PREFACE.

In the following account of some of the more interesting and prominent irrigation works in India I shall confine my detailed descriptions, as I did my observations, to the works which exist under conditions similar to those in the United States, and shall refer only briefly to the other though equally important features of the irrigation problem in India.

I examined only the principal canals, navigable and nonnavigable, and entirely neglected the deltaic and inundation canals, as there is little or no probability that such works will ever be constructed in the United States. Transportation by railways and wagon roads is so easy and general all over our country that there is little likelihood our canals will ever be made navigable; accordingly, though I saw and examined several navigable canals, little reference will be made to their features. The more important reservoirs and tanks were examined, especially those under construction. Little will be said of wells, though in the future improved methods of pumping will be used in the United States.

India stands preeminent for her gigantic engineering undertakings. No other country has so vast and so fertile an expanse of territory, with such convenient slopes for the construction of canals, and at the same time such an abundant water supply. In general there is great similarity between the climate and topography of the great northern plains of India and portions of our arid West, especially the eastern slope of the Rocky Mountains and the great California Valley. Central India and the Deccan have many features in common with the central portion of the arid region, particularly portions of northern Arizona and southern Utah. The climate is as similar to that of our Middle Western States as is the topography: The average annual precipitation rarely exceeds 30 inches, while the precipitation during the autumn, or rabi, crop varies between 2 and 6 inches.

This autumn crop is the one that will be generally considered and discussed in this report, since during the time of its maturity the climatic conditions are very similar to those existing everywhere in the arid regions of the United States. Two crops are annually grown in India, one of which is sown in early spring at the beginning of the monsoon or rainy season, and is called the summer or kharif crop.
Herbert M. Wilson, "Irrigation in India" (Washington: G.P.O., 1903.

This crop depends little on irrigation for its maturing, as the greater proportion of the rain of the entire year falls during the summer. In the autumn, however, the rainfall is very light, and, as before stated, the temperature and precipitation are both similar to those in the West.

Though the conditions of government and people are so different in India from those in America, many useful examples and lessons may be drawn from the method of administration and legislation practiced there, as well as from the financial success or failure that has attended the construction of their works. The conditions under which Americans must undertake irrigation enterprises are not so different from those existing in India and southern Europe as would at first appear. Any works we may construct must depend for their utilization and revenue on immigration, as they will be largely in a sparsely inhabited country. In order to induce this immigration people must be convinced of the benefits and utility of irrigation. Conditions similar to these exist in portions of India where the most successful irrigation projects have been carried out. Irrigation works have frequently been undertaken in portions of India that were already overpopulated. They have rendered the land more fertile and sufficiently productive to support nearly double the population which it was previously capable of sustaining. This, too, has been accomplished despite the prejudices to be overcome, and the difficulties encountered in inducing people to make use of the water furnished; difficulties far greater than we would have to contend with in inducing immigration to our arid West. A few of the great canals of the Northwest Provinces and the Punjab were undertaken in districts that were sparsely inhabited. These canals are among those of India that have paid the largest interest on the original outlay. Within ten years from their construction the country was fully populated, although the immigration was often from remote portions of India.

Any imperfections which may appear in this account of works examined and in operation are in no way due to lack of assistance from the engineers in authority. It is impossible to speak strongly enough of the hospitality and kindness with which I was everywhere treated. In fact, owing to the limited time at my disposal, the greatest difficulty experienced was to leave the hospitable guides and entertainers, who were apparently willing to spend days in showing and explaining the works they had in charge.

PREFACE TO SECOND EDITION.

This account of some of the more important irrigation works of India was first published in Part II of the Twelfth Annual Report of the Director of the United States Geological Survey, for 1890-91. The demands for this report were so great that the entire edition was exhausted within a few years. Recently, and largely as a result of the renewed activity in irrigation in the Western States through the creation by Congress of the Reclamation Service of the United States Geological Survey, there have been increased calls for this report. At the instance of Mr. F. H. Newell, chief engineer of the Reclamation Service, I have made a careful revision of this report from such available data as I have succeeded in accumulating during the intervening years. This edition is published as one of the series of Water-Supply and Irrigation Papers of the Geological Survey.

Comparatively few new works have been built in India since 1890. The Bhatgur and Tansa dams have been finished and are in successful operation with but slight modifications from the plans as previously published. The great Periyar project has been completed with slight modifications. These changes are noted in the accompanying text. In addition, the matter concerning inundation canals and that descriptive of deltaic canals have been extended. Under the latter head the Kistna project is described in more detail, as is the Sangeemantic project, both of which contain works which will interest American engineers. Under title of "Tanks" the Rushikulya project is described, both because of the interest attached to the dam and because it is a combined project including the diversion of water from a running stream and its storage in a reservoir located at a considerable distance from the canal head.

The most important feature of the revision is the bringing of all the financial and statistical data concerning the more important works in each province up to 1901, the date of the last official Indian reports. At the close of 1901 the area of India, including native States, was 1,325,000 square miles, the total population was 294,306,701, and the total expenditure upon all classes of irrigation works by the Government of India had been $337,850,000. In the year 1900-1901 the expenditures on account of irrigation amounted to $11,500,000, and the revenues to $12,075,000, showing a profit of 5.2 per cent on the capital outlay for construction. The total area cultivated in India the same
Herbert M. Wilson, "Irrigation in India" (Washington: G.P.O., 1903.

year was 180,151,000 acres, and the total area irrigated was 18,911,105 acres, or, counting areas double cropped or those irrigated more than once in a season, the area irrigated was 33,096,031 acres. The estimated value of the irrigated crops in 1900-1901 was $150,000,000, and of these it is interesting to note that the area under cultivation in wheat amounted to over 16 million acres, and in cotton to over 8 million acres, and that the total value of the latter crop alone was $52,573,000.

Construction, including in large measure repairs, was most active during the past few years, in order to afford employment in famine-stricken regions. The demands on the water stored in reservoirs in the southwet portions of India—those which had been afflicted with drought and consequent famine during the last few years—were greater than ever before. Some of the more notable tanks in Bombay and central India were called upon to do their highest duty, and in consequence many of those projects which were constructed as protective works and were never anticipated to be revenue-producing have recently earned moderate net revenues.

H. M. W.

Washington, D. C., December 22, 1903.
IRRIGATION IN INDIA.

By HERBERT M. WILSON.

INTRODUCTION.

The principal sources from which the information in the accompanying report was obtained were (1) conversations with engineers in charge of works and examination of their office material, (2) personal examination of the works themselves, and (3) books and official reports. In the following narrative I will endeavor to sketch hastily the route traveled and give a brief outline of works visited.

For a week before my departure I was busily engaged in reading all the books and reports on Indian irrigation procurable, in order to plan the trip so as to see the most in the least space of time, for I had but five months for the entire journey. I finally decided that the two months spent in India should be devoted to the northern and central portions, and the route was planned so as to see only such works as were within easy access of the railway lines.

Through the cooperation of the director of the United States Geological Survey I was enabled to leave Washington on December 1, 1889, well equipped with letters of introduction to the various secretaries of the public works departments of India, carrying also letters from the Secretary of State to our diplomatic and consular officers abroad. In New York letters of introduction to prominent English engineers were obtained from the secretary of the American Society of Civil Engineers and others, and on December 4 I sailed for Liverpool.

A few days were spent in London, where, through the courtesy of Mr. James Forrest, secretary of the Institution of Civil Engineers, a number of letters of introduction to Indian officials were obtained. From London I proceeded to Brindisi, Italy, and embarked December 30 for Bombay, arriving there on January 13, 1890.

In Bombay I called upon Mr. W. C. Hughes, secretary to government for the irrigation branch of the public works department, and he gave me letters to several of the engineers in the Bombay Presidency, and kindly aided me in so arranging my tour in that presidency as to see only such works as were most accessible. From Mr. W. Clerke, chief engineer of the Bombay waterworks, I also received much valuable assistance and advice, and on January 18 I proceeded
to Poona with the intention of visiting the Fife reservoir. In the absence of the chief engineer, Colonel Cruikshank, R.E., Mr. Rebsch, executive engineer of the Mutha canals, devoted two or three days to showing me over the works under his charge.

We drove from Poona to Lake Fife, a distance of 12 miles up the valley of the Mutha River. The road here, as everywhere in India, was excellent, being well macadamized for the entire distance. On both sides were well-cultivated fields, the principal crops grown being sugar cane, millet, and wheat, and the care with which the water was applied to these crops was the first object which attracted attention. I also observed that Indian peasants fully appreciated the value of fertilizers. The city officials of Poona make a handsome profit annually by removing excrement from the residences and mixing it with ordinary soil, the whole being sold by the cartload to farmers.

Lake Fife is a large artificial reservoir, formed by a dam three-quarters of a mile long and nearly 100 feet in height. The water is backed up the valley for nearly 15 miles, and the available storage capacity of the lake is about 65,000 acre-feet. The Mutha canals are taken from the dam at the lower end of the lake, one along the right and the other on the left bank of the Mutha River. The right-bank canal is nearly 100 miles long and passes through the city of Poona, which it supplies with water; it is also used in irrigating the rich land lying between it and the river. The left-bank canal is much shorter, and also controls a large area of valuable land.

The topography of the Upper Mutha Valley seemed very familiar. Had I been suddenly transported in my sleep to northeastern Arizona the similarity of the topography of the two regions could not have more strikingly impressed me. At Lake Fife the Mutha River makes its exit through a narrow canyon similar to those of the mesa country in northern New Mexico and Arizona, and flows thence through a broad and gently sloping valley, which gradually widens till it becomes an extensive plain. The slope from the bottom of the stream toward the surrounding hills is regular, but rather steep, and suddenly terminates at the foot of cliffs which are similar in their abruptness and sharpness of outline to the mesa cliffs of our Southwest. The soil in the Mutha Valley is rather shallow, and wherever uncultivated is covered with a low, scrubby grass, dried and parched by the sun. At the canal edge the barren slopes are suddenly merged into endless green and well-cultivated fields. The slopes of the hills are rocky and barren, covered with a growth of low trees, among which babul or mesquite is the most prominent.

After examining Lake Fife, Mr. Rebsch and myself proceeded down the line of the Mutha canal and followed some of the minor distributaries through the fields, watching their ramifications, until we reached the smallest private ditch used in irrigating the crops. The construction of these canals is similar to that of small canals in the United States. The chief feature noticed was the substantial method of constructing all bridges, head-gates, and other regulators. Here, as elsewhere in India, timber is seldom used, owing to its cost and the rapidity with which it is destroyed by insects and rot. All bridges on this canal are constructed of masonry, and the smallest regulating gates consist of masonry passages let into the banks of the canal and closed with iron shutters. The system of distribution of the water is very complete every square foot of desirable land being under cultivation.

On January 21 I engaged a tonga, a sort of dogcart, drawn by a team of ponies, in which a three days' trip to Bhatgur reservoir and the Nira canals was made. The trip to Bhatgur was made in the night in order to avoid the heat. The road is macadamized the entire distance, and is lined on each side with a double row of trees, which furnish a dense and agreeable shade. The gradients are sufficiently easy for a railway, while all drainage passages, large or small, are crossed by masonry bridges. In order to avoid excessive grades a range of low hills about halfway in the journey is pierced by a tunnel nearly one-fourth of a mile long. This tunnel is about 20 by 30 feet in cross section, and is lined with masonry throughout.

At Bhatgur I was met by Mr. H. Beale, assistant engineer in charge of construction of the dam. During the day we went over the entire length of the dam and viewed all the works of construction. It was my good fortune to see the Bhatgur dam when it was about two-thirds completed and while the construction was being vigorously pushed. I was thus enabled to examine with care the details not only of the method of masonry construction, but also the management and character of the labor employed.

The topography above the Bhatgur dam is very similar to that at Lake Fife. The dam is constructed on a modern cross section, similar to that obtained by the Bouvier or the Rankine formula. It is located in a rather wide part of the river; the object being to afford sufficient spillway for the large volume of water which comes down the river in the spring floods. Its length is 4,067 feet and its greatest height is 130 feet above the foundations. The river at this point is subject to maximum floods of 50,000 second-feet. This reservoir is used as a storage basin to supply the Nira canals, which are taken from the Nira River at Vir, a point 20 miles below the dam. During my visit to Bhatgur 1,500 laborers were employed on the work and completed about 5,000 cubic feet of rubble and concrete masonry per day and 1,000 cubic feet of finished dressed-rubble facing. Stone for the construction of the dam was quarried close to the abutments, and kunkar, a dirty stone which produces a very good hydraulic cement, was found within a short distance of the dam site. Sand was procured from the river bed and charcoal for burning was obtained in the adjacent hills.

