Wm. A. Lamb.

Water-Supply and Irrigation Paper No. 87 Series I, Irrigation, 15

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

IRRIGATION IN INDIA

(SECOND EDITION)

BY

HERBERT M. WILSON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

The publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topography Atlas of the United States, folios and separate sheets thereof; (8) Geologic Atlas of United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

The Bulletins, Professional Papers, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage, K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. Complete lists of series I to P follow. (WS=Water-Supply Paper; B=Bulletin; PP=Professional Paper.) The following Water-Supply papers are out of stock and can not be supplied: Nos. 1-14, 19, 20, 29-33, 46, 57-64.

SERIES I—IRRIGATION.

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SERIES J—WATER STORAGE.

WS 33. Storage of water on Gila River, Arizona, by J. B. Lippincott. 1900. 98 pp., 33 pls.
WS 40. The Austin dam, by Thomas U. Taylor. 1900. 51 pp., 16 pls.
WS 45. Water storage on Cache Creek, California, by A. E. Chandler. 1901. 48 pp., 10 pls.
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WS 58. Storage of water on Kings River, California, by J. B. Lippincott. 1902. 100 pp., 32 pls.
WS 68. Water storage in Truckee Basin, California-Nevada, by L. H. Taylor. 1902. 90 pp., 8 pls.
WS 73. Water storage on Salt River, Arizona, by A. P. Davis. 1903. 54 pp., 25 pls.
WS 86. Storage reservoirs of Stony Creek, California, by Burt Cole. 1903. 62 pp., 16 pls.

The following paper also should be noted under this heading: Reservoirs for irrigation, by J. D. Schuyler, in Eighteenth Annual, Pt. IV.

SERIES K—PUMPING WATE

WS 1. Pumping water for irrigation, by Herbert M. Wilson. 1896. 57 pp., 9 pls.
WS 8. Windmills for irrigation, by E. C. Murphy. 1897. 49 pp., 8 pls.
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SERIES L—QUALITY OF WATER.

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WS 22. Sewage irrigation, Pt. II, by George W. Rafter. 1899. 100 pp., 7 pls.
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WS 79. Normal and polluted waters in northeastern United States, by M. O. Leighton. 1903. 192 pp.

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ILLUSTRATIONS.

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.

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 Peryiar 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 Sangamanicut 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 1,559,603 square miles, the total population was 294,266,701, 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 7.5 per cent on the capital outlay for construction. The total area cultivated in India the same year was 180,151,093 acres, and the total area irrigated was 18,611,106 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 $8\frac{1}{3}$ million acres, and that the total value of the latter crop alone was $52,773,000.

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 semihumid 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, 1902.*


MAP OF INDIA
LEGEND
1 Bari Doab Canals
2 Sirhind "
3 Western Jumna "
4 Eastern Jumna "
5 Ganges "
6 Agra "
7 Lower Ganges "
8 Dun "
9 Betwa "
10 Sone Canals
11 Midnapore "
12 Orissa "
13 Mutha System
14 Nira "
15 Ekruk Tank
16 Ashti "
17 Mhasvad "
18 Sukkur Canals
19 Ghar Canals
20 Begari "
21 West Nara "
22 Dad "
23 Fuleli "
24 Jamrao "
25 Kistna "
26 Eden "
27 Saran "
28 Cauvery "
Irrigation Canals
Tanks
Scale
100 80 60 40 20 0 100 200 300 miles
AFGHANISTAN
BALUCHISTAN
ARABIAN SEA
RAJPUTANA AGENCY
BOMBAY
GUJARAT
CENTRAL INDIA AGENCY
CENTRAL PROVINCES
HAIDARABAD
MADRAS PRESIDENCY
BUNDELKHAND AGENCY
CHOTA NAGPUR
BENGAL
ASSAM
UPPER BURMA
LOWER BURMA
OUDH
NEPAL
GREAT TIBET
HIMALAYA MTS.
BAY OF BENGAL
PESHAWAR
SRINAGAR
JAMMU
KANDAHAR
LAHORE
AMRITSAR
SIMLA
QUETTA
MULTAN
RURKI
DELHI
ALIGARH
AGRA
JEYPORE
JEYSULMERE
AJMERE
LUCKNOW
KARACHI
Mt. Abu
JHANSI
ALLAHABAD
PATNA
DARJEELING
INDORE
BARODA
NAGPUR
CALCUTTA
MANDALAY
CUTTACK
BOMBAY
POONA
HAIDARABAD
RANGOON
Indus River
Jhelum River
Chenab River
Ravi River
Sutlej River
Jumna River
Betwa River
Ganges
Brahmaputra River
Mahanadi
Godavari
Kistna
Irawaddy River
Vindhya Hills
Western Ghats Mts.
Eastern Ghats Mts.
Mouths of the Ganges
MYSORE
MADRAS
PONDICHERRY
TRICHINOPOLY
GOA
Kistna River
Cauvery River
66° 70° 74° 78° 82° 86° 90° 94°

IRRIGATION IN INDIA.

By Herbert M. Wilson.

INTRODUCTION.

The principal sources from which the information in the accompanying report was obtained were (1) conversation 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 63,000 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 20 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 lime 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 Bhatgar, 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 next 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 20 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 160,000 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 distributary 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 rivaled 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 Bhatgur. 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 kunkar, 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 11½ 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 bogie 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 Gangetan 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 are, 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 long to enable it to soak into the ground. On these benches small crops of rice, garden truck, and grain are cultivated.

The River Jumna is first crossed and the Gangetan Plain entered at Allahabad, between which place and Calcutta the country is extremely level and fertile, having a strong resemblance to the broad, level prairies of the Mississippi Valley. Throughout this portion of the route fine fields of wheat, millet, barley, indigo, cotton, sugar cane, and poppy were passed in endless succession, while occasional groves of mangoes, cocoanut, and date palms relieve the prairie-like appearance of the country. The entire region is divided into innumerable small fields, each of a few acres, but no fences or houses were to be seen, though laborers dotted the fields. All live in villages, from which the laborers sometimes travel several miles to work.

I arrived in Calcutta on the morning of January 30, and called on Dr. W. King, the director of the geological survey of India, who gave me letters of introduction to some of the officials I was desirous of meeting. Mr. B. F. Bonham, American consul-general, treated me with the utmost courtesy and did everything in his power to aid me during my short stay. One day was spent at the office of the surveyor-general of India, Col. H. R. Thuillier, R. E., who kindly aided me in the examination of the methods of work of the topographic division and of the great trigonometric survey.

On the 31st I called on Col. J. M. McNeill, R. E., the secretary for government of the public works department of Bengal. With him I discussed the arrangement of my tour through his presidency, and from him I received letters of introduction to his various executive engineers. Colonel McNeill kindly telegraphed to Mr. R. B. Buckley, superintending engineer of the Soane canals, to arrange a hasty trip over his territory, and on the following day I reached Arrah, where I called upon Mr. Buckley. That day was spent in examining the maps and office records of the Soane canals, and on the following morning I set out on a tour of inspection. Mr. Buckley kindly placed at my disposal his canal steamer *Kudra*, on which I lived for three days, and Mr. Buckley also telephoned over the canal lines, arranging for various engineers to meet me and show me various points of interest.

I started early in the morning of February 2, and steamed up the canal against the current at the rate of about 8 miles an hour. The rate of travel was rather slow, owing to the velocity of the stream and to the great number of locks which had to be passed. At Arrah the canal is 86 feet wide at bottom, about 9 feet deep, and discharges about 2,000 second-feet of water. From there to the headwaters at Dehree, a distance of 65 miles, the Arrah branch follows the general direction of the Soane River on its western side, gradually increasing in width toward the head, where it is 180 feet wide at bottom, 9 feet deep, and discharges about 4,300 second-feet.

As Nasregunge, a large village midway between Arrah and Dehree, 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, 2¾ 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, scarcely 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 Torrent 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 it 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 Dehree, 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. Conduitt, 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 tonga 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 Ghauts. 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 at 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 $21\frac{1}{2}$ 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 950,000 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 Aligarh, where a couple of hours were agreeably spent. From Aligarh I went by rail to Rajghat, which station was reached late in the evening. There, thanks to the thoughtfulness of Mr. E. 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 5 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 contact. 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 $7\frac{1}{2}$ by $11\frac{1}{2}$ 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 30,000 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 12 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 Cockhorn, the office 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 meet them. Accordingly, I decided not to visit the works of the Western Jumna nor the Bari 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 Amrister 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 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 Rupar, 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.

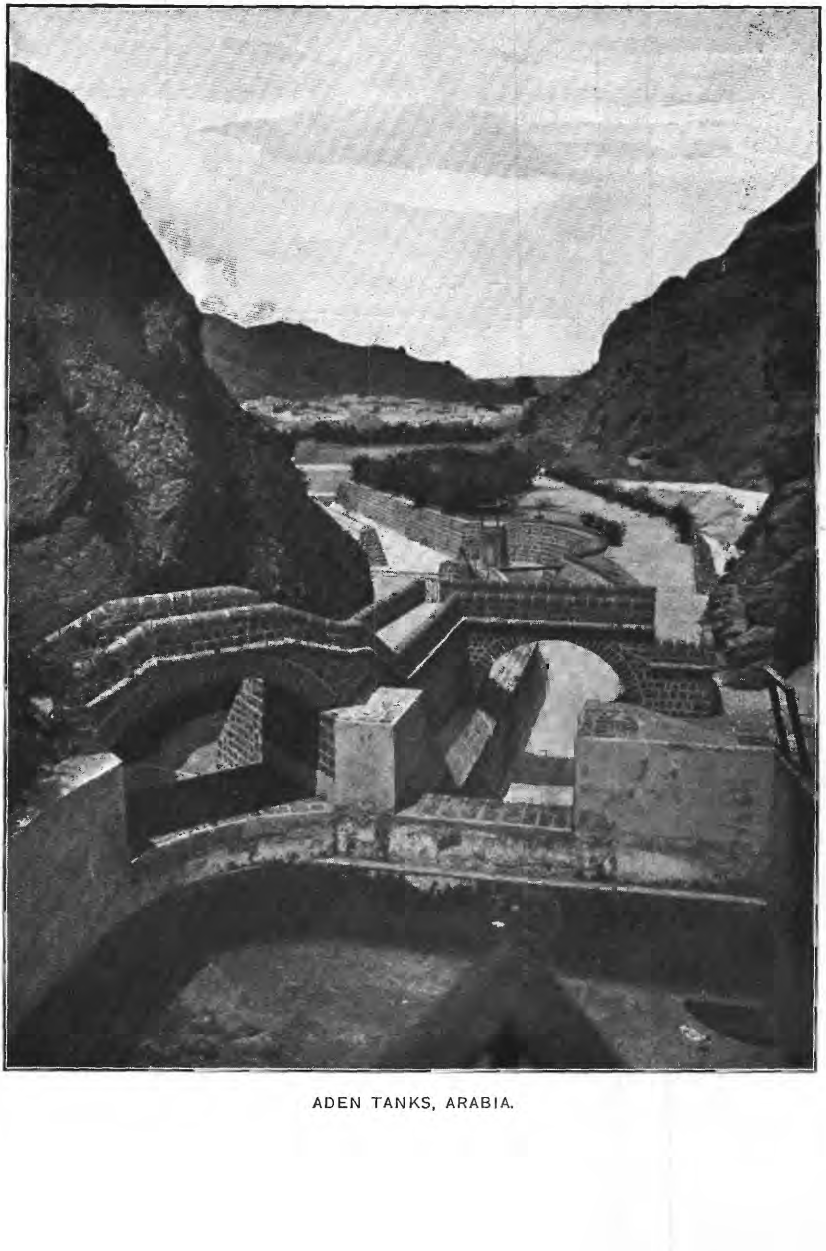
Next morning, February 15, I reached Roorkee, where I found that Mr. M. King, executive engineer, had made elaborate preparations for the trip over the line of the canal. I also found Col. G. T. Skipworth, R. E., chief engineer of the Northwest Provinces and secretary to government, and Mr. W. J. Wilson, his assistant secretary. They had made preparations for the annual inspection of the lines of the canal, but as they 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 Roorkee 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 Rutmoo Torrent at Dhanowri. 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 Ranipur torrents over the Ganges canal. These works were also examined on the return trip to Roorkee, 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 Hindun 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



ADEN TANKS, ARABIA.

portion 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 drainage 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 mentioned 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 inclosure are constructed many unique masonry instruments with which were conducted the observations of the ancient astronomer.

On March 3 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 headworks of the Cavour canal are, and show me over them.

On April 2 I was met at Chivasso by Signor Canavotte 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 Dora Baltea, 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 Pò 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 Dora Baltea to it.

Above Saluggia, near Cigliano, 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 tail 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 800 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.

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CHAPTER I.

FINANCE AND STATISTICS.

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 of 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 these 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 Sidhnai canal in the Punjab and 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 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 semihumid 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 can not necessarily be expected, as 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 uncoursed 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 $6\frac{2}{3}$ cents per cubic yard, while surface excavation costs $2\frac{1}{2}$ 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 $3, 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 80 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 previous to the introduction of modern irrigation works. According to Col. Baird Smith, the whole of the region irrigated by the Eastern Jumna canal would have been devastated by the famine of 1837–38 without the aid of the irrigation which that canal afforded. With its aid the population was comfortably supported and the gross revenue derived from the use of the water was $2,445,000, of which the Government received a yearly net income of $250,000, and this shortly after the completion of the work. In the same year the united Eastern and Western Jumna canals were estimated to have saved property to the value of $10,000,000, and as a result of this showing the British Government shortly afterwards began the construction of the great Ganges canal and other similar works, From the report of Major Baker, R. E., it appears from actual measurements made on the Western Jumna canal in 1838 that the gross value of crops on lands irrigated by that canal was $7,500,000, of which $750,000 was paid to the Government as land and water rent; the remainder aided to feed and support the inhabitants of 500 villages during a period of devastating famine. Without irrigation this land would, during that drought, have been totally unproductive.

As an indication of the increased revenue derived from the use of water and the capability of the soil to pay that increase, it appears that in the presidency of Madras the rate of assessment in the tank region is about $2.30 per acre on irrigated land, as against 55 cents per acre on land not irrigated. It is difficult to show in a satisfactory manner what has been the actual result of the irrigation works in India as financial undertakings. The figures given convey little idea of the actual benefit derived from the canals, as much of this is collected as the land tax, which forms nearly half the total revenue of the Indian Government.

Another difficulty in reviewing the financial results of Indian irrigation works is found in the fact that in several cases capital shown by the Government accounts does not include the value of the old native works, upon which the British undertakings were founded. Recognizing these difficulties, Major-General Dickens presented to the select committee on public works a statement of which the following is a summary, which was given as the nearest approximate to the truth that could be obtained. This statement was for the year 1875–76 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 work is opened and before it is doing its full duty and returning 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 Soane 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 commission 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 outturn 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 Bari 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 these two canals by $7,200,000, an amount equal to about two-thirds the cost of the works, and but for the protection they afforded the Government would have lost heavily from the necessity of remitting revenue and otherwise providing for famine relief. 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 result which obviously supplies a wholly inadequate test of their value to the country.

Up to the year 1878 the capital outlay on canals completed in the Northwest Provinces had been $21,800,000. The area irrigated that year was 1,461,000 acres, the value of the crop raised on which was estimated at $30,000,000. Half of the area irrigated was occupied by autumn crops, which but for irrigation must have been wholly lost, and it may be safely said that the wealth of these provinces was consequently increased by $15,000,000, so that three-fourths of the entire first cost of the works was thus repaid to the country in that same year. The net revenue to the Government from irrigation in these Provinces was $1,550,000, or 7¼ per cent on the whole capital outlay of $28,750,000, of which about $6,250,000 was still unproductive.

The results of irrigation are not so favorable in Bengal and Behar as in the above two provinces, chiefly because irrigation is there 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 Godaveri, the Kistna, and the Cauveri, 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 Godaveri and Kistna 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 40 cents to $1.70 per acre. In considering this question it should be borne in mind that there are other causes of financial ill success of 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 1879–80 $5,830,000, which amounts within a very small fraction to 6 per cent of the whole capital, including about $16,250,000 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 defined projects to have been $52,850,000. Between 1877 and 1900 the gross outlay was $285,000,000, the grand total expended on such work from 1867 to 1900 being $337,850,000. In the year 1900–1901 the expenditures on account of irrigation aggregated $11,500,000 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 1850 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 $420 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 $29,300 per annum, and in 1845 it was $48,200 per annum. [b]

[a] Report of the Indian Famine Commission, Part 2, London, 1880.

[b] Smith, R. Baird, F. G. S., Italian Irrigation, London, 1855, vol. 1, 318–340.

LAND AND CROPS.

The following table gives the area and population of the principal provinces of India according to the census of 1901:

Area and population of principal provinces of India.

Province.	Area.	Population.	Density per square mile.
	Square miles.		
Bengal	151,185	74,744,866	494
United Provinces and Oudh	107,164	47,691,782	445
Punjab	97,209	20,330,339	209
Central Provinces	86,459	9,876,646	114
Madras	141,726	38,209,436	269
Bombay	123,064	18,559,561	151
Burma	236,738	10,490,624	
Other provinces	143,704	11,996,343	
Total British territory, including Burma, etc	1,087,249	231,899,597	232
Total native States	679,393	62,461,549	92
Grand total, India	1,766,642	294,361,046	162

Of British-born inhabitants, in 1891 there were 100,551; of agriculturists, 171,735,000, or 60 per cent of the whole population; and of manufacturers, 27,470,000. The mortality in India varies from 21 to 28 per thousand.

The following table shows the areas cultivated and irrigated in the various provinces during the year 1900–1901:

Area cultivated and irrigated in principal provinces of India.

Province.	Acres cultivated.	Acres irrigated.	Net revenue.
Bengal	51,607,700	716,271	$13,066,000
Madras	24,509,613	6,579,284	18,854,000
Bombay	21,000,594		9,791,000
Northwest Provinces	25,614,892	1,800,000	15,107,000
Punjab	24,521,071	6,000,551	9,561,000
Oudh	8,965,323		5,181,000
Central Provinces	15,250,582		2,908,000
Sind	3,729,433	2,568,503	3,129,000
Others, including Burma	23,116,657	946,497	13,286,000
Total, including minor subdivisions	198,51[illegible] 865	19,538,923	90,883,000

Counting irrigated areas cropped twice, the total acres irrigated 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:

Extent and character of crops.

Crop.	Area under cultivation.	Crop.	Area under cultivation.
	Acres.		*Acres.*
Rice	70,093,373	Tea	502,173
Wheat	20,164,824	Indigo	984,449
Other food grains	92,566,949	Tobacco	1,005,541
Sugar cane	2,577,742	Total, including other crops	229,362,381
Cotton	9,614,720		
Oil seeds	12,962,072		

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 cotton 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 $52,773,000. Cotton is produced chiefly in Guzerat, 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 Northwest 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 construction of the great canals of the Punjab and Northern Provinces is due the quality and prominence which it possesses.

Rice is an extensively cultivated crop, but it is limited to the deltas of the Orissa, Godaveri, and other large rivers and to Bengal; 80 per cent of the crops raised in such regions is rice. Elsewhere little is grown excepting in the lowlands along the coast. In Bengal the average yield per acre is 1,200 pounds of clean rice. Millet is more extensively and generally grown than any other crop excepting in the special rice districts. A variety of sorghum called jowari and a spiked millet called bajra are the most common varieties. They are wet weather or spring crops and are used somewhat by the natives for food, but are chiefly used as fodder. Oil seeds form an important crop. These are usually grown as a second crop after rice and pulses. Oil is extensively used in India for lamps and for food. The largest oil-seed producing provinces are Bengal and the Northwest, but these crops are also extensively grown in Madras and elsewhere.

All kinds of vegetables and fruits are produced everywhere in India, these being the chief food of the natives. Among the more important kinds are potatoes, which are grown especially in the hills, maize, tomatoes, eggplants, mangoes, oranges, lemons, melons, figs, plantains, and cocoanuts. Cocoanut palms are grown most abundantly on the west coast lowlands, and date palms in Bengal. The production of the ordinary spices is rather abundant. They are mostly, however, for home consumption, for use in curries, etc., as tumeric, chile, chicory, coriander, and others. Sugar cane is very extensively cultivated throughout India, especially in the Northwest Provinces, and in Bombay, but it is an expensive crop to produce, both because of the time required to mature it and the amount of water necessary to irrigate it. The varieties of sugar cane produced in India are not equal to those produced in America and in the West Indies, the proportion of saccharine matter being comparatively low.

Jute is a plant almost exclusively produced in India and very extensively exported. It is chiefly grown in northern and eastern Bengal. Indigo is extensively grown in the Northwest Provinces, Punjab and Madras, chiefly by the natives. It is most extensively produced, however, in Behar by English capitalists. The expense of making the dye from the plant is such that the natives are seldom able to cultivate and manufacture it; hence the factories are usually under the control of British capital. Poppy for the production of opium is grown extensively in the Ganges Valley near Patna and Benares, and in central India. Its cultivation requires much care and attention and is usually an indication of intelligence and prosperity on the part of the cultivators. Tobacco is generally grown in small quantities everywhere in India. The best is produced in Madras, whence the variety known as Trichinopoly is extensively exported. Coffee is produced in small quantities in southern India only. Tea is extensively 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 Gangetan 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 Vindhaya 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, 29,002 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 16,400 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 altitude among the glaciers of the Himalayas. Its drainage basin in the Himalayas alone is about 32,550 square miles in area, while with its affluents the whole basin drains 311,600 square miles. This river, with its branches, affords the chief source of water supply and drainage to the provinces of Punjab and Sind.

The northeastern slope of the Himalayas is drained by the Brahmaputra River, which, like the Indus, rises north of the mountains, draining about one-half of their northern slope, and after breaking through the Himalaya Range it flows westwardly through the valley of Assam to its junction with the Ganges River, 100 miles from the sea. The drainage basin of the Brahmaputra north of the Himalayas is about 95,000 square miles in area. Like the Indus, its upper basin is at a great altitude. As yet its waters are but little used for irrigation, as the country through which it flows generally receives a fair rainfall. The average elevation of the Indian watershed between the headwaters of the Brahmaputra and Indus rivers is above 18,000 feet in altitude.

The Ganges River and its tributaries drain the larger portion of the southern slope of the Himalayas. The catchment area above an elevation of 1,000 feet is very small relatively to that of the Indus and Brahmaputra, while the total catchment area is 414,000 square miles. This river flows eastward through the great plains of the Northwest Provinces and Bengal to its junction with the Brahmaputra, whence it flows southward to the Bay of Bengal. The southwestern slope of the Himalayas, in the province of Punjab (which name means "The Five Waters"), is drained by the main five tributaries of the Indus, viz, the Sutlej, Ravi, Chenab, Jhelam, and Indus rivers, all of which join below Mooltan, whence they flow southward to the Arabian Sea. All these rivers are extensively used in irrigation.

The southern foothill ranges of the Himalayas north of the Punjab and the Northwest Provinces are from 3,000 to 4,000 feet high, and are called the Sewaliks. Between the Sewalik Hills and the sub-Himalayas is a disconnected line of valleys from 2,000 to 2,500 feet in altitude. These valleys are called the Duns. The sub-Himalayas, which form a higher range or belt of hills north of the Duns and between them and the main range, are from 15 to 50 miles in width north and south, and are sometimes separated by several successive dun-like valleys. These latter are artificially drained and cultivated in places and are very fertile. In the sub-Himalayas are the mountain resorts of the various provincial governments of India, at altitudes varying between 7,000 and 8,000 feet. In a portion of the northern or Gangetan Plain to the east of the Ganges is a broad belt from 10 to 15 miles wide. It is a broad, grassy tract, traversed by sluggish streams, with extensive morasses and marshes, and is called the Tarai.

The great northern plain stretches with an unbroken surface along the foot of the Himalayas from the upper Indus in Punjab to the Ganges delta near Calcutta and in a wide valley along the Brahmaputra called Assam. Its area is about 500,000 square miles, and it is nowhere above 1,000 feet in elevation and appears to be perfectly flat. The northern, central, and eastern portions are well watered by rivers having their sources in the Himalayas or in the Ghauts. Assam has a periodical rainfall, and the whole of this northern plain forms the best cultivated, the richest, the most populous, and the most civilized district of India. This plain receives the water of four great river systems—that of the Indus, of the Brahmaputra, and the combined Ganges, Jumna, Sutlej, etc., draining the southern Himalaya slopes, and the Betwa, Chumbul, and Soane, draining the Vindhaya Mountains and northern Ghauts.

The third great topographic division of India is the table-land before alluded to, generally called the Deccan, and includes the Central Provinces, Hyderabad, Bombay, Madras, and Mysore The highest peaks of the northern Deccan are Mount Aboo, 5,650 feet high, on the west and Mount Parasnath, 4,450 feet high, on the east, while the hills generally vary from 1,500 to 4,000 feet in altitude and consist of ridges separated by broad, high plains and masses of forest.

The eastern and western Ghauts are great, irregular ranges of mountains, extending the whole length of the eastern and western coasts. The eastern Ghauts average 1,500 feet in elevation; the western Ghauts ascend sharply from the sea to an average elevation of 2,000 feet, with peaks varying from 6,000 to 8,700 feet in height. The western slope of this range is extremely rugged, having much the appearance of the mesa edges in the western United States. The eastern Ghauts are a series of broken spurs, not continuous like the western Ghauts, and afford easy access to the interior. The inner plateau between these mountain ranges is from 1,000 to 3,000 feet in elevation, dotted with peaks and ranges over 4,000 feet in elevation, and it is approached through the western Ghauts by only a few difficult passes. The general appearance of this country is very similar to that of northern New Mexico and Arizona and of southern Utah.

