid on it in the direction of the current; upon these the stringers were laid. At the base of the falls a crib-work of logs and squared timbers was laid, and the stringers and facing were continued upon it. At the foot the apron rests upon a timber crib 20 feet wide and 10 feet high, built of squared timbers laid close at the face and back. The bed at the foot of the apron is protected by heavy stone, thrown in loose. At the western end of the apron is a sluice-way, 6 feet wide and 346 feet long, for the passage of logs down-stream.

Concrete dike.—The course of this is shown on the map, and the causes which led to its construction by the government have been set forth in treating of the geology of the falls. The total length is 1,870 feet, and the cost was about $212,000. As previously stated, the dike consists of a solid wall of concrete 38 feet high and 4 feet thick, cemented to the lower edge of the limestone strata, and extending into the bed of sandstone. In the construction a shaft was first sunk on Hennepin island, and the tunnel driven from it in both directions under the limestone. The wall was built up in sections as the tunneling progressed. The lower portion was made wider so as to allow the leaving of a passageway for the workmen and materials, and a space was also left between the under surface of the limestone and the top of the wall for another passageway. Under the lower passageway a drain was left in the concrete covered by a plank. Afterward the two passages and the drain were all filled with concrete tightly rammed in.

Tunnels.—These are a peculiar feature in the improvements at Minneapolis. The position of the soft sandstone underlying the hard layer of Trenton limestone permits the excavation of these underground tail-races with great readiness. They are dug out of the sandstone usually with picks up to the limestone, which is used as a roof. The sides of sandstone are left vertical. Thus a rectangular tunnel is made. It is always important to remove the layer of shale, about 15 inches thick, which intervenes between the limestone and the sandstone, because if not there is danger of its falling. In the summer of 1880 a sheet 3 inches thick fell while a tunnel was being excavated and killed three of the workmen. The removal of this shale sometimes requires blasting.

The width is ordinarily 15 feet, and as the tunnel is always excavated to the limestone the depth depends upon the head of water required. Ordinarily the tunnels are 20 feet in height. As there is no special tendency to lateral movement of the rock, there is no necessity of timbering the tunnel as the work progresses, unless there should be a very heavy body of water above, sufficient to force its way through the seams in the limestone to a great extent, but as the sandstone is easily worn by running water it is important that this should eventually be protected. The old method of doing this has been to timber the floor and sides, leaving the limestone roof uncovered, as it merely scales off slightly. Sets made of 8 by 6 inch squared timbers are placed in position and then planked over on the floor and two sides. The disadvantage of this method is that the timbering rapidly decays on the walls where exposed to the air. A better practice now being pursued is to put in a timber flooring, but to build the sides of stone or brick. The new tunnel to the saw-mills on the west side of the river has vertical sides with brick facing 12 inches thick. In a tunnel proposed for the east side, it was Mr. Morris' intention to build the walls of brick with a slight batter.

The cost of running a tunnel is very nearly the same at all places at the falls; for a tunnel with a cross-section of 15 by 20 feet it averages about $10 per linear foot for the excavation, and $1 per linear foot for timbering, where that is used alone.

There is in use now by the manufactories not far from 5,230 linear feet of tunnel, of which 2,730 feet are on the west side and 2,500 upon the east side of the river. There has been, including the excavation for the government dike, at least 1.8 mile of tunnel excavated about the falls of Saint Anthony.

THE RIVER BELOW SAINT ANTHONY FALLS.

When the river leaves its new channel and enters the old river valley at the junction with the Minnesota, it passes from the rock to the soft drift bed which, with two exceptions, characterizes it to the Gulf. Consequently the slope is comparatively uniform and gentle, and there is, as might be expected, no available water-power below the Minnesota river, with the exception of the two places just alluded to; there the river-bed is of solid rock, and accordingly at Rock Island rapids and at Des Moines rapids there are available water-powers.

From the foot of Saint Anthony falls down to the mouth of the Minnesota river the slope is great, and it is possible to construct a dam at Meeker's island, just above the foot of the gorge, where the river is 800 feet wide, and obtain a head of 30 feet, without injuring the power at Saint Anthony falls. In connection with the navigation of the river, it was once proposed to build a dam at this point.