On the morning of the 22d I left Bhatgur, proceeding by tonga to Vir, the head of the Nira canal, where I was met by Mr. W. H. Le Quesne,
executive engineer in charge of the Nira system. The first two days were spent in looking over the reports and detailed maps in the office, in examining the great diversion weir at the head of the Nira canal, and inspecting the first 12 miles of the latter. The Vir weir is constructed throughout of concrete, faced with dressed-rubble masonry, and is 2,340 feet in length and 40 feet in greatest height above the river bed. A few hundred yards downstream is a subsidiary weir, similar in construction to the first, but only 615 feet long and 30 feet in height. This lower weir backs the water up against the toe of the upper one, thus producing a water cushion, on which the great floods fall harmlessly. The maximum flood over this weir may be 100,000 second-feet, when the water will be about 8 feet in depth on the crest of the main weir. Our trip down the canal was made in a rowboat, and we were thus enabled to examine several aqueducts and a siphon on the way. The first 10 miles of the canal are for diversion line only, being required in making grade to get the canal out of the confining banks of the Nira River. At about the tenth mile the first distributor is taken off to the irrigable lands.

On January 23 I left Vir for Lonand, where I took the train for Poona. This trip is one of the most interesting in India, the road passing through the celebrated Bhore Ghauts, a range of rugged, bluffy hills which break down precipitately to the western ocean. The summit of these Ghauts forms the edge and top of the great interior plateau of the Deccan. The scenery along the entire descent is similar in every respect to that east of the line of the Southern Pacific Railroad near Red Bluff. The road runs with heavy grades and sharp curves along the edges of nearly vertical trap cliffs, in a place that in almost any other country would be considered quite impracticable for railway construction. The expense of such a line in the United States would exceed $100,000 per mile. Owing to the very heavy rainfall, which averages 250 inches per annum, the greatest precautions have been taken for the passage of all drainage lines. Numerous viaducts are crossed in rapid succession, the frequency of their recurrence being rivalled only by that of the many tunnels, there being 33 of these in a few miles.

I had been very desirous of making a visit to the celebrated Tansa reservoir, near Bombay, in the company of Mr. Clerke, the chief engineer, and on arriving in Bombay, on the 24th, I found he had arranged a trip with the governor of Bombay, Lord Reay, a few of the municipal officers, the governor's staff, Mr. Baldwin Latham, and myself. We left by special train on the evening of the 24th, arriving at Atgoan on the following morning. From Atgoan we had a pleasant tonga trip of 7 miles to the site of the Tansa dam. Here I was as fortunate as at Dhatgur. I found the great dam more than half completed and construction being vigorously pushed. Two days were spent in inspecting the works, which consist mainly of an enormous rubble-

masonry dam 9,350 feet in length. When completed it will be 145 feet in maximum height. This dam is intended to furnish water for the city of Bombay. The rock for its construction is quarried at the dam site, but kuukar, for the production of cement, has to be brought long distances by rail or road cart. The aqueduct line, which carries the water to the city of Bombay, is partly in tunnel, partly in masonry conduit, partly in iron pipes. It has seven inverted siphons crossing drainage valleys, the greatest being 114 miles in length.

On January 28 I left Bombay for Calcutta, a distance of about 1,200 miles. This trip was full of interest. During the early part of the first day the Thule Ghauts were ascended, the difficulties of construction being quite equal to those on the line between Poona and Bombay. Railway travel in India, while inferior in comforts to the United States, is still decidedly superior to European modes of making lengthy trips. The cars, like those on European railways, are short, and on only a few are boggie trucks used. These latter, however, are rapidly finding favor, and at no distant day will be universally employed on the Indian railways. Each compartment, of which there are two in every first and second class carriage, will hold from five to six persons. The seats are placed lengthwise of the train and are well cushioned. There is a hanging seat or bed suspended from the roof, similar to those seen in an American immigrant car. This can be lowered at night and used as a berth. Each passenger must carry his own bedding, which in that warm climate consists of nothing more than a blanket and a pillow, and spreading these on the seats or hanging beds he can pass a comfortable night on the road. In the center of the car, between the two compartments, is a small closet and toilet room. A table may be set up in the center of each compartment on which to spread lunches. Men and women are never permitted to travel in the same compartment. Good meal stations are placed at convenient intervals on all lines of railway, and ample time is given for eating.

The main portion of central India lying between Bombay and the Ganges Plain is rather sparsely inhabited. The region is elevated and consists of uneven, rolling country, similar to that along the southern New Jersey coast or in the wooded districts of Missouri and Indiana. A dense growth of jungle, consisting of low trees, mesquite, teak, etc., with an undergrowth of tall, stiff jungle grass from 5 to 10 feet in height, covers the entire country. The streams draining this area, during the dry season, but little rills, flowing through very broad, wide, sandy beds, that serve to indicate the enormous size these rivers attain during the flood season. There is little irrigation practiced in this region. In some sections moderate areas are irrigated from tanks of various sizes. The sloping hillsides are terraced, like those of Japan and China, by the construction of embankments. These produce level benches, where the flood water is held back sufficiently
I was met by Mr. Inglis, the executive engineer of the Arrah canal, who showed me the heads of some of the distributaries, the escapes, and also the mode of applying the water to the fields. I reached Dehree at 8 o'clock on the following morning. During the absence of the executive engineer in charge of the head works at Dehree, I was met by Mr. Williamson, the overseer of the shops at that point, who spent the day explaining the various works. These are of the most interesting and important nature, and consist of the great weir across the Soane River, 22 miles long and 14 feet in height, of the scouring sluices and regulators at the heads of the canals at each end, and of the general machine shops for the construction and repair of engines, dredges, and other metal works used on the canal system. The Soane River was then very low, seaward discharging more water than was required to fill the main eastern and western canals. Thanks to this fact, I was enabled to watch the operations of the automatic sluice gates, which were lowered and raised for my inspection.

From Dehree I proceeded again by steamer down the Buxar branch of the main western canal, passing through immense fields of grains and vegetables, where but a few years before had been but a desert waste. One work of particular note passed was the Kao Nulla siphon aqueduct, whereby the canal is carried over the bed of the Kao Towrent and the latter in a semisiphon is passed under the aqueduct. A little farther on was a similar work by which the canal is carried in an aqueduct over the Thora Nulla. In the evening I arrived at the town of Buxar, where I met Mr. Horn, the executive engineer of the Buxar branch, and left the same night for Allahabad.

During the trip along the Soane canals many interesting scenes were noticed. Numerous canal boats loaded with grain or stone were passed. These were being taken to the railway or floated out on the Ganges River, whence they made the trip to Calcutta. The boats are peculiarly shaped, being higher at the stern than at the bow, varying from 15 to 25 feet in length, and having a width of about 10 feet. In the center is erected a pole, perhaps 12 feet in height, to which are attached numerous light strings, and each of these is drawn by a native on the towpath. On these canals it is not unusual to see ten or more men towing one boat.

The important roads cross the canal by means of well-constructed masonry or iron bridges. A peculiar accident has occurred to many of the masonry bridges, as the pressure of the earth embankments behind the abutments causes them to act as retaining walls. The pressure has in several cases caused the arches to spring upward at the center or key, leaving a slight crack on top. These bridges have been constructed strong enough to perform their duties as bridges, but are not sufficiently strong to act as retaining walls.

The smaller roads and footpaths terminate at the canal banks, where catamaran-shaped ferryboats are used to cross the canal. These
boats are unique in construction. Each pontoon is composed of riveted sheet iron and is 2 feet wide by 2 feet deep and 15 feet in length. Between the two is supported a wooden deck 6 feet wide, sufficiently large to carry the ordinary two-wheeled bullock cart with its team. A chain is laid from one bank of the canal to the other, long enough to rest on the bottom of the canal, so as not to impede traffic, and passing through a ring on the deck of the ferryboat. By pulling on this chain the occupants are enabled to draw the boat across the canal.

The canal banks are lined throughout with plantations of trees, the property of the canal government. These are cut and sold as may seem desirable to the canal officers, all trees thus removed being replaced by young growths. Among the more usual trees are the sissoo, somewhat like the teak in general character, and used in the construction of furniture, carts, etc., the sal, also used for furniture and fuel, some mangoes, and some mesquite.

Owing to the low velocity, about 3 feet per second, which is necessary to give the navigable branches, considerable deposits of silt accumulate near their heads, and lower down, where the water is clearer, reeds and rushes line the banks well out toward the middle of the stream. Large steam dredges are kept at work on the upper lines of the Soane canals, giving them much the appearance of the Suez Canal. These dredges have mostly been constructed at the shops at Delhi, and are of iron throughout, as are also the scows. Large steam passenger boats ply on the main canals, stopping at the various villages lining their banks and terminating their runs at the railway. These boats are crowded with people, which indicates a profitable passenger traffic.

Among the most interesting scenes observed were the enormous crowds of pilgrims, afoot, on camels, or on bullocks. These pilgrims make journeys between distant shrines, often occupying six months in the longer trips. Each devotee carries a pole across his back, from the ends of which are swung the few necessaries of food and clothing.

The locks along the canal are substantially constructed of brick masonry, sometimes singly and sometimes in pairs, and average in their lift from 7 to 12 feet. These locks are sufficiently long and wide to accommodate the big passenger steamers. Beside and around the locks is always constructed a waste weir and channel through which the greater part of the discharge of the canal used in irrigation and not required in operating the lock is passed. In this channel is necessarily a high fall with a drop equal to that of the lock. This fall is built of the most substantial masonry in order to withstand the jar caused by the great body of water passing over it.

On February 5 I arrived at Allahabad, the capital of the Northwest Provinces and Oudh, where, during the absence of the chief engineer and secretary for government, Col. G. T. Skipworth, R. E., I was very courteously treated by Mr. H. W. Conduit, the office assistant. He gave me some official reports and letters to engineers in the northwest and arranged for a visit to the Betwa, Ganges, and other canals by writing to the executive engineers in charge, informing them of my approaching visit and requesting them to render such assistance as might be required. On the same day I proceeded to Orai, where I was met by Mr. W. P. Vonder Horst, the executive engineer of the Betwa canal. The 6th was spent in examining the office records and maps and making such notes and tracings as were deemed necessary. On the same evening we left by rail for Chirgaon, whence a short tunga ride took us to Paricha, the head of the Betwa canal and the great Betwa reservoir.

The Betwa reservoir is constructed in the channel of the Betwa River where it emerges from the Northern Ghants. The weir is located in a rather wide part of the river bed, crossing the stream in an irregular line, abutting in one place on a large island and on another on a broad rock in the middle of the river. The total length of this weir, including the islands on which it abuts, is about 4,300 feet, and its greatest height in the middle of the channel is 60 feet. The entire dam acts as an overflow weir, in order to give sufficient wasteway to the enormous flood of 750,000 second-feet which may pass over it. Such a flood would bank 17 feet deep over the crest of the weir. In order to withstand the shock of this body of falling water two small subsidiary weirs have been constructed in the channel below the deepest portions of the weir, thus giving a water cushion on which the maximum height of the overfall is 21 1/2 feet. The net storage capacity of this reservoir available for irrigation purposes is nearly 37,000 acre-feet.

The canal system heading immediately above the dam controls an area of about 380,000 acres, of which about 400,000 is excellent arable land. The balance is very poor and barren. This area of irrigable land is included between the Betwa, Pahug, and Jumna rivers, and at present about 135,000 acres are irrigated by the canal system. The flushing sluices on the end of the weir adjacent to the canal head and the regulators at the canal head are of great interest, owing to the pressure of nearly 60 feet under which the gates are operated.

From Paricha I proceeded by rail to Agra, and on February 9 went to Narora, where are located the head works of the Lower Ganges canal. In order to reach Narora it was necessary to go by rail to Aliagarh, where a couple of hours were agreeably spent. From Aliagarh I went by rail to Raighat, which station was reached late in the evening. There, thanks to the thoughtfulness of Mr. F. A. Carswell, the executive engineer in charge of the Narora works, I was met by a hand car or trolley, in which I was pushed by natives 8 miles to the bungalow at Narora, where the following night and day were spent. I was received by Mr. Carswell with the same hospitality that had been accorded me by all the other officials with whom I had come in con-
fact. The larger part of that evening and the next day were spent in examining the office reports and maps and examining the head-works and the river training system of the Lower Ganges canal. These head-works consist of a great weir 4,135 feet in total length, 3,700 feet of which are composed of an overfall weir 14 feet in height above the foundation, 315 feet consisting of sluice gates adjacent to the head of the canal. The head of the canal adjacent to the end of the weir consisted of 26 regulating gates, each 71 by 114 feet in the clear. The maximum flood coming down the Ganges which may pass over this weir may be as great as 230,000 second-feet.

The river training works are interesting and extensive. They are necessitated by the low character of the river bottom, in which the canal is constructed for some miles before its diversion line gets out of the bottom and reaches the summit of the bluff. Where these bottom lands are traversed the river is apt to change its channel, and if not controlled would cut its banks, thus destroying the canal. The regulating works are carried for 4 miles above the head of the canal and 15 miles below it, and consist of long earthen embankments or groynes, which jut straight out into the river channel at right angles to its course and are protected on their ends by rock paving and rock noses.

Sixteen miles below the Narora weir the Lower Ganges canal crosses the great Kali Nadi Torrent, which in time of floods becomes an enormous river. The canal is carried across this torrent on an aqueduct which provides water way for a flood of 130,000 second-feet. The channel of the canal on the top of the aqueduct is 130 feet wide and 7 feet deep. Previous to 1885 there was in this place a short aqueduct calculated to pass a flood of 90,000 second-feet; but in that year it was destroyed by an unprecedented flood of nearly 130,000 second-feet, and has since been entirely remodeled and reconstructed.