The western Ghauts form the watershed of the central plateau. Only short streams flow from them into the Indian Ocean, the main drainage making its way eastward across the central plateau, breaking through the eastern Ghauts and emptying into the Bay of Bengal. The chief rivers, viz, the Godaveri, Cauveri, and Kistna, rise in the western Ghauts; their deltas in Madras form extensive and fertile plains, which their waters irrigate. The chief population of this central region is on the eastern slope, and here irrigation is extensively practiced, not only from great rivers in their lower or coast levels, but also by means of storage in the western portions of Madras, Mysore, and in Bombay. Of the important rivers of this region the drainage basin of the Godaveri is 119,000 square miles; that of the Kistna is 59,500 square miles, and that of the Cauveri 30,300 square miles in area.

The flood discharges of the various great Indian rivers are enormous. The Indus above Sakkar discharges as high as 380,000 second-feet, which is equivalent to 15 second-feet per square mile of catchment. The Ganges in flood may discharge 1,350,000 second-feet, which is a little less than 5 second-feet per square mile of catchment; the Godaveri discharges in great floods 1,350,000 second-feet, or 11 second-feet per square mile; the Kistna a little less than 1,200,000 second-feet; and so small a stream as the Soane, rising in the Vindhayas, with a catchment area of about 34,000 square miles, discharges 1,700,000 second-feet, equivalent to 50 second-feet per square mile of catchment. One river in southern India, the Gadanamathi, having a catchment of only 29 square miles, discharges in flood 28,000 second-feet, or 972 second-feet per square mile, and other rivers discharge nearly as large relative amounts.

The following table, giving some details of discharges, etc., of various large rivers near their mouths, is taken from Heywood:[a]

Discharges of large Indian rivers.

Rivers.	Extreme breadth of river bed.	Extreme breadth of channel.	Least breadth of channel.	Fall per mile.	Rise in monsoon.	Greatest depth in dry season.
	Miles.	*Miles.*	*Miles.*	*Feet.*	*Feet.*	*Feet.*
Ganges	$5\frac{1}{4}$	$2\frac{1}{4}$	$1\frac{1}{4}$	----------	27	30
Kistna	$1\frac{1}{2}$	$1\frac{1}{4}$	$\frac{3}{4}$	1.17	35	10
Godaveri	4	$2\frac{1}{2}$	$1\frac{1}{2}$	1.09	30	10
Cauveri	1	$\frac{3}{4}$	$\frac{1}{2}$	3.5	12	6

Rivers.	Surface current in floods per hour.	Flood section.	Flood discharge per second.	Least discharge in dry season per second.	Longest duration of flood.	Area of delta.
	Miles.	*Sq. feet.*	*Cubic feet.*	*Cubic feet.*	*Days.*	*Sq. miles.*
Ganges	4 to 7	288,000	1,800,000	45,000	40	--------
Kistna	$7\frac{1}{2}$	153,000	1,500,000	1,125	10	--------
Godaveri	$4\frac{1}{4}$	216,000	1,500,000	2,250	10	3,000
Cauveri	6	37,800	300,000	None.	10	--------

The geology of India varies with the topography. The great northern plain is an alluvial deposit, on the surface of which not a pebble can be found excepting near the foot of the hills. It probably belongs to the post-Tertiary, judging from a few fossil mammals, fishes, and crocodiles which have been found, and is probably the result of delta deposits. The Sewalik Hills also belong to recent geologic times and are composed of micaceous sandstones, interspersed with bits of clay and marl, their age being Miocene or Pliocene. The sub-Himalayas belong to the Tertiary epoch and are of

[a] Jackson Hydraulic Works, London, 1885, p. 250.

marine origin, composed chiefly of sandstones, argillaceous shales, schists, and limestones. The main range of the Himalayas is composed chiefly of schistose rocks, mica-schists, and gneiss, and some granite and limestone.

In the Deccan the oldest rocks consist of gneiss, which is found in large portions of Bengal and Madras and is pre-Silurian. The great mass of the central plateau, perhaps 200,000 miles in area, consists of what is known as Deccan trap, which forms the most striking physical feature of the landscape. Most of the great ranges of mountains, with their rugged outlines and the square buttes or ghauts and mesas, are the denuded edges of basaltic flows. It is from these jagged or step-like ranges that they receive their name of ghauts, which means "steps." The soil is largely composed of disintegrated laterite, a ferruginous and argillaceous rock occurring over the trap but also found elsewhere. High-level laterite is usually a result of the decomposition of trap, and the soil of much of the central plateau which it forms is very poor in quality. Low-level laterite is more sandy, often containing gravel, and forms most of the better soil fringing the coast.

METEOROLOGY.

The rainfall in India is exclusively from the evaporation of the Indian Ocean and the two bays which surround the peninsula. The distribution of rainfall is extremely variable, ranging from a couple of inches per annum in portions of the Sind to over 600 inches in a limited area in Assam. By far the greater part of the rainfall is brought direct from the ocean between the months of June and October by the regular periodical wind known as the summer monsoon. In upper India the cessation of the summer rains is followed by a rapid fall of temperature under a perfectly clear and cloudless sky. A cool and dry current sets in from the northwest, down the Ganges Valley toward Bengal and from the north across the northern Deccan, south of which it turns and sets toward the Bombay coast. The plateau of Hyderabad, Madras, and Mysore receives a small amount of rain in October and even later. In lower Bengal and on the coast a few inches of rain are expected in October and are of importance to the late summer crops and in sowing or germinating cold-weather or autumn crops. The latter part of October and November and the earlier portion of winter in northern India are generally rainless. The late winter rains, which are small in amount and are regular only in upper India, rarely set in much before January.

With regard to this periodic distribution the rainfall in different parts of India may be summarized thus: From June to September rain falls more or less heavily throughout the entire area, excepting upon the dry plains of the Sind, where it is extremely rare and sometimes fails altogether. In a portion of the Punjab and in the Carnatic the summer rain is restricted to occasional showers. In October, when 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 Gangetan 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 20 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 26.5 inches at Muthra or Agra, while Aligarh has a minimum of 24 inches. In Bengal the maximum average on the coast is 105 inches, and the minimum average on the plains at Patna is 38 inches. In Assam at Chara 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 Calicut; 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 Trichinopoli 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 average 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 54.4°. 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 $2,000,000, showing a fair net profit. Ten years later, in 1888, there were 43,520,000 acres of State forest land, the net revenue after deducting all working expenses being $2,020,000.

The British officials generally hold that the effect of forest denudation 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.[a]

[a] Thornton, W. T., Journal of the Society of Arts, London, 1878, vol. 26, p. 279.

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 Toghlak 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 Chouting 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 1753 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 Sombe were replaced by masonry dams.

The line of the Eastern Jumna canal was surveyed in 1822 by Lieutenant Debude, and the canal was opened in 1830. The ancient 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 Cautley 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 guaranty.

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 $150,000,000 expenditures, were outlined, and the following sums were expended: In 1867, $1,096,000; in 1868, $2,344,250; in 1869, $10,040,000, and so on. The total expenditures for the first ten years actually amounted to $52,850,000. 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 252 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 zemindar 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 zamindar 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 can not 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 Coopers Hill 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 superintending 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 zilahdars, ameens, 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 superintending 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 "tatil," an Indian word meaning closed. Breaches of "tatil," 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 scarcity, repairs, misappropriations of water, etc., are all referred to him, and he either decides them himself or empowers the supervisorial 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. Zilahdars, of which there are generally two under the assistant engineer, have under them 5 or 6 ameens, under whom are from 8 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 zilahdar, 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 balances of water rent due for lands irrigated by the canal 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 canal, 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 $25], 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 [$1] 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 or not; and similarly all land cultivated from wells which have been dug or reopened within 20 yards of the canal boundary, or within 10 yards from any branch stream from it, subsequently to the construction of the canal, 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 sunset to sunrise 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 leviable.

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 are 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 so 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 depute, 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 unauthorizedly; 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 tenures.—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 1,695 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 2,392,000 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 of 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 metaled 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 $9,170,000. The total gross revenue during 1900–1901 was $175,200; the working expenses were $139,000; and the net revenue was $36,200. The area irrigated during that year was 124,972 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 35 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 $200, and the working expenses per acre irrigated varied from 30 cents to $2. The latter high figures were in both cases charged on the Mutha 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 1,439,869 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.

Total outlay to date	$7,994,000
Gross revenue during the year	1,071,000
Working expenses	266,000
Net revenue	805,000
Net profit, less simple interest on the borrowed capital	464,000

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 495 miles were navigable; they commanded an area of 2,753,000 acres, of which 1,446,374 acres were actually irrigated. The total capital outlay on the three major works, viz, Midnapore, Orissa, and Soane 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 181.5 per cent as a maximum. In this province there were 5,102 miles of main and branch canals and 11,737 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 2,967,814 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 $27,400,000; 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 Mutha 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 $9.30 for each acre irrigable. Of the 10 largest of these major works, the most expensive, the Orissa system in Bengal, cost $27 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.[a]

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, 1893, pp. 269–294.

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 Sidhnai 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 $6,866,000. These works are designed to irrigate 723,720 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 general 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 $737,000. 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 naught in the case of some works in Bombay to 16 per cent in some of the works of Burma and 24 per cent in some 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 7,201,578 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 11,409,528 acres. The rate of working expenses per acre on all the classes of works varied between 40 cents and $2.60. 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 33,096,031 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 irrigation 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:

Crops irrigated on Sirhind canal in 1900–1901.

	Value.	Area.
		Acres.
Barley	$124,000	14,646
Maize	641,000	96,238
Wheat	1,247,000	120,654
Mixed grains	176,000	26,431
Cotton	101,000	11,626
Sugar cane	293,000	7,770
Millet and pulses	1,781,000	306,000
Fodder crops	428,000	85,520
Vegetables	222,000	16,629
Oil seeds	117,000	21,268

It will be interesting to examine the items of cost, interest, and revenue of such a canal as this, and to make comparisons between these costs and returns and what might be derived from a similar work if made in the United States. In making this comparison the amounts reported in the revenue returns for such expenditures as pensions, furloughs, and navigation works must be deducted from the total outlay and due allowance made for the difference in cost for each class of construction 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 $12,000,000, of which, exclusive of the cost of land and maintenance, $400,000 was for head-works, $6,500,000 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 $2,200,000, 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 Sirhind 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 $3 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 73 cents per acre more, or such a work as the Sirhind canal would have cost $15.35 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 90 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 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.[a]

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 embankments 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

[a] Cautley, Col. Sir Proby T., The Ganges Canal, London, 1860, vol. 3, p. 24.

watershed of the country, so as not to interfere with drainage, and that irrigation be prohibited in localities which appear to possess naturally a malarious character.

On this same subject Capt. Douglas Galton, of the army sanitary commission, wrote an interesting article[a] in which he gives several instances where localities that have been sandy deserts devoid of vegetation had by means of irrigation been converted into rich grain fields. For many years the irrigation measures have not been attended by any effects prejudicial to health. The subsurface water had been, however, gradually rising nearer to the surface, and at the same time fever had greatly increased. In Madras, where during drought little fever prevailed, during the southwest monsoons large districts were flooded and fevers became prevalent. It was observed in the Punjab that the fever appeared not to have been generated so much during heavy rains as from the conditions which follow them, and the remedy required is the rapid removal of water to prevent stagnation. In almost all low-lying tracts saturated with moisture the people were fever-stricken. Captain Galton sums up by saying: "The whole evidence shows the high fever death rate to be largely due to the stagnating water in the soil." The objections on the score of health are, generally, defective drainage, the stagnation of the water, the deterioration of well water by infiltration, or the application of too much water. These are all remediable and within the control of the engineer.

On the line of the Mutha canals in Bombay, where sugar cane is extensively cultivated, it is found that the stagnating waters retained by the roots of the plants are producing fevers, and as a consequence the government is endeavoring to reduce the area under sugar cane, hoping thus to reduce the extent of the fever. In the Northwest Provinces regular observations are made of the height of the spring level, and these are submitted annually with the revenue reports, thus indicating by the rise of this level the necessity for artificial drainage works to prevent supersaturation of the soil.

Another of the more important ill effects of irrigation is the production of alkali, or the efflorescence of alkaline salts on the surface of lands irrigated. That the effect of irrigation, however, is not altogether bad in this respect may be surmised from the following remarks made before the famine commission by Major Grey, C. S. I.:[b]

> Canal irrigation has rendered fit for cultivation large tracts in the Bahalpur State which were utterly unculturable because of alkali, and that when heavily irrigated the salts were washed off or driven into the soil.

Mr. E. O'Brien testified to practically the same effect, and stated that if properly effected canal irrigation is a cure for efflorescence. Mr. E. C. Corbin found that on lands covered by efflorescent salts

[a] Galton, Capt. Douglas, Sanitary Progress in India: Journal of the Society of Arts, London, 1876, vol. 24, p. 526.

[b] Report of Famine Commission, London, 1881, Appendix V, p. 4.

canal water has eradicated the evil of alkalinity, and that land before worthless is now highly productive.

In all probability the most valuable report on the effects and causes of alkalinity was that made by the "Reh" (alkali) commission for the Aligarh district of northern India, of which Mr. H. S. Reid was president, and among the members of which were Mr. Medlicott, the superintendent of the geological survey of India, Mr. Burch, the director of agriculture and commerce, and others. This report was printed in full by Prof. E. W. Hilgard,[a] of the University of California, and its substance is as follows:

Tracts rendered unculturable by excess of alkali exist more or less throughout the Northwest Provinces of India, but it is due to the introduction of extensive irrigation works that no appreciable increase of the area of alkali lands is perceptible. In the earlier of these irrigation works no provision for drainage was made, and they were simply built for the purpose of affording an abundance of irrigation water. Gradually, however, it was noted that crops began to languish and that the lower lands were rapidly being converted into swamps, while on the higher lands alkali spots were rapidly enlarging, while new spots were being formed where none had previously been known. The cause was apparent, and there was no difference of opinion regarding it. Not only near but within even considerable distance from the canals the subsoil water level has been raised from a depth of 50 feet to within a few feet of the surface. This subsurface water has brought up with it by a leaching process all the alkali salts existing within the subsoil thus traversed, and by evaporation these salts were diffused throughout the many feet of substrata, accumulating at the surface to such an extent as to render cultivation unprofitable and even to make the soil absolutely barren, covering it with a white crust of salt. While the committee agree that the most damage has been brought about by the rise of this subsurface water by the sidewise soakage from the high-lying canals, they state that the trouble has been greatly aggravated by the extravagant use of water by the peasants. The remedies suggested are as follows:

First, a deepening of the two canals so as to lower their water levels, and hence that of the soakage subsurface level, at least several feet below that of the land to be irrigated. Secondly, they recommend the establishment of a system of drainage. It unfortunately happens that both of these measures frequently offer great engineering difficulties in a region where, from the scantiness of rainfall, the surface conformation of the country is not favorably sculptured.

The investigations of the committee all point in one direction, viz, that the introduction of canal irrigation is the principal cause of alkali extension, and that when the removal of soakage water takes

[a] College of Agriculture, Appendix 7, Report of 1886, Sacramento, 1886, p. 34.

place almost exclusively by evaporation, irrigation by canals must end in a destructive crop of alkali where the indigenous resources of the ground in that way were comparatively harmless. *As a remedy the members of the committee almost unanimously proposed deep drainage*, and great importance was attached to keeping the natural drainage of the country open. No dams or cultivation should be allowed in the natural drainage courses, and the more water that can be gotten to flow away from the canal tracts the better, while any alkali that it may carry away in solution is so far a gain. The committee agreed that the lavish use of canal water which the gravity-flow system encouraged caused extensive saturation of the soil. As a résumé of the evil effects of irrigation it becomes apparent that they are almost all produced by a wasteful use of water and careless alignment of canals, advantage not being taken of the natural drainage of the country, together with careless irrigation of those portions of the country which are too low to afford natural drainage. It is apparent that alkalinity, once fairly developed, can never be cured under existing conditions of water level, and the same is doubtless true of malarious fevers. The primary conditions of alkalinity and fever may be expressed as defective water circulation, though mere surface drainage is ineffectual for the removal of alkali.

Relative to double cropping the soil the chief engineer of the Punjab said in his report for 1889:

> The area double cropped on the Bari Doab canal was 14.1 per cent of the whole area and nearly one-fourth of the autumn crop. It seems to be slowly increasing, which is not satisfactory, as the practice is generally detrimental and exhausting to the soil.

Similar opinions have been expressed by other engineers, and the practice of double cropping is not encouraged unless accompanied by the free use of fertilizers.

Regarding the effect of irrigation on the navigation of rivers and its effect on riparian rights, Col. Baird Smith states:[a]

> At the head of the Jumna canals the Jumna River carries at low season, during four months, a minimum of 3,500 second-feet. The canals use 3,000 second-feet, leaving the river bed practically dry. At Agra, which is about 303 miles lower down the same river, the Jumna carried at the same period about 3,500 second-feet and is an unfordable stream.

This supply is derived from subsurface drainage and seepage from canals, so that the canals have not in the least affected navigation. The Ganges River at Hardwar carries at least 8,000 second-feet, of which 6,700 second-feet may be abstracted by the canal. Still, at Narora, lower down on the same stream, and the head of the Lower Ganges canal, the stream is large enough to admit of 2,000 second-feet being taken by that canal without affecting navigation.

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[a] Irrigation in Italy, London, 1856, vol. 1, p. 385.

WATER DUTY AND EVAPORATION.

In discussing the source of supply the engineer has to determine the quantity of water required and the area of irrigable land. It is then necessary to determine the "duty of water" for the crops to be irrigated, the qualtity of the soil, and the loss to be anticipated from evaporation and absorption.

The "duty of water" is an expression which is used in India, as in the United States, to indicate the area of land which a fixed unit of water will irrigate, and, as in America, the unit adopted is 1 cubic foot per second of flow, or, as we express it, 1 "second-foot." In referring to the contents of reservoirs the Indian engineers usually quote them as holding so many cubic feet of water, but owing to the difficulty in dealing with the billions of cubic feet which a large reservoir will store, I prefer to use the American unit "acre-foot," by which is meant a quantity of water necessary to cover an acre 1 foot in depth, or 43,560 cubic feet. In designing canals in India the expenditure is frequently reckoned per linear mile of canal, and this has been found to be generally from 6 to 8 cubic feet per mile. Such a method of computation is possible only when the main and branch lines of canals have been previously determined, as it enables the engineer to regulate the cross sections of the canal along its entire length, diminishing the same as the water is expended.

The duty of water differs greatly with different soils and crops, and has usually to be determined by the engineer for each locality. The following results indicate the variability of duty as discovered in India. On the Mutha canals, near Poona in Bombay, the duty of water in 1888, during the autumn season of four months, was as follows: Wheat required 2.18 acre-feet per acre irrigated, or the water performed a duty of 170 acres per second-foot. Sugar cane, however, required 19 acre-feet per acre irrigated, the water performing a duty of 43 acres per second-foot.

Sir P. T. Cautley, from results obtained experimentally on the Delhi and the Doab canals in 1845, discovered that for that region 800 second-feet constant discharge was a fair irrigation supply for 100 miles in length of canal, assuming that a district having an area on each side of the canal from 4 to 5 miles wide would be irrigated. On each 100 miles he discovered that the canal would irrigate 237.4 square miles, and allowing that only one-third of the area controlled was irrigated, the above supply would suffice for 820 square miles.

Before proceeding to a further consideration of the duty of water, it will perhaps be well to examine some of the theories regarding its determination. The following remarks are liberally quoted from an extremely interesting investigation of this subject made by Mr. J. S. Beresford,[a] executive engineer in the irrigation branch of the Indian public works department, Northwest Provinces.

[a] Memorandum on the Irrigation Duty of Water: Roorkee Professional Papers, No. 212, 1875.

Theoretically, 1 cubic foot of water running for a month will cover an area of 60 acres to a depth of 1 foot. It is generally held that 5 inches is a safe allowance for one watering. Mr. Beresford is of the opinion, however, that more than 2 or 3 inches is rarely given. In order to determine the depth of moistened soil, the following experiment was made on July 25, when a fall of 5.5 inches of rain was gaged at the Mankri station. About five hours after the cessation of this rainfall the field examined was covered with a film of water averaging 1.5 inches in depth. Several holes were dug, and the depth of moistened soil was found to be from 16 to 18 inches. In other fields near by, free from surface water, the depth was from 12 to 18 inches—that is, 5.5 minus 1.5, or 4 inches of water will moisten ordinary loam to a depth of from 16 to 18 inches. A few days previously holes had been dug in irrigated fields of the same soil that had been recently watered, and the depth of moistened earth was found to be from 11 to 12 inches. On the 30th the 1.5 inches of standing water had disappeared, and more holes were dug; one in a low place, the other where the ground seemed a few inches higher. The depth of water in the former was 34 inches, in the latter 18 inches. The conclusion reached was that the ground absorbed the rain uniformly everywhere up to a fall of 4 inches in ten hours, the duration of the storm referred to. What fell in excess accumulated in low places and soaked those to a much greater depth.

Not a drop of rain had fallen before the 25th of July excepting a fraction of an inch on the 5th and 9th, which softened the ground sufficiently for plowing. Allowing 4 inches as the depth required for one watering, and that in the hottest weather, this is given only once a month—for if watered oftener a proportionately less quantity will suffice—the theoretical duty of 1 second-foot of water is 180 acres in the summer months. In the autumn, however, crops are rarely given more than two waterings, many only one, and the theoretical duty during the autumn season, allowing the watering to be lighter than in the summer and probably about as frequent, ought to be 320 acres, or the theoretical duty in the locality examined should, for the year, be 500 acres.

The actual duty obtained on the best divisions of the Ganges canal in the neighborhood under examination is not over 160 to 180 acres per second-foot, or about one-third of the assumed theoretical duty. There are sufficient statistics to show what the actual duty is. The next important thing is to make the theoretical and actual duty approach as closely as practicable. Considering the Ganges canal as a great machine, its principal parts are the main canal, the distributaries, the village water courses, and the cultivator who applies the water. Each cubic foot entering the head is expended principally as follows:

(1) In waste by absorption and evaporation in the main canal.

(2) In waste from the same causes in the distributaries and in the village water courses. (3) In waste through carelessness of the cultivators in not distributing the water evenly, or in allowing the ground to get saturated to an unnecessary depth. (4) In useful irrigation of the land. The object is plainly to increase the last by reduction of waste through all the rest.

From a consideration of the actual duty obtained by various experiments as compared with the theoretical duty Mr. Beresford shows that the efficiency of the canal under consideration is sometimes as low as 25 per cent. The next point established by him is the nature of the waste called absorption and evaporation, and what proportion is due to each. This discussion is extremely interesting. The loss by evaporation is the first considered. Taking a distributary 30 miles long with a water surface averaging 10 feet wide, the loss by evapora-

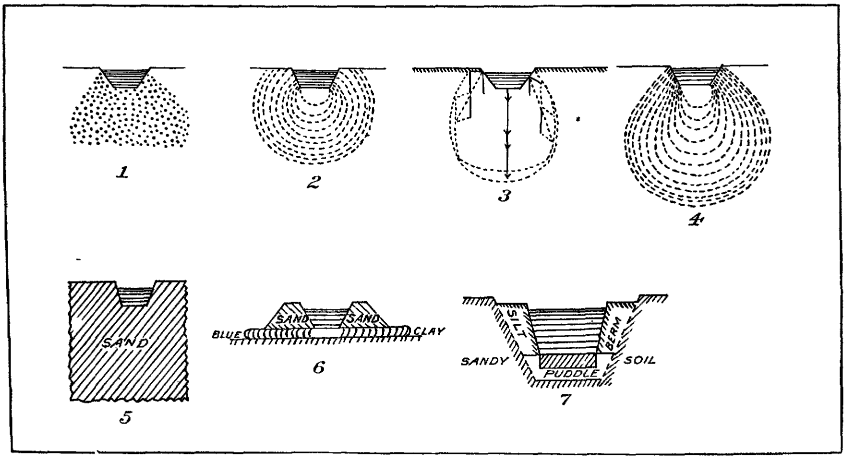


FIG. 1.—Percolation and evaporation.

tion per second in this length of water course would be 0.8 of a cubic foot by computation, and assuming that the area of water surface in the village channels equals twice the surface in a mile of the distributary, the loss by evaporation in all the village channels would be 1.6 cubic feet, or the whole loss by evaporation on the distributary 30 miles long with its minor water courses would be over 2.5 second-feet, or about 5 per cent of the probable discharge. From this we see that evaporation is not of so much consequence as far as the different channels are concerned even in the hottest weather, and may be neglected in the autumn season. The chief loss must therefore be due to percolation and absorption. The former may be said to be due to cultivation, the latter to capillary attraction.

With the aid of the accompanying illustrations (fig. 1) the following discussion will be readily appreciated. Absorption is a more complicated process than percolation. The latter takes place in bowlders or coarse gravel in a manner similar to that by which water issues through pipes or strainers in the bottom of a vessel, and the quantity discharged per second will depend on the size of the interstices of the stones, their number, the head of the water, etc. The thicker the bank through which the water is escaping, the longer and more broken the channels of escape will be and the greater the friction; but the question of discharge depends on the same principles as does the discharge through pipes. If the gravel is considered to be broken into very fine sand and the embankment formed of this material, the principles of discharge are quite changed. The interstices are now very small and act in the same manner as do capillary tubes. If empty the water rushes in and fills the cavities, and if the particles are sufficiently fine they are rammed close together, and the embankment is of a certain width, the water is retained in the cavities with greater force than that due to the hydrostatic head pressing it through. The force that thus retains the water is termed capillarity, and, although it may in reality be the same thing as gravitation, it may in this discussion be considered as quite a separate force.