ROCK ISLAND RAPIDS.

These rapids are 896 miles from the source of the Mississippi and 382 miles below Saint Anthony Falls. They are 14.75 miles long, with a total fall in low water of 20.4 feet, giving an average slope of 1.383 foot per mile.

The rapids consist of a series of pools alternating with rapids over rock in place, which crosses the river in a series of dams. These are called "chains", and there are ten such designated on the United States engineer's maps, with the following names: Upper, Smith's, Sycamore, Crab Island, Saint Louis, Campbell's, Winnebago, Duck Creek, Moline, and Lower Chain.

Geology.—The rock forming the bed of the river is Magnesian limestone in place. The river here leaves its ancient trough and bed of soft drift to flow across the country, cutting a new channel in the limestone rock which underlies the soil. Hence the concentration of descent at the rapids and the swell in the uniform curve of the profile of the river, as shown on the curve sheet.

The slope is greatest at the lower portion of the rapids, about half of the total fall occurring in the last 5 miles, and the utilized power is taken there. The Rock Island rapids have long proved a serious impediment to the navigation of the river, and the United States government has been engaged for many years in improving them in this respect. The local officer in charge of the work and of the entire river from Saint Paul to the mouth of the Illinois river, with the exception of Des Moines rapids, is Captain Alexander Mackenzie, to whose kind assistance there has already been occasion to refer. The system used has been to blast out a channel where the chains are, 200 feet wide and 4 feet deep in low water. It is now proposed to increase these dimensions to 400 feet and 6 feet, respectively.

General description.—Beginning at the foot of the rapids, and extending up-stream over 2.5 miles, is the island from which the rapids take their name. It embraces nearly 1,000 acres of land and averages 3,000 feet width. The main channel of the river, through which all vessels pass, is on the north side of the island, while on the south is the south channel or slough, as the subordinate channels are named in the Mississippi valley. The government has taken possession of the island, and is now erecting, on a very extensive scale, an arsenal and manufactories for the War Department. The island is beautifully laid out with a broad central avenue, bordered by rows of trees, and is a place of great interest to the visitor. Colonel D. W. Flagler, major of ordnance, is the commanding officer, and to his kindness this report is much indebted.