On February 15 I left Narora for Lahore, the capital of the province of Punjab. In the absence of Col. F. J. Home, R. E., the Chief Engineer for Irrigation in the Punjab, I presented my letters of introduction to Mr. Cockburn, the officer assistant, who had been instructed by Colonel Home, in anticipation of my arrival, to furnish what aid he could. In the Punjab I was less fortunate than elsewhere. The works of that region are among the greatest and most interesting in India. I reached there in the midst of the busiest part of the field season. Most of the engineers were far out of reach of railways or other convenient modes of travel, in charge of the construction of works, and as time was limited it was impossible to go far out of the way to visit them. Accordingly, I decided not to visit the works of the Western Jumna nor the Burig Doab canals, but to devote the remaining time to a thorough inspection of the Sirhind canals, which are the most modern and perhaps the most interesting of any of the canals of India.

I at once proceeded to Amristar in hope of meeting Major Ottley, R. E., the supervising engineer, from whom I expected information and assistance in the trip. Here, again, I was disappointed, and found no one who could give assistance or advice as to how to visit them best. Accordingly I decided to go to Ludhiana, the nearest railway point to the canal. I reached there on February 14 and called on Mr. J. Dempster, executive engineer in charge of the Sirhind canals. I did not receive much encouragement from Mr. Dempster, as he said that owing to not having been previously advised of the trip and the shortness of the time it would be nearly impossible to arrange conveniently to show me the canals. From Ludhiana to Rumur, where the head-works of the canal are, is a distance of about 60 miles, and to make this trip it would be necessary to engage an elephant and to procure the necessary traveling outfit. As I did not know where to find these, and Mr. Dempster was apparently too busy to aid in the search, I reluctantly abandoned the journey, and on the same day left by train to visit the Ganges canal.

Next morning, February 15, I reached Roorkoo, where I found that Mr. M. King, executive engineer, had made elaborate preparations for the trip over the line of the canal. I also found Col. G. T. Skipworth, R. E., chief engineer of the North West Provinces and secretary to government, and Mr. W. J. Wilson, his assistant secretary. They had made preparations for the annual inspection of the lines of the canal, but as it would not be prepared to set out on their trip for a few days, Mr. King had arranged to take me to the head-works and return to Roorkoo in time to accompany the inspecting party. A portion of the 15th was spent in examining the office records and maps, and early on the following morning Mr. King and I set out on a tonga drive along the banks of the canal bound for Hardwar, where are situated the head-works. Owing to the heat, though the distance was but 20 miles, two relays of horses had been sent out to hasten the journey. Two heavy bullock carts laden with camp equipage, etc., and an elephant which would be required in making journeys away from beaten roads, had also been previously forwarded to Hardwar. In the course of the drive along the canal banks we had an excellent opportunity for investigating the level crossing of the Ramsoo Torrent at Bhurawer. We also examined the great aqueduct by which the Ganges canal is carried across the Solani Valley and the superpassages which conduct the waters of the Puthri and Ramipur torrents over the Ganges canal. These works were also examined on the return trip to Roorkoo, when I was enabled to observe other points of interest that had escaped notice on the first inspection.

We spent the night at Hardwar and on the following day set out on the elephant to examine the various river training and regulating works, whereby the greater part of the water of the Ganges River is guided into the Hardwar channel, from which it is diverted into the canal. These training and regulating works extend for a distance of
several miles above Hardwar and are unique from the fact that the supply of water being at all times abundant for the demands of the canal, no permanent dam has been thrown across the river. The bed of the river is here broken up into several channels and is very wide, but by means of a row of three temporary dams constructed of bowlders the majority of the water is turned into the Hardwar channel. These temporary dams, it has been found, can be more cheaply reconstructed annually after their destruction by the regular floods, than a great permanent weir could be built across the entire channel. Above the temporary bowlder dams a permanent masonry wall has been constructed on one minor channel besides a series of permanent bowlder embankments and bars, the latter to prevent the retrogression of grades. Groins and other training works so confine the main body of water to the Hardwar channel that during times of greatest flood, when all of these works are submerged, little or no damage is done to the permanency of this channel. At Myapur, the head of the Ganges canal, below the training works, a permanent weir with the usual scouring sluices has been thrown across the Hardwar channel, thus training the water into the regulator at the head of the canal.

On the following morning we continued our inspection of the head-works and in the afternoon returned to Roorkee. The 18th was spent at Roorkee in a visit to the Thomason College of Civil Engineering, where Colonel Brandreth, the president, kindly showed me over the building and furnished numerous valuable reports and other information.

On February 20 I reached Okhla, near Delhi, at which place are situated the head-works of the Agra canal. Here, thanks to the kindness of Colonel Crofton, superintending engineer, who had written from Roorkee of the intended visit, I was met by Mr. C. G. Palmer, the executive engineer of the Agra canal, with whom I visited the works under his charge. The head-works of this canal consist of a low weir 10 feet in height and 2,573 feet in length from the right bank, the left wing resting on an island in the middle of the river. Wings and heavy earth embankments, 20 feet wide on top, are carried across the island and the east channel and thence up the left bank to the railway bridge at Delhi.

This canal receives its water supply from the Jumna River, which, however, does not at all times carry sufficient water to fill it. Its supply is accordingly augmented by means of a cut from the Hindum River, which empties the water of that stream into the Jumna above the diversion weir. In the weir there is the usual set of scouring sluices at the end adjacent to the canal head and the customary regulating gates and lock for navigation purposes at the canal entrance. Like the Ganges River at Narora, the Jumna here requires the construction of great river training works similar in their general character to those on the Lower Ganges, but in order to throw the greater
portions of the water toward the right bank of the river, where the
canal head is, alligator groins have been run at right angles to the
line of the weir, by means of which the water is trained in the desired
direction.

After examining the office records and maps at Okhla, Mr. Palmer
and I made a trip by tonga down the line of the canal to examine some
of the works of interest. We passed several inlets by which the drain-
age of small streams heading in the hills to the south is admitted to
the canal. The water enters by stone culverts, and the core of the
canal embankment at these places is usually constructed of rubble
masonry. These inlets are generally controlled from a gate tower.
Near the Ali Torrent the canal banks are protected on the upper side
by a long earthen dam, forming a storage reservoir which catches the
drainage of several small streams from the hills and passes this through
an outlet or spillway into a superpassage of sheet iron carried over the
 canal. The water retained in the reservoir is allowed to settle, and
when clear of silt is admitted into the canal, but in time of floods the
superabundant discharge is carried over the spillway previously men-
tioned and discharged into the Jumna. Many hundreds of small tanks
have been constructed all through this region, and one very large one
is now under construction on the Surwa River about 15 miles above
Baroda.

Among the most interesting sights from a scientific point of view to
be seen in India are the ancient astronomical observatories erected by
the old Arab astronomers at Delhi and Jeypur. At the latter place I
had an opportunity to examine carefully the observatory of the Shah
Jehan, which covers a couple of acres of ground and is surrounded by
a high stone wall. Within this enclosure are constructed many unique
masonry instruments with which were conducted the observations of
the ancient astronomer.

On March 8 I reached Bombay, and a few days afterwards left for
home.

At Aden I stopped a day, thus giving sufficient time to examine
the strange old reservoirs (Pl. II), constructed in a gully above that
town, which supply it with water. It is only once in several years
that a sufficient rainfall occurs in this arid region to fill the tanks.
There are several of them, one above the other far up the gully, and
it was my good fortune to be there a few days after the occurrence of
the first storm that had filled them in three years. They are most
carefully constructed, lined throughout with hydraulic cement, thus
preventing any leakage through their rock bottoms, and are closed
by substantial dams with wasteways and masonry conduits leading
from one to the other, so that the least possible amount of water will
be lost by absorption. The total storage capacity of these tanks is
about 12,000,000 gallons.

From Aden I proceeded direct to Suez, where I took the train for
Cairo, arriving there on March 18. Here I called upon the American consul-general, Mr. Eugene Schuyler, who informed me how best to see the irrigation works in the immediate vicinity. By him I was introduced to Col. Sir Scott Moncrieff, the minister of public works for the government of Egypt, from whom valuable information and numerous reports relative to the irrigation works of that country were obtained. The next day the Barrage du Nil was visited, it being readily reached by a railway trip from Cairo occupying about an hour. Two other trips to the Barrage were made, during which ample opportunity was had to examine the works. Construction was being rapidly pushed, and there were probably 6,000 workmen employed on them.

A few days later I proceeded to Brindisi, Italy, thence to Rome, where I arrived March 30. In Rome, thanks to the kindness of the American minister, the Hon. A. G. Porter, I called upon the minister of finance, under whose direction are the irrigation works of Italy. From him I received a letter to Signor Carlo Sospizio, the director of the Cavour canal at Turin, and on the following day I reached Turin. Signor Sospizio was very courteous, and arranged to have one of his subengineers meet me the following day at Chivasso, where the head-works of the Cavour canal are, and show me over them.

On April 2 I was met at Chivasso by Signor Canavozze Oreste, an assistant engineer. With him the following two days were spent in an inspection of the line of the Cavour canal as far as the inverted siphon crossing the River Sesia. The trip was made from Chivasso in a carriage along the canal banks as far as the aqueduct crossing the River Doru Ballea, below Saluggia. From this point the carriage was sent around the road to Saluggia and we examined the canal and aqueduct on foot, rejoining the carriage at Saluggia.

The weir across the River Po at the head of the Cavour canal is a temporary one, constructed of brush and rocks, and is not over 5 feet in height. This weir has to be annually repaired, but this is less expensive than the construction of a permanent one would be. When the River Po is low, and does not discharge sufficient water for the wants of the canal, additional water is supplied by the subsidiary Canal Farini, while the Canal Rotto adds some of the water of the Doru Ballea to it.

Above Saluggia, near Ciglione, is an interesting arrangement for lifting the water from a low- to a high-level canal. This consists of four levels of canals. Between the two lower ones is placed an extensive pumping plant, operated by turbines which receive their water from the upper of the two lower canals and fall into the lower canal, whence the water is distributed to low-lying fields. The lower of the two upper canals supplies water by means of an immense wrought-iron pipe, 3 feet in diameter, with a head of about 66 feet, to the pumps below, and these force it, through another pipe of the same dimensions, a total height of 140 feet, to the high-level canal, whence it is distributed to the upper fields.

From Saluggia we proceeded by rail to Santhia, near where the Canal Cigliano passes over the Ivrea canal and at the same time supplies it with water. The night was spent in Vercelli, and in the morning we proceeded to Greggio, where the Cavour canal passes under the River Sesia in a great siphon nearly 600 feet in length, which carries the entire capacity of the canal. This system consists of four channels or conduits constructed of masonry, oval in shape, the inside diameters of which are 9 by 15 feet.

On the following day I proceeded to Milan, thence over the celebrated St. Gotthard route through Switzerland to Paris, where I arrived on April 6. In Paris, through the courtesy of the minister of public works, I received a letter to M. Caméré, engineer in chief of bridges and roads, located at Vernon, with whom I examined the various barrages which regulate the navigation of the Seine. At Paris the examination of irrigation works came to an end, and I proceeded thence direct to the United States.

LIST OF WORKS ON INDIAN IRRIGATION.

In the following list are arranged alphabetically by authors the titles of works which were referred to in the preparation of this report. This list does not pretend to be a complete list of works and pamphlets published on Indian irrigation:


—Movable Dams in Indian Weirs. Proceedings Institution Civil Engineers, 1889.

IRRIGATION IN INDIA. 

[Herbert M. Wilson, "Irrigation in India" (Washington: G.P.O., 1903.)]
VALUE AND NECESSITY OF IRRIGATION.

In view of the interest in the subject of irrigation which has been recently developed in this country, it will be well to observe what benefits have been derived financially and otherwise from the irrigation works that have been in active operation in India during the last century, and also to note what Indian and English statesmen and engineers have to say on the subject of the extension of irrigation in India. Because of the similarities of the countries, climates, and the conditions under which irrigation works are operated in America and India, some useful lessons may be drawn from these comparisons. It has already been shown that the conditions of the utilization of the waters of irrigation works are quite similar in the two countries, and that the autumn crop in India is cultivated under circumstances almost identical with those under which our ordinary summer crops are grown in the arid regions.