Fig. 1, No. 1, represents a channel in a gravel soil or one composed of coarse sand, and the dots indicate the manner in which the water would trickle through the ground. No. 2 represents what would probably take place if the action of gravity were suspended and only absorption brought to play in a homogeneous soil. But gravity, which is always in play, modifies this capillary action, and the water has actually to follow the resultant of two forces. No. 3 explains this action, where the straight lines and their resultants indicate the distance to which capillarity and gravity alone and combined will carry the particles of water, and the result would be as shown in No. 4.

That absorption does not make itself more visible in high embankments is due to two reasons, the first being that the soil in low places is much more clayey than elsewhere, and there only are high embankments constructed, and the second that absorption ceases when the absorbing medium is limited. In an embanked channel the absorbing medium immediately stops at the outer slope, and only what has evaporated is made good by absorption. If we dig a hole in a bank of sandy soil, as represented in No. 5, and the hole be filled with water, this will dry up in a few moments, but if a layer of clay is spread on the ground, as in No. 6, and an inclosure made with the same sandy soil rammed as a natural bank and filled with water, the latter will not decrease beyond what the banks at first absorb. In the first instance the absorbing medium is unlimited; in the second it is limited to the soil in the embankment. It is for this reason alone that sandy embankments can dam up water at all. A very interesting experiment suggested by Mr. Beresford well illustrates this action. Take a bottle and close the mouth tightly with a small piece of sponge. If the bottle is then turned upside down, the sponge will become saturated, but unless pressed by the finger will give out no water. If another large, dry sponge is placed in contact with it, the water at once begins to flow through the sponge in the neck of the bottle, and this continues until the second sponge can absorb no more.

We may fairly conclude that it is the layer next the wetted perimeter that limits the quantity absorbed; that the greater its area the more it will pass through to the still greater area of the next layer. Everything being equal, we may say that absorption varies as the wetted perimeter. Hence, for sections of canals of small length we may take the loss as being so much per mile, but in general the discharge and wetted perimeter decrease with the length, but the latter not nearly in the same proportion as the former. Thus the loss up to any point may be found when the loss between two other points is found. The total loss up to any point is the loss in the first mile multiplied by some function of the length. This, in some cases, has been found equal to five-sixths.

Mr. Beresford next enters into an interesting computation in which the efficiencies of the various causes of waste are considered as algebraic factors with the numerical values determined as above, while the efficiency of the cultivator, which varies within wide limits, is taken as being between 0.5 and 0.9, where unity represents his efficiency at the theoretical limit. He finds the loss from percolation to be 1.25 cubic feet in the first mile, and in long lengths of canal about a quarter of a cubic foot per mile. The final result obtained indicates that for each cubic foot entering the distributary only 0.68 is available for fields beyond the tenth mile.

The remedies heretofore applied to lessen these defects have been few. The distributary of to-day is the same as that of thirty years ago, so far as construction of channel is concerned. The minor water courses are rarely constructed or attended by an engineer, and as a rule are badly aligned and constructed and not maintained. The cultivator is the only part of the machine which has been improved. Mr. Beresford is of the opinion that the widest field for improvement is in the minor water courses. The same applies to the private irrigating channels of the farmer of our own West. These minor channels are certainly on an average 25 per cent longer than need be. They even run a long distance through sandy ground, which absorbs a great proportion of water. The size of discharge of the module or regulator is frequently not suited to the length or conditions of the water course; and two different water courses sometimes run side by side, thus increasing the wetted perimeter and the consequent loss. The first recommendation made by Mr. Beresford is in all cases the construction of a good map. This is desired by all canal engineers, but it is rarely made, because it is thought to mean an endless amount of surveying. The saving from the construction of such a map would be more than paid for in the saving of water. It is recommended that all small water courses be puddled when running through sandy soil. A layer 3 inches thick (fig. 1, No. 7) would suffice. If the cost of this was as much as $100 per mile it would not be exorbitant, for in the length of a mile, if the discharge at the head is 1 second-foot and the loss 25 per cent, the saving effected would increase the duty by from 20 to 40 acres.

The losses in distributaries, although proportionately less than in the minor channels, are often large, especially in new channels. The particles of sand or silt carried in suspension are usually dropped in the upper reach, but particles of clay or very fine sand are carried to the very tail and are often deposited on the sides and bed to a considerable thickness, forming a more or less impervious lining or silt berm. The deposit on the bed, even a long way down, is more charged with sand than is the berm. The sand being heavier, drops to the ground, and as it is rolled along picks up the lighter particles of clay. It is not recommended that the sides of the distributaries be puddled unless in the first few miles, but the bed in sandy soil might be advantageously puddled everywhere to a thickness of several inches. A temporary measure suggested by Mr. Beresford is to collect clay and, breaking it into fine particles, throw it in near the canal head or at the falls, when the action of the water will thoroughly break up the clay and carry it into the berms and water courses miles below, thus rendering them impervious.

In 1867 Mr. E. C. Palmer, executive engineer of the irrigation works, Northwest Provinces, made some interesting experiments in the same direction on the Bari Doab canal.[a] Among other experiments conducted, one was made to determine the time required to saturate thoroughly an acre of ground. In these experiments the discharge orifices were 15 feet in length, each of the same dimensions and working under the same heads. The experiments were repeated on different varieties of land. It was found that an average depth of 3 inches of water on the whole surface represents a thorough watering on average soil. In sandy soil it was as much as 4 inches. This gives 10,454 cubic feet, or about one-fourth acre-foot, as the volume required to water 1 acre. In ordinary soil the average is actually a little over 0.2 of a foot, or 9,150 cubic feet. In these experiments the quantity of water varied, according to the soil and other circumstances, between 9,000 and 14,500 cubic feet per acre for one watering, and the time required to water an acre varied from two to twelve hours. In the dry season wheat required four waterings and 10,500 cubic feet of water. For the first watering, in order to prepare the ground for plowing and sowing, 8,000 cubic feet were required, and the same amount for each of the remaining four waterings on the standing crop. An acre of wheat, therefore, required 42,500 cubic feet to mature the crop, or nearly an acre-foot of water per acre. At the prices then current the cost to the

[a] Palmer, E. C., Irrigation Experiments: Roorkee Professional Papers, No. 35.

State was 75 cents per acre and the water rate derived was $1.60 per acre. The time required to cover an acre of land was 0.445 day, or 2.2 acres per day. For standing crops the rate is about 4.4 acres per day, as they ordinarily require not more than half as much water as is necessary for plowing.

The losses by evaporation and absorption and the duty of water are now well known in India on the various lines of canal and for the numerous reservoirs that have been in operation for many years. In the Northwest Provinces the duty of water for the year 1888 varied, for different crops, from 120 to 194 acres per second-foot, and the money value was from $143 to $286 per second-foot. From experiments conducted on the Betwa canal in the same province it appears that mixed sugar-cane and indigo crops (which need much water) required a total volume in eighty days of 310,000 cubic feet per acre for wet-weather crops, while the autumn crops required 150,000 cubic feet, or about 3½ acre-feet per acre. In some experiments made on the Nira canal to ascertain the amount of wheat which could be irrigated in a given period of time, it was found that with a second-foot of flow 8 acres of wheat could be irrigated in twenty-four hours.

In estimating the supply of water necessary to irrigate a given area of land it has been found from actual experiment that a large proportion of the land covered by any given irrigation system is always unirrigated and that water need only be provided for a certain small percentage of the total area of irrigable land. This land is not irrigated for several reasons. It may be occupied with buildings or roads or be in use as pasturage. A certain proportion receives water by seepage from adjacent irrigated fields, and another portion is occupied by towns and villages. In drawing up the projects of the great canals in the northwest it was found by data derived from experience on the Jumna canals that each second-foot of discharge was capable of irrigating 218 acres, and it was reckoned that for each acre irrigated there would be 2 other acres unwatered. Hence each second-foot represented a duty of 654 acres, or approximately 1 square mile. In drawing up the project for the Soane canals in Bengal Colonel Dickens reckoned three-quarters of a second-foot to every square mile of gross area. To date the Soane canals have been in operation fifteen years, and yet there is a demand now for not over 100 acres in 640, and the system of distributaries as designed for these canals has proved to be unnecessarily elaborate. In the Punjab it is customary to design works to irrigate only from 20 to 30 per cent of the area covered, and where water for more is demanded it is usually not given, as it is bad for the land, producing water-logging and its consequent evils. The experiments made on the eastern Jumna canal in 1845 showed that on the Saharanpur division one-fifth only of the total area cultivated was actually watered, and on the two other principal divisions the percentages were one-fourth and one-third, respectively. A similar experiment conducted the same year on the western Jumna canal showed that of the total area cultivated from one-half to one-third only was actually watered.

In gaging the velocity of discharge of rivers in India floats are usually employed. In some of the great rivers where there are weirs constructed the depth of water passing over these weirs gives a measure of the volume of discharge; in a few cases only are current meters used. In the canals the discharge is almost invariably obtained by means of wooden floats, sometimes floating on the surface and sometimes submerged. These are timed for given distances, usually marked out in an aqueduct or other portions of the channel where permanent gage rods are established. On the minor distributaries V-shaped weirs are in general use for the measurement of discharge.

MOT.

CHAPTER VI.

WELLS AND INUNDATION AND DELTAIC CANALS.

WELLS.

As before stated in classifying the irrigation works, lift irrigation from wells is extensively practiced throughout India. Wells are economically among the most important irrigation works in India, because they are the most general. They vary in depth from 10 to 60 feet, and may be unlined if shallow, lined with stone dry-packed, or with masonry.

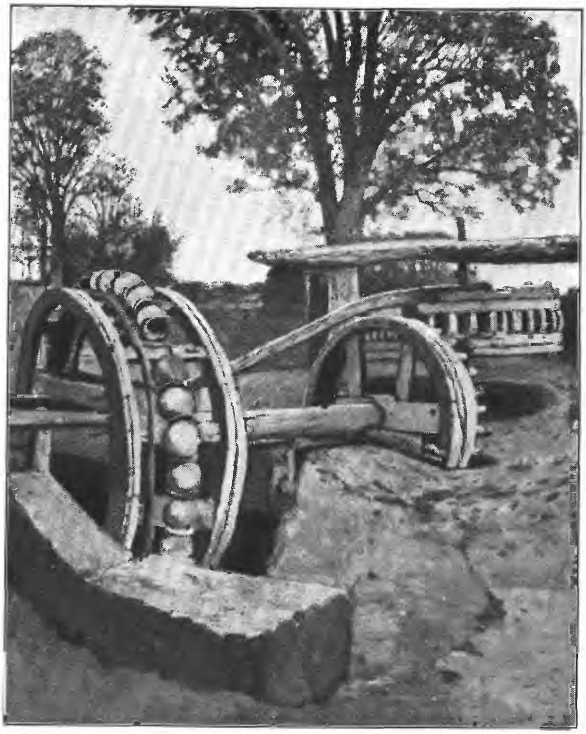
The modes of lifting water from wells are of different kinds, viz, by means of a bucket raised by a well-sweep and called the paecottah, extensively used in Bengal; by means of a mot, whereby a leathern bag is raised from the well by bullocks walking away with a rope—a method that is practiced most extensively in the Northwest Provinces, in central India, and Bombay—and lastly, by means of the Persian wheel (Pl. IV, *A*), employed chiefly in the Punjab. As an indication of the extent to which wells are employed in irrigation, we find in the Central Provinces 650,000 acres irrigated from tanks, while 120,000 acres are irrigated from wells. In Madras there are 31,000,000 acres under cultivation, of which 5,320,000 acres are irrigated by canals and tanks, and 2,000,000 acres by 400,000 wells. In the Northwest Provinces in 1888 the area irrigated by wells was 358,600 acres, or 23.6 per cent of the whole area under cultivation. In Coimbatore there are said to be 100,000 wells sunk, in many cases through hard rock, to a depth of 80 or 90 feet, and capable in ordinary seasons of irrigating from 1 to 4 acres each. As a contrast with the utility of canal or tank irrigation it has been estimated that the Ganges Canal alone replaces the work of 300,000 men and 1,300,000 bullocks, besides increasing the value of crops irrigated by wells by 50 per cent.

The paecottah of southern India, also called the lât in upper India or in Egypt the shadouf (fig. 2), is usually worked by two men who labor from six to eight hours daily. Authorities estimate that they will raise from 400 to 2,000 cubic feet per second per day. From moderate depths three men working two paecottahs will water three acres a season. The mot (fig. 4) is a leathern bucket made of a whole oxhide, and is raised by two bullocks walking down an incline and drawing after them the rope attached to it. When the bucket reaches the surface it is emptied automatically or by an attendant. In Bombay the bullocks usually return by walking backward; elsewhere they are not trained to do this, and they face about to return (Pl. III). Sometimes two yoke of oxen are used hitched alternately to the rope.

FIG. 2.—Paecottah.

From the Calcutta Engineers' Journal it appears that two bullocks working ten hours a day for a season of ninety days will raise with the mot 162,000 cubic feet of water, or about 3¾ acre-feet.

The Persian wheel (fig. 3) consists of a large wheel revolving vertically in a shallow well. On its outer periphery are a large number of



A. PERSIAN WHEEL.

B. PAECOTTAH.

small buckets. These lift the water and empty it into a trough, whence it runs into the ditches. The wheel is made to revolve by

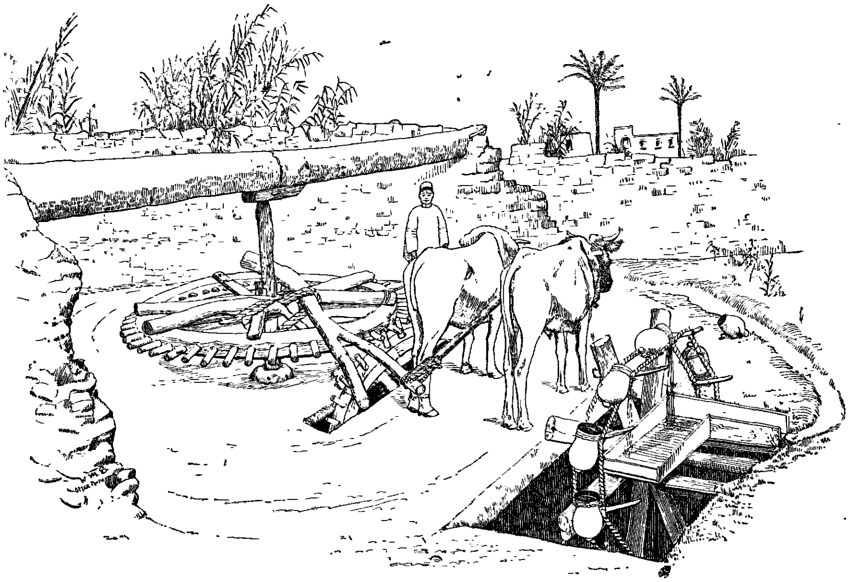


FIG. 3.—Persian wheel.

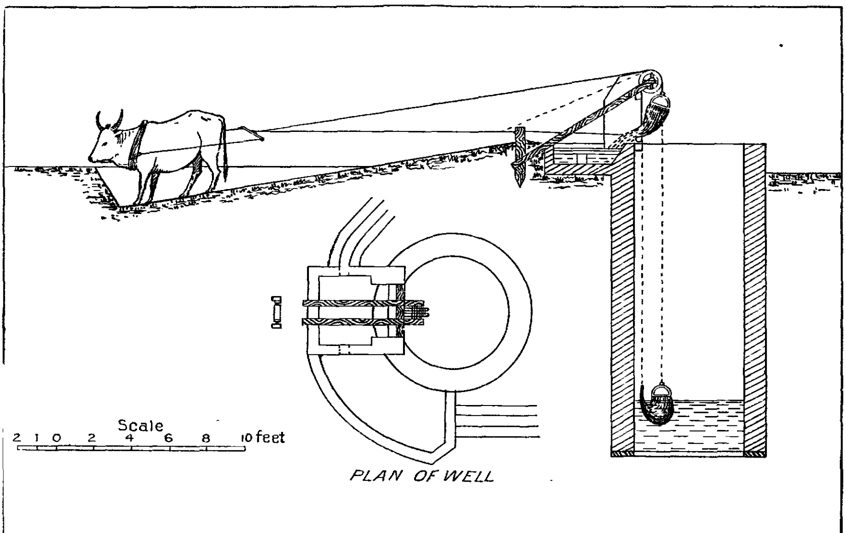


FIG. 4.—Single mot.

means of a cogged gearing and is turned by two bullocks walking in a circle and hitched to a horizontal sweep. By this method it is estimated that 2,000 cubic feet of water may be raised per day.

INUNDATION CANALS.

The inundation canals of India have been constructed and are chiefly used in the valley of the Indus, and as they have no permanent head-works they depend for their utility on two conditions generally absent in the United States. First, the stream from which an inundation canal is taken must flow at a high elevation relative to the surface of the surrounding country; that is, its bed must be practically on the summit of a ridge, as is the case with the lower Sacramento and Mississippi rivers. Second, the river must be subject to great annual floods lasting through a long period. Inundation works have been among the most profitable canals operated in India, chiefly because of their simplicity of construction. As a general thing the inundation canals diverted from the rivers of the Punjab and Sind are used to irrigate the lowlands only. Cuts are made from the river inland for a certain distance, thence the canal line follows the general slope of the country. By these canals the autumn crop is watered when the river is in flood. Large quantities of silt are left in the beds of the canals or heaped up at their mouths, varying from 1 to 8 feet in depth, and this is cleaned out during the cold season. From the main canal the water is distributed to the fields by branch canals and minor channels in a mode similar to that employed in irrigating from other canals.

There are no works at the heads of inundation canals to control the supply of water. They are constructed on rivers whose courses are so uncertain that they may at any time desert the head, when the water will have to be brought into the canal by a new mouth excavated the next season. Under any circumstances the deposit of silt at the head is considerable and would naturally be increased by anything in the shape of a dam. The labor in clearing the silt is a heavy annual charge on the benefits received from the water and the numerous deserted channels in various parts of the country show that unless carefully maintained these canals soon become useless.

Channels thus opening direct from the river and unprovided with regulating works are subject to several disadvantages. The current of a river may set on the mouth of the canal or on the bank and wash it away. The supply may become too great in the large floods or may be altogether cut off owing to the destruction of the head or the changing of the course of the river. The violent action on the mouth of the channel may be checked to a certain extent by revetments and groynes and other river-training works, but these also have the effect of diverting the action of the stream from its natural course and may throw it away from the canal head.

Nearly all Indian rivers from which inundation canals are diverted flow in broad curves through wide flood plains. At places where the curves have changed are extensive depressions containing water, called *dunds* in Sind and *sotas* in Bengal. These are similar in all respects to the bayous or lagoons of the Lower Mississippi and neighboring rivers. These depressions are frequently the sites of the heads of inundation canals, though not infrequently such canals head in the true bank of the main river from which they draw their supply. The object in using dunds as canal heads is that they are much larger than the canals they feed, and as the velocity through them is correspondingly low, silt which would otherwise be deposited in the canal is deposited in the dunds, thus reducing the cost and difficulties of canal clearance.[a]

Experience seems to have taught the native rulers of India, who constructed most of the inundation canals, the necessity of locating head-works at points where they would be screened from the full force of the current during flood. Experiments by Colonel Tremenheere, R. E., on these show that: 1. Inundation canals which draw their sup-

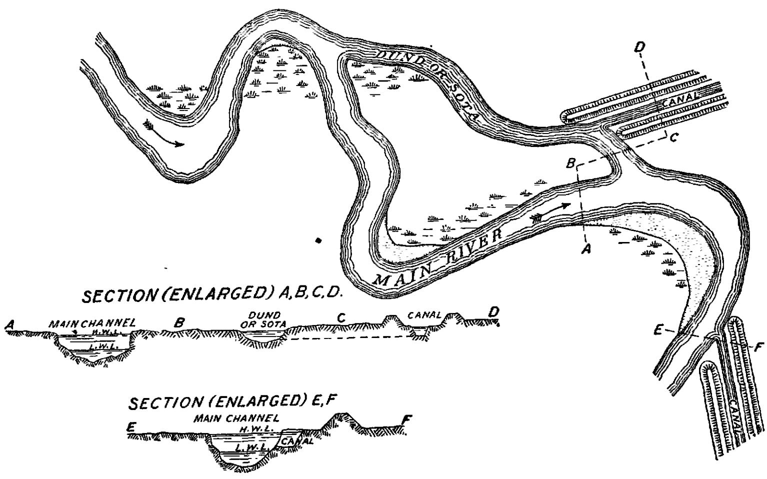


FIG. 5.—Inundation canal heading in dund.

ply from branches separated from the main river by islands covered by brushwood and long grass contain a comparatively small amount of suspended matter. 2. Canals having their heads in the main stream where the velocity is normal usually contain silt to the extent of one three-hundredths by weight, and that about one-third of this quantity may be deposited in the canals. 3. Canals having their heads in the main streams at a point where the channel is restricted and the velocity increased may contain silt to the extent of one two-hundredths by weight, of which one-half may be deposited in the canal.

In the Punjab the inundation canals begin to fill with water about the last of April and run dry toward the end of September. During the earlier months, when the flood is high, lift irrigation is practiced. The superiority of the river water for agricultural irrigation over

[a] Buckley, R. B., Irrigation Works in India and Egypt, E. & F. N. Spon, London, 1893, p. 18.

well water is demonstrated by the fact that near the heads of the Punjab canals the cultivators prefer to pay canal rates and to lift the water from the canals rather than from wells.

The freshets in the Indus commence in March and high flood is most frequent in August. The lower stages commence at the end of October. The velocity of the current in the dry season varies from $2\frac{3}{4}$ to $3\frac{3}{4}$ miles per hour. In the freshets it is from 5 to 7 miles per hour and has sometimes reached a maximum of 8 miles. The width of the water surface of the Indus in low water or the dry season varies from 1,500 to 5,000 feet, the average depth being from 3 to 6 feet. The rise of ordinary floods is from 5 to 7 feet in twenty-four hours and averages 50 feet above low-water level. The highest recorded flood was 92 feet above low-water level.

From the borders of the Punjab the Indus flows for a distance of 450 miles through an arid alluvial plain, almost every portion of which has at some time been swept by the river or its branches. Owing to the deposits of silt the bed and banks of the river are continually rising. It has been estimated that the Indus annually brings down sufficient silt to form an island 42 miles long by 27 miles broad and 40 feet deep. When the river bed attains a certain height the water falls over the bank and the river changes its course. It is this movement which causes the difficulties of irrigation in the Sind, and has resulted in the construction of inundation works.

Inundation canals are generally carried away from the river in an oblique direction. They vary from 10 to 300 feet in width and from 4 to 10 feet in depth, and resemble natural water courses more than canals. The following table gives an idea of the dimensions of six of the larger inundation canals in the Sind, and their cost and revenue for the year 1899–1900:

Sind inundation canals.

Name.	Main canal.	Discharge of canal.	Area irrigated.	Duty, acres irrigated per second-foot.	Average annual rainfall.	Capital outlay to 1900.
	Miles.	*Second-feet.*	*Acres.*		*Inches.*	
Begari	158	5,664	186,500	55.62	0.79	$1,148,000
Desert		3,509	149,660	53.78	1.90	845,000
Ghar	298	3,210	250,000	39.24	.83	147,000
Sukkur	130	3,439	90,000		.87	470,000
Fuleli	1,043	3,352	380,000	34.69	.80	563,000
Jamrao	101	3,200	250,000		4.58	2,220,000
Total			1,306,160			5,393,000

In the Punjab the capital outlay on the five inundation works for which capital accounts were kept was, to the end of 1901, $687,000.

The working expenses were $197,000 and the net revenue $74,000. The average per cent of net revenue on capital expended on these canals was 9.58, while on the Indus and Shahpur canals an interest of 23.55 and 28.76 per cent, respectively, was realized.

The following table gives the important data concerning the six principal inundation canals of the Punjab:

Punjab inundation canals.

Name.	Main canal.	Discharge of canal.	Area irrigated.	Average annual rainfall.	Capital outlay to 1901.
	Miles.	*Sec.-feet.*	*Acres.*	*Inches.*	
Upper Sutlej	225	9,780	247,683	13.0	$276,000
Lower Sutlej	363	5,700	271,545	6.8	
Chenab	262	4,894	130,455		
Indus	713	5,164	225,000	6.6	238,000
Jhelum (Shahpur)	79	1,125	42,000	12.8	72,000
Muzaffargarh	886	7,284	318,225	5.2	
Total			1,234,908		

The total area irrigated in the Punjab by inundation canals was 1,220,000 acres, about two-fifths of which were autumn crops.

DELTAIC CANALS.

Before entering into a discussion of the perennial canals of the higher lands of India a general description will be given of the great works constructed near the mouths of the larger deltaic rivers, as many of the weirs and mechanical modes of controlling water in use on them will be of interest. These canals have been constructed in an almost level country, with low slopes, and are universally intended for navigation as well as for irrigation. Aside from the mechanical details referred to, these canals are of little interest to the American engineer, as the conditions do not favor similar works in our country.

Deltaic canals are true perennial canals, but are here distinguished from the latter because they are situated on a different class of rivers from those found in the United States, and apart from the head-works, regulators, and other prominent works upon them do not resemble such irrigation canals as are likely to be constructed in this country. As the name implies, deltaic canals usually head at the points at which rivers divide into numerous branches as they enter their deltaic tracts near the ocean, as does the Mississippi near New Orleans. A number of such canals have been built in India, of which several large ones are in Madras and two in Bengal.[a]

[a] Buckley, R. B., Irrigation Works in India and Egypt, E. & F. N. Spon, London, 1893, p. 93.

A river which runs through the soft soil of a delta easily changes its course, and the relative dimensions of the main channel and its bifurcations or branches are sometimes greatly altered by floods. An example of the extent of such changes may be cited in the case of the floods on the Mahanadi River, which were carefully measured. It was calculated that during the period which elapsed between the floods of 1855 and 1872 the capacity of the Mahanadi branch had diminished to the extent of nearly 80,000 cubic feet, or 10 per cent of its ordinary volume. A common feature of deltaic rivers is observed in the diminution of the areas of their cross sections as they approach the sea. This is shown in the discharge at the head of any particular reach of the river being always greater than the noted discharges at the heads of the branches which take off at the lower end of such reach.