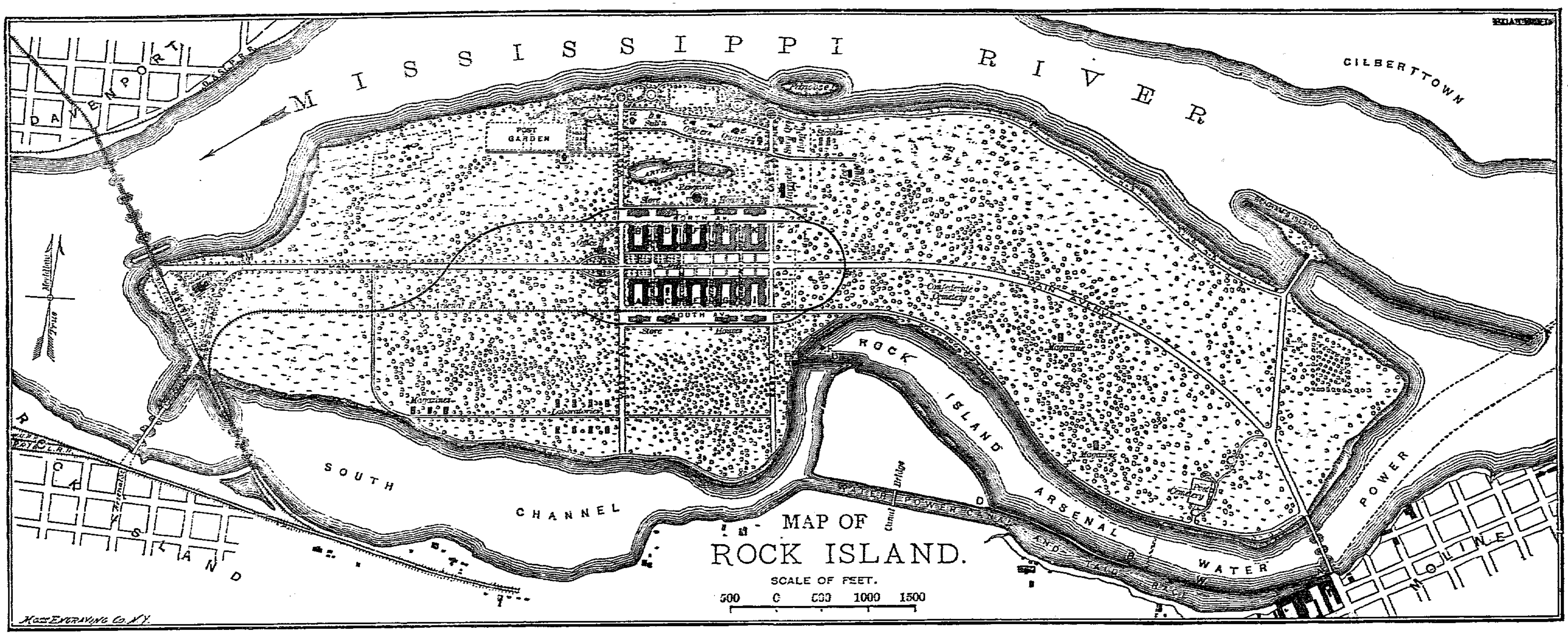
Directly at the foot of the rapids, on the northern or Iowa side of the river, is the city of Davenport, and opposite, in Illinois, is Rock Island, both large and thriving cities. About 3 miles above Rock Island city, on the same side of the river and opposite the head of Rock island, is the town of Moline, a corruption of the French word *moulin*, meaning mill. This is a manufacturing center of considerable importance, a specialty being agricultural implements, wagons, etc. Rock Island is connected with the Illinois shore by wagon-bridges at both extremities, and the Chicago, Rock Island, and Pacific railroad, which crosses the river between Davenport and Rock Island (city), crosses the lower extremity of the island. The bridge across the main channel is one of the finest on the river, having railroad tracks above and the highway below.

All manufactories at Davenport, Rock Island (city), or Moline, have, of course, close connection with the through lines of railroad and every facility for transportation.

All water-power improvements, with the exception of three unimportant mills at the upper part of the rapids, are on the south channel in its upper portion. Power is, or has been, used by the manufactories at Moline, and is now used to drive the machinery of the government manufactories at the arsenal.

The first improvement was made at Moline, and hence the power has come to be known, what there is of it, as the Moline water-power. The rather peculiar condition exists of very fine and substantial works, with scarcely any power obtainable from them, owing to the silting up of the head of the channel, and there is an unfortunate disagreement between the Moline Water-Power Company and the government, whereby the use of the power has been to some extent delayed.

History of the development.—To understand this it is necessary to review briefly the history of the improvement. In 1841-'42, Messrs. David B. Sears and John W. Spencer, after obtaining a charter from the state of Illinois, built


MISSISSIPPI RIVER
DAVENPORT
GILBERTTOWN
POST GARDEN
SOUTH CHANNEL
ROCK ISLAND
ARSENAL WATER POWER
MOLINE
Canal Bridge
MAP OF ROCK ISLAND.
SCALE OF FEET.
500 0 500 1000 1500

a dam across the south channel from Moline to the island, and a saw- and grist-mill was erected at Moline. In 1851 the power passed, by sheriff's deed, into the hands of Pitts, Gilbert & Pitts. Finally, owing to failure to pay bonds, the entire property came under the control of Mr. Horace K. White, jr., in 1864. Mr. White held the property as trustee for himself and associates. In February, 1865, the present Moline Water-Power Company, of which Mr. Charles Atkinson, of Moline, is president, obtained a charter with the expectation of buying the water-power and adjoining property; formed the company in December, 1865, and, at the same date, bought the water-power, franchises, and adjoining land.

About this time the question of the use of the power at Rock Island by the government was agitated; and in November, 1865, General Rodman, who was then the commanding officer, addressed a letter to the agent of the water-power company with reference to an arrangement whereby the government could have a partial use of the power.