The Indian financier divides the irrigation works into two great classes, called major and minor works. Major works are generally those of more importance from an engineering point of view, and have been in some cases almost entirely constructed by the British Government, while the minor works are of smaller pretensions and in many cases modifications or improvements of existing ancient irrigation systems. The portion of the major works that are constructed from capital provided from the general revenues of India are styled “protective works.” “Productive works” are usually constructed from capital which has been borrowed, and it is expected that a sufficient profit will be realized from their operation to pay interest on the borrowed money. Many minor works are also productive works. In general, protective works are constructed as a protection against famines, and they act in the amelioration of these in two ways. First, they are constructed during famine times to give employment to the people and furnish them money and food for their sustenance, and second, after their construction they are expected to furnish sufficient water for irrigation purposes to render them a protection against future droughts and the resulting famines. The majority of these famine protective works consist of storage reservoirs constructed in the more arid portions of India.
The reason for the success of the greater productive works in northern India is twofold. First, these works are constructed in a country similar to that of the western United States, so barren and devoid of water that nobody could live there or produce crops of any sort until canals had been dug and water provided for irrigation. Accordingly, all those who immigrated to the neighborhood of these canals were at once compelled to use and pay for the water, otherwise they would have been unable to raise crops. It is owing to the fact that those works have been able to do their full duty and the total amount of water furnished by them has been in constant demand that they have earned interest. On the contrary, the protective works, which have usually proved financial failures, have been built in regions where in ordinary years the precipitation has been sufficient to produce good crops, but where during occasional years the crops suffer from lack of water, and it is then only that the irrigation works are called upon. Such works being only utilized occasionally, produce only moderate returns during occasional years. Were these works constructed in a less inhabited region and in one lacking sufficient precipitation to raise crops, they would doubtless then do constant duty, and it might reasonably be expected that they would become productive works. In some few cases, such as those of the Sidhmai canal in the Punjab, the Betwa canal, and reservoir in the Northwest provinces, works originally constructed as protective works have received such a constant demand for their waters that they are now productive, returning a moderate interest on the capital.

Anywhere in our arid West where irrigation works may be constructed it is reasonable to suppose, judging from analogy, that when a sufficient population settles below them, these works will be called upon to furnish all the water they can provide, and if properly and carefully planned and estimated for should return fair interest on the original outlay. Only semi-arid regions, such as western Kansas, the Dakotas, Nebraska, and Oklahoma, have been subjected to famines. These occur every few years, and are the results of the country having been settled during periods of fair rainfall. Following these good years came a season or two of minimum rainfall when the crops were parched. It is only because of the increased transportation facilities in our West and the extensive charities undertaken by the Government and people that settlers in that portion of our country have been saved from famine. It is in such regions as those in India that the Government has devoted the most time, attention, and money for the construction of irrigation works as a means of protection against such losses, and convincing arguments have been brought to prove that money expended in such protective works is saved to the Government.

The high price paid for labor as compared with that in India is the argument generally used to prove that similar profitable returns from irrigation enterprises in this country cannot necessarily be expected. But the cost of construction here would be proportionately so much greater as to demand a higher return from the use of water in order to pay a corresponding rate of interest. It is not improbable that with the increased amount of work done by an American laborer as compared with that of a Hindoo coolie, and with the aid of many mechanical devices, the discrepancy in cost is not so great. Moreover, returns derived from irrigation works in the two countries are more nearly equalized from the fact that we can impose a higher tax for the use of water than it is possible to demand of the poor farmers in India, where from 2 to 5 acres support a large family. The apparent low cost of Indian labor is at first glance against this argument. Men, women, and children are engaged alike in the construction of all works. As common laborers women and children receive about 4 cents per day, and men from 8 to 10 cents. Skilled masons and machinists receive from 18 to 22 cents per day, and carpenters and blacksmiths nearly the same.

In the interior towns of the Bombay Presidency contract prices are about as follows: At the Bhatgur dam uncoarsed rubble masonry costs $1.75 per cubic yard, while at the Tansa dam it costs $2.50 per yard. In the Northwest Provinces earth excavations in deep canal cuts cost 6½ cents per cubic yard, while surface excavation costs 2½ cents. In the Punjab, according to the revenue reports, water in the canals yields a return of from 70 cents to $1.25 per second-foot, while the water rate charged per acre irrigated was from 70 cents to $1.15. In Bombay, according to the revenue report of 1889, the water rate derived was $1.15 per acre irrigated, and ranged from 35 cents to $1, the latter figure being abnormal and paid for the irrigation of sugar-cane crops, which require an enormous amount of water in their cultivation. Against these prices we are able to obtain in the central arid regions of America a revenue of from $1.50 to $3 per acre, which is equivalent for a duty of 50 acres per second-foot to from $120 to $240 per second-foot utilized. In California and other portions of the country where water is scarce and the crops valuable the rate is usually many times higher than the above.

In the province of Sind in the Indus Valley, including the southern Punjab, there is an enormous and thirsty waste of sandy desert where the annual precipitation is always below 10 inches, even falling as low as 3 or 4 inches. There nothing can be grown without the aid of irrigation, and the entire area under cultivation and the population supported thereby are entirely dependent on irrigation. The works in that region are chiefly inundation canals with a few perennial canals mostly taken from the Indus River. In the Sind alone over 3,000,000 acres are under cultivation, and yield an annual revenue of about $3,700,000.

In Bombay and the Northwest Provinces nearly double the population is now sustained that was supported previously to the introduction of modern irrigation works. According to Col. Baird Smith, the whole
HERBERT M. WILSON, "IRRIGATION IN INDIA" (Washington: G.P.O., 1903.

32 IRRIGATION IN INDIA. [NO. 57.

Continuing its full revenue, the great Ganges canal was fourteen years in operation before it paid 4 per cent on its simple capital, and Colonel Crofton, the late inspector-general of irrigation in India, appears to think that ten years is by no means an unreasonable time to elapse after an irrigation work has been put in operation before it can pay interest on its cost. Gen. R. Strachey in 1865 gave it as his opinion that it was not likely that even 5 per cent would be realized in ten years on the capital stock on any but the smallest irrigation works, while Col. Baird Smith took it for granted, in reporting on the proposed Sirun canal, that the works would not be self-supporting for sixteen years after they had been opened for irrigation.

The following quotations are from the reports of the select committee appointed in 1888 by the British Government to report on measures of protection from and prevention of famine. This report bears great weight, owing to the high character of the members of the commission, both as engineers and men of experience in the construction and management of irrigation works and as statesmen of broad views, whose integrity can not be doubted. This commission consisted of Gen. Richard Strachey, James Caird, H. S. Cunningham, H. E. Sullivan, and J. P. Peile. Their remarks relative to the value of irrigation works were as follows:

It is not only in years of drought and as a protection against famine that irrigation works are of value. In seasons of average rainfall they are of great service and a source of great wealth, giving certainty to all agricultural operations, increasing the output per acre of the crops, and enabling more valuable descriptions of crops to be grown. The following instances may be quoted from the mass of evidence before the commission: The outlay on completed canals in the Punjab up to the close of 1877-78 had been $11,300,000. The total area irrigated by them was 1,324,000 acres. The value of food grains raised on two works, the Western Jumna and the Hari Doab canals, was $14,400,000. It may, without exaggeration, be reckoned that one-half of these crops would have perished if unwatered, or would not have been raised at all if the canals had been absent. so that in that one year alone the wealth of the Punjab was increased by $15,000,000. The net revenue for the year in the Punjab was only $610,000, being about 5½ per cent on the capital outlay on works in operation. The net revenue for the year in the Punjab was only $610,000, being about 5½ per cent on the capital outlay on works in operation. A summary, which was given as the nearest approximate to the truth that could be obtained. This statement was for the year 1874-75 only, and no allowance was made for the value of the old native works, which General Dickens stated did not exceed $2,500,000. The total expenditure to date was $77,500,000; the total receipts were $6,150,000, and the working expenses were $2,000,000. This shows that the irrigation works of India, taken altogether, paid at that time a revenue, direct and indirect, of 5½ per cent to the state. This includes some works which were only partially in operation. General Dickens anticipated that when in full operation they would eventually pay 6 to 7 per cent.

As an indication of the time which must necessarily expire after a canal is opened and before it is doing its full duty and return-
The results of irrigation are not so favorable in Bengal and the United Provinces as in the two provinces, chiefly because irrigation is less necessary since the rainfall is more abundant. There is sufficient evidence of its value in Madras. The three great deltaic systems of irrigation, the Godavari, the Krishna, and the Canveri, yield direct returns of 8.6, and 31 per cent, respectively, on the capital spent on them. During the year 1876-77, a year when every unirrigated district was importing a large part of the food of its population, the value of rice produced in the deltas of the Godavari and Krishna rivers is calculated at the prices then prevailing to have been not less than $25,000,000. The ordinary rental of land in Northern India is doubled by irrigation, while in 11 districts of Madras the average rental rises from 50 cents to $1.50 per acre. In considering this question it should be borne in mind that there are other causes of financial success in irrigation works: the one temporary, the other permanent. In the one case the works may fail to pay for a time because of the slowness with which the people adapt themselves to the new system of cultivation, a difficulty which arises in almost every new work, or because of errors in the details of the scheme which experience detects and which are easily remedied. In the other case the failure may be due to the inherent defects of the scheme and to the fact that the water costs more than it is worth. In the former case there may be reason to expect that the water will be eventually fully utilized and the deficit be converted into a surplus, though the accumulated excess charges during a series of years may amount to a large sum which receipts will only gradually wipe out. In the latter case, though there may be room for improvement and economy in the distribution and use of the water, it may be impossible ever to realize a surplus. a

According to the same authorities the net income of the whole works in operation in British India was in the year 1870-80 $5,830,000, which amounts within a very small fraction to 6 per cent of the whole capital, including about $16,800,000 spent on works not yet brought into operation. If this part of the outlay be excluded the income is found to be more than 7 per cent on the capital actually utilized. Compilation of the administrative reports of the various provinces of India shows a total expenditure in the first ten years of work (1867-1876) on combined projects to have been $85,830,000. Between 1877 and 1900 the gross outlay was $285,000,000, the grand total expended on such work from 1867 to 1900 being $375,850,000. In the year 1899-1901 the expenditures on account of irrigation aggregated $91,900,000 and the revenues $12,075,000, the profit earned on the capital outlay being 7.5 per cent.

The following statement of the water rents derived from the use of the Western Jumna canal in the Punjab between the years 1820 and 1859 will give a fair idea of the rapidity with which the income from the use of irrigation works increases. In 1820 the water revenue was $120 per annum; in 1830 it was $28,800; in 1840 it was $112,900. On the Eastern Jumna canals in the Northwest Provinces the water revenue was in 1830 $3,000 per annum. In 1840 it was $29,200 per annum, and in 1845 it was $48,200 per annum. b

Counting irrigated areas cropped twice, the total area under cultivation were 32,059,993; and counting areas of all kinds cropped more than once, the total area under cultivation was 229,362,381 acres.

The following table gives the areas under cultivation of the principal crops produced during the same year:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Area under cultivation (Acres)</th>
<th>Crop</th>
<th>Area under cultivation (Acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>76,093,573</td>
<td>Tea</td>
<td>570,372</td>
</tr>
<tr>
<td>Wheat</td>
<td>29,164,824</td>
<td>Indigo</td>
<td>954,449</td>
</tr>
<tr>
<td>Other field grains</td>
<td>92,366,940</td>
<td>Tobacco</td>
<td>1,665,541</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>2,377,743</td>
<td>Total, including</td>
<td>29,362,381</td>
</tr>
<tr>
<td>Cotton</td>
<td>3,614,739</td>
<td>Other crops</td>
<td>229,362,381</td>
</tr>
<tr>
<td>Oil seeds</td>
<td>12,962,072</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Irrigation works for which accounts were kept paid 7.5 per cent interest in 1897-98 on the capital outlay. The estimated value of the irrigated crops in that year was $150,000,000.

It will be observed from the first table that the proportion of area irrigated to the total area under cultivation is very large, one-sixth of the whole being irrigated. Since the introduction of improved irrigation works and the great increase in the area of land brought under the control of these works the quantity of the more valuable food crops, and more especially those which come in direct competition with foreign countries, has greatly and rapidly increased. The production of rice was largest in 1866, at the close of the American civil war, when the exports amounted to $185,000,000. Since then the exports of this product have decreased considerably, and now its average is on the increase and amounts to about $82,773,000. Cotton is produced chiefly in Gujarat, the Deccan, the Central Provinces, Sind, and Bombay. The yield is as high as 100 pounds of cleaned cotton per acre, but the staple is short and the product is not as valuable as that of the United States.

Another crop which is being extensively exported in recent years is wheat. It is grown generally everywhere, but does not thrive where rice does nor south of the Central Provinces. The Punjab is the greatest wheat-producing district, then the North-west Provinces, Oudh and and Bengal south of the Ganges. In the Central Provinces wheat occupies 23 per cent of the cultivated area, in Bombay and Sind 6 to 12 per cent, and all India has an area under wheat one-third as large as has the United States. The output per acre is rather small. In the Punjab it is 13 bushels per acre; in other places a trifle more or less. Wheat is an autumn crop and is all irrigated. To the con-
sively cultivated in Assam, where it is indigenous, but it is also raised about Darjeeling in the foothills of the Himalayas. It is an expensive crop to prepare for market and is cultivated chiefly by Europeans. Its quality is constantly being improved and the amount exported is annually increasing.

The advantage of using manure is apparently well understood, and if not extensively used it is because of the limited means of the cultivators. The rotation of crops is not generally practiced, since owing to the extensive use of water for irrigation it does not seem to be so necessary. The soil throughout India differs essentially in different localities; it is generally very fertile on the great Gangetic Plain, while the black cotton soil of the Deccan is perhaps the most fertile in the world.