There are many advantages in irrigating upon a river delta, as the soil there is usually a rich alluvium and the slope of the country always uniform and gentle. Moreover, the branches of the stream flowing through the land are of uniform slope, and thus afford excellent drains for the surplus water. As the river channels flow in built-up ridges somewhat above the level of the surrounding country, it is possible by throwing a weir across the delta head and running branch canals along the margins of the streams to easily command the whole delta area for irrigation. As from the nature of the conditions the whole area under command of the canals is subject to inundation, it is necessary to confine the floods to the river channels by means of a series of marginal embankments or levees. As such rivers have a tendency to change the amount of flood which they pass through different branches, it is generally necessary to regulate the discharge of each of these by weirs across both the main and branch channels. Furthermore, because the cross sections of the branches reduce as they approach the sea it is essential in designing levees that provision be made to permit the discharge of the full volume which any branch may have to carry.

An admirable example of deltaic canal is furnished in Egypt in the delta of the Nile, between Cairo and Alexandria. A few miles below the former city, at the head of the delta, is a great masonry weir, the Barrage du Nil. This consists essentially of two great open regulating bridges placed across the two deltaic branches of the Nile, the Damietta and Rosetta branches. The floors of these regulators are at the level of the river bed, and the only obstruction offered to floods are the piers. The openings between the piers are 16.4 feet in the clear, covered with arches, which carry the roadway overhead. There are 71 spans in the Damietta barrage and 61 in the Rosetta barrage. The entire length of the former is 1,765 feet and of the latter 1,525 feet, and these afford an obstruction to the Nile amounting to about one-fourth of the original waterway.

In the presidency of Madras the most notable canals of this character are those at the deltas of the Godavari and Kistna rivers. On the Godavari system there were completed, at the end of 1899, 503 miles of main canals and 1,905 miles of distributaries, which commanded 1,267,200 acres and actually irrigated 653,400 acres. The total expenditure on this work to end of 1899 was $4,355,000. The weir at the head of this canal was constructed in 1844. The river drains an area of 115,570 square miles above the weir, and the crest of this latter is 38 feet above mean sea level and 33 miles from the coast. The maximum discharge of the river at this delta head was 1,210,000 second-feet, with a depth of 15½ feet over the weir crest. The head-works at Douleshwaram consist of a weir across the river 18,000 feet in length and of three sets of scouring sluices and regulators from which the three main canals irrigating the eastern, central, and western deltaic regions are supplied. The river is broken by islands to a length of 4,500 feet, on which earth embankments connect the various portions of the masonry weir. There are also flanking embankments, making the earthwork in all 7,000 feet long, and there are 2,500 feet in length of wing walls. The total length of the masonry weir is 11,946 feet. It is founded on walls 6 feet in diameter sunk 6 feet in the river bed, and is 19 feet thick, consisting of a core of sandstone faced by a curtain wall 7 feet high and 4 feet thick at the base, having a masonry fall 28 feet broad and 4 feet thick. Below the weir is a massive stone apron 80 feet broad. On both banks are masonry wing walls and revetments. The three sets of regulating sluices have the following dimensions: The eastern consists of 13 gates 6 by 8 feet, the central of 15 gates 6 by 8½ feet, and the western of 15 gates 7½ feet high and varying from 5½ to 6 feet in width. The mean supply to the eastern delta during the summer season is 2,826 second-feet, which is the carrying capacity of that canal. The area irrigated is 170,000 acres. The maximum discharge of all the main canals during 1899 was 13,201 second-feet. The carrying capacity of the main central canal is 1,745 second-feet, and it irrigates 122,400 acres. The supply of the western canal is 3,950 second-feet and it covers 319,580 acres. The canals vary in bottom width from 114 feet on the central canal to 225 feet on the western canal, with varying depths of from 7 feet on one to 10 feet on the other.

The River Kistna has a course of about 800 miles from its source in latitude 18° 01′ and longitude 73° 14′, down to the sea, about 45 miles south of Masulipatan on the Coromandel coast. Its drainage area may be taken at 97,050 square miles, and its maximum flood discharge at 820,000 feet per second (fig. 6).

The idea of damming this river by an anicut at Bezwada, 60 miles above its mouth, where the configuration of the country lent itself in an exceptional manner to the construction of such a work, was first mooted in the year 1792, but nothing was definitely decided until 1847, when Maj. (now Sir) Arthur Cotton and Capt. (now Sir) Atwell Lake submitted a joint report on the proposed anicut and on the scheme of irrigation for the eastern and western deltas. After considerable discussion the court of directors sanctioned the construction of the anicut, together with subsidiary works, on the 5th of January, 1850, for a sum of $513,000. The head sluices and locks were commenced in 1852 and completed in the following year. The anicut itself was commenced in November, 1853, and completed in 1855, in spite of great delays and losses caused by an extraordinary flood and an outbreak of cholera.

The head-works consist of a weir 3,198 feet in length, and the greatest flood rose 19½ feet above its crest. The eastern main canal has a

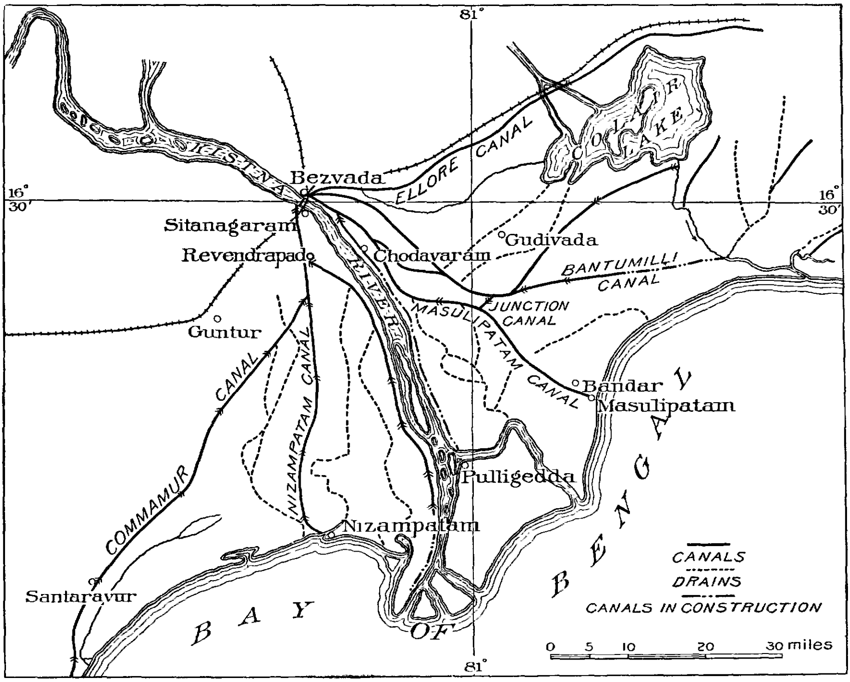
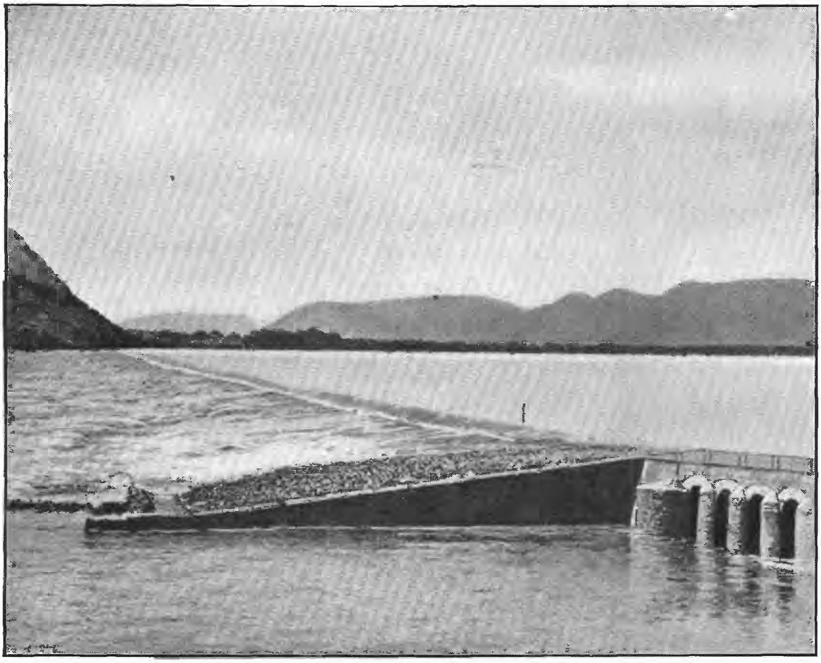


FIG. 6.—Kistna canal system.

bottom width of 200 feet and a depth of 8¼ feet. The western canal has a bottom width of 230 feet and a depth of 8 feet. The total length of main canals in 1899 was 372 miles and of distributaries 1,625 miles. The total area of irrigation in 1899 was 505,087 acres. The crest of the weir at the head-works is 6 feet in width and 15⅕ feet above the top of the foundation. The total width of apron below the crest is 257 feet. (Pl. V, A.) The foundation consists of a double row of wells, and at each end of the weir is a set of scouring sluices of 30 gates, each 6 feet wide. The regulating gates are of the same dimensions. The crest of the weir being too low for the required supply, a temporary dry stone wall 4 feet high is annually built on it, and after the stone has



A. KISTNA ANICUT, WITH RIVER IN MODERATE FLOOD.

B. HEAD SLUICES OF EASTERN CHANNEL FROM KANIGIRI RESERVOIR.

been washed off by floods it is used in the repair of the apron. Shutters have recently been substituted for this temporary device.

The Cauvery deltaic canals, from the river of that name in Madras, irrigated 919,540 acres in 1899. The length of main canals is 844 miles, of distributaries 1,250 miles, their maximum discharge being 31,060 second-feet. So far the cost of these works has been $704,000.

The data upon which the size of the head sluices and main canals were calculated was 2 cubic yards of water per hour per acre, or a duty of 66 acres per cubic foot per second. This, it was calculated, could be maintained for the ultimate proposed area of irrigation of 470,000 acres throughout the irrigation season except for about forty days in the year. Experience, however, has proved that, owing to the heavy clayey nature of the delta soil and care taken in the distribution of the water and its utilization by the ryots, that a duty of 90 acres per cubic foot per second may be reckoned upon, pointing to an ultimate development of no less than 700,000 acres, or 50 per cent in excess of the originally calculated irrigable area.

The East Tamileru escape or Chattaparru outlet at 40 miles 20 chains, Ellore Canal, eastern delta, was built in 1890–91 to provide for passing the flood water of the east branch of the Tamileru out of the canal. The work consists of four arches, 20 feet span each, at either end, and eleven small arches between 7½ feet span each, the latter fitted with screw-gearing shutters. There is a footbridge over the entire work.

The Sangam anicut project was sanctioned in 1881 for the purpose of improving and extending irrigation in the northern section of the Penner River delta. Its principal features were the construction of a weir 4,290 feet long; a head sluice of 40 vents, of 4½ feet span each, to supply the main canal; the excavation of a main canal 6 miles long and 157 feet bottom width, to fill the Kanigiri reservoir; improvements to an existing branch channel, which was to be supplied from the main canal; raising the banks of the Kanigiri reservoir, to increase its capacity, and the excavation of distributaries from the Kanigiri reservoir and Duvur tank. The anticipated ultimate area of irrigation under the project was 94,000 acres producing a net revenue of $78,900.

The works have been carried out more or less as they were designed. The project came into operation in 1886–87, and there has been a steady increase of cultivation, except in 1891–92, when there was a falling off, owing to the scarcity of water, which amounted nearly to famine in the Nellore district. According to the returns of 1895–96 the area irrigated was 77,347 acres and the net revenue, after deducting working expenses, amounted to $44,000.

Sangam anicut is built across the Penner River at the village of Sangam and consists of a solid wall of masonry with scouring and head sluices, all founded on wells. The rear of the anicut is provided with a substantial sloping apron built of large bowlders with the interstices filled in with concrete and strengthened by binding walls.

The length of the anicut crest between south wing and scouring sluice is 4,076 feet; top breadth, 4½ feet. The upper course is built to a thickness of 2 feet, with cut laterite set on edge in Portland cement. The crest is 7 feet above deep bed of river, or 10.50 feet above M. S. L. The anicut has been designed to discharge

597,000 cubic feet per second and the wings and other masonry works attached to it have been built to meet the contingency of an additional 5 feet rise of water in the river during extraordinary floods. The scouring sluice, which is built in continuation of the anicut, is constructed of brick in surki mortar, except the floor and apron, which are paved with cut stone, and the sides and faces of piers cased with cut laterite. It is provided with 14 vents, 6 by 6 feet, which are opened and closed by means of screw-gearing shutters. The under sluice is also intended to pass down the regulated share for the Nellore anicut system lower down the river.

The Sangam head sluice is built in similar style to that of the scouring sluice and has 21 vents, 6 by 6 feet, for the regulation of water into the Kanigiri main canal, which supplies the Kanigiri reservoir. It has been designed to supply water for the irrigation of 94,000 acres by a discharge of 4,800 cubic feet per second when water in river is flush with anicut crest. The floor level of the sluice is 98′ M. S. L., or 2 feet above that of the under sluice.

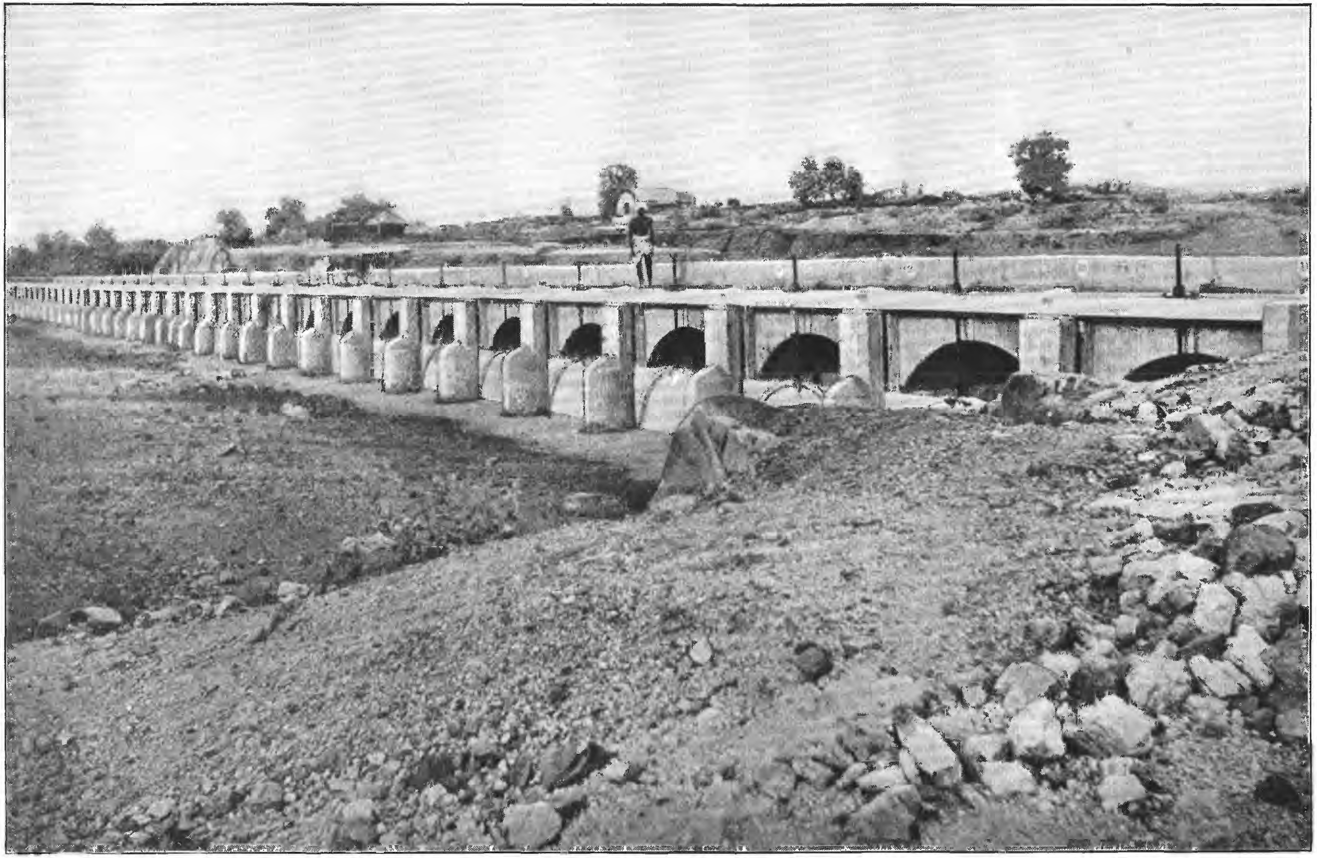
Kanigiri tank head sluice, southern channel, is intended to discharge sufficient water for the irrigation of 17,500 acres under southern channel and 10,500 acres under branch or central channel. It is built of brick in surki mortar, the floor and apron being paved with cut stone. It is provided with 4 vents, 6 by 4 feet, and worked with screw-gearing shutters. Eastern channel head sluice is built of brick in mortar with the exception of the floor, which is paved with cut stone, and the piers cased with cut laterite. [Pl. V, *B*.] It has 16 vents, 6 by 4 feet, capable of discharging 934.5 cubic feet per second when the reservoir maintains F. S. L., the area to be irrigated under the channel and its branches being 62,300 acres. The supply of water to the channel is regulated by means of screw shutters. The sill level is 73′.

Kanigiri masonry dam or flush escape [Pl. VI] is intended to pass the surplus of the reservoir over rocky ground, and is built entirely with rubble in surki mortar, the crest being placed 2 feet below F. S. L. (94′.95) of the reservoir, or 92′.55 M. S. L.; but in order to maintain a full supply, grooved iron standards have been fixed on top, provided with planks for raising and lowering the water as required. The length of the dam is 280 feet, with a top breadth of 4½ feet.

Kanigiri escape sill is placed on the same level as the crest of the masonry dam and acts jointly with it. The masonry is composed of brick in surki mortar, resting on rock foundation. The escape consists of 31 arches of 9 feet span with a roadway on top, and in front screw-gearing shutters have been fixed to hold up the water to F. S. L.[a]

The principal remaining deltaic canals in India are the Midnapore and Orissa canals in Bengal. According to the revenue report of Bengal for the year 1901, it appears that the total capital outlay to date on the Orissa canals, exclusive of interest charges, was $17,436,000, and on the Midnapore canals, $5,953,000. The Orissa canals were originally constructed by the East India Irrigation and Canal Company and the source of supply is derived from three principal rivers—the Mahanadi, the Brahmini, and the Byturni. The minimum discharge of all these rivers during the cold weather or autumn crop is 6,612 second-feet, and the maximum discharge of the canal is 6,058 second-feet. The gross area commanded is 597,792 acres, of which at present 274,974 are irrigated. The works consist of 280 miles of main and branch canals and 1,123 miles of distributaries. There are three distinct weirs at the head of this canal. One at the point where the

[a] Administrative report Irrigation Branch: Public Works Dept., Madras Presidency.



KANIGIRI RESERVOIR ESCAPE.

river bifurcates is 3,600 feet in length and 12 feet above the river bed. The second weir is across the Mahanadi River itself, and is $1\frac{1}{4}$ miles long and 12 feet high. The third, across the Biropa River, is 1,980 feet in length and 9 feet above the river. The system of canals is capable of great extension.

The Midnapore canal was also constructed by the East India Irrigation Company. Its supply is derived from the River Cossye, the catchment basin of which is so small that the supply of water in the canal varies with the rainfall on the district covered by the canal itself. The works were commenced by a company in ignorance of the real supply available, and the distributaries have actually been constructed to command an area of 180,000 acres, of which 125,000 are at present irrigable.

The canal is divided into four lengths, the first of which is taken off above the weir at Midnapore. In the twenty-fifth mile this tails into the river where the second weir is built across it. The canal crosses the river at this point and the second length is diverted on the opposite bank. A large portion of the remaining length of the canal is constructed principally for navigation. The automatic sluice gates constructed in the weir at Midnapore are of peculiar interest and will be fully described in another place.

Deltaic canals.

Name of canal.	Province.	Main canals.		Area irrigated.	Rainfall.	Expenditure to 1901.
		Miles.	*Discharge, sec.-ft.*	*Acres.*	*Inches.*	
Orissa	Bengal	280	6,058	274,974	75.8	$17,436,000
Midnapore	do	72	1,500	125,000	59.6	5,953,000
Godavari	Madras	503	13,478	662,210	42.8	4,355,000
Kistna	do	372	8,942	547,806	27.4	4,465,000
Penner	do	31	6,634	145,470	30.1	1,987,000
Palar	do	163	5,546	45,206	25.2	697,000
Kurnool	do	190	1,440	62,098	25.2	7,275,000
Cauvery	do	844	45,525	919,539	52.3	919,000

CHAPTER VII.

PERENNIAL CANALS.

SOURCE OF SUPPLY.

Perhaps the first consideration in designing any irrigation work is the source of supply. In the case of perennial canals this may be from perennial streams or from storage reservoirs. In either case the Indian engineer deems it necessary first to make a thorough examination of the hydrography of this source to ascertain the quantity of water available and the point of the river's course at which the canal can be taken off. The head-works are almost invariably located high up on the river to command a sufficient level and if possible to tap the stream where the water is clear and not laden with silt. By thus locating the head-works it is usually possible, owing to the greater slope of the country, to reach the high lands or watersheds of the areas to be irrigated with the shortest possible diversion line. By diversion line is meant that portion of the canal's course which is necessary to bring the line to the neighborhood of the irrigable lands, and which is usually unprofitable, as it does not irrigate directly any land. The disadvantages of locating the canal head-works high up on the streams are serious. The country having an excessive fall requires rough hillside cuttings, perhaps in rock, and the line is, moreover, intersected by hillside drainage, the passage of which entails serious difficulties.

Perennial canals are taken chiefly from the great perennial rivers which issue from the Himalayas, from whose melting snows the canals receive an abundant and constant supply of water. The smaller perennial canals in portions of Madras and Bombay are chiefly fed by storage water collected in reservoirs and tanks in the hills. The great rivers of the Punjab and the Northwest Provinces rarely discharge less than 4,000 second-feet, and some discharge many times this volume, while in times of flood their discharge increases to as high as 1,200,000 second-feet and more.

In the arid region of the United States no such streams as these exist, though a few of our great rivers, as the Missouri, Columbia, Rio Grande, Sacramento, and their principal branches, carry large volumes of water, much of which it is to be hoped will at some future time be utilized for irrigation. Because of the similarity existing between these and the great Indian rivers, the country which they traverse, and its climate during the cultivation of the autumn crop, the use of the waters of these great streams will be of immediate interest to us and may furnish useful lessons and examples when we commence the construction of similar works. The topography of the Punjab and Northwest Provinces at the foot of the Himalayas has been described in detail in another place. It is very similar in many respects to that of the great California Valley on the western slopes of the Sierras and that of the Colorado and Wyoming plains at the foot of the Rockies. The rivers issue from the sub-Himalayas and Sewaliks through foothills similar in appearance and with surface slopes corresponding to those of the Feather, American, Stanislaus, and other rivers flowing from the Sierras in California, or to the Arkansas and Platte rivers issuing from the Rockies.

In designing these great perennial canals the Indian engineer first makes a careful topographic survey of the entire region to be irrigated, and numerous trial lines are run before the final location of the main and distributary canals is decided upon and the position of the head-works definitely fixed. In the case of the rivers having a constant regimen training works are unnecessary, as the head-works are generally located in narrow portions of the river where the banks are firm and the channel stable. At the entrance to some of the larger canals heading in the plains, notably the Agra and the Lower Ganges, expensive river-regulating works are required to control the movements of the river channels.

The machinery of a great canal consists usually of the following parts: The head-works at the point where the canal is diverted from the river, the main canal, the distributaries, and the minors. Each of these units of the system has its own set of regulating works and escapes to control the supply of water in the canal. Between different canals these differ but slightly, the point of greatest difference usually being at the head-works and in the first few miles of diversion line. Here various devices have been resorted to for the passage of hillside drainage.

GANGES CANAL, NORTHWEST PROVINCES.

It is probable that the first attempt to construct a canal on the interfluve between the Ganges and Jumna rivers occupied by the present line of the Ganges canal was made by Mohammed Aboo Khan at some time early in the eighteenth century. This canal consisted of a shallow ditch 12½ miles long taken from the west Kali Nadi and was filled by means of a temporary weir thrown across that stream. No masonry works were constructed, and much damage was done by the flooding of lands above the weir. The second attempt here made was in 1827, when Captain Debude tried to restore the above by putting in permanent head-works across the Kali Nadi. This plan contemplated the extension of the canal through Meerut to Aligarh, and it was also intended that a dam should be thrown across the Hindun River and the water of both streams utilized. This was merely an attempt to improve on old and bad methods. The third and present project was purely a British one. In 1836 Col. John Colvin, C. B., proposed to build a canal from the Ganges River heading at Hardwar.

The famine of 1837 and 1838 caused an increased desire for the construction of this canal, and in 1839 Lord Auckland, the Governor-General, sanctioned the surveys. In 1840 Sir P. T. Cautley made the first surveys and reported on the project, and from then to 1845 about $50,000 per annum was expended chiefly on surveys. In his report[a] Colonel Cautley said:

> To deny the value of irrigation to agriculture in an arid country is like denying the value of manure to an European farmer.