Contract of the government and the Moline Water-Power Company.—The result finally was that in the summer of 1867 an agreement was made between General U. S. Grant, who was then Secretary of War, and Mr. Atkinson, whereby the Moline Water-Power Company ceded the entire water-power, and so much of the river-bed as was necessary for its development, to the United States, with these conditions:

That the water-power company have the free use of one-fourth of the entire power, and the privilege of renting for a specified time, at the rate of 50 cents per square inch per annum, so much additional power as the Secretary of War may deem it expedient to authorize to be rented.

That the government should develop and maintain the power, and in such a manner as to allow the water-power company to avail itself of its privileges.

That the government should spend $100,000 upon the improvement of the power, as much as was necessary, up to the limit of $40,000, upon the wing-dam; and the remainder upon the extension of the dam on the Moline side, no unnecessary obstruction to be made to the use of the then existing power during the progress of the work, nor any payment of water-rents to be required until the $100,000 were expended.

In view of the above it was mutually agreed that neither the company nor the government should at any time make any obstruction of the water-power as it then existed or should exist when further developed.

The difficulty has been, and is now, the claim on the part of the Moline Water-Power Company that the government has not made good the conditions of the agreement. The chief points of complaint appear to have been that the yearly accumulations of silt in the pool, and also that existing previous to the contract, had not been removed; that the remains of works used in the improvement had not been removed, nor stone excavated in the canal; and that the wing-dam had not been completed. This latter Colonel Flagler is engaged in building, and he hopes by its aid to remove the silt.

Without involving ourselves in the consideration of an interminable amount of correspondence, investigation, etc., over which numerous commissions have sat, and out of which no small amount of annoyance and unpleasantness has been engendered, it is sufficient to state that the power, as it now exists, is practically worthless to the Moline Water-Power Company, without pretending to say whether the government is to blame or the water-power company is simply unfortunate. The head of the channel is so silted up that the manufactories have, with one exception, abandoned their wheels and use steam-power entirely.

The works for the improvement of the power are of government construction and of a most substantial character, as will presently be seen.

Opposite Moline the south channel is 700 or 800 feet wide. There is a bend in this channel below Moline to the northwest, and then south and west. The dam starts from the Moline side at the bridge, and runs down 2,280 feet, nearly parallel with the shore, to a dike, which runs 1,650 feet farther in the same general direction, striking the side of the channel again. It then runs along the shore 2,300 feet to the maximum point of the bend, where a dam about 650 feet long crosses the channel to the Rock island shore. Thus there is formed a pond or pool in the south channel. The space between the dam and dike and the Moline shore serves as a tail-race, which is continued across the neck of land at the bend by a canal, 2,100 feet long and 150 feet wide, excavated in the rock. This tail-race is intended for the Moline manufactories, which took their power at the upper end of the long dam by wheels, situated directly at the foot of the dam, transmitting the power across the tail-race by shafting. The power for the arsenal is taken at the Rock island end of the short dam which crosses the channel at the bend. The wheels are placed at the foot of the dam, and the power is transmitted several thousand feet to the government works by means of wire rope.

Opposite the northern end of the island, in the main channel, is a small island, about 1,000 feet long by 100 feet wide, called Benham's island. A dam, 450 feet long, cuts off the channel between the two islands; and from the upper end of Benham's island a wing-dam runs up stream some 2,400 feet. This is intended to deflect the water into the south channel. Colonel Flagler is engaged in continuing this wing-dam about 1,300 feet farther, at the angle shown in the map. He fears that if it is carried beyond this distance it may interfere with navigation. It is feasible to obtain a head of 4.5 feet at the Benham's Island dam, and Colonel Flagler has a scheme for establishing a gun-forge there, using the water-power. The ore or pig-iron could be floated directly to the place.