The kharif or wet-weather crop is matured chiefly by the rains of the summer monsoon. It is sown as soon as the spring rainfall admits of the plowing of the land, and it is reaped in September or October. The rabi or autumn crop is the dry-weather crop and requires the largest amount of artificial watering for its cultivation. It is sown in October and is reaped in March or April. The principal crops produced during the wet season are rice, cotton, sugar cane, etc. During the autumn season the more hardy grains are produced, especially the food grains, such as wheat, barley, etc. The millet and fodder grains are chiefly sown in the higher lands and depend for the most part on natural rainfall, as their requirements in the way of water are usually less than those of other crops.

CHAPTER II.
TOPOGRAPHY, METEOROLOGY, AND FORESTRY.

TOPOGRAPHY AND GEOLOGY.

India includes within its borders the highest mountains in the world and some of the mightiest rivers and greatest plains. Topographically it may be divided into three distinct parts, each possessing different topographic features. First, the Himalayas, which form a great mountain barrier on the north and shut out the rest of Asia, forming a controlling factor in the climate and physical geography of India; second, the plains of the great rivers issuing from the Himalayas, the Indus and Ganges plains; and third, south of these plains a high, steep-sided table-land supported by the Vindhyas Mountains on the north and by the western and eastern Ghauts on either side of the peninsula. This great interior table-land is broken by many peaks and mountain ranges separated by broad and fertile valleys.

The Himalayas take their name from an Indian word which means literally "dwelling place of snow," and consist of a great mountain range 1,500 miles long, the general trend being from northwest to southeast. This mountain range may be likened to the Sierra Nevada, bordering the eastern side of the great California Valley. Approached from the southern or plains side there is the same general appearance of low, rolling foothills, the higher peaks being so far back from the edge of the valley as to be scarcely discernible. This mountain range or aggregation of mountain ranges is also similar to the Sierras in its composite formation. On top and behind it is a high arid plateau which corresponds to the Nevada desert.

The highest peak in the Himalayas is Mount Everest, 29,028 feet above the sea, while peaks above 20,000 feet elevation abound in all parts of the range. There are numerous well-traveled trails leading from India through Kashmir and Nepal into Tibet and China, and the passes on these are from 16,000 to 19,000 feet high, and for several days the traveler remains above 16,000 feet in altitude. Only one pass is as low as 14,400 feet.

The Indus River rises well north of the first great range of the Himalayas and drains nearly half of their northern slope, and after flowing around the western extremity of the range it turns and flows southwardly, being joined by various tributaries which drain the southern and western slope. Its main drainage area is situated at a great
the rains have ceased in upper India, Bengal, etc., the heavy rains of Madras set in and continue until the middle or end of December. About this time begin the light rains of upper India, which are experienced in the Northwest Provinces and fall at intervals to the end of March, after which the dry season continues till the end of June, the beginning of the monsoon. In lower Bengal and in Assam the rains become more frequent from January on, and are chiefly afternoon storms. On the coast of Malabar they are earlier than in Bombay. In Madras occasional showers are expected after February, but the steady rain begins only in October.

In the Ganges delta the mean annual precipitation is from 60 to 70 inches. On the great plain, including the Northwest Provinces, it averages 40 inches, and at the summit of the great plain west of Delhi it varies from 25 to 30 inches per annum. At the mountain stations in the sub-Himalayas the annual precipitation ranges from 90 to 120 inches. Farther in the Himalayas, at an elevation of 10,000 feet or above, the rainfall is only 10 or 20 inches, while the snowfall may be 6 to 8 feet or more. There is a difference of from 10 to 15 inches between the precipitation over the southern and northern portions of the Gangetic Plain. In the Punjab the highest average precipitation is in the sub-Himalayas, where it is 68 inches per annum. At Mooltan it is but 7 inches per annum, which is a low average, and at Dera Ismail Khan the annual precipitation is 8.2 inches per annum, nearly the average of the Punjab. In central India the annual precipitation in the lower lands varies between 90 inches at Jeypur and 32 inches at Khundwa, while the minimum in the mountains, such as Mount Aboo, is 61 inches.

In the Northwest Provinces the general average is 20.5 inches at Muthan or Agra, while Aligarh has a minimum of 21 inches. In Bengal the maximum average on the coast is 106 inches, and the minimum average on the plains at Patna is 38 inches. In Assam at Gara Punji the maximum average of the world is reached in an annual precipitation of 368 inches, while in the same place in 1861 30 inches fell in twenty-four hours and 805 inches fell during that year. In Bombay in the western Ghauts the maximum average is 250 inches, and the minimum average in the lowlands at Duhlia is 17 inches. The general average of Bombay is 67 inches. In the Sind the maximum average of 16 inches is at Negar, and the minimum average, 4.3 inches, at Jacobabad. In Madras the highest annual precipitation is 132 inches at Manalore and Callcut; the lowest at Belary and Tuticorin is from 16 to 18 inches, the average of Madras being 44 inches.

The following average annual temperatures at different points in India indicate the tropical character of the climate and the small percentage of cold weather which prevails. At Trichinopoly and Madras, on the southeast coast, the annual averages are 82.8° and 82.4°, respectively. On the southwest coast, at Goa and Cochin, the annual aver-

age temperature is nearly 80°; at Calcutta it is 79.2°, and at Bombay 78.8°, the latter city being the coolest of the three presidency towns. At the hill station of Simla, at an elevation of 7,100 feet, the average annual temperature is 54.2°. The highest monthly temperature occurs at Mooltan in June, and is 95°; at Delhi it is 94.3°. The lowest monthly temperature is at the high hill stations, being at Simla 39.6° in January.

FORESTRY.

In recent years the British Indian government has paid much attention to the preservation of its forests, and is now reaping the benefit in the large income derived from the sale of timber.

The establishment of the government department of forestry is of recent date, brought about by the destruction of forests for fuel, for charcoal, and other wasteful causes. In 1844 and 1847 the subject was first taken up by the governors of Bombay and Madras. In 1864 Dr. Brandis was appointed inspector-general of forestry, and in 1867 the regular training of forestry officers was commenced at the schools of France and Germany, where it is still continued. At present discriminate timber cutting is allowed, but the burning of hill brush is stopped; the forest areas are surveyed and demarked, plantations laid out and maintained, and forestry conservation otherwise carried on.

Forests are classified as reserved and open. The former are the immediate property of the State and are managed by the forestry department, their development being a source of wealth. Cattle are excluded from them, destructive crops and undergrowth destroyed, and the cutting of timber is strictly regulated. The open forests are less carefully guarded, but certain kinds of timber trees are protected. Large amounts of money are annually spent in the plantations, and wherever needful young trees are planted to replace those removed. In 1878 there were 12,000,000 acres of reserved forests. The revenue was $3,320,000 and the expenditures $3,000,000, showing a fair net profit. Ten years later, in 1888, there were 13,520,000 acres of State forest land, the net revenue after deducting all working expenses being $2,920,000.

The British officials generally hold that the effect of forest destruction on rainfall is doubtful and much disputed. Contrary to what might have been expected, there is no evidence to show whether the actual rainfall has decreased or increased in consequence. They all agree, however, that forest destruction has acted injuriously by letting flood waters run off too rapidly and that these waters are lost. They also do much damage as floods. Three-quarters of a century ago immense tracts of southern India were overspread with jungle and the slopes of the Ghauts were universally timber clad. Most of the level woodland has since been cleared for cultivation and the timber cut down for fuel. But another and scarcely less evil has
resulted. Formerly the water was partially protected from evaporation by the sheltering trees. Its flow on the surface was mechanically reduced by the jungle grass and tree trunks; it had time to be absorbed by the vegetable mold and to sink into the earth, thereby insuring the permanence of the natural springs. Not till this was done did the residue find its way to the rivers, and then at a comparatively tardy pace. Now, however, as a rule the rivers are in violent flood for about as many days as they used to be for weeks in moderate flood."


CHAPTER III.

HISTORY AND ADMINISTRATION.

HISTORY OF IRRIGATION WORKS.

Among the first mention made of the irrigation works of India are those of Arab historians of the works constructed by the early Mohammedan emperors in the Northwest Provinces and in the Punjab. Small works, especially tanks, probably existed at much earlier dates in southern India.

It is related that about 1351 A. D. the Emperor Feroze Tughlak built 50 dams across rivers for the promotion of irrigation and 30 reservoirs for irrigation purposes. The first important canal specifically mentioned was built by the same emperor, and was taken from the Choutting River to Hansi and Hissar. Fifty years later this canal became partly disused after the emperor's death. The next important mention of irrigation work is that the great Emperor Akbar constructed, in 1567, a canal from the river Jumna. It is stated that this canal was constructed by the aid of forced labor, but the laborers had privileges thereafter of using the water, and the superintendent saw that all parties, rich and poor alike, received their share. This was the first Western Jumna canal. In 1626 the Shah Jehan had the celebrated architect, Ali Murdan Khan, construct the Delhi Canal, which follows much the same line as does the present Western Jumna. At first this canal was constructed on a high bank following the water courses, but the banks burst and the canal became inoperative. The architect then ran a new line as far as Delhi, following the watershed. On this canal an escape was introduced for the discharge of surplus water. It had one channel 60 feet in depth cut through solid rock. About 1788 these ancient Mogul canals ceased to exist, owing to the decline of the Mogul power and to the constant wars, which at that time prevented their being kept up.

The Eastern Jumna Canal was also begun by Ali Murdan Khan and headed at the foot of the sub-Himalayas. This canal reached to Saharanpur and beyond. It was abandoned after the first season, owing to its bad alignment, as it was constructed in the lower drainage lines and bottoms. In 1780 Zabita Khan reopened this canal, but it was carried away during the first season and was then abandoned.

The first of the modern irrigation works of magnitude was commenced under the Marquis of Hastings in 1817, when Lieutenant Blaine established the head of supply of the Western Jumna canal at
a point high up on that river. This work was practically a restoration of the old Mogul canal, following and using the low lines of drainage to Delhi. No bridges were constructed and only earth embankments were used. The new development of these canals is due to Col. John M. Colvin, who in 1820 extended the above project beyond Delhi, and constructed many bridges and drainage works. Ten years later the earth banks across the drainages of Patrala Sombre were replaced by masonry dams.

The line of the Eastern Jumna canal was surveyed in 1822 by Lieutenant Debade, and the canal was opened in 1830. The natural bed was cleared to a depth of 4 feet below the surface level and in general a new alignment was made which was fairly good, following up the highest divide or watershed. Owing to the steepness of fall given at first the levels retrograded and nearly destroyed the canal. Colonel Cantley rectified this by the introduction of falls, and in 1840 he introduced better works for the passage of side drainage.

Up to this time the irrigation works of India had been constructed chiefly by the East India Company. In 1858 the Government granted the Madras Irrigation Company and East India Irrigation Company 5 per cent on the capital invested, and these companies commenced the construction of works, the Government retaining considerable command over their operations, inspecting the plans and sanctioning the expenditures. Both of these experiments proved costly failures to the State; and in 1867 the Government purchased the works of the East India Irrigation Company when the latter was practically bankrupt. The Madras Irrigation Company has succeeded only one year in paying working expenses, but still carries on work under Government guarantee.

In 1867 the Government decided to construct its own irrigation works and great activity prevailed at once, the Government irrigation force being largely increased. In 1869 schemes for ten years' work, involving $1,500,000,000 expenditures, were outlined, and the following sums were expended: In 1867, $1,096,000; in 1868, $2,344,300; in 1869, $10,040,000, and so on. The total expenditures for the first ten years actually amounted to $5,850,000. Since then the Government works have generally proved satisfactory investments, and as they have certainly added to the wealth and prosperity of the country and have mitigated the severity of famines, large sums have been annually appropriated for the maintenance of existing works and the construction of new ones.

ADMINISTRATION AND LEGISLATION.

The administration of the irrigation works of India is conducted by the public works department, and the engineers are all civil servants in the employ of the British Government. Their status is fixed by law, their promotions are usually by seniority, as in the army and navy, and, like the members of those branches of the governmental service, they receive stated salaries, according to the grades they occupy. They are entitled to leaves of absence and furloughs, and are retired with pensions after certain periods of service.

By parliamentary act of August 2, 1858, all the territory of India was vested in Her Majesty the Queen. All tributes and payments are received and disposed of in her name. In the British cabinet the secretary of state for India was vested with the powers previously held by the board of control under the old East India Company régime, and later on, by act of January 1, 1877, at Delhi, India, Her Majesty assumed the title of Empress of India.

The executive authority of India is vested in a governor-general called the viceroy, who is appointed by the Crown and acts under orders of the secretary of state for India. He is empowered in council to make laws for all persons, whether British or native subjects, foreign or otherwise. The governor-general has a council of seven members, whom he consults in the formulation of all laws.

Of the larger presidencies the governors of Bombay (including Sind) and of Madras are separately appointed by the Crown, and have each their own council and civil service, and in all orders they directly address the secretary of state. Bengal and the Northwest Provinces have lieutenant-governors and a legislative council, but these officers are appointed by the governor-general of India. The other minor provinces have lieutenant-governors or commissioner magistrates, but no councils or legislative powers. Each province is divided into districts, at the head of which is a deputy commissioner. Below this officer is a commissioner and joint magistrate, a deputy collector, and minor officers.