On the strength of the report made in 1840 the board of directors decided on the construction of the Ganges canal as an irrigation work, the canal as sanctioned being designed to carry 6,750 second-feet. When Lord Ellenborough was Governor-General, between 1842 and 1843, he did everything to discourage the project and so modified the sanction that only a small navigation canal could be constructed. During Lord Ellenborough's governorship to 1847 Colonel Cautley was in England attempting to further the project, and the works were carried on by Major Baker. In 1848 Lord Harbinge became Governor-General, and sanctioned the work as originally devised, urging its immediate construction, which was at once prosecuted by Colonel Cautley.

In 1845 Colonel Cautley submitted detailed estimates for three separate projects, in each of which the discharge at full supply was to be 6,750 second-feet, of which it was assumed that 1,000 second-feet would be lost by evaporation, absorption, and navigation. The last of these projects was estimated to cost about $4,670,000 and render irrigable an area of 1,470,000 acres. When in 1847 the Government directed that these works should be constructed, among other instructions they said that the primary object of the canal was to be irrigation, navigation being carried only as far as not inconsistent with irrigation, thus reversing the instructions of Lord Ellenborough's government.

Water was first admitted into the canal in 1854 and irrigation commenced the following year. During the next few years defects in the works gradually came to light, and in 1864 an investigation was ordered by the government. At the close of that year detailed estimates were submitted for rectifying the principal of these defects. Previous to this Sir Arthur Cotton reported on the works considered by him necessary for the improvement of the canal. In his report he stated that the head of the canal was too high up on the river; that the whole canal had been so cut as to carry the water below the level of the surface, entailing a vast unnecessary excavation; that the whole

[a] The Ganges Canal, 3 vols., London, 1860.

of the water was admitted at the head, so that it was conveyed in places 350 miles to the land to be irrigated, and that there was no permanent dam across the river at the canal head so as to secure the supply of water. In addition to this Sir Arthur Cotton enumerated 14 minor defects in the canal. In 1868 the attention of the government was drawn to the question again by a note from Colonel Strachey, in which he pointed out that though the existing Ganges canal was able to supply the upper portion of the interfluve, there would be tracts lower down to which the available water in the river could hardly be distributed by the construction of a lower canal, as suggested by Sir Arthur Cotton. This led to the projection of the system of works

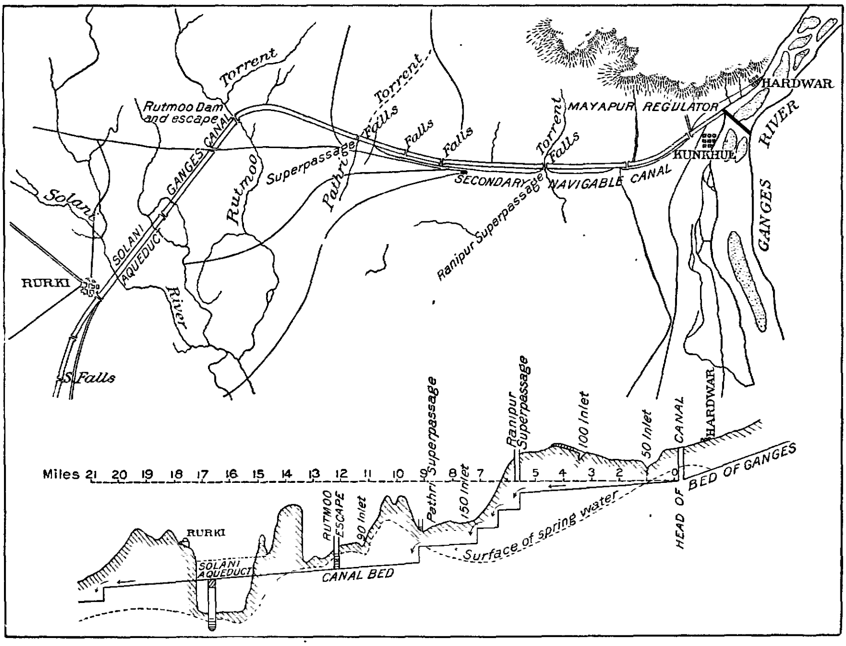


FIG. 7.—Plan and profile of Ganges canal, Hardwar to Roorkee.

known as the Lower Ganges canal and to material alterations in the measures for rectifying and completing the old Ganges canal.

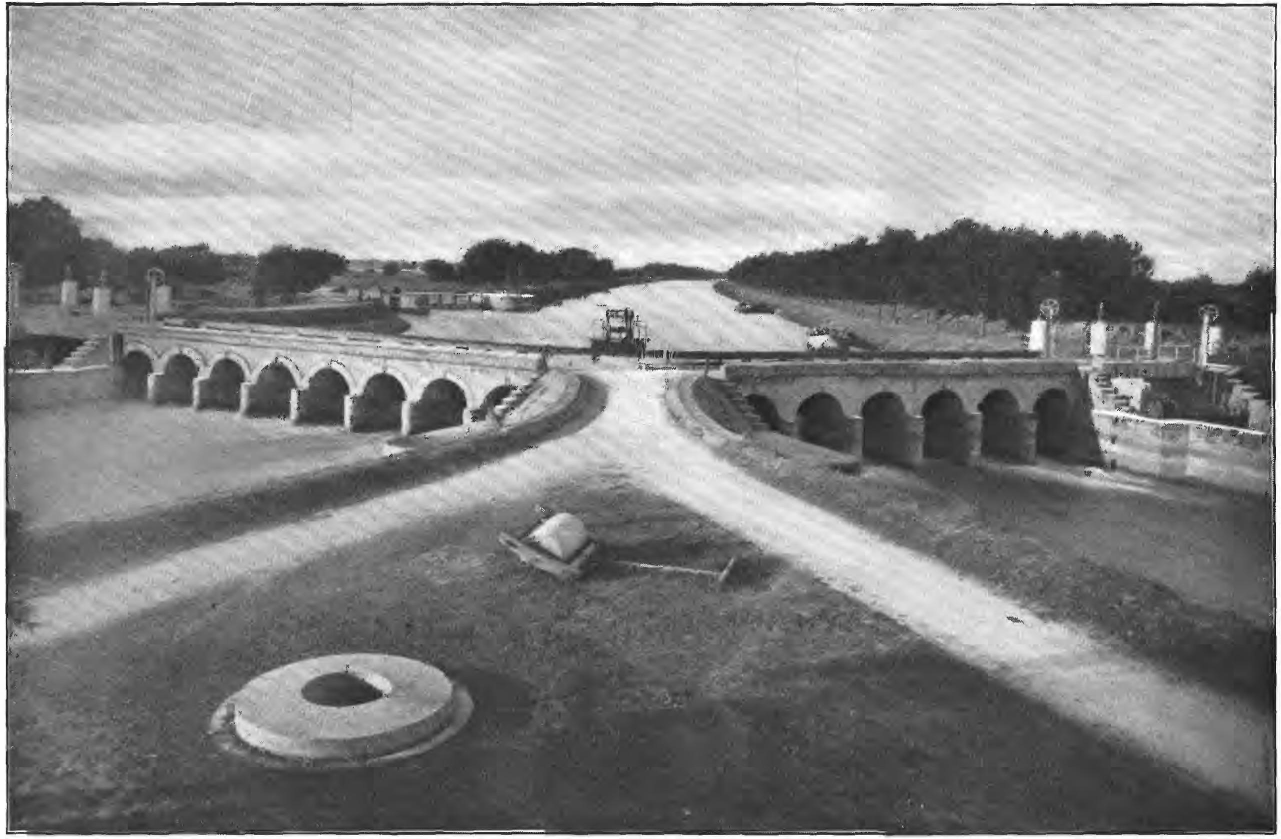
This canal is the largest in existence. As at present constructed its head-works are situated near the city of Hardwar, about 20 miles above the railway town of Roorkee. At this point the Ganges issues suddenly from between the foothills of the Himalayas onto the broad level plains. In the first 20 miles of its course (fig. 7) the canal encounters a considerable amount of sub-Himalaya drainage, and the works for the passage of this drainage and for the reduction of the slope of the canal by means of falls are important. The slope of the river bed in this section is from 8 to 10 feet per mile

A short distance above Hardwar a branch of the Ganges about 300 feet in width separates from the main river and, hugging the Hardwar shore, rejoins the stream a half mile below Hardwar. The discharge of the main river at this point in the dry season is about 8,000 second-feet, the greater part of which is diverted by training works and temporary bowlder dams into the Hardwar channel. This has been deepened and given a uniform slope of 8½ feet per mile to the canal head. At Myapur the canal is taken from the Hardwar channel, the water being diverted into it by means of a weir and sluices across the channel and a masonry regulator at the head of the canal. To the sixth mile the canal crosses several minor drainages which are admitted by means of little inlets. At the sixth mile it is crossed by the Ranipur Torrent, passed over it by means of a masonry superpassage about 195 feet in breadth. In the tenth mile the Puthri Torrent having a catchment basin of about 80 square miles, or twice that of the Ranipur, is carried across the canal by a similar superpassage 296 feet in breadth. The sudden flood discharges in these torrents are of great violence, the Puthri Torrent discharging as much as 15,000 second-feet and having a velocity of about 15 feet per second.

In the thirteenth mile the canal encounters the Rutmoo Torrent, with a slope of 8 feet per mile and a catchment basin half as large again as that of the Puthri. This torrent is admitted into the canal at its own level. In the side of the canal opposite to the inlet is an open masonry outlet dam or set of escape sluices. In the canal just below this level crossing is a regulating bridge by which the discharge of the canal can be readily controlled. Thus in time of flood, by opening the sluices in the outlet dam and adjusting those in the regulator so as to admit into the canal the volume of water required, the remainder is discharged through the scouring sluices, whence it continues in its course down the Rutmoo Torrent.

In the nineteenth mile, near Roorkee, the canal crosses the Solani River and Valley on an enormous masonry aqueduct. The Solani River in times of highest flood has a discharge of 35,000 second-feet, and the fall of its bed is about 5 feet per mile. The total length of the aqueduct is 920 feet. The banks of the canal on the upstream side are revetted by means of masonry steps for a distance of 10,713 feet and on the downstream side for a distance of 2,722 feet. For 1¾ miles above the aqueduct and for a distance of half a mile below it the bed of the canal is raised on a high embankment. The greatest height of the canal bed above the country is 24 feet. The aqueduct proper consists of fifteen arches of 50 feet span each. In addition to these great works there are in the first 20 miles of the canal five masonry works for damming minor streams and a number of masonry falls.

Beyond Roorkee the main canal follows the high divide between the Ganges and the West Kali Nadi, and continues in general to follow the divide between the Ganges and the Jumna to Gopalpur, a short distance below Aligarh, where the main canal bifurcates (Pl. VII),



GOPALPUR BIFURCATION, GANGES CANAL.

forming the Cawnpur and Etawah branches. The former branch tails into the Ganges at Cawnpur and is 170 miles in length. The Etawah branch is also 170 miles long and tails into the River Jumna near Humerpur. The Vanupshahr branch leaves the main line at the fiftieth mile and flows past the towns of Vanupshahr and Shahjahanpur. It formerly terminated at mile 82½, emptying into the Ganges River, but it is now continued to a point near Kesganj, where it tails into the Lower Ganges canal. The first main distributaries are taken from both sides of the canal a short distance below Roorkee. The nature of the country offers abundant facilities for escapes from the canals. Five are constructed on the main line, four on the Cawnpur branch, and three on the Etawah branch, besides numerous small escapes to the distributaries. These escapes will be described in another place. They are essential for the proper regulation of the canal in the discharge of local drainage.

The maximum discharge of the canal is 7,782 second-feet. The average annual rainfall over the area irrigated is 31.9 inches. The entire area commanded is 2,800,000 acres. The culturable area is 1,820,000 acres, and the area irrigated is 1,600,000 acres. The maximum area irrigated within any one year, including both spring and autumn irrigation, was 2,800,000 acres in 1883; the total length of main canals is 419 miles. There are 2,552 miles of distributaries and 859 miles of drainage cuts and escapes, or a total of 3,830 miles.

Of the total area irrigated in 1893, 96,543 acres, or 13.4 per cent of the whole, were double cropped and the duty performed by the canal for the autumn crop was 135 acres per second-foot on the discharge at the head, or 155 acres per second-foot on the discharge utilized. The total capital outlay on these works to the end of the year 1893 was $10,127,000, and the working expenses for that year were $375,000. The working expenses per second-foot of discharge at the head were $103, or 52 cents per acre irrigated. The total water rate derived was $1.30 per acre irrigated, or $253 per second-foot of discharge at the head. Among the principal crops culivated in 1888 were 106,000 acres of sugar cane, valued at $2,332,000; 228,300 acres of wheat, valued at $3,275,000; 31,400 acres of rice; 80,000 acres of indigo, and a grand total, including all other crops, of 601,900 acres, valued at $7,600,000. The net profits in 1888 were 5.4 per cent on the capital invested.

The number of days in the year when water was supplied for irrigation and the canal was in active operation was, in 1888, 275. In this year a comparatively small supply of water was used, the mean supply being only 2,400 second-feet.

LOWER GANGES CANAL, NORTHWEST PROVINCES.

As described in relating the history of the Ganges canal, the Lower Ganges canal was undertaken at the suggestion of Sir Arthur Cotton, in 1868, after an investigation by Col. R. Strachey in 1865, as a means of relief or improvement of the Ganges canal. It irrigates a part of the Ganges-Jumna interfluve that was originally intended should be commanded by the Ganges canal proper. The work comprises a masonry diversion weir at Narora, about 3 miles below the railway crossing at Rajghat. It relieves the Ganges canal of 128 miles of the Cawnpur branch and 130 miles of the Etawah branch, and as originally projected was intended to carry 6,500 second-feet in the spring season and 3,270 second-feet in the autumn season. In 1871 the works were commenced, but were delayed awaiting a revised estimate submitted in 1876, when the work was finally commenced. It is now considered as a work separate from the Ganges canal.

The weir is a substantial one, resting on masonry wells, usually 20 feet deep; the front and rear curtain walls rest on smaller wells. The weir is 3,800 feet long and is 10 by 10 feet in cross section, having a vertical overfall to a paved floor. It is constructed chiefly of brick. There are 42 weir scouring sluices opposite the canal head, each 7¼ feet wide. The regulator at the canal head is constructed of masonry and has 30 openings each 7 feet wide. The weir crest is 7½ feet above the sill of the canal and this can be raised to 10 feet by means of shutters. For the first 26 miles of main canal the bed is 216 feet wide; the full supply depth is 10 feet and the slope one-tenth of a foot in 1,000.

In the first portion of its line the canal is compelled to follow the low river bottom for some distance before its grade enables it to surmount the banks and reach the summit of the interfluve. In this low reach the canal is threatened constantly by the encroachments of the river and extensive river-training works are necessary to preserve its integrity. These extend for a distance of 4 miles above the canal head and 15 miles below, and consist chiefly of long earthen groins or embankments, sometimes 2½ miles in length, projecting into the stream at right angles to its course and protected at the end by loose rock noses. The general slope of the Ganges River and of the country at this point is about 1½ feet per mile and the greatest flood the river has discharged is 350,000 second-feet. Its minimum discharge has been as low as 1,200 second-feet. The velocity in the canal is very low, being but 2 feet per second, and as a result much silt is deposited and the growth of weeds is excessive. The maximum discharge of the canal as now constructed is 5,100 feet. The average annual rainfall on irrigable land is 34.5 inches; the gross area commanded is 4,387,200 acres, and the culturable area 2,435,400 acres, and 1,187,326 acres will be irrigated when the project is completed, though at present but 833,951 acres are irrigable. The total length of the main canals is 557 miles. There are 2,159 miles of distributaries and the total length, including escapes and drainage cuts, amounts to 3,123 miles.

The capital outlay to the end of 1893 was $12,073,000. The total receipts in that year amounted to $114,000, a little less than 1 per cent net profit on the capital invested. The area irrigated in 1888 during the autumn crop was 327,000 acres, of which 184,000 acres were irrigated by wells. Twenty-three per cent of the whole was double-cropped, and in the autumn season 1,765 second-feet of water were utilized, the duty on which was 185 acres per second-foot. The cost of maintenance of the distributaries was $13 per mile. There were 222 acres irrigated per mile of distributaries at a cost of a little less than $6 a hundred acres, and the average depth of water used in these was 3.1 feet. The most notable works on this canal will be described in their proper place. They are the training works, the weir and other head works, and the great aqueduct at Nadrai, by which the canal is carried over the Kali Nadi Torrent.

AGRA CANAL, NORTHWEST PROVINCES.

The Agra was the third of the great perennial canals of the Northwest Provinces visited by me. This canal was contemplated when the question of the remodeling of the Ganges canal was being agitated in 1864. It was then pointed out that water might be drawn from the River Jumna below Delhi to supplement the irrigation of the Ganges-Jumna bench lands. The idea was further discussed in 1866. In 1867 projects were submitted and in 1868 the works were sanctioned for the purpose of famine relief. The works as eventually sanctioned in 1872 correspond closely to the present completed Agra canal project. It was formally opened in March, 1874. In 1875 it was found that the original weir was insufficient. The great flood of that year had seriously injured the scouring sluices and the works were then reconstructed. The head works of the canal are situated at Okhla on the River Jumna, 10 miles below Delhi, and consist of a weir about 2,573 feet in length at a point where the river is 4,400 feet wide. The left wing of the weir rests on an island, whence it is continued as an earth embankment 20 feet wide on top. This weir rests on wells sunk in the deep sands of the river bed. On the upstream side it has a slope of about 1 in 4, the downstream slope being very long, as flat perhaps as 1 in 20. As originally constructed in 1870, this weir was not more than 130 feet in width from toe to heel, but after being injured by successive floods it was carried out and added to until its width is now over 240 feet. The scouring sluices are 139 feet long at the end of the weir, and are composed of 16 gateways of 16 feet each. The regulating sluices consist of 12 openings, each 6 feet wide and 10 feet high, to the springing of the arches, and are so located as to avoid the deposit of silt at the canal head. The water of the river is deflected toward the right bank against the regulators by a series of groynes and river-training works. There are about 8 miles of embankment along the river margin to protect the low land from inundation and to prevent the flank wall of the weir from being turned.

From Okhla the canal follows the high land between the Khari Nadi and the Jumna, and its course throughout is fairly parallel to that of the Jumna, about 3 to 12 miles from its right bank. It finally tails into the Ootunghun River about 20 miles below Agra. The main branches connect the canal with Muttra and Agra.

The source of supply is from the Jumna River. The highest recorded flood was of long duration and rose 50 feet above low-water level, the velocity then being 12 feet per second and the discharge about 1,300,000 second-feet. The supply of the Jumna having fallen occasionally below 800 second-feet it is supplemented by a cut from the Hindun River, which discharges into the Jumna just above the diversion weir, and is capable of supplying 300 additional second-feet. The grade of the canal from the head to the thirty-second mile is 6 inches per mile. There is a fall of 5.75 feet, beyond which the gradient is increased to 1 foot per mile to the end. In the first portion of the canal the bed width is 70 feet per mile and the depth from 6 to 10 feet, while the velocity is from 2 to $2\frac{1}{2}$ feet per second. Below the first fall the bed width is decreased to 60 feet and the maximum depth to 7 feet. Beyond the one-hundredth mile the velocity is from $1\frac{1}{2}$ to $2\frac{1}{2}$ feet per second, the bed width 20 feet, depth 5 feet, and the discharge about 200 second-feet.

The Hindun cut is 9 miles in length and 24 feet wide at the bottom, with a mean depth of $5\frac{1}{2}$ feet. The works of especial interest on this canal beyond those of the weir and head-works proper are an interesting superpassage made of boiler iron situated at about the eighth mile, and some drainage settling basins constructed as reservoirs for the collection and concentration of numerous small drainage channels. The total length of main canal as completed is 134 miles and there are 558 miles of distributaries. Its total maximum discharge is 1,500 second-feet. The average rainfall on its irrigated lands is 27 inches; the gross area commanded 768,000 acres, nearly all of which is culturable, while the area irrigated is 240,000 acres. The total capital outlay to the end of 1888 was $3,010,000, and the net revenue varies between 3 and $4\frac{1}{2}$ per cent per annum.

Of the total area irrigated in 1888, 11 per cent was by means of wells. The water rate charged was $233 per second-foot of water utilized, or $1,120 per mile of canal; the cost of maintenance was $11.50 per mile, and 74 acres were irrigated per linear mile at a cost of $5.15 per 100 acres. The average depth of water used in the autumn season was 1.2 feet. The principal crops cultivated were much the same as those cited for the Ganges canal, the cultivation of indigo heading the list with an acreage of 28,500 acres, cotton being second with 22,000 acres, and pease next. The area of wheat cultivated was 14,500 acres, and the total value of all crops $1,090,000.

The canals of the Duns are usually small and have been constructed in a mountainous country at a rate of expenditure that would be considered quite unwarranted and prohibitive in the United States. There are five principal canals in the Duns, ranging from 11 to 19 miles in length and aggregating 67 miles. They have annually returned over 6 per cent interest. These canals command 5,000 acres, more or less, each. The works are simple in character, but owing to the great rainfall expensive masonry aqueducts crossing high valleys and broad torrents are numerous, and in many cases the canal channels are constructed wholly of masonry for long distances. The total maximum discharge of these canals is 240 second-feet, and the precipitation on the irrigated lands averages 100 inches. They irrigate a gross area of 25,000 acres. The capital outlay on their construction was $1,070,000, and while the average interest received is over 6½ per cent, on some of them it exceeds 12 per cent. The crops cultivated are similar to those produced elsewhere in the Northwest Provinces, but wheat and rice far exceed in amount all other crops together. In 1888 there were 15,400 acres of food crops grown, nearly four-fifths of which consisted of wheat and rice.

SIRHIND CANAL, PUNJAB.

Of the important perennial canals in the Punjab, the Sirhind far exceeds all others in matters of engineering interest, as it is the most recent and modern in construction, besides being one of the greatest. Of the other important canals of the Punjab, the principal are the Bari Doab and the Western Jumna, two of the most profitable canals in northern India. The Sidhnai canal, which has only recently been opened, was, as originally constructed, an inundation canal and is still partially operated as such. Though I saw little of the Sirhind or Sidhnai canals, a brief description of each will be given, as they represent some of the latest developments of irrigation as practiced in India.

In the time of the Emperor Feroze attempts were made to utilize the waters of the Sutlej River for irrigation. These attempts were, however, of little moment. Maj. W. E. Baker first showed the practicability of a canal from the Sutlej to irrigate what was known as the "Hard Desert" in the districts of Hissar and Bhuttiana. The few wells there were so deep that irrigation from them was impossible, while the water was impure and brackish. The population was scanty and lawless, their chief occupation being cattle raising. The question was not how to improve agriculture, but how to create it.

Major Baker proposed heading the canal above Rupar, utilizing the line of the old canal of Mohammed Shah, but Col. Baird Smith, who examined this project, reported that "the occupation and repair of old canals was the most fruitful source of evil in the existence of canals," and he suggested a new alignment.[a] Major Baker's investigations were carried out in 1840, and the project then submitted was very similar to that of the now completed Sirhind canal. In 1860, at the request of the Maharajah of Pattiala, who offered to defray the expenses, the whole question was investigated by the British officers.

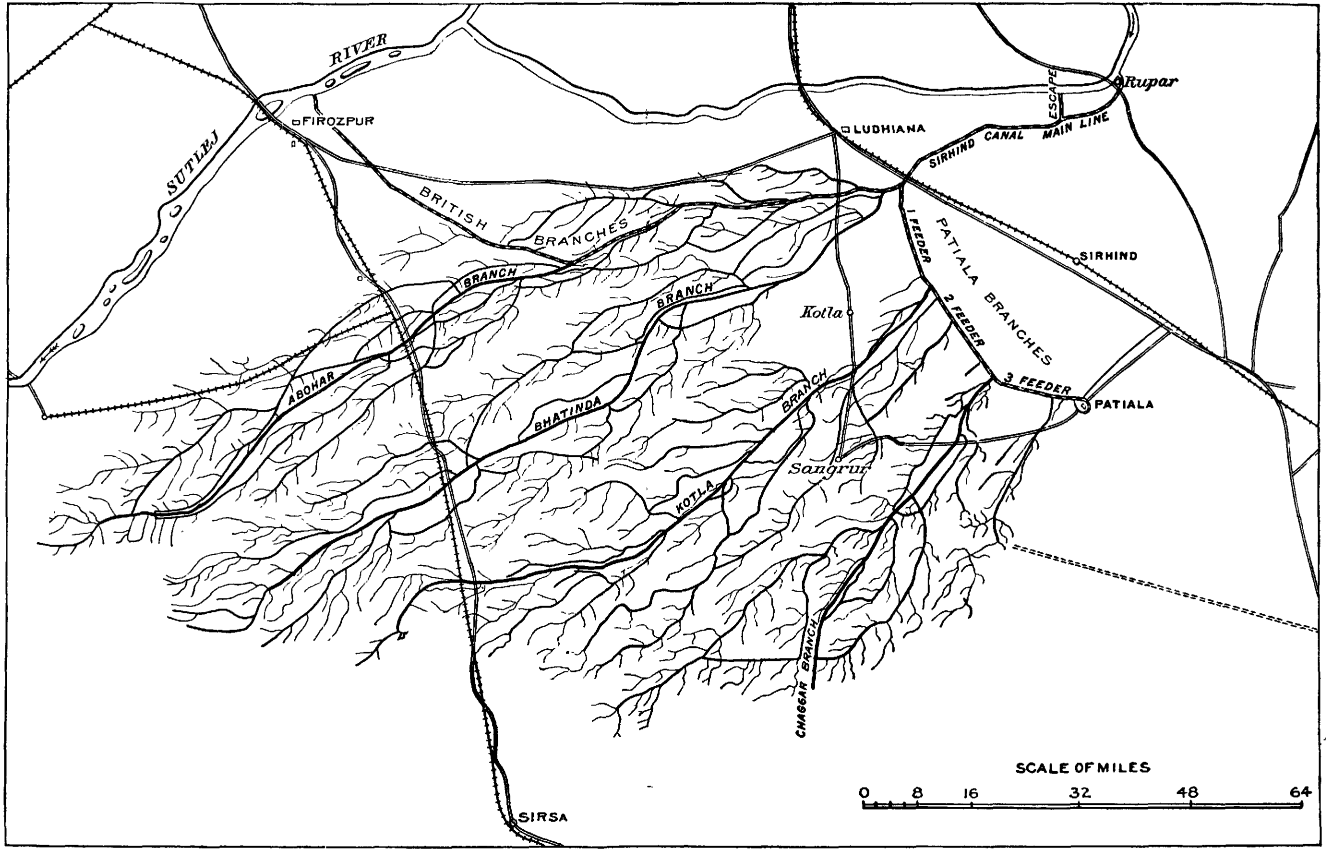
[a] Smith, Col. Baird, Irrigation in Italy, London, 1856, vol. 1, p. 256.