Amount of power.—The head of water obtained by the paper-mill at Moline, which is the only one using the power, varies from 3 to 7 feet. Colonel Flagler, who considers the obstruction to the power as merely temporary, and expects eventually fully to restore it, says that the head of water will then be at Moline 6 feet at high water and 7 feet at low water, while on the government wheels it will be 6.8 feet at high water and 7.8 feet at low water. He estimates that the total flow into the south channel will give an average of 3,500 theoretical horse-power, of which, according to the agreement, 875 horse-power will belong to the Moline Water-Power Company, and the remainder, 2,625 horse-power, will belong to the government. This it is the expectation to use at the shops, obtaining from 2,000 to 2,200 effective horse-power. Colonel Flagler attributes the small flow of water into the south channel partly to the Moline chain of rock which crosses the river at its head, and partly to the mud deposit. He hopes, by means of the wing-wall, flood-gates in the Benham's Island dam, and a movable coffer-dam, which can be cheaply constructed, to scour out the deposit from the head of the channel; and then he will cut a channel (shown by the dotted lines) through the rock. With the channel once cleaned out, it is the expectation that it can be kept free from further deposit.

Moline Water-Power Company.—The Moline Water-Power Company owns the Moline shore of the south channel to a point below the end of the long dam; but, with the present improvements, there are only about 17 lots available for power, because the government will not allow the taking of power except from the dam. The following are the manufactories upon these lots supplied with wheels, in their order down stream: Moline Plow Company, lots 1 and 2; Moline Paper Company, lot 3; Deere & Co. (agricultural tools), lots 4 and 5; lots 6, 7, and 9 unsold; Moline Wagon Factory, lots 10, 11, 12, and 13; Union Malleable Iron Foundery, lots 14 and 15.

As before mentioned, all have abandoned their wheels, with the exception of the Moline Paper Company, which uses four 75-inch Dayton wheels, under a head of from 3 to 7 feet. These can not be run under a head of 3 feet, and part of the time steam is used. The manufacturers who leased the power from the water-power company are chiefly heavily interested in the company itself, and hence do not occasion much difficulty to its officers.

Provided the full power is restored, as previously explained, the water-power company could utilize all the surplus from the government wheels, as well as its own power, upon the seventeen lots opposite the long dam.

Further improvement of the rapids for water-power.—There was at one time a scheme proposed for utilizing power at Davenport, on the Iowa side of the river. The plan was to start on the north side of the main channel, at a point just above the Moline chain, and extend a canal along the bank about 3 miles to Davenport. At the upper end it would run across a point of land for perhaps half or three-quarters of a mile, but the remainder of the distance it would be formed by a retaining-wall, built in the river parallel with the shore. The wheels would be set in the river at the lower end of the canal. A head of 5 or 6 feet would be available at the foot of the canal. Major Hoffman, who is connected with Captain Mackenzie's office in Rock Island (city), was employed to report upon the plan. He reported against it, as it would cost from $1,000,000 to $1,500,000, and would be liable to interfere with the navigation. By a continuation of the canal about 3 miles farther up stream, the head available would be increased by only from 1 to 1.5 foot, while the expense would be very much greater.

It is not probable that any power of magnitude can be obtained at Rock Island rapids, except the Moline power, without a very heavy expense. At Moline there is the double advantage of a greater slope, nearly double the average, and a small channel of considerable length, unused for navigation, and admitting of a comparatively inexpensive improvement. The same advantages do not exist at other points.

The Moline water-power is not the only one used at Rock Island rapids. There are three small mills, each with about two runs of stones, at different points above Moline, using undershot wheels, run by the current of the river mainly. They have ordinarily a slight head of about 15 inches, obtained in two cases by wing-dams, and in the other by a dam run across to an island. The wheels work best when the river is 2 or 3 feet above low stage. They have a vertical range of 3 or 4 feet, but are sometimes completely drowned.

Engineering constructions, etc.—The limestone bed of the river forms a firm foundation for the dams.