India is divided into British territory and the native states. The former is governed as above described, the latter by native princes, with the help and advice of a resident at his court who is called a political agent and whose duties are purely diplomatic. The highest land officer in nonregulation provinces, as the Central Provinces or the Punjab, is a deputy commissioner. This officer collects revenues and administers civil justice. He is the unit of administration, the sole responsible head of his jurisdiction, and on his energy and character largely rests the efficiency of the Indian government. In India there are 222 districts under deputy commissioners. These districts each average in area 3,800 square miles, and have each an average population of 800,000. They are divided into divisions, and these again subdivided into the ultimate unit of subdivision, which is known as a tahsil. The subdivision is in charge of an assistant magistrate or executive officer, and the tahsil is in charge of a deputy collector or fiscal officer. Land is the main source of revenue of the Indian government, and hence the levying and collection of the land tax is the main work of the administration of that government.
In Bengal permanent settlements have been largely made. The zaminder or headman of a village makes the payment for the whole village to the government, he taking from each cultivator his portion of revenues and retaining for himself a proportion of the same. In Madras the cultivator is the rent-paying unit, as the zaminder is in Bengal. In Bombay revenue settlement is proceeded with as elsewhere, only in more detail, by a careful revenue land survey. Each field is marked out, measured, and assessed separately. This method is simple, as the government recognizes only the owner of each field. With these owners terms of settlement are made for periods of thirty years. In the Northwest Provinces and the Punjab the village is taken as the unit, as is the case in Bengal, and the payment is made to the government by the village. Terms of settlement are also made there for periods of thirty years.

In order to convey a clear understanding of the method of promoting irrigation development in India, it is essential first to give a brief outline of the present attitude of the English rulers toward irrigation. At first the government permitted private corporations to construct and operate irrigation works, the earliest work planned by British engineers being undertaken by a private corporation on a guarantee of interest by the East India Company. During the last thirty years the government has been active in the promotion and construction of nearly all good works projected. These projects are studied, examined, and reported on usually several times during a series of years, and when the government is finally satisfied with them, either as financial investments or as measures for the relief or prevention of famine, the work is sanctioned and the funds for its construction appropriated.

The government of India is as a rule greatly in favor of the extension of irrigation works. It encourages enterprises by granting loan funds for the construction of works whenever it can be proved that profits, increase of interest, and all the maintenance charges will probably be derived. It also constructs works as a means of famine relief in certain places, even when profits cannot be obtained. The government further fosters the use of irrigation waters by making the water rates very low, or by even giving water away in years of scarcity.

As shown in the succeeding acts, the government of India has entire control over all sources of water supply, and so exercises it as to make it the greatest benefit to the community at large. The powers of control over the waters for irrigation are entirely centralized.

Each province of India has a separate branch of the Public Works department, known as the irrigation branch, at the head of which is a chief engineer, generally also secretary to government of that province, and over all the chiefs of engineers is an inspector-general of irrigation, attached to the staff of the governor-general of India. The officers in the upper grades of the irrigation branch are nearly all Europeans, and are recruited from the royal engineers, or from civil engineers educated in well-known colleges either in England or India. The civil engineers from England receive a technical education at Coateshill College, and the majority of those from India are educated at the Thomason Civil Engineering College at Roorkee, or at the colleges in Bombay or Madras. The lower grades of officers are composed of selected noncommissioned officers and soldiers and from natives who have passed an examination after studying for a period at some college.

The chief engineer is the head of the department in the province, and this latter is divided into circles presided over by superintendent engineers. Each circle is again divided into divisions, over which executive engineers preside. Each division is again divided into subdivisions, of which there are generally several under the charge of an assistant engineer. This concludes the list of the upper grades. Under the assistant engineers again come the lower grades of subordinates who have charge of the different works.

Besides the engineering establishment proper, there is the revenue establishment, which works in conjunction with it, and whose duties are mostly concerned with the administration and the measurement of the fields for assessment. This establishment consists chiefly of natives, and is presided over by a deputy magistrate, under whom are subjudges, amneces, and patrols.

All of the upper grades—that is, from the assistant-engineers upward, including the deputy magistrate—have to pass an examination in canal law, and are given magisterial powers, which enable them to inflict punishments for breaches of this law. The powers conferred vary with the standing of the officers. The executive engineers may pass on estimates within certain limits connected directly with the construction or maintenance of works in their division. All estimates involving considerable expenditure are sanctioned by the superintendent engineer within certain limits, beyond which the sanction of the chief engineer, practically that of the government of the province, is required. All large projects, such as a new canal system or storage reservoir, pass to the inspector-general, and are referred by him to the government of India and to the secretary of state.

The rules and regulations by which water is served to cultivators are detailed in the canal acts given further on. In irrigating districts water is served to cultivators on certain days, very often on three days in one week, or possibly they are allowed to use it during one week and are deprived of it for another. The period in which they are not allowed water is known as a period of "tatili," an Indian word meaning closed. Breaches of "tatili," or the taking of water when its use is not allowed, render the individuals committing the act liable to fine or imprisonment. The executive engineer of the division has entire control over the distribution of the water, and complaints regarding sear-
city, repairs, misappropriations of water, etc., are all referred to him, and he either decides them himself or empowers the supervisory officer or deputy magistrate to do so. The assistant engineer is generally a European, and his right-hand man, as far as irrigation matters are concerned, is the deputy magistrate, who is generally a native of some standing and education. The assistant engineer has magisterial powers, and his time is largely employed in trying cases and settling disputes. Zilahurs, of which there are generally two under the assistant engineer, have under them 2 or 5 ameuns, under whom are from 2 to 10 patrols. These latter note the fields as they are irrigated, and when the irrigation is complete their measurement is made by the ameen, the whole being superintended by the zilahur, who is held responsible for the correctness of the measurement.

The first act bearing with any importance on irrigation legislation was Act VII, by the governor-general of India in council, passed April 12, 1845, and entitled "An act for regulating the levying of water rent, tolls, and dues on certain canals of irrigation constructed by the government in the Northwest Provinces and the protection of said canals from injury." From clauses in this act the following extracts are made:

And it is hereby enacted that the said lieutenant-governor of the Northwestern Provinces shall be competent to draw out rules to regulate the levy of water rent and the supply of water for irrigation. * * * The rules thus drawn out shall be published for general information in the Government Gazette.

And it is hereby enacted that all works of water rent due for lands irrigated by the said canals shall be levied either by temporary deprivation of the benefits of the canal or by the same process as is prescribed for the recovery of balances of land revenue.

And it is hereby enacted, that whoever willfully causes any obstruction to any of the said canals, or to any of the water courses drawn and supplied therefrom, or damages the banks of the canals, or the works constructed for its maintenance, or willfully defiles the water in the canal, shall be liable to the penalties hereinafter described.

And it is hereby enacted, that all persons offending against the provisions of this act shall be punishable, on conviction before the magistrate, by imprisonment without labor for a term not exceeding fourteen days, or fine to an amount not exceeding 50 rupees [about $2.50], or both: and in default of payment of such fine by additional imprisonment for fourteen days.

On May 31, 1845, the lieutenant-governor of the Northwest Provinces, under authority of the above act, passed resolutions regarding various canals, from which the following extracts are made:

In conformity with Section VIII of the aforesaid act, the superintendents of the said canals are invested with the powers of deputy collectors for the levy of rents, and of joint magistrates for the enforcement of penalties under the aforesaid act, and their assistants are declared competent to exercise the same powers under their directions and on their responsibility. The subordinate establishments of such superintendents have the power of subordinate revenue and police officers for the aforesaid purposes. An appeal lies direct to the commissioner of the division against orders passed by the superintendent or his assistants in the capacity of deputy collector, and to the sessions judge against orders passed in the capacity of joint magistrate.

When it may be more expedient to give water on contract rather than according to the surface irrigated, the terms of contract may be as follows:

Where the water flows naturally, 2 rupees [81] per annum for every square inch of opening taken from the summit level of the water and having a free course.

In the event of any person secretly taking water from the canal in any manner, for which rent is leviable, without coming under engagements to pay the rent, or secretly taking more water than he has engaged to pay for, he shall be chargeable with double rates for all water so taken.

All land brought into cultivation within 20 yards of the canal or any branch stream from it, subsequently to the construction of the channel, shall pay water rent, whether taking water from the canal or not.

When from the carelessness of cultivators either in not properly closing the heads of their water courses or in leaving the water courses in bad order, the water overflows and spreads over waste or fallow land, a fine shall be levied not exceeding the highest rate of water rent leviable on the extent of land flooded.

It shall be in the power of the canal officers to close the whole of the branch water courses from estent to surprise for the purpose of forcing the water onto the lower parts of the canal; and also, when necessary, for any period not exceeding three days in a week. At other times the water shall be at the command of the cultivators, provided it be in the power of the canal officer to furnish a supply. Persons taking water once so as to benefit a crop shall be liable to the charge for the whole year, or the whole crop, as the rate may be levied.

Special agreements between individuals and the superintendent for the use of water for irrigation, for driving machinery, or for other purposes, on other terms than those embodied in these rules, shall be constructed as other ordinary contracts are.

In addition to these, rules are laid down defining the powers of the superintendents and their assistants and other officers on the works, as well as rules giving the charges which villages or individuals are subject to who do not take water for irrigation, but who use it for watering live stock or for domestic purposes. The charges for filling reservoirs or tanks are also specified, as are the tolls for rafts or boats.

The right of ownership of water was summarily settled in India in 1873 by the passage of "An act to regulate irrigation, navigation, and drainage in northern India." The preamble tersely states the claims of the government thus:

Whereas throughout the territories to which this act extends the government is entitled to use and to control for public purposes the waters of all rivers and streams flowing in natural channels, and of all lakes and of the natural collections of still water, etc.

This statement of rights is perfectly plain, and in India the government has no need to use its power to enforce these claims. This act is known as "Northwest canal provinces Act No. VIII, of 1873," and
lays down all of the fundamental laws governing canal administration in those provinces.

The principal act establishing the laws covering irrigation in the presidency of Bombay is Act No. VII of 1879, which was amended in 1880 by Bombay Act No. III. The preamble reads as follows:

Whereas it is necessary to make provision for the construction, maintenance, and regulation of canals for the supply of water therefrom, and for the levy of rates for the water so supplied in the Bombay presidency, it is enacted, etc.

The act then goes on to define what are understood as canals, water courses, and drainage works; defines the various officers appointed by law, with their powers, and makes the following further provisions:

Whenever it appears expedient to the governor in council that the water of any river or stream flowing in a natural channel, or of any lake, or any other natural collection of still water should be applied or used by the government for the purpose of any existing or projected canal: the governor in council may, by notification in the Bombay Government Gazette, declare that the said water will be so applied or used after a day to be named in the said notification not being earlier than three months from the date thereof.

At any time after the day named any canal officer duly empowered in this behalf may enter on any land, remove any obstruction, close any channel, and do any other thing necessary for such application or use of the said water, and for such purpose may take with him, or depose, or employ such subordinates and other persons as he deems fit.

Following this, equally broad powers are given canal officers to enter or examine land in connection with projected works, to inspect and regulate water supply, to enforce repairs, and prevent accidents. Additional regulations are formulated providing for suitable canal crossings, the removal of obstructions to drainage, and the construction of drainage works. Further:

Every owner of a water course shall be bound to construct all works necessary for the passage across such water course of canals, water courses, drainage channels, and public roads existing at the time of its construction, and of the drainage intercepted by it, and for affording proper communications across it for the convenience of the occupants of neighboring lands to maintain such water course in a fit state of repair for the conveyance of water.

This act further provides for compensation in cases of damage, the remission of water rates when allowable, compensation on account of the interruption of water supply, and for further causes.

Part 4 of the act lays down the rules for the levying of water rates, and opens by stating that "such rates shall be leviable for canal water supplied for purposes of irrigation, and for any other purpose as shall from time to time be determined by the governor and council." Special rates are laid down to be charged where persons use water unauthorisedly; also when water is permitted to run to waste. Provisions are made for the obtaining of labor on the canals in times of emergency, and penalties are provided for damage done to canals and other works.

Land tenure.—In southern India, including Bombay and Madras, while the landholders do not own land, they possess certain rights in it, such as the right to hold and to till it so long as they make payment of part of the produce to the government, while the government possesses the right to a share of the land revenue. In northern India, including the Northwest Provinces, Punjab and Bengal, there is a class of superior landholders between the cultivator and the government. The cultivator tills the land and pays the rent to the landlord, and the latter pays a portion of this to the government. These proprietors are associated together in villages, with an elected or hereditary head, who is responsible to the government for the rent of the entire village. In Bengal there are about 130,000 landlords or heads of estates, who are entitled "zemindars," or may even be rajahs. In the central provinces there are 28,000 separate estates. In the Punjab 1,605 zemindars hold 5 per cent of the total area of that province; 33,020 village communities hold 91 per cent of the total area, and 1,711 other landholders have charge of 4 per cent of the total area. In the northwest provinces the area is divided in about the same proportions among the various classes of holders. In southern India, where the cultivators or ryatwari hold the land, it is leased to them for fixed periods of thirty years, though they can resign these holdings at the end of each agricultural year. They can sell or mortgage the land, and at the death of the holder his heirs inherit the right to the lease. In Madras there are 2,952,000 ryatwari or individual tenures on which the average assessment is $5. In Bombay there are 1,367,600 ryatwari.