A project was submitted in 1862, and in 1865 the British Government decided that any canal constructed here should be devised irrespective of boundaries of British or native States. In 1868 the project was vigorously pushed, the size of the main channel was increased, and the head-works were moved 15 miles down the river to a point very near Rupar, and in 1869 the works were actively commenced.

This project (Pl. VIII) comprises a main canal from the Sutlej supplied by a masonry diversion wier. The length of this main channel is 41 miles. Of the branches, the eastern ones irrigate native State lands and are called the Pattiala branches; the remaining or western branches are known as the British branches. The heaviest portion of the work is in the first 10 miles, where the line crosses many hill torrents draining into the Sutlej. The head-works are, like those of the Ganges and Jumna rivers, situated at the point where the river emerges from the hills through a rocky bowlder channel, and where the general fall of the country is over 8 feet per mile. The maximum depth of the cutting through the spur at the head near the town of Rupar is 45 feet, and the average depth of cutting in the first 7 miles is 28 feet. The drainage in places is passed over the canal by masonry superpassages, while one torrent is diverted into the river by a cut terminating above the head-works. At the forty-first mile the main canal ends and the two branches diverge. Three miles below the bifurcation the British branch is again divided into the Bhatinda branch, 100 miles long, and the Ubohar branch, 125 miles long. On the Pattiala side the main feeder is divided into three sections by the diversion of the Kotla, Gagger, and Choa branches, respectively 90, 56, and 25 miles in length. The end of the feeder is the junction of the Choa and Pattiala branches, the latter being 6 miles long and terminating at Pattiala.

The principal works of interest on the line of the Sirhind canal are the head-works at Rupar, the superpassage crossing the Siswan Torrent, which in time of flood discharges 20,000 second-feet, and the superpassage across the Budki Torrent, which in time of flood discharges 30,000 second-feet. The siphon for a drainage crossing at Hurron Torrent, though small, is likewise deserving of particular mention in its place.

The water supply of the Sirhind canal is less than was anticipated. The least discharge of the river ever recorded was 2,818 second-feet, while the average minimum discharge is 5,150 second-feet. The maximum discharge of the canal as designed is 7,849 second-feet, and the maximum flood discharge of the river has been as great as 100,000 second-feet. The rainfall over the irrigable area varies between 10 and 35 inches per annum, and during the autumn crop is from 1 to 6 inches. The gross area commanded by the canal is 4,558,602 acres, of which 1,170,000 acres are irrigable. During the autumn crop of 1901 only 406,805 acres were irrigated, of which 161,967 acres were double cropped.



SIRHIND CANAL SYSTEM.

The total length of main canals is 41 miles and the total length of main branches 538 miles, while there are 4,636 miles of principal distributaries. The total outlay on this canal to the end of 1901 was $19,663,000, and since the canals were opened the net annual revenue has constantly increased, until in 1901 it amounted to 4.7 per cent. In the year under consideration the duty per second-foot in the autumn season on the supply entering the canal head was 108 acres, or $113, and on the supply utilized it was 110 acres, or $121. The average water rate per acre irrigated was 95 cents, the working expenses being 40 cents per acre, and the cost of establishment was 15 cents.

CHENAB, BARI DOAB, AND WESTERN JUMNA CANALS, PUNJAB.

As before stated, these three canals are among the oldest and best paying of their kind in India. In 1351 Feroze Shah constructed the first channel where the Western Jumna canal now exists, and at different periods up to 1817 the works were reconstructed and utilized. In 1817 Captain Blaine prepared to restore them. The supply of the Western Jumna is derived from the Jumna River at a point where it leaves the Sewalik Hills, where the fall is great and the bed composed of shingle and bowlders. On the opposite bank the Eastern Jumna heads at nearly the same place. In 1870 permanent head-works, distributive and drainage works, were constructed to replace the old ones, and a little later the main canal was almost entirely realigned. At the end of 1878 the total receipts since the works were taken in hand by the government had exceeded the working expenses and interest on the capital by $12,500,000, or about four times the first cost of the work. The total length of the main canal and branches in 1901 is 391 miles, and there are 2,210 miles of distributaries. The area irrigated is 870,500 acres and the maximum discharge of the canal is 6,350 second-feet. The total expenditure on this work to the end of 1901 was $10,730,000, and this earned revenue of 9.1 per cent. The gross receipts in that year were $835,000, and the gross outlay $325,000, the net revenue being $510,000.

The Bari Doab canal derives its source of supply from the Ravi River, and commands 1,641,660 acres of land between the Ravi and Bias rivers. In 1633 the Shah Jehan construct d the first canal in this neighborhood. The project for the new canal under British rule was first reported on in 1850, when the works were commenced. In 1856 they were revised, and water was admitted to some portions of the canals in 1859. In 1874 the works were decided upon as now constructed, and were estimated to produce a profit of 8.8 per cent. Recently a considerable amount has been expended in the construction and improvement of falls and rapids. The total outlay to the end of 1901 was $14,115,000 and the interest in that year was 12.9 per cent on the capital outlay. The maximum discharge of the canal is 6,500 second-feet, and the area irrigated 849,074 acres. There are 369 miles of main canals and branches and 2,725 miles of distributaries.

The Chenab Canal is diverted from the river of that name, and commands 2,910,470 acres. It consists of 430 miles of main and branch canals and 2,059 miles of distributaries. To the end of 1901 its cost was $11,111,000, when it earned 14 per cent interest on that outlay. In the same year it irrigated 1,384,046 acres on a maximum discharge of 10,474 second-feet.

SIDHNAI CANAL, PUNJAB.

Estimates for a permanent inundation canal from the reach of the Ravi River were submitted in 1875 by Mr. E. C. Palmer. In this project the head of the canal was located at the top of the straight reach called the Sidhnai. Owing to bad alignment (as Mr. Palmer's project followed a low depression for many miles), the position of the head-works was abandoned, and a new site selected at Tatyraj, where the section of the river is 770 feet across and the banks consist of stiff brown clay.

The maximum discharge of the river is 18,000 second-feet, and is not likely to be exceeded. Gage records show that all idea of the construction of a perennial canal from this part of the river must be abandoned, as twice since 1875 the Ravi has been absolutely without flow during the cold season. As constructed, the only masonry works on the canal besides the head-works are the bridges and the heads of distributary channels. The area commanded is about 381,000 acres. Of this the present works provide for the irrigation of 194,900 acres. The duty was assumed to be 60 acres per second-foot, and the discharge of the canal was placed at 800 second-feet. The rainfall on the irrigated area has averaged 5.9 inches per annum. When the canal project was reported on in 1883 most of the country was covered with jungle to within about 3 miles of the river. This jungle consisted of coarse grass, brush, and tamarisk. The crops now grown on this land during the summer season are sugar cane, indigo, rice, cotton, and millet, and during the autumn season wheat, barley, turnips, and lentils.

On the line of the canal no drainage or protective works are required except one or two very insignificant ones. At first the canal was only excavated to half width, but all the masonry works were constructed of full width. As finally aligned the canal leaves the Ravi River at right angles and runs straight for 2,000 feet, where a long curve commences, ending at 3½ miles. It then keeps along the divide to Chauparata, whence it runs mainly in the bed of the old river Ravi. There are four main distributaries and six minor ones.

The head-works consist of a regulator with 8 sluice openings of 10 feet each. The curtain walls of the regulator and river banks are founded on wells 10 feet below the present river bed. Wells were adopted in preference to concrete, though they are more expensive, and it was not certain that the latter could be put in 10 feet below the bed. The weir consists of a wall 750 feet long, founded on concrete in the center and on wells for 20 feet from each bank.

The maximum discharge from the canal is 2,452 second-feet, the bed width of the main canal is 80 feet, the depth of water 5 feet, and the velocity of flow 1.85 second-feet. The discharge of the river varies between nothing at extreme low water and 18,000 second-feet at maximum flood.

The total cost of this work to the end of 1901 was $620,000. The net receipts for the same year amounted to $34,500, or 5.8 per cent on the capital invested. The water rate charged per acre irrigated during the autumn crop was 62 cents and the duty during the same season was 85 acres or $57.

THE SOANE CANALS.

Like the Sirhind canal in the Punjab, the Soane system in Bengal may be taken as an example of the most recent practice in the construction of a perennial canal system. The Soane canals are included in one system heading at a common point and having a common diversion weir. They consist of two main lines, one flowing from each bank of the Soane River. The Soane River is a tributary of the Ganges, rising in the central plateau of India and having a course of about 350 miles through the high country. Near Rhota it breaks through the hills, which at this point are 2,100 feet above the sea, whence it flows northeasterly for 75 miles through the Gangetan Plain to its junction with the Ganges near Arrah. In the plain it flows through the districts of Shahabad on the left or west bank and Patna and Gaya on the east bank. These are among the most fertile and highly cultivated districts in Bengal, densely populated and studded with ancient cities. The successful operation of the Soane canals is largely due to the acreage which is cultivated during the autumn season.

The works of the Soane canal were first undertaken by the East India Irrigation Company, but given over to the Government when scarcely any work had been done. The scheme was originally proposed in 1853 by Lieut. C. H. Dickens. A plan to utilize the larger portion of the volume of the Soane was, however, amplified by the same officer in 1861. In 1862 the secretary of state approved of the project, and after discussion by Sir A. Cotton and Colonel Rundall it was forwarded for the approval of the Government in 1864. In addition to the features now existing it was proposed in the original project to construct reservoirs in the hills south of Rajmahal to supplement the available discharge of the river. This part of the scheme was considered too expensive, however, and the plans were changed. In 1869 the work was undertaken by the Government. It was estimated to give a net profit of 12½ per cent on the outlay. In 1871 it was decided to reconstruct the slope of the canal, as the supply of water was not as great as had been anticipated.

The catchment basin of the Soane above Dehree, where the head works are situated, is about 22,000 square miles in area, and in flood the river discharges 750,000 second-feet, though the maximum flood provided for is 1,250,000. For about 40 miles below the diversion weir the floods seldom overtop the river banks, but below that point to its junction with the Ganges it is almost deltaic in character, considerable overflow taking place. To about this point the canal follows the bank of the river rather closely, after which it diverges and follows the high ridge between the Soane and Ganges.

The diversion weir across the Soane is at Dehree, a point 25 miles below where the river leaves the Kymore Hills, and is the longest weir in one unbroken length of masonry that has ever been constructed, being $2\frac{1}{3}$ miles long and 8 feet high. In high flood the river rises $8\frac{1}{2}$ feet above the crest of the weir. The main western canal (Pl. IX)

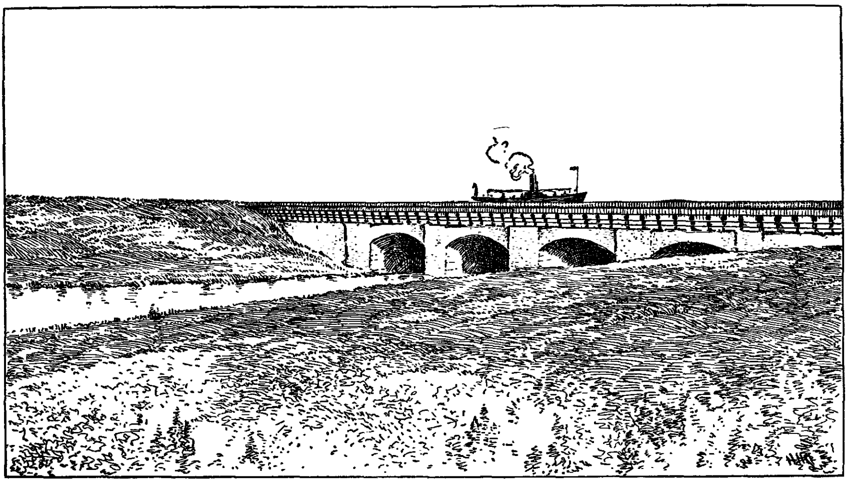


FIG. 8.—Thora Nulla aqueduct, Soane canal.

takes off from the weir on the west bank where it encounters a rather deep cut. It crosses the Kao Torrent by a large siphon aqueduct in the ninth mile and similar drainage channels in the seventeenth and twenty-first miles. The Arrah canal leaves the main western at the fifth mile and follows the bank of the Soane to the thirty-third mile, where it leaves it and passes close to the town from which it takes its name, tailing into the Ganges. On this line are 13 locks with an aggregate fall of 161 feet. The Buxar canal leaves the main western at the twelfth mile and is almost straight from that point to the Ganges at Buxar. The total fall in this line is 153.75 feet, and in the twenty-ninth mile the canal crosses the Thora Torrent (fig. 8) on an aqueduct with 4 arches, each of 30-foot span. The other main canal of this system, the main eastern, takes off from the Soane weir on the eastern bank opposite to Dehree and is 7 miles long, its termination

SOANE CANAL SYSTEM, BENGAL.

being at Poon Poon Torrent. The Patna canal leaves the main eastern at the fourth mile, and, after following the river bank for 60 miles, is diverted to the ridge and tails into the Ganges near Patna. It was estimated by F. T. Haig, R. E., when chief engineer, that these canals would pay both interest and working expenses on the outlay until 1887, when it was expected that they would return a net profit of 4½ per cent.

The important feature of the head-works is the mode of construction of the weir, the automatic action of the scouring sluices, and the arrangement of regulating gates. These are elsewhere described in detail in connection with the subject of automatic scouring sluices, on pages 121–122, 127–128. The weir and principal works were designed by H. C. Levinge, chief engineer of the East India Irrigation Company.

The minimum discharge of the Soane River at Dehree is 5,260 second-feet in summer and 1,870 second-feet in autumn. The maximum discharge of the canals is 6,350 second-feet, of which the main eastern canals discharge 1,850 and the main western series 4,500 second-feet. The average rainfall upon the area irrigated is 41 inches. The gross area commanded by the entire system is 1,733,509 acres, of which 1,016,400 acres are irrigated. There are 367 miles of main canals and 1,217 miles of distributaries. The average discharge utilized in the autumn of 1901 was 3,300 second-feet, and the duty performed during the autumn was 110 acres per second-foot of the supply utilized. The water rate per acre was 85 cents. The total length of village channels or minor canals is 1,525 miles; the total number of outlets for distribution of water is 6,000, the area irrigated per outlet being 93 acres.

In the Arrah division, Mr. W. A. Inglis, the executive engineer, calculated the supply of water spread over the country was equal to an effective rainfall of 5.7 inches. On the assumption that one watering of 6 inches in depth is given every fifteen days, 1 second-foot of discharge should irrigate 60 acres if the outlet were constantly open, or 40 acres if the discharge outlet were open for only ten out of fifteen days. The cost of repairs to the head-works in 1890 was about $16,000 per annum and the cost of maintenance exclusive of head-works about $81,000. The charges for silt clearances amount to $30,000 per annum, the total amount of clearances being 10,850,000 cubic feet and the rate about $3 per 1,000 cubic feet. The silt clearances were made by means of large steam dredges. The total cost for weed clearance was $1,600 in 1888, and the mileage rate or cost of repairs varied from $30 per mile on distributaries to $65 per mile on smaller branches, $211 on larger branches, and $2,800 on the main western canal.

The following is a statement of traffic on these canals for the year 1888. There were 218 miles of canal open for navigation. The tollage receipts from private boats amounted to $12,000; on government boats $1,400, and on rafts $3,500. These with minor items make the total receipts from tollage $18,600. The maintenance charges, including navigation establishment, were $11,800 and the net revenue from navigation was $6,800. The total number of cargo boats was 4,547; of passenger boats 530. The total tonnage of these boats for cargo traffic was 71,243 long tons and for passenger traffic 12,437 long tons, and the total ton-mileage was 4,635,000 miles. The estimated value of the cargoes was $1,785,000 and the passengers carried numbered 46,170. There were estimated to be 3,089,000 cubic feet of rafts, valued at $107,000. The tollage receipts per ton-mile on boats was 3 mills, and tollage on rafts per hundred cubic feet was 11 cents.

The total outlay on the Soane system to the end of 1901 was $17,558,000 and the revenue in 1901 was $175,000. The gross receipts were $370,000. There was a net revenue, after deducting all working expenses, of $162,000, or 1.8 per cent, on the capital outlay.

CROSS SECTION, SLOPE, AND ALIGNMENT.

In designing a canal system the Indian engineer, having decided on the location of the head-works and ascertained the source of supply and the area and location of irrigable lands to be served, next considers the proportion of width to depth of his channel, the cross-sectional area being fixed by the supply of water to be discharged at any point. On the Western Jumna canal the proportion of depth to width is that which the Jumna River has in the course of years formed for itself, found by trial to be about 1 on 13. On the Bari Doab the proportion fixed in construction was 1 on 15, and on the Sirhind 1 on 14. In the case of the Nira canal, which is nonnavigable and of a smaller capacity than those just described, the proportion is much less, the depth being 7½ feet and the bottom width 23 feet. On the Soane the main western line has a depth of 10 feet and a bottom width of 100 feet, or a proportion of 1 on 11. The Betwa, which, like the Nira, is nonnavigable, is relatively deeper than the larger canals, being 5 feet deep to a 15-foot bed width on some branches, and on others 6 feet deep to a 30-foot bed width. The proportion first given is such as will apply only to canals so great as to correspond in their general characteristics to large rivers.

The side slopes of the canal (fig. 9) are generally arranged according to the facilities for excavation, and are such that the ground will stand at a natural angle. In the soils in which the canals are generally excavated in Bombay the side slopes are usually 1 on 1½ on the inside and 1 on 2 on the outside. The matter of fixing the cross section has been a difficult one to solve on account of the conflicting conditions of the supply of water required and velocity permissible. This is fixed by the liability to growth of weeds, the deposit of silt, or the destruction of the banks by erosion.

Having determined the quantity of water, fixed the proportion of width to depth, and ascertained a maximum for both, the slope of the bed becomes one of the most important remaining problems in the design of the canal. If the slope be too great, the bed of the canal and its sides will be eroded and the integrity of the masonry and other structures endangered. If it be too small, a larger section of channel will be required to discharge a given quantity of water, and additional works, as falls, may be necessary to overcome the excess of surface slope in the country. The growth of weeds and aquatic plants and the deposit of silt will become a troublesome evil. As it is difficult to avoid both extremes, a compromise has generally to be made. It is, perhaps, well to err on the safe side and give to the bed the greatest

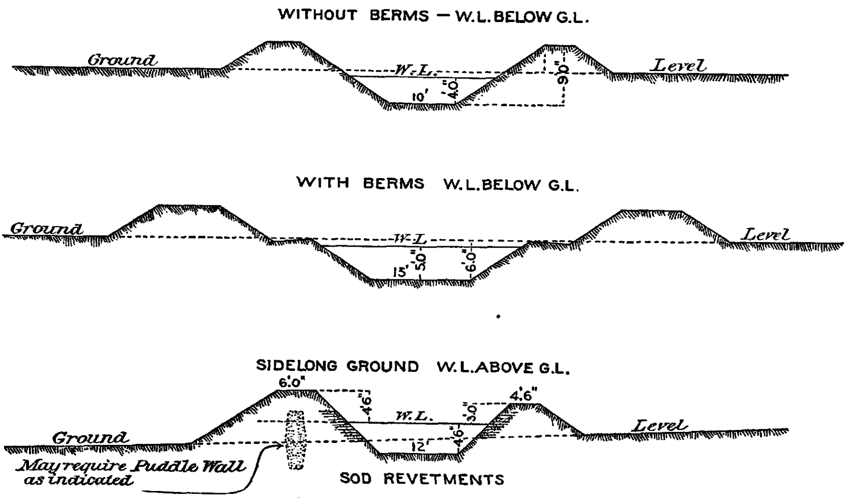


FIG. 9.—Canal cross sections.

slope apparently desirable. If this slope should prove to be too great or the fall of the country too rapid, the difficulty may be remedied by introducing falls and rapids in the channel to diminish its general slope and concentrate the loss of grade in a few places. In different soils and in different canals the velocity given for the prevention of the growth of weeds and the deposit of silt differs largely, but it has been found generally that the minimum velocity is about 1½ feet per second. According to American experience this is too low, as we usually consider that 2½ or 3½ feet per second is the minimum. In India the maximum for ordinary soils rarely exceeds 4 feet per second. In America it is often much higher.

One of the greatest difficulties encountered in India in determining the velocity, slope, and cross section to be given to a canal has been the introduction of navigative works. These are generally antagonistic to the requirements for irrigation purposes only. The velocity of the current in navigable canals must be low in order to permit traffic in both directions. In the Ganges canal, with a bottom width of 170 feet and a 7-foot supply, a slope of 14 inches per mile has been given in the sandy soil of the upper reaches, and the resultant velocity is such that the current has just ceased to cut the banks and to deposit silt. In the first portion of the canal where the bed is in gravel and bowlders the fall is 24 inches per mile. From there on the slope of from 15 to 17 inches has been found to be too great, the water having done much damage to the banks. The larger portion of the reach of 20 miles from Hardwar to Roorkee is extensively riprapped now and the engineers are continually adding a lining of bowlders to the bed and sides of the canal.

The velocity of 3 feet per second, which was originally given to the Soane canal, caused much damage by erosion and had to be remedied. Colonel Anderson, R. E., made some interesting remarks on this subject in the Roorkee Manual, among which were the following:

> Where the fall of the country is tolerably uniform the slope of the bed of the main channel must be less than that of the branches. This, again, must be less than that of the distributaries and minors, the object being to secure, as far as possible, a uniform velocity, so that the matter carried in suspension may be carried on from the head and deposited over the irrigated lands. At the head of a canal it is sometimes desirable to reduce the width in order that with an increased depth the velocity may be the same as that in the channel lower down.

He says that the accumulation of silt in the main channels is a serious impediment to obtaining a supply of water until the crops are mature, and their clearances are enormously expensive. If the silt can not be carried to the fields, it is a step in advance to prevent its accumulation in the main channel. It is easier to clear out the minor branches without cutting off the supply from the main river. Escapes are introduced at intervals in all canals for the control of the discharge of water and to facilitate silt clearances and as a prevention of its deposit.

The following interesting observations were made by Major Crofton in his report on the Ganges canal relative to velocities of current: Where the current seemed to be perfectly adjusted to a light, sandy soil the velocity of the surface was found to be from 2.3 to 2.4 feet per second and the mean velocities, using 0.80 as a coefficient, were found to be 1.85 to 1.93 feet per second. In one place, where silt was being constantly deposited, the mean velocities were from 2 to 2.3 feet per second. On the same canal in very sandy soil, with nearly a full supply of water, the maximum surface velocity was found to be 3.08 and the mean velocity 2.49 feet per second. In one of the distributaries, where the soil is sandy with a fair proportion of clay, the mean velocity was 1.93. Here silt was deposited but no weeds grew. On the Western Jumna canal Colonel Dyer, R. E., found that silt was deposited with mean velocities of from 2 to $2\frac{1}{4}$ feet, and in sandy soil 2.7 feet per second was the highest mean velocity for noncutting. Jackson's and Neville's formulae are those most usually employed in the determination of velocities and corresponding cross sections. In designing the proportion of excavation to embankment and the width of berm, several interesting but involved formulae are employed by the Indian engineers, of little service, however, as guides to the designers of American canals.

Great care and judgment must be exercised in the alignment of an irrigation canal. Any change of direction causes a loss of velocity, and the slope should be changed if it is essential to introduce a curve. The water drawn into branches and distributaries loses velocity in passing through the head-sluices unless they possess the full waterway of the channel, and due allowance should be made for this by adding to the slopes at the heads of branches. The Indian engineers have always deemed it essential in designing their canal systems to make a thorough and detailed survey of the country to be irrigated, so that the most perfect alignment and command of the lands can be obtained. Trial level lines and careful transit surveys are run, after a rough survey has been made, and the whole is shown on a large scale contour map. A complete delineation of the drainage of the country is one of the primary objects, as is also the direction of the drainage outlets and the interfluves. The nearer the line of the canal approximates to the summit of the watershed the better will be the alignment, as the interference with the surface drainage of the country will then be the least possible. In encountering cross drainage provision must be found for its safe passage, and unless the streams are very small they should never be permitted to enter the channel. The canal should always be made to tail into some drainage line or river, so that the surplus may not be lost, and in order to insure a sufficient scour it is deemed advisable to increase the velocity at the end. When practicable all embankments are formed by ramming the soil in thin layers. Where the channel runs through sandy soil the beds and banks should be covered by an impervious puddle.

Great care has been used to fix the permanency of all transit points and bench marks, etc., on the surveyed lines of canals in India. On the outer edge of the berm are placed masonry mileposts, with smaller masonry pillars every one-fourth mile, while on the inside whitewashed stones are laid into the ground every 100 feet. At frequent intervals large substantial masonry benches are established.

HEAD-WORKS.