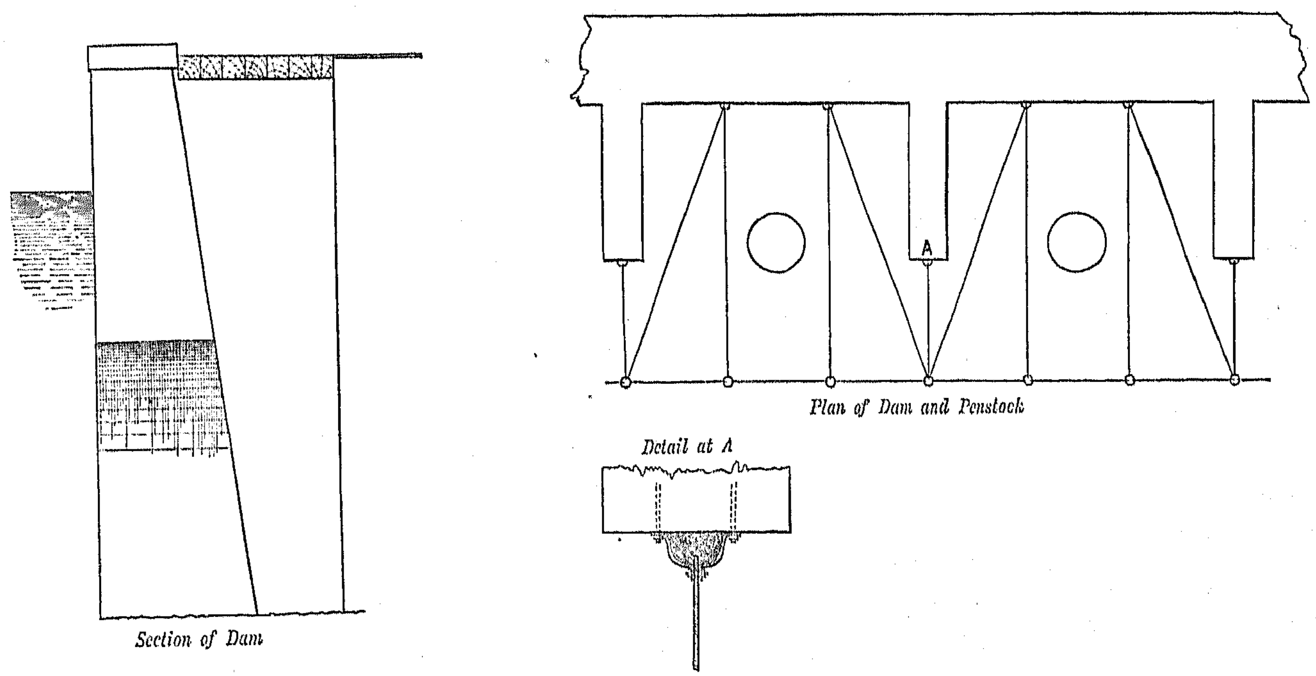
Dam from A to B.—This is built of Joliet limestone, obtained at Joliet, Illinois. The stone is of a light-yellow or buff color, and is extensively quarried for building purposes. It, and the Grafton and Anamosa stones, are the three varieties used in the buildings on Rock Island. The last two varieties are of a light-gray color. Colonel Flagler considers that the Grafton stone is superior to that from Joliet, where exposed to water and frost. The dam is built solid of rough-dressed, regular-coursed masonry. It is 2,280 feet long, 22 feet high at the upper end, and 24 feet at the lower end, 8 feet wide at the base, and 4½ feet wide at the top. At distances of 10 feet are buttresses 3 feet thick, with 11 feet breadth of base. At intervals are openings between the buttresses to pass the water into the penstocks of the mills.

Dike from B to D.—The first 1,750 feet, to the point at which it strikes the shore of the channel, is a very fine specimen of work. It consists of a riprap of stone, excavated from the tail-race, laid around a core of beton. The beton core starts from the rock bed 5 feet wide, and rises about 22 feet, with a width at the top of 3 feet. On each side of this the riprap is laid, 66 feet wide at the base, 14 feet at the top, and 25 feet high. The sides are faced with smooth-laid riprap. Colonel Flagler thinks now that the core was unnecessary, as the small holes in the carefully-laid riprap are silted up sufficiently to prevent all leakage. The remainder of the dike, which extends along the bank to the short dam, is of earth, faced with riprap. The total length of the dike is 4,050 feet.