In these southern presidencies each village is indicated on the revenue map with a defined boundary, and each field is marked out and numbered on the village plan. The different classes of soil are indicated in colors with a description of the class of tenure, marked in a register accompanying each map, in which are also indicated all particulars of soil, tenants, and amount of assessment. The size of the field is determined by the extent of the particular variety of soil which can be cultivated with the assistance of a pair of bullocks. Thus in light, dry soil a field will constitute 20 acres, in heavy dry soil 12 acres, and in rich garden land 4 acres. Some of the circumstances affecting the classification of land and the value of the fields are the position of the latter with respect to the village, the facilities for agricultural operations, the character of the soil, and the opportunities for irrigation.
CHAPTER IV.
EXTENT AND CHARACTER OF IRRIGATION.

CLASSES OF WORKS.

The irrigation works of India are divided by the engineer into two great classes, (1) gravity irrigation and (2) lift irrigation. The former includes four great groups, namely, perennial canals, intermittent canals, periodical canals, and inundation canals. The water supply for these may be supplemented by storage works. These will be treated as a third class.

Perennial canals are taken from the rivers, the discharge of which at all times suffices for the irrigation of the lands without the aid of storage. Intermittent canals are taken from intermittent streams, the water of which must be stored in order to furnish a constant supply. Periodical canals are taken from streams having an available supply during the rainy season only, and are used altogether in the cultivation of the summer crop. Inundation canals are taken from rivers having a constant discharge of some magnitude, but are fed by those rivers only when in flood.

Lift irrigation is chiefly illustrated by wells. Of these there is little to say, although the area irrigated by them is considerable. They are used in a country where labor is cheap, and are valuable adjuncts of irrigation, catching the seepage water from the canals and irrigated fields which otherwise would be wasted. Owing to the cost of labor it is doubtful if they will ever be used to any extent in America.

Canals are divided into two great classes, those for irrigation only and those which are also employed for purposes of navigation. The conditions required to develop an irrigation canal are usually, first, that it shall be carried at as high a level as possible, so as to have sufficient fall to irrigate the land to a considerable distance on both sides of it; second, that it shall be fed by some source that will render it a running stream, in order that the loss of the water consumed in irrigation may be constantly replaced in the canal. The chief requirement for a navigable canal, on the contrary, is that it shall be as nearly as possible a still-water canal, so that navigation may be equally easy in both directions, and no water is lost except by evaporation, absorption, and at the points of transfer from the higher to the lower levels. Hence it is most economically constructed at a relatively low level. In India, among the earlier great perennial canals, it was considered the rule to make them navigable as well as irrigable, but since the introduction of modern modes of transportation, the development of the railway system, and the construction of excellent metal roads throughout the country, the authorities have generally come to disapprove of the use of irrigable canals for navigable purposes.

EXTENT OF IRRIGATION.

In the presidency of Bombay, exclusive of the Sind, there are 35 irrigation works in operation, of which 3 are major protective works, 7 are major productive works, and the remainder are minor protective and productive works. The total capital outlay on these to end of year 1900-1901 was $9,179,000. The total gross revenue during 1900-1901 was $178,200; the working expenses were $139,000; and the net revenue was $39,200. The area irrigated during that year was 123,972 acres, of which about three-fifths were in autumn or dry-weather crops. The gross revenue assessed was $1.73 per acre, and the water rate averaged $1.33 per acre irrigated. This water rate ranged, however, from 30 cents to $4 per acre, the maximum price being very unusual and due to the large amount of sugar cane which was irrigated on the canal where that rate was levied. The working expenses per mile varied from 70 to $90, and the working expenses per acre irrigated varied from 30 cents to $2. The latter high figures were in both cases charged on the Mitha canal, where a large amount of sugar cane was under cultivation.

In the Sind the net area cropped in 1901 was 1,873,674 acres. The area irrigated from canals was 1,413,487 acres; irrigated from other sources, 362,913 acres; and the total area irrigated was 1,776,400 acres. The area under wet-weather crops was 1,438,809 acres, and under autumn crops about 366,530 acres. The irrigation’s share of the net revenue for that year was $1,196,500. The financial statement for the works of the Sind for 1900-1901 was as follows:

Financial statement of Sind Irrigation Works.

<table>
<thead>
<tr>
<th>Total outlay to date</th>
<th>$7,094,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross revenue during the year</td>
<td>$1,071,000</td>
</tr>
<tr>
<td>Working expenses</td>
<td>906,000</td>
</tr>
<tr>
<td>Net revenue</td>
<td>805,000</td>
</tr>
<tr>
<td>Net profit, less simple interest on the borrowed capital</td>
<td>464,000</td>
</tr>
</tbody>
</table>

The average rainfall for all of Sind during the year was 4.98 inches.

In Madras the great irrigation works are constructed in the deltas of the principal rivers. The approximate cost of the works of Madras, without interest, to the year 1899 was $60,225,000; the total area of cultivation due to irrigation was 6,898,839 acres, and the total revenue was $7,722,000.

In Bengal, at the end of 1901, there were in operation 738 miles of main canals, of which 435 miles were navigable; they commanded an area of 2,139,000 acres, of which 1,446,371 acres were actually irrigated. The total capital outlay on the three major works, viz., Midnapore, Orissa, and Some canals, was $27,475,000.
In the Punjab the capital outlay to end of 1901 for major works only was $38,097,000; the total net revenue was $3,333,000, or 8.4 per cent interest on the capital outlay. On inundation works the capital outlay was $777,000, and the interest on this outlay varied from 10.8 per cent as a minimum to 191.8 per cent as a maximum. In this province there were 8,102 miles of main and branch canals and 31,757 miles of distributaries. The working expenses were from 25 to 60 cents per acre irrigated, and the establishment cost from 10 to 25 cents per acre irrigated. The area irrigated during the summer crop was 3,023,737 acres, and during the autumn crop 2,647,814 acres.

The Northwest Provinces, including Oudh, have an area of about 55,000 square miles, of which 30,000 square miles may be said to have been protected by irrigation works at the end of the year 1894. The total outlay on irrigation works in these provinces at the end of 1893 was $37,400,000; the net revenue for that year was $1,270,000, which is 4.6 per cent interest on the capital outlay. The net interest on four principal works—the Upper and Lower Ganges, Agra, and Eastern Jumna canals—was 4.97 per cent. The total working expenses for the same year were $961,000. There were in operation 1,427 miles of main and branch canals and 6,748 miles of distributaries. The total area under irrigation was 1,799,866 acres, of which 706,221 acres were summer crops and 1,093,645 acres were autumn crops. The value of the principal crops was $10 per acre.

FINANCIAL AND AGRICULTURAL RESULTS.

Of major productive works, the capital for which has been provided from borrowed money, there are 35 in the six principal provinces. The capital expended on these works to the year 1900 was about $100,000,000, while the sanctioned estimates for the completed projects were $103,572,000. These 35 major works are designed to irrigate, when fully completed and irrigation has been fully developed, something more than 10,356,000 acres. Of 6,000 miles of main and branch canals no less than 2,300 miles are navigable. The cost of making these canals navigable can not be readily ascertained, but should be eliminated in determining the true cost of each irrigable acre. The Mutho canal, in Bombay, which is the most expensive of any canal of its kind, derives a considerable income from the supply of water for domestic purposes to the city of Poona. It may be said that the works of this class average $8.30 for each acre irrigable. Of the 10 largest of these major works, the most expensive, the Orliss system in Bengal, cost $87 per acre, and the Ganges canal, which covers the largest area of all, and is at the same time the cheapest, cost a little under $6.30 per acre. In addition to the 6,000 miles of main canals constructed in these 35 systems, there are 18,000 miles of principal distributaries. Up to

a Buckley, R. B., Irrigation Works in India and Egypt. London, 1901, pp. 239-244.

In the present time only 12 of the 35 major productive works have been worked at a profit of more than 4 per cent, but the profit from these 12 has been more than sufficient to cover the deficiencies of the other 23. The net result is that the works of this class have covered the interest charges, with a gross excess to the government of nearly $12,642,000.

For the first twenty years these modern British works were not altogether profitable. During the past ten years, however, since nearly all have been in full operation, the net revenue return for the 35 works together has averaged more than 4 per cent per annum on the $100,000,000 gross capital outlay.

Among the six provinces in which this class of work lies, Madras and Sind are preeminent as those in which all the works have been in operation for more than ten years and are thoroughly successful. In the Northwest Provinces all four works are now thoroughly successful, paying over 5 per cent net revenue, and in the Punjab there is little doubt that all of the works will finally be successful, while the older ones already pay well. One of the youngest works, the Sindhi canal, is very remarkable in having paid nearly 14 per cent on its capital during the second year it was in operation. Of the Bengal works little hope can be entertained, as the normal rainfall there is too large and too regular to make irrigation an urgent requirement for agricultural prosperity. These works must be looked on as a protection against occasional drought and famine rather than as a source of profit.

Of major protective works there were in operation in 1900 in the six principal provinces 5 works, the capital expenditure on which was $6,886,000. These works are designed to irrigate 735,729 acres, at an average capital cost of nearly $8 per acre. There are completed in these systems 400 miles of canals and 800 miles of main distributaries.

Of minor works the capital of which has been provided from the national revenues of India about 80 were in operation in 1900, distributed throughout nine provinces, including Burma and Beluchistan. The capital expended on these works was $15,040,000 and the net revenue was $837,000. The percentage of net revenue on the total capital outlay to the end of the year under consideration averaged nearly 5 per cent, and varied from nothing in the case of some works in Bombay to 10 per cent in some of the works of Burma and 24 per cent in some in inundation canals in the Sind. These works comprise altogether 6,500 miles of canals, 2,650 miles of distributaries, and render irrigable an area of about 7,201,678 acres. The works of this class taken collectively are more remunerative than the major productive works, which were specially constructed to pay nearly 5 per cent. The numerous small works in Bombay are unproductive, and there is but little hope that the returns derived from them will materially improve.
In 1900 there were irrigated by major productive works alone
11,409,428 acres. The rate of working expenses per acre on all the
classes of works varied between 40 cents and $2.90. The gross area
irrigated by all three classes of works was 18,611,106 acres, while the
entire area under irrigation, including that watered by wells and that
double cropped, was 33,096,081 acres. The average water rate charged
was less than $1.40 per acre. The average value of crops per acre varied
from $10 to $35, and the percentage of rate charged on the
value of the crop was between $3.30 and $8.25. Gaged by the standard
of the percentage of rates charged, theoretically the gage of the
severity of the charge on the cultivator, the Bombay rates, which are
actually the highest, are shown to be the lowest, and this is really the
fact because of the very high value of the sugar-cane crop so exten­sively
cultivated in that province. The gross value of the crops irrigated
in 1900 by all the four classes of irrigation works administered
by the government reached the sum of $155,000,000.

At a moderate compensation it may be said that one-half of this
sum is the increased value of the outturn from the fields due to irri­
gation from the canals. This figure shows perhaps more readily than
any other the value of the agricultural interests which are bound up
with irrigation works of India.

The agricultural results of Indian irrigation, and an idea of the cost
and returns of building and operating canals can best be obtained by
citation of the results on a typical perennial canal, as the Sirhind canal,
in the Punjab. In 1900-1901 the amount and value of the principal
crops irrigated on the British branches only of this canal are as follows:

<table>
<thead>
<tr>
<th>Crop</th>
<th>Value</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>$124,000</td>
<td>14,646</td>
</tr>
<tr>
<td>Maize</td>
<td>641,000</td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>1,247,000</td>
<td>139,954</td>
</tr>
<tr>
<td>Mixed grains</td>
<td>176,000</td>
<td>18,431</td>
</tr>
<tr>
<td>Cotton</td>
<td>194,000</td>
<td>11,893</td>
</tr>
<tr>
<td>Sugar-cane</td>
<td>293,000</td>
<td>7,770</td>
</tr>
<tr>
<td>Millet and pulses</td>
<td>1,781,000</td>
<td>396,900</td>
</tr>
<tr>
<td>Fodder crops</td>
<td>428,000</td>
<td>83,320</td>
</tr>
<tr>
<td>Vegetables</td>
<td>222,000</td>
<td>16,693</td>
</tr>
<tr>
<td>Oil seeds</td>
<td>117,000</td>
<td>21,298</td>
</tr>
</tbody>
</table>

It will be interesting to examine the items of cost, interest, and re­
venue of such a canal as this, and to make comparisons between these
costs and returns and what might be derived from a similar work in
America made in the United States. In making this comparison the amounts
reported in the revenue returns for such expenditures as pensions, fur­
loughs, and navigation works must be deducted, and the total outlay
and due allowance made for the differences in cost for each class of con­
struction in the two countries and for the water rate to be charged.

To the end of 1901 the total expenditure on the Sirhind canal was
$19,663,000, of which $6,749,000 was interest while the work was under
construction, and $1,000,000 was leave and pension allowance to
employees.