The head-works of canals are usually located at the points where the rivers emerge from the hills, in order to obtain a sufficient command of land and allow the canals to reach the summits of the interfluves with the shortest possible length of diversion line. In India, owing to the great volume of flood water required to be passed over the diversion weir, it is necessary to have an extremely wide waterway, and it is usual to locate the weir in a relatively wide portion of the channel. If the only consideration in the location and construction of a weir was the raising of the water of the river to the level of the canal bed, in order to obtain the shortest possible diversion line, the most favorable location would be in the lower courses of the river, where the fall is gradual and the banks shallow. Such an obstruction of the bed in these localities would, however, raise the surface of the water in freshets, rendering necessary the construction of artificial embankments and other protective works, and would be extremely objectionable. A rock bed, though a great advantage and always to be preferred, is not considered an indispensable requisite in constructing weirs.

Several great Indian weirs have been thrown across rivers whose beds consist entirely of pure sand, reaching far below the foundations. In such constructions the chief requirement is a strong apron beneath the weir to break the fall of the water and prevent the foundations from being undermined. Prof. George Davidson says:

> In order to reduce the first cost of construction it has become a custom in America to build bridges and dams across streams at the narrowest points available, or to contract the streams for that purpose. This frequently involves great difficulty to the engineer in laying the piers and abutments, and also brings in an additional danger by adding to the scouring effect of the water on a contracted channel; it also produces the evil effects by the formation of shoals below the scouring-out channel. The proper location for such works, especially across rivers with unstable banks, is in the broad reaches of the stream, where the depth of the water is less and where a bar has been already formed across the river by natural causes.[a]

A dam across a river is analogous to a bar, and should be located and treated as such. If this is placed at the broadest part of the stream the cost of construction may be increased, but not necessarily. Instances of the location of weirs in the broadest reaches of rivers may be cited in the case of nearly every weir constructed in India. The weir at the head of the Ganges canal occupies the full width of the channel; those of the Bári Doab and of the Soane are thrown across at points where the width of the river is an average. The weir at Okhla, at the head of the Agra canal, is also constructed in a broad reach.

The head-works of Indian canals consist essentially of the weir across the river by which the level of the water is raised and its flow checked; of a set of scouring sluices placed in the weir at the end adjacent to the canal head, the object being to create a constant flow past this head, thus preventing and carrying off any excessive deposit of silt, keeping as they do the course of the main channel of the river close to the canal head; and, lastly, of a regulator across the head of

[a]Davidson, Prof. George, Irrigation Works of India: U. S. Senate Doc. No. 94, Forty-fourth Congress, Washington, D. C., 1875.

the canal channel, by which the proper quantity of water is admitted to it. In a few cases, as those of the Ganges and Jumna canals, where the canal is taken from a branch of the river, a permanent dam is thrown across this channel only, the water being diverted to it by means of the river-training works.

WEIRS.

The weirs employed are of various kinds, but are always constructed substantially of masonry and are well founded. They may rest on solid rock foundations and be nearly vertical with an overfall onto a rock bed, or flat and low, founded on wells in sand, with a vertical overfall onto an apron of masonry; or they may be similar to the latter with the exception that instead of the vertical overfall the downstream slope may be constructed of loose-packed rock on a long slope of, say, 1 on 15 to 1 on 20. Only rarely are temporary weirs constructed simply of loose bowlders. The two great classes of weirs are solid weirs, such as those above indicated, or open weirs, in which the obstruction is temporary, as needles or removable sluice gates.

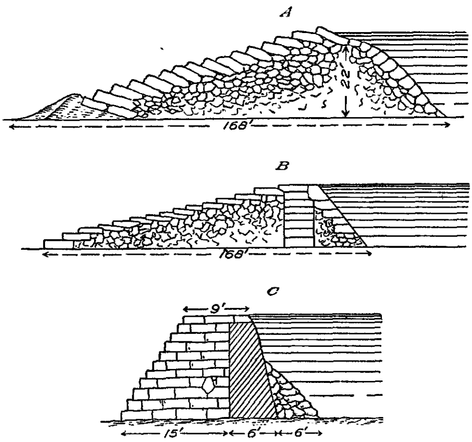


FIG. 10.—Three ancient weirs.

The antiquity of weirs is very remote. The first great weir, that at Tulkad, on the river Cauveri, is said to have been constructed by one Madwa Rou, A. D. 894. Many others are said to belong to the sixteenth century, while others are of intermediate dates. The new works of the Indian natives are of minor importance, with the exception of the Poorniah channel, constructed in the early part of this century to lead the sacred waters of the Cauveri River to Misau. Rough stone weirs exist at the heads of most of the channels in Misau. These raise the water level to the required height, the lowest being 7 feet and the highest 25 feet. The canals are for the most part supplied with regulating sluices at their heads and with escapes for getting rid of flood waters.

The accompanying illustration (fig. 10, *A*) shows the section of a native weir constructed early in the present century, the breadth of which, parallel to the course of the stream, was 168 feet. This weir consisted of a mass of rubble and large stone, the front face formed of stones $1\frac{1}{2}$ by 1 foot, while the apron was composed of rough stone blocks 9 by $3\frac{1}{2}$ by 2 feet, laid in uneven courses. All the interstices were filled with large rubble. Repairs were first made in 1842, and thereafter were carried out on a slightly different plan, (*B*) the general section being retained. The repaired dam appeared as here indicated. These illustrations give a fair idea of the attention given by the natives to this class of work and indicate the fallacy of trusting to size and position of the material instead of to the homogeneity of the work. Notwithstanding the employment of large blocks of stone and skillful application of material the dam was breached five times between 1842 and 1863.

A later development is indicated in the cut given of the Muddur weir (fig. 10, *C*). General Greene retained the native section of this weir, but corrected its chief failing by building an impervious brick and mortar face against its upper side. The natives, with the object of decreasing the depth of water flowing over the weir in flood times, carried the work in a curved line, its general direction tending upstream. The length of the weir was nearly double the actual breadth of the river, and its crest was at different levels in different places; the part next the head sluice being invariably lower than the rest relieved the head of water pressure against it during flood. All these features, shown by experience to be desirable with the native works, are so many defects with the solid masonry work now adopted. The regulators in the old works at the heads of canals were mostly constructed of rough stone posts, the openings between which were stopped with rough timber and fulfilled their objects in an imperfect manner.[a]

In regard to the two main designs adopted by modern practice for weirs, namely, the open and the closed or solid weir, the advantage of the latter is that it is self-acting and if well made requires no repairs or maintenance. Its first cost, however, is greater than that of an open weir, and it interferes with the regimen of the river, causing deposits of silt above it and perhaps making the river seek another channel. The open or scouring sluice weir interferes but little with the normal action of the river. The scour produced by opening the gates prevents the deposit of silt and its first cost is less than that of the closed weir. Another form of weir, the best examples of which are to be found in the barrages of France, consists of a weir open the whole width of the channel, the object being to prevent in time of flood the water being backed up, thus submerging valuable property above the weir. The obstruction in the river channel may be entirely removed by opening the gates the full width of the weir.

The ordinary weir consists of a masonry floor acting as an apron, properly founded and carried across the entire width of the river flush with the level of the bed and protected from erosive action by curtain walls up and down stream. On a portion of this is constructed the upper work, which may consist of a solid wall and part masonry

[a] Sankey, Maj. R. H., Roorkee Professional Papers, No. 141, Roorkee, India.

piers, the interstices between the latter being closed by some temporary arrangement, thus creating the scouring sluices. Weirs proper are in no instance to be looked upon in the light of storage works. They may for a trifling period during the dry season answer that purpose, but the irrigation from them depends in all cases on the continual flow of a small quantity of water or upon an auxiliary supply from storage waters situated higher up. In speaking of the mode of constructing low diversion weirs with long slopes, Col. Baird Smith says:

> In rivers with beds of pure sand and having slopes of 3½ feet per mile such weirs may be constructed and maintained at a very moderate expense, and the elevation of the beds of the rivers on the upper sides of these weirs to the full height of the crowns is an inevitable consequence of their construction and no arrangement of under sluices has yet been effective to prevent this result.

In regard to founding these structures on wells, he further says:

> In pure sands acted on by currents due to a fall in the river bed of 3½ feet per mile, and exposed to the action of floods from 12 to 15 feet deep, well foundations in front and rear of 6 feet in depth have been proved by experience to be safe.[a]

As a general rule the masonry apron should have a thickness equal to one-half and a breadth between three and four times the vertical height of the weir forming the obstructive part of the dam. The efficiency of the dam depends upon the construction and careful maintenance of the apron. In time of freshets the water backed against the toe of the weir has a protecting effect on the apron by producing a water cushion, and as the flood rises the height of fall from the weir crest gradually diminishes, and in a flood of 16 feet over an ordinary weir it wholly disappears, leaving scarcely a ripple on the surface to indicate the existence of the masonry mass below.

In the construction of weirs in rivers with sandy beds, wells may be considered as the feature of Indian engineering. These are essentially open blocks or cylinders of brick usually sunk in the bed of the river at low stage and are protected by temporary sheet piling placed between their outer edges, while the intermediate spaces are being filled in with concrete, thus forming a solid wall floating in sand, upon which is built the superstructure of the weir, scouring sluices, apron, and retaining walls. Whatever the form of foundation, be it gravel or hardpan, solid rock or wells, the first portion of the weir constructed is the scouring sluices, which are carried on at the same time with the regulators at the head of the canal. This order is pursued because after the construction of the scouring sluices the water in the river may be diverted through them while the work upon the remainder of the weir is progressing, and especially so that it may be passed through them when the closing of the weir is effected. The heaviest flood of water takes place through these scouring sluices, and in their construction the very best workmanship and material are required.

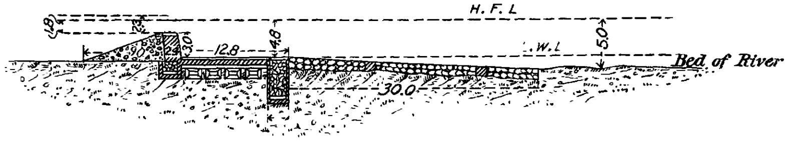
[a] Smith, Col. Baird, R. E., Italian Irrigation, London, 1856.

The weir may, if desirable, progress at the same time with these preliminary works. The cross section of the weir is neither as long nor as flat as that of the foundation and sluiceways. When the closing of the weir is effected the low water in the channel is diverted through the sluiceways, sand or other material available is carried across the last opening, foundations are built up as rapidly as possible, and the superstructure closed.

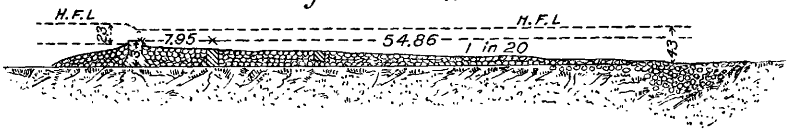
Where a good rock foundation is obtainable in the bed of the stream close to the surface the weir is given an entirely different cross section from that of weirs constructed of other material, and is built throughout of the most substantial masonry laid in cement. In the case of some weirs, the overfall height of which is not great, the cross section is made nearly vertical upstream, and a slight slope, perhaps 4 on 1, is given on the downstream face, which is usually so curved as to carry away the flood water with the least shock to the dam. In the case of higher weirs of this character, or those over which great floods may be discharged, it is usual to make the downstream face nearly vertical, giving a sufficient top width and slope to the upper face to insure the stability of the structure and bring the resultant line of pressures within the middle third. The object of the vertical slope on the downstream face is to give a clear overfall for the flood water. This drops on the water cushion formed by the construction of a subsidiary weir placed some little distance below the main weir, and backs the water up against its base. In all forms of overfall weirs liable to the severe shock of large floods it is customary to construct these subsidiary weirs, some examples of which will be given in their proper places. In the location of such weirs, a broad reach of the stream is chosen for the site of the main weir in order to reduce the height of water passing over its crest; while the subsidiary weir is, if possible, located in a narrower place so as to produce the greatest depth of water on the toe of the upper weir. Scouring sluices of limited cross-sectional area are introduced in such weirs as these, their object being to keep a clear channel immediately in front of the canal regulators.

Of weirs founded on wells in sandy rivers, that at the head of the Lower Ganges canal at Narora presents a peculiar type, being substantially built of masonry and with a profile similar to that of the masonry weirs just described. This weir is constructed entirely of brick, chiefly because of the cheapness of the material at Narora. It consists of a wall 8 feet wide at bottom and 7 feet at top, the crest of which is 9½ feet above the river bed. The upstream slope is vertical while the downstream slope is nearly so. It is protected on the upper side by a quantity of loose rocks or bowlders thrown into the river bed nearly flush with the crest. On the downstream side is an apron nearly 150 feet wide to receive the impact of the falling water. The first 40 feet of this apron is composed of masonry resting on four rows of shallow wells, abutting at its lower end against a row of wells.

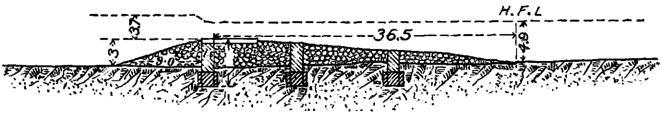
NARORA WEIR—LOWER GANGES CANAL
Length 1260 metres



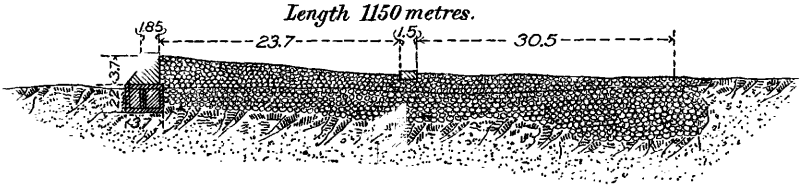
OKHLA WEIR—AGRA CANAL
Length 743 metres



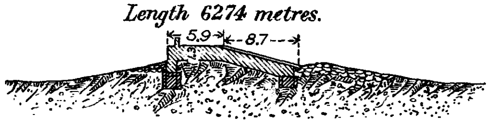
DEHRI WEIR—SONE CANAL
Length 3825 metres



BEZVADA WEIR—KISTNA CANAL
Length 1150 metres.



GODAVARI WEIR
Length 6274 metres.



Note: Dimensions in Metres

CROSS SECTIONS OF MODERN WEIRS.

Below this is a considerable depth of loose hand-packed bowlders carried out to the extreme toe of the apron.

The total length of the masonry portion of this weir is 4,125 feet, including the scouring sluices at the head of the regulator, which are 427 feet long. The left end of the weir rests on an earth embankment a little outside of or beyond the river channel. This embankment is 1,000 feet long with an angle at the shoal end, and is carried up the stream for some distance, thus protecting the low river bottom on that side from flooding. Detailed drawings of this weir showing its cross section, the plan of its foundations, and the arrangements of the embankment and canal head are presented. (Pls. XI and XII and fig. 22.)

Another and very common type of weir founded on wells is that represented by the weirs at the heads of the Agra and Soane canals (Pl. X.) The weir at the head of the Agra canal, as first constructed, had too bold a cross section, and during several successive years the lower end or toe was carried away in time of flood. It has remained intact ever since its reconstruction in 1875. This weir is without foundations of any sort, resting on the river bed. It consists of a wall of masonry 4 feet wide on top and a little wider at base forming the main crest line of the weir, the height of which is 10 feet above the river bed. From this crest the slope upstream is carried to a distance of 40 feet, and consists of large stones hand packed and laid dry. The downstream slope is very flat, averaging about 1 on 20, and is carried a distance of 26 feet to a point at which is constructed another masonry well similar to the first and resting on the river bed, its line being parallel to the axis of the weir for its entire length. Some distance below this is a smaller well similar to the two previously mentioned. The entire remaining portions of the weir consist of large stone blocks dry packed, the walls acting as bars to prevent their sliding.

This weir is 2,573 feet long from the right bank at the canal head, the left wing resting on an island in the middle of the Jumna River. An embankment 20 feet wide on top was carried thence to and across the east channel and thence up the left bank of the river for some miles. The scouring sluices are 139 feet wide, and are substantially founded on four lines of wells. In order to prevent the destruction of this weir by the action of flood waters, groins of a peculiar shape, called alligator groins, are constructed on both the upstream and downstream sides at intervals across the channel of the river and parallel to the course of the stream. The object of these is to deflect as much water as possible toward the right bank with a twofold object—first, the destruction of an island which obstructs the channel just above the canal head; and second, to aid the under sluices in sucking or drawing water toward them at low water, thus affording a sufficient discharge in front of the canal head.

The Soane weir (fig. 12) is similar to the Agra weir in general construction, but resembles that at the head of the Midnapore canals more than any other. It consists of three parallel lines of masonry running its entire length and varying from $2\frac{1}{2}$ to 5 feet in width. The main wall, which is in the central axis of the weir, is 5 feet wide and 8 feet high, and all three lines of walls are founded on wells sunk from 6 to 8 feet in the sandy bed of the river. Between these walls is a simple dry stone packing. The upstream slope is 1 on 3, the downstream slope 1 on 12, and the total length of the lower slope is

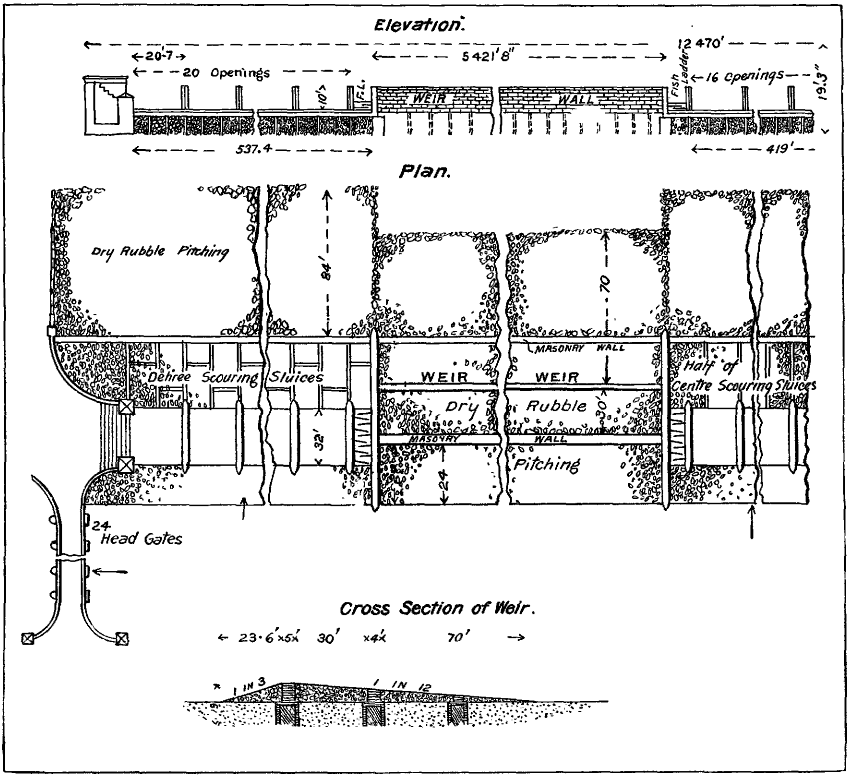
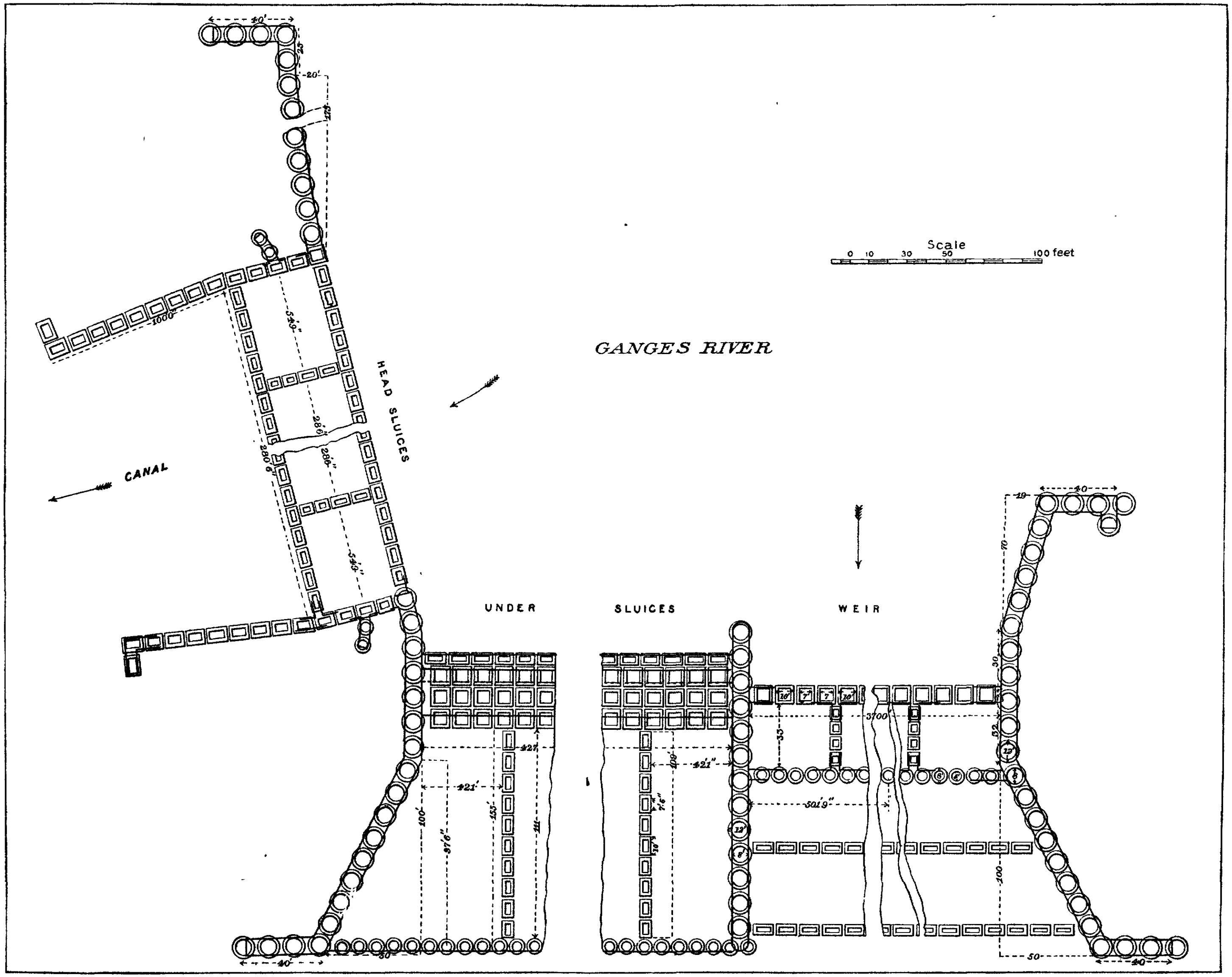


FIG. 11.—Plan of Soane weir.

94 feet. The total length of the weir is 12,470 feet, and it is 19.3 feet in height, including its foundations. On top, hinged to the lower edge of the crest wall, is a row of iron shutters (fig. 13), each 18 feet long and 22 inches high, which are supported by struts, so that when the river is low they increase the diverting height of the dam by 22 inches, and in time of flood they fall automatically, thus giving the flood a solid masonry crest over which to flow. These shutters are held in place by an iron rod hinged to their centers on the upstream side at about one-third of the height from the base.



NARORA WEIR, LOWER GANGES CANAL. PLAN OF WELL FOUNDATIONS.

The weir across the River Ravi (fig. 14) at the head of the Sidhnai canal represents a new and different type of construction. At the

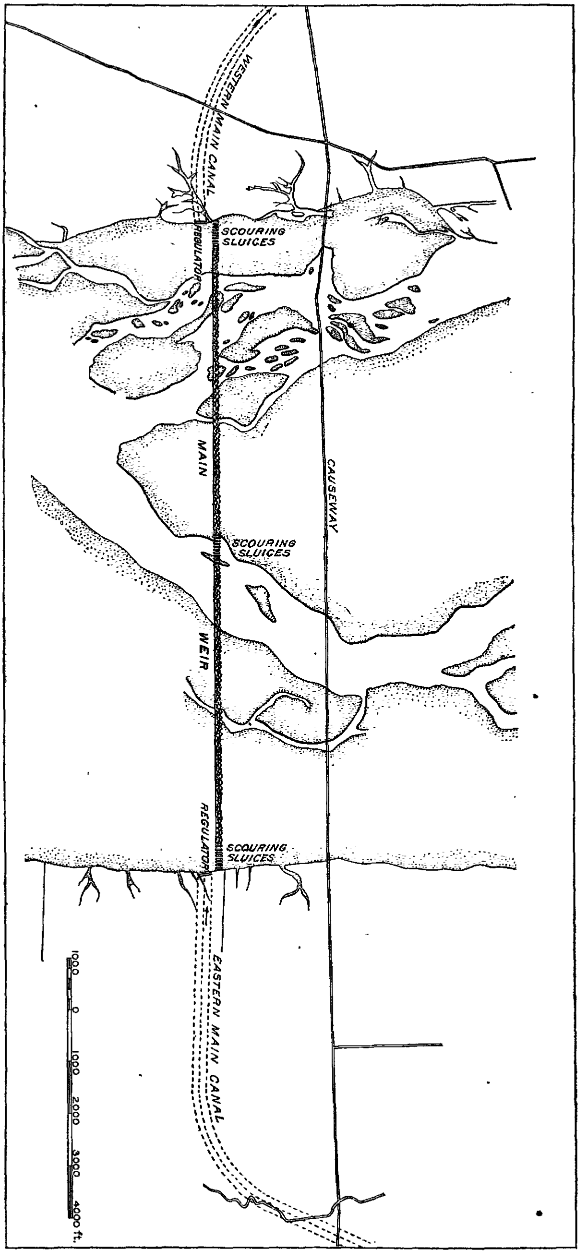


FIG. 12.—Plan of head-works, Soane canal.

point where the weir is built (fig. 15) the river bed for 250 feet on the left bank and 200 feet on the right bank gives a good clay foundation for a reasonable depth below the top of the weir, but the central portion, 390 feet long, is of sand too deep to permit of carrying the foundation to the underlying clay. A trench was dug through this

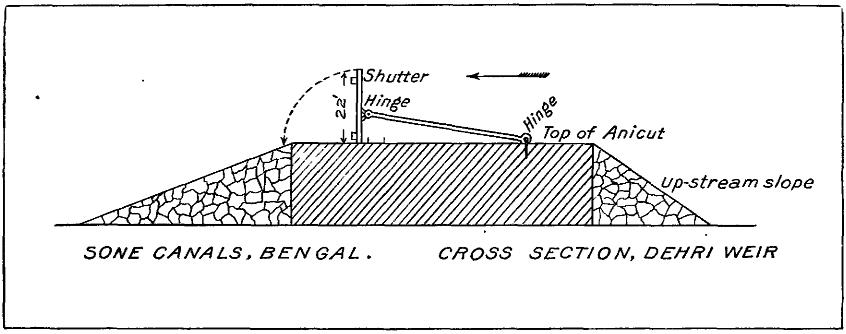


FIG. 13.—Shutter on Soane weir.

central sandy portion to a depth of 13½ feet below the crest of the weir, and for a distance of 400 feet, and sheet piles 10 feet long were driven into the sand as a protection for the foundation, and to prevent excessive percolation below the level of the weir. The highest recorded flood would pass 10 feet over the weir crest. The crest of the weir supports a row of wooden needles which are readily removable and are 7.5 feet long. They are placed between masonry pillars about 16 feet apart, thus increasing the effective diversion height of the weir by their length. This mode of construction is indicated in fig. 19, and the action of the needles is more fully described elsewhere.