Tail-race canal.—This was excavated across the neck of land to give a discharge passage for the Moline manufactories. The total excavation made is 2,280 feet long, 200 feet wide at the top, 150 feet wide at the bottom, and averages 17 feet deep. The land is rocky, and in some places there was a covering of a few feet of earth, while at other places the rock surface was bare; hence the canal is practically a cut through the solid Magnesian limestone. This was found to be very uneven in nature. In some parts it contained cavities and seams, and then again a very hard, tough variety would be encountered. The most experienced blasters had difficulty in preventing the charges from blowing out through the tamping. Colonel Flagler said he would rather work in solid granite.

Short dam across the south channel.—This crosses the channel at the bend. It is built in much the same manner as the long dam already described, of rough-dressed, solid masonry of Joliet limestone, with regular coursing. The wheels now in use by the government are at the foot of the dam, and it is the intention to set wheels along its entire length. Because of sinking the wheel-pits the foundations were built down into the limestone ledge about 7 feet. The height of the dam proper is 26 feet. The buttresses are vertical at the face, with 8 feet depth and 16 feet between centers. There are 41 openings between the abutments to admit the water to the wheels, and it is the intention to have eventually 40 wheels ranged along the dam, 20 driving the machinery of one line of shops by wire rope and shafting and 20 the other line in the same manner. The plan of the works is an ingenious one, and the part already carried out at the dam is the first step in a carefully arranged scheme. Colonel Flagler is making a remarkably thorough study of teledynamic transmission; and as the writings of former engineers, both of this country and abroad, are in certain respects incomplete in this rather modern method of transmitting power, he is conducting careful experiments with the temporary line of wire rope now in use. The results of his investigations, when published, will be of great value to the engineering profession.

There are now in place at the Rock island end of the dam four 65-inch wheels, of the Houston pattern, which was decided to be the most suitable for a power liable to floating *débris*. These wheels gear upon a horizontal line of shafting running parallel with the dam directly above them, and the wheel-house is built on the dam and buttresses as a foundation wall. A heavy flooring of 14 by 14 inch pine timbers laid close rests upon the buttresses as piers, and on this the machinery is placed. Outside of this a light flooring extends beyond the buttresses 6 feet, arranged so that it can be readily taken up. Overhead is a traveling crane. When new machinery is to be set the light floor can be removed, the machinery carried in and placed by the traveling crane, and the power increased without interfering with the working of the rest of the wheels.



Penstock in use at Rock Island, Ill. Designed by Colonel D. W. Flagler.

The buttresses, besides serving as piers for the machinery, also form part of the sides of the penstocks. Owing to the variation in the head of water, a wooden penstock would be alternately exposed to air and water, and subject to rapid decay. On this account Colonel Flagler devised the unique penstock used at the dam. It consists of a heavy oak floor always below the water surface, with sides of one-quarter inch plate-iron. The penstocks are 14 feet by about 16 feet. Four-segment Phœnix columns form the posts which hold the iron plates. These are riveted in between the segments of the columns. The plate which forms the continuation of the side of the penstock beyond the buttresses is fastened to the latter by means of two segments of a Phœnix column, which are bolted to the masonry, as shown in the drawing. The plate is riveted between them, and to prevent leakage the column is filled with cement. The plates are stiffened to resist the thrust of the water by means of buckstays, which are placed closer toward the bottom, where the pressure is greatest. The columns are stayed to the masonry as shown, by means of the bars fastened to eye-bolts let into the masonry. Colonel Flagler stated that the cost of this kind of penstock did not exceed by more than 30 per cent. the first cost of a good oak one.

DES MOINES RAPIDS.

These are the lowest rapids met in the Mississippi river. They are 114 miles below the Rock Island rapids, and 3 miles above the mouth of the Des Moines river, which enters from the west. The rapids are 11.1 miles long, and in ordinary low water have a total descent of 22.17 feet, or 1.994 foot per mile, while the average slope of the Rock Island rapids is only 1.385 foot per mile. The head of the rapids is at Montrose island, and the city of Keokuk is situated at their foot on the Iowa bank. The rapids are somewhat similar in character and extent to the Rock Island rapids, but they are more uniform, not consisting to so great an extent of a succession of rapids and quiet pools. Previously to improvement by the government they formed a very serious obstruction to the navigation of the river, prohibiting it in low water, while it was possible for light boats to navigate Rock Island rapids at all stages. By excavating a channel and building a canal, navigation has been rendered safe at all stages of the river.