Though such a work would have been constructed in a much shorter
time in the United States, owing to the substitution of mechanical
means for hand labor, the rates paid in our country for interest would
probably equalize this charge. The total original cost of the works
was $2,000,000, of which, exclusive of the cost of land and mainte­
nance, $400,000 was for head-works, $8,500,000 for the main canal and
branches, and $1,100,000 for right of way and navigation works. The
office establishment in India is an expensive one and, less pensions,
costs $2,500,000, while the tools and plant cost an additional $1,100,000.

In the main canal and main branches the earthwork alone cost
$2,600,000, and on the distributaries this item cost $800,000, making
$3,400,000 for earthworks.

For the total 1,170,000 acres of irrigable land controlled by the Sir­
hind canal the cost for earthwork was $4.25 per acre. Our contract
prices in the West being, say, 10 cents per cubic yard against their 4
cents, this earthwork would have cost us $10.62 per acre. The masonry
works—as falls, weirs, regulators, and bridges—cost in all $2,400,000,
or $3 per acre irrigated. In India rubble masonry costs about $5 per
cubic yard. In our West it averages, say, $6. Hence these works
would have cost us $6 per acre. In our works, however, we would
avoid the expense of the numerous masonry bridges constructed in
India; again, we would do comparatively little masonry work, but
would use iron and wood, which are relatively far cheaper. The cost
for these items would accordingly be proportionately less. Perhaps
one-third can be deducted for the cheaper material, and it would cost us,
therefore, $4 per acre irrigated. The drainage works and escapes
cost about 75 cents per acre more, or such a work as the Sirhind canal
would have cost $4.35 per acre irrigated against $8 in India.

Owing to the recent completion of the Sirhind canal it irrigates at
present only 1,170,000 acres. This, however, paid in 1900-01 a surplus
revenue, after paying interest on the capital outlay, of 4.7 per cent per
annum, and of 9.1 per cent net revenue on that outlay. The water
rates charged averaged 50 cents per acre irrigated. We could charge
at least $2, and in some localities more. As the cost of construction in
America would be twice that of India, while the receipts per acre
would be nearly three times as great, it is not improbable that under
similar circumstances such a work when fully utilized would yield
from 5 to 12 per cent, and when doing its maximum duty it would realize as a minimum 10 per cent on the capital invested.

In addition to the amount realized from such a work as compared directly with that obtained in India, there is one source of revenue in our country which does not exist in India. That is the annual increase in value of the land served by the canal. There is no such increment available to private enterprise in India, because the Government is the owner of the land. In America, however, where land can be purchased at from $1.25 to $2.50 per acre, and when supplied with water right will sell for from $40 to $100 per acre or bring an equivalent revenue, the increased return from such an investment is obvious.

CHAPTER V.
ALKALI AND DUTY.

OBJECTIONS TO IRRIGATION.

In 1845, during surveys for the great Ganges canal project, a committee was appointed, under instructions from the governor-general of India, for the purpose of reporting on the causes of unhealthfulness which existed along the line of the Delhi canal, and ascertaining whether injurious effects on the health of the people were likely to be produced by the contemplated Ganges canal. Their report is one of the most complete and exhaustive ever prepared relative to the effects of canal irrigation on the health of the neighborhoods irrigated. The members of the committee were Maj. W. E. Baker, R. E., president; Surg. T. E. Dempster, and Lieut. H. Yule.6

Among the more important conclusions reached were:
(1) That in considerable portions of the district under the influence of existing canals sickness has been largely developed.
(2) That this sickness is not attributable to the results of irrigation but to the canal works or water courses of private individuals having intercepted the natural drainage of the country, and having thus led to the formation of swampy tracts diffusing malarious influence around them.
(3) That where the soil is light and the irrigation carried on by means of main distribution channels, all the advantages of canal irrigation may be gained without the prevalence of any of those evils to be found in localities differently constituted.
(4) That if care is taken to irrigate only that land which has an open soil and which has such slope and low drainage lines as to prevent water-logging, no unhealthy results will follow irrigation.
(5) That irrigation with free surface drainage may be regarded as quite innocuous.
(6) That when malarious influences are developed by irrigation their effects are almost strictly local.

This committee recommended that the Ganges canal be kept as much as possible within soil, that is, that its ordinary surface level should be below that of the country. That earth wanted to complete enhancements be never obtained from excavations made outside the canal except from such localities as would readily admit of drainage. That the canal and its branches be taken as much as possible along the

cent for the bad years, when there will scarcely be any rainfall, the average acreage irrigable during the dry season will be about 1,800. To this may be added 200 acres of wet-weather crop sown in the tank bed. The total cost of constructing this system of tanks is estimated as being $2,800, and the total revenue is estimated to be 75 cents per acre, from which it will be seen that the scheme as a whole is estimated to pay 4 per cent.

In 1887 the construction of tank No. 4 was authorized, in addition to which a tunnel 5,800 feet in length was authorized to be constructed under the stream channel, with shafts at every 50 feet and curved passages around each shaft, with a short piece of open excavation 900 feet in length. From the last shaft to the surface of the ground is an open channel 2,500 feet in length to connect the tunnel with tank No. 4. The object of this tunnel is to intercept the subsurface drainage and thus assure a supply to the tank, which will immensely increase its utility as an irrigating reservoir.

For many generations there has been an old tunnel at this site, which frequently fell into decay and disuse until again cleaned out. Its alignment is shown in the accompanying illustration (fig. 9). About the year 1883 a portion came to grief through a flood finding its way down some of the shafts, and since then it was not used until its repair was proposed in 1887. By the latter part of 1887, 40 shafts and a half mile of the tunnel had been completed. The water-bearing stratum had been reached and a discharge of half a second-foot obtained. The old tunnel worked with a constant discharge of 5 second-feet for forty years. As the new channel is better located and in better soil, it is estimated to give at least as good results as the old one did. The slope of the tunnel is 3 in 1,000, the sections 3 by 1.7 feet, or, say, 5 square feet, which with a mean velocity of 1.8 feet per second will give a maximum discharge of 9 second-feet.

The estimated cost of this work is nearly $4,000. The rates paid were 10 cents per lineal foot in depth of shaft and 20 cents per lineal foot of horizontal tunnel, the excavation being entirely in earth. The returns estimated are as follows: Discharge, 9 second-feet; area irrigable by 1 second-foot or duty, 120 acres; rate per acre, $1.50; gross revenue, about $1,600. The maintenance charges will amount to practically nothing.

CHAPTER IX.
RIVER TRAINING AND LAND RECLAMATION.
RIVER CONSERVANCY.

In connection with all irrigation works maintained on the great plains and deltaic rivers of India, river training and improvement works must be constructed in order to maintain the stream in the channel which will cause it to do least injury to the various irrigation works. During seasons of flood the branches of these great rivers change, as does the Missouri River, tearing into enormous tracts of the surrounding country, and they would, if not properly guided, destroy great portions of the canal and remove hundreds of acres of valuable irrigable land. In addition to this destruction of property, they cause severe inundations during the times of flood, which destroy valuable crops and property.

These inundations, when of small magnitude and confined within reasonable limits, do little harm and even much good may result from them. They do not increase the healthiness of the neighborhood, but the silt deposited by the water tends to fertilize the land, thus enabling richer crops to be produced with much less trouble. Autumn crops which lie along the edge of inundations of this minor class are usually defended by earth embankments, which are often miles in length. These embankments are of no great height or solidity, and are merely built in comparatively shallow water to save the crops, but inundations of greater magnitude, where the waters attain great force and extend through the heart of a large district, destroying houses, bridges, and canals, and washing away land, are of another kind. In providing a remedy for this class of inundation the engineer must possess great skill and patience.

The planting of Nanel grass, which is a long, coarse variety of water grass, when the plantations are properly arranged and progressively made, gives one of the best means of reclaiming parts of the river which are beyond the proper boundaries of the waterway. This grass thrives in the streams of India, the cost is much less than that of any other treatment, and the reclamation is performed by the action of the river itself, by the deposition of silt due to the reduction of the current, so that water highly charged with silt at the upper end of a plantation is often found to issue from the lower end with little or no discoloration.

Above and below the head-works of the Lower Gauges canal at
Narora the river flows through a low bottom land which is limited at some distance back from its banks by a bluff about 60 feet in height. It was immediately found necessary to construct training works to prevent the stream from cutting into this bottom land, thus turning the end of the weir from above, or perhaps cutting into the bank and destroying the canal itself below the weir. These training works extend 4 miles above the head of the canal and about 15 miles below it (fig. 65). The works consist on the upstream side of the weir of a long earthen embankment from which other embankments of earth jut out at right angles to the course of the stream, thus forcing the current over to the other side. At first these embankments, or, as they are called, "groins," were constructed so as to point downstream, making an angle of perhaps 45° with the course of the current, but it was found that they did not work well. They have since been realigned so that they project at right angles to the stream, and are placed exactly one-half mile apart, and they are found to perform their work excellently. As yet none have failed.

These groins are often very long, some as much as 2½ miles in length. They are simply straight embankments of earth 10 feet wide on top, with slopes of 1 on 2. The last 150 feet at the end of the groin, or the nose, as it is called, is paved with heavy stones to a depth of 2 to 3 feet, and at 50 feet from the end a spur 50 feet in length, similarly paved, is run at right angles to the line of the bank, pointing upstream.

At Hardwar, the head of the Ganges canal, the river runs between high, steep gravel and rock banks, on which it is able to make no impression by erosion, and training works are therefore unnecessary below the weir. Above it, however, the bed of the stream is so broad and is divided into so many channels during the dry season that it is necessary to construct extensive training works to keep open a permanent channel, known as the Hardwar Channel, which passes in front of the head of the canal and supplies it with water. The fall of the river above the head-works is 8 feet per mile, and at low-water stage it has a velocity of 6 feet per second. This velocity is many times greater in periods of flood. As shown in the plan of the head-works at Hardwar (fig. 18), the training works consist of bars sunk into the river channels to prevent the retrogression of grades and the consequent destruction of the dams; of weirs to turn the water into the Hardwar channel; of rectangular groins projecting into the river similarly to those on the Lower Ganges canal, in order to keep the water in the Hardwar Channel; and, lastly, of embankments of bowlders to protect the weaker portions of the river banks. Great difficulty has been encountered in maintaining the integrity of the noses of the groins, as the heavy floods undercut these and cause them to fall into the river. Great concrete blocks 3 by 5 by 2 feet in dimensions, weighing 2 tons each, are first dropped into the river as a foundation for the groins. When these reach the water surface the end of the groin is built up of loose concrete blocks in a regular manner, and the remainder of the groins, constructed of bowlders, is run back from this end. As the floods wash away the foundation blocks the built-up portion of the groin falls in and replaces them, furnishing a new foundation, and this in turn is itself replaced. Thus in the course of a few years the bed of the river becomes filled to such a depth with these blocks that further destruction ceases to take place, and the groins will then stand for many years.

At the head of the Agra canal, at Okhla, the weir which diverts the
water into the canal head is, as before described, constructed of loose hand-placed rocks, and to preserve its integrity, and at the same time to train the course of the Jumna River toward its right bank and against the head of the canal, groins of a peculiar form of construction are run out at right angles to the line of the weir (fig. 95) and parallel to the course of the river. These works are known as "alligator groins" from their peculiar form, which somewhat resembles that of an alligator. They are constructed of loose stones dumped into the river without any foundation on which to rest, the tops and sides of the groins being carefully hand laid, so as to give them shape and integrity. The floods annually wash away portions of these groins at first and during low season they have to be repaired, but, like those on the Ganges canal, in the course of a few years the mass of rock underlying the groin becomes so great that repairs rapidly diminish in amount or entirely cease to be necessary. The tendency of the water in the river is to flow in a direction nearly parallel to the line of the weir and toward the under sluices, thus destroying the weir. These groins cause portions of the water to flow over the weir at right angles to it, thus doing it no injury. Other portions of the stream are forced over against an island, indicated in the accompanying plate, and tend to remove it, at the same time furnishing a supply for the canal head.

Spoonbills, or legs, are run out from the groins at right angles, and a berm 10 feet in width is built around the end of the groin and the spoonbill. The portion annually destroyed is the berm. This falls into the river, leaving the main body of the groin intact. The top of the groin is built at an elevation of 1 foot above highest flood level, and the top of the spoonbill is 7 feet below flood level.

**LAND RECLAMATION.**

A good deal has been done in some of the more swampy portions of India toward the reclamation of swamps and their conversion into valuable agricultural properties. This reclamation has been most extensively practiced in what are known as "duns," especially because it increases the healthfulness of these regions by substituting for marshes dry land under cultivation. Swamp reclamation has been practiced in various parts of the United States and the methods are essentially the same in character as those employed for the same purpose in India.

In reclaiming marsh lands, such as those in the "duns," it has been considered usually essential first to make a complete survey of the region in order to discover the slope of the lands in the direction in which cuttings for the purpose of drainage can best be made. The lines on which the drainage cuts shall be made having been laid down, it remains simply to so design these cuts that they shall command the gross area of the swamp in the most economical manner, and shall completely remove the water from it. Some of these drainage works have added thousands of acres of valuable land to the agricultural regions, and have changed fever-stricken neighborhoods to healthy cultivated fields where fevers are scarcely known. The financial returns from some of these works have been even greater and more satisfactory than those from irrigation works proper, and reclamation works of this character are now presented in India with as much zest as is the construction of canals or storage works.