The Des Moines rapids are in charge of Major Amos Stickney, whose office is at Keokuk; and under his direction very fine works have been carried out. No water-power is in use, but there is an opportunity for making available a power of large amount.

Geology.—The geological history of the Des Moines rapids is much the same as in the case of the rapids just described; the river has left its ancient trough, and is now wearing a new one through the rock. The bed throughout the length of the rapids lies in what are known as the division beds, separating the Keokuk limestone from the underlying Burlington limestone. These division beds consist of cherty layers alternating with layers of hard gray limestone, and average about 40 feet in thickness. The Keokuk above contains the celebrated "geode bed". The dip of the strata is toward the southwest, and at the rapids the inclination of the river-bed is nearly the same as this dip. Perhaps it is on this account that the slope is more uniform than at Rock Island rapids.

Navigation.—In improving the navigation of the rapids a channel was blasted out of the bed of the river, along the west shore from Montrose island, 3.27 miles long, down to the little village of Nashville. This channel is 200 feet wide, and has 5 feet depth of water in a low stage of the river. From the lower end of the channel a canal was built along the west bank, 7.6 miles, to the foot of the rapids, entering the river again at the city of Keokuk. The canal is formed by a retaining embankment running along the bed of the river, except at a few points where the banks project into the stream. The depth at extreme low water is 5 feet. The width is 300 feet, with the exception of 2 miles of heavy cutting through rock, where the width is reduced to 250 feet. At the head of the canal is a guard-lock, which is left open whenever the river lowers to a stage of 2.5 feet above low water; 2.28 miles above the foot of the canal is the middle lock, with a lift of about 13 feet; and where the canal enters the river again is the lower lock, with an ordinary lift of about 11.5 feet, but it is sometimes entirely flooded by high water in the river. These locks are finely constructed of carefully-cut masonry, and are worked by very complete hydraulic machinery. (*a*) Over $4,000,000 have been expended in the improvement of the Des Moines rapids.

As is the case with the Rock Island rapids, the slope is greatest in the lower portion. In the first 4,800 feet from the lower lock there is a rise of 4.21 feet, then 2.22 feet in the next 3,600 feet, and 1.67 foot more in the succeeding 3,600 feet to the middle lock, making the fall, in ordinary low water, from a point opposite the middle lock to the foot of the rapids, 8.1 feet. The total fall, from opposite the guard-lock of the canal to the foot of the rapids, is 18.31 feet.

Plans for improvement of the power.—The plan which was actively proposed several years ago by the citizens of Keokuk was to avail themselves of the advantages presented by the ship-canal on the west bank of the river. The rapid fall at the lower part of the rapids makes it practicable to get a good head of water. The west bank rises as a steep bluff, close to the river for the most part; and at its foot is the ship-canal, and also the line of the Chicago, Burlington and Quincy railroad. There were two proposals made in connection with this scheme—one was to tap the ship-canal by two hydraulic canals, one passing around the middle lock and the other around the lower lock; the other was to run a hydraulic canal from above the middle lock, on the land side of the ship-canal, all the way down to its lower end at Keokuk, there using the full head obtainable, averaging 16 feet. This scheme was reported on by Mr. D. C. Jenny, a civil engineer. There was much opposition to it, and a commission of United States engineers, appointed to consider the matter, decided against it, on the ground that it would interfere with navigation. The tendency would be to draw down the level in the upper level of the canal, increase the current, and, possibly, draw in sediment. It does not seem probable that water-power will ever be used from the ship-canal.

The following points concerning the proposed improvement are taken from Mr. Jenny's report: He states that, with the present condition of the structures for filling the canal at the upper end, there might be 700 theoretical horse-power developed, and by suitable improvements this could be increased to 2,000 horse-power without detriment to the canal or to its use for navigation. The two plans, viz., of a long hydraulic canal around both locks

a A full description of these locks, etc., by Mr. R. R. Jones, Major Stickney's assistant, will be found in the *American Engineer* of March, 1881.