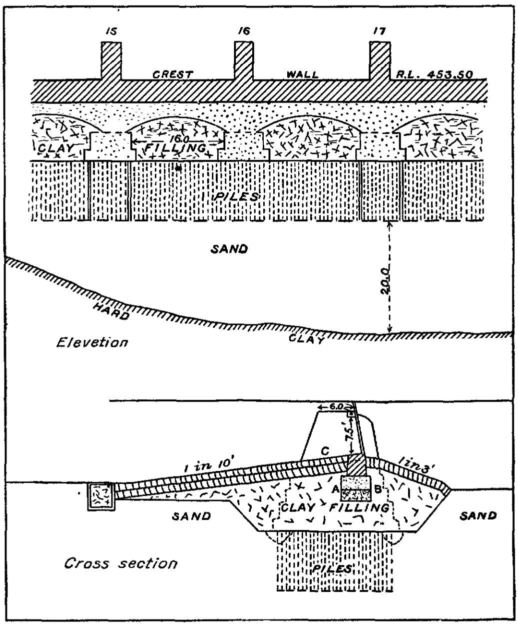
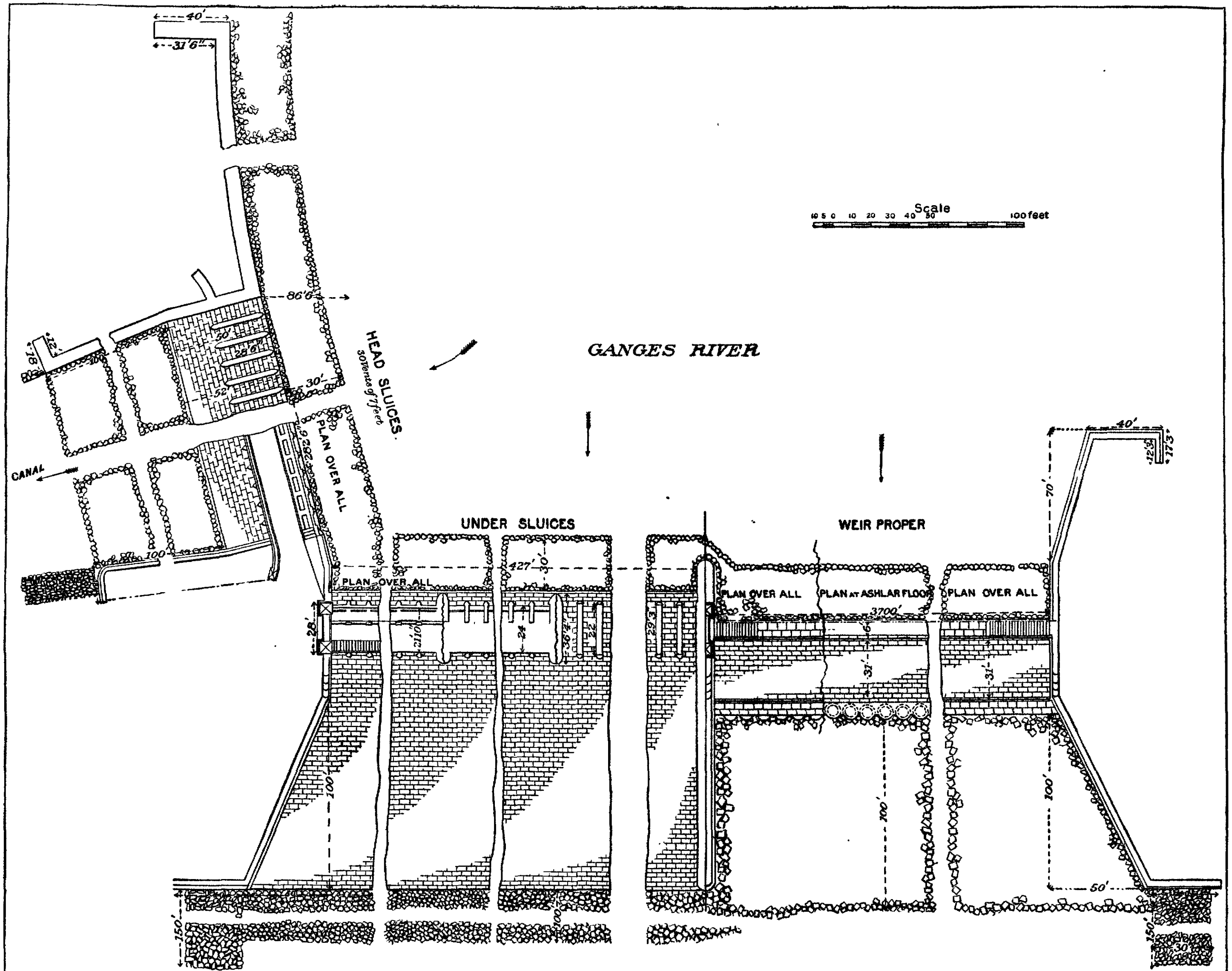


FIG. 14.—Sidhnai weir.

Of temporary weirs, the most notable example is that at the head of the Ganges canal above Hardwar (fig. 18). At this point the bed of the river is composed of bowlders of various sizes to a considerable depth. The head-works of the canal consist of a number of separate structures extending up the river above the head of the canal proper



NARORA WEIR, LOWER GANGES CANAL. PLAN OF SUPERSTRUCTURE.

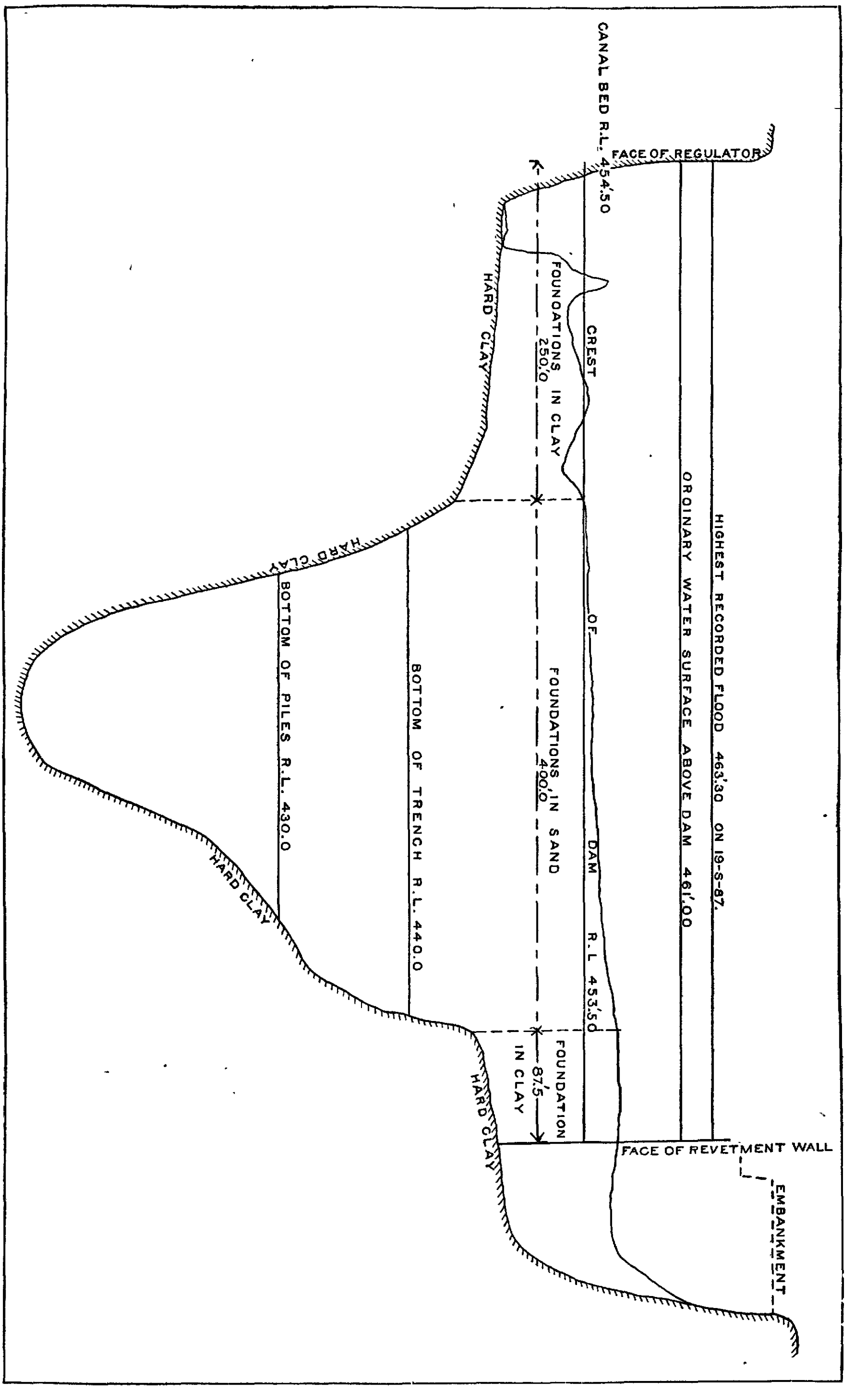


FIG. 15.—Sidhnai canal; section of river in line of dam.

a distance of several miles. The bed of the river is divided into several channels, the principal one being the Hardwar channel, from which the canal is diverted and into which the greater part of the water in the stream is trained by means of various works. The general plan of these works is given in the accompanying sketch. At the upper end of the bifurcation of these channels is a masonry wall or bar constructed across the left-hand channel, the object being to force the water toward the Hardwar or right bank. The Hardwar channel from this point on is protected and trained by means of a series of permanent bowlder embankments, terminating on their ends in masonry noses. On a minor channel a little lower down a permanent weir is constructed, close to the right bank, to prevent the Ganges from cutting too far in that direction; and a trifle below this, crossing a channel leading to the left bank, are the diverting weirs proper, consisting of a series of three temporary bowlder dams, built across the channel one behind the other in such a manner that the leakage through the first will be caught by the second and turned back into

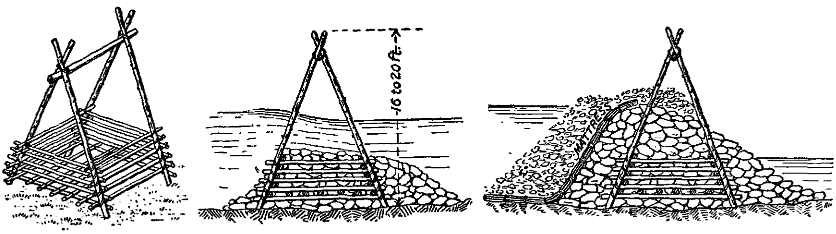


FIG. 16.—Details of temporary dams, Ganges canal heads.

the Hardwar channel, and that from the second will be caught by the third and diverted again to the Hardwar channel. These dams are destroyed each year by the floods and it has been found necessary entirely to rebuild them annually, new bowlders being brought down for the purpose, as the old ones are carried too far away to be economically collected. Experience has shown that this mode of construction of temporary weirs is less expensive than would be that of a permanent one at this place.

Large pyramidal-shaped cribs of timber are formed in the roughest manner and when placed in position are filled with bowlders (fig. 16). Bowlders are then thrown on top of these to strengthen and raise them higher and the channel face is covered with small branches and smaller bowlders and sometimes with earth to prevent excessive leakage. The velocity is about 10 feet per second in the major portion of the Hardwar channel, and its abrading effect is excessive, in consequence of which lines of temporary and of permanent bowlder banks and some masonry dams are carried from this point the entire distance along the sides of the channel to the main regulating weir below Hardwar. Just beneath and below the bowlder weirs above referred to masonry bars are sunk in the bed of the side channel to prevent retrogression of levels, and a few hundred yards below and about opposite the city of Hardwar is a third channel leading from the Hardwar into the left channel. This is stopped by a permanent half-open masonry dam laid on a solid bed of masonry. In times of floods the sluice gates may be removed, while at low water their insertion closes the channel.

The regulating gates are at Myapur, at the head of the canal. Here are also the weir and scouring sluices proper. The latter works consist of a weir of solid masonry founded on the bowlder bed, with 15 scouring sluices, each 10 feet wide. The weir proper is only 525 feet in length, of which 200 feet are occupied by the scouring sluices and their piers. The sluiceways are deep and are closed by double sets of gates, some of which are raised and lowered by means of a traveling winch, the remainder being closed by simple planks or flashboards laid in the grooves.

SCOURING SLUICES.

The scouring sluices placed in open weirs consist of the foundation, the floorway, and the superstructure. The floor must be deep and well constructed and carried for a little distance above the weir and for a considerable distance below it. Above this are built up masonry piers at regular intervals, placed from 6 to 12 feet apart, and grooved for the reception of planks or needles, or closed with automatic gates or some other device which can be rapidly removed or replaced. By this means the water is kept under control and when low can be raised to the level of the crest of the weir by closing the gates, while in time of flood they are opened to secure a scouring of the river channel in front of the canal regulators. The masonry flooring is carried the entire width of the sluiceway, flush with the river bed and abuts well into the bank of the river. This is protected by a curtain wall of masonry up and down the stream.

The sluices in the weir at the head of the Lower Ganges canal at Narora are 38 in number, each 7 feet 10 inches in the clear. They have a total length of 427 feet, and the masonry piers separating them are but 2½ feet wide. The total length of these piers parallel to the course of the stream and at right angles to the line of the weir is 36 feet 4 inches, and they are practically two stories high, the upper deck or gallery having been constructed to have sufficient headroom to raise the gates (fig. 22). These gates are lifted by traveling winches running on rails on the upper deck. The sluiceways, like the main weir, are founded on a series of wells sunk in the sands and connected by brick masonry arches between which is a solid filling of brick (Pls. XI and XII). The total breadth of loose stones on the upstream approach to the sluiceways is 30 feet, and the total breadth of the bed of the sluiceways is 150 feet. Beyond this masonry flooring is carried and flooring of broken stone well packed for a distance of 100 feet farther. The depth of the floor is 3 feet. The arrangement of sluiceway relative to the remainder of the weir and head-works is shown in Pl. XIII. The sluice gates are substantially constructed of wood and iron, and are two in number in each opening, the upper row when lowered abutting against the top of the lower row. In time of great floods both sets of gates may be entirely raised clear of the flood line.

The gates in the weir at Myapur, at the head of the Ganges canal, are similar to those described, and are represented in the accompanying illustration (fig. 17). The sluices in the weir at Okhla, at the head of the Agra canal, are similar in design to all others of this class, and contain 16 openings having a sluiceway of 138 feet. The openings, 6 feet wide by 10 high, are built into a masonry structure 19 feet high, and the gates slide between piers $2\frac{1}{2}$ feet thick; they are raised by a

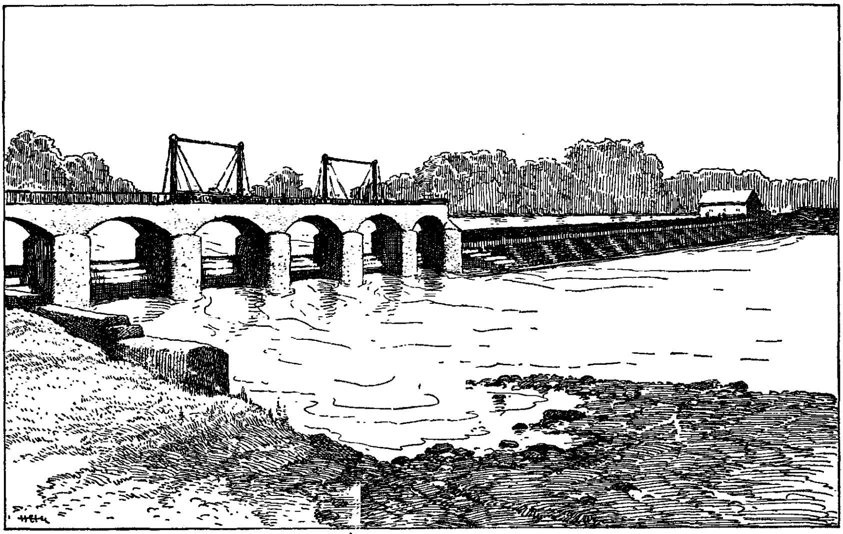
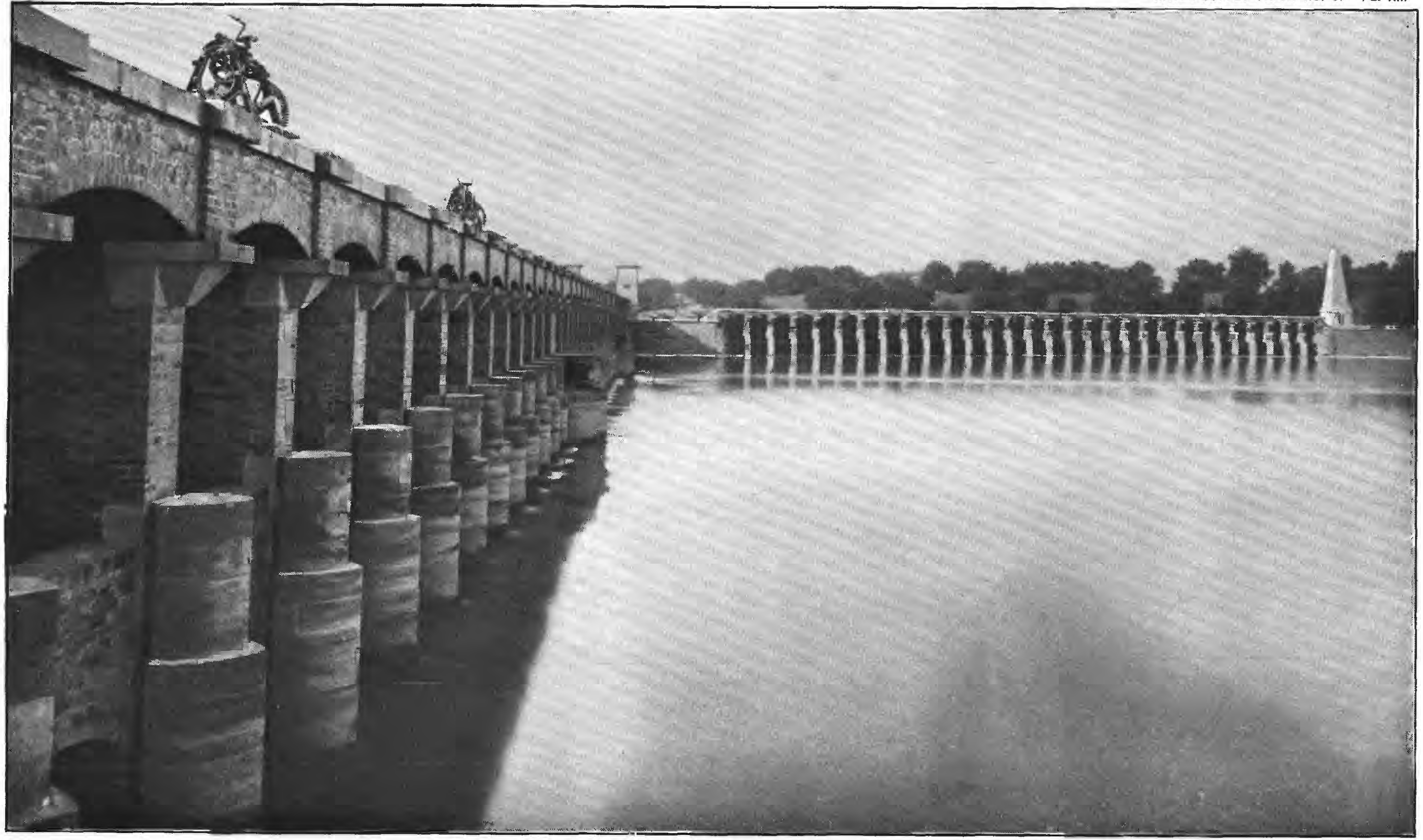


FIG. 17.—Myapur dam, Ganges canal.

traveling winch from above. The floor is founded on four lines of wells, and is 11 feet below the crest of the weir. The pavement of this floor is 8 feet wide upstream, 41 feet downstream, and 12 feet in the center of the weir. This is practically a single structure resting on the sand of the river bed, and is subject to considerable leakage. It is required not only to carry the weirs and their superstructure, but also to withstand the force of a torrent of water 16 feet deep.

Among the earliest and for that reason most interesting series of automatic sluiceways constructed are those in the Mahanadi weir, in lower Bengal, at the head of the Orissa canals. The sluiceway consists of 10 bays each 50 feet wide and separated by masonry piers. Each bay is closed by a double row of timber shutters fastened by wrought-iron bolts and hinges to a heavy beam of timber embedded



HEAD-WORKS, LOWER GANGES CANAL, NARORA.

in the masonry floor of the sluice.[a] There are seven upstream and seven downstream or rear shutters, the latter 9 feet high above the floor, and the former 7½ feet high.[b] During floods the upper row of shutters, which fall forward, are fastened down by clutches in an almost horizontal position, while the rear set, which fall backward or downstream, are kept in a horizontal position by the rush of water over them. In the dry season the rear shutters do duty by damming the water up, and for this purpose are provided with strong wrought-iron struts attached to their lower sides. In order to lift these the upstream set are first raised. This operation being aided by the press of water beneath, they are permitted to rise to a vertical position by means of a chain guyed to the floor above them. Relieved of the water pressure by this upper set of shutters it then becomes possible to raise the lower set, after which the upper set are lowered again into their original position, and the weir is in position to withstand a

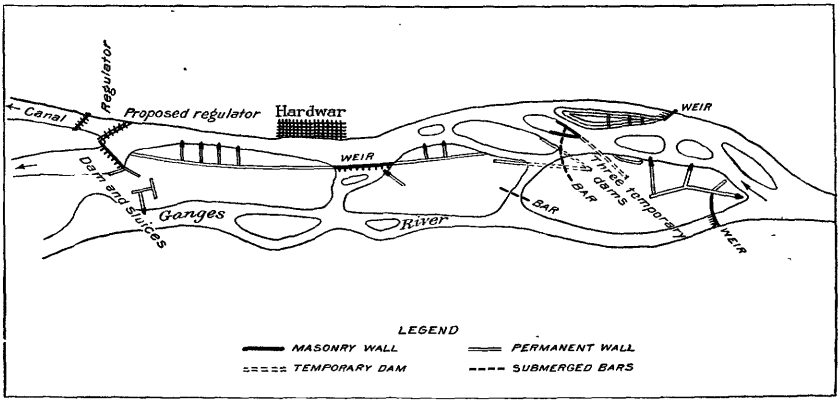


FIG. 18.—Head-works and weir training works, Ganges canal.

flood, as the lower set can be instantly dropped by merely removing the bolts which support them. The redamming of the water is accomplished in less than a minute. By reversing a lever each upper shutter is released, when they rise more or less rapidly, but with a comparatively slow motion until near the water surface, when they are brought home with a jerk, which does not seem, however, to cause a great strain.

Probably the best example of automatic or self-acting sluice gates are those constructed in the weir at Dehree, at the head of the Soane canals.[c] The sluiceways in this weir consist of three separate sets, one of which is placed close to the head of the main western canals, and are 537 feet 4 inches in length, containing 20 openings separated

[a] Roorkee Professional Papers, vol. 7, 1870, p. 75.

[b] Medley, Lieut. Col. J. G., Manual Thomason, College Civil Engineering, Irrigation Works, Roorkee, India, 1873, vol. 9, p. 118.

[c] Buckley, R. B., Fixed and movable weirs: Proc. Inst. C. E. London, 1879–80, vol. 60, p. 64. Medley, Lieut. Col. J. G., Manual Thomason, College Civil Engineering, Irrigation Works, Roorkee, India, 1873, vol. 9, p. 118.

by masonry piers. In the middle of the weir is another set of 16 openings 419 feet in length, and at the extreme eastern end of the weir, below the head of the main eastern canal, is another set of sluiceways 537 feet 4 inches, with 20 openings. In addition to these sluiceways there are, as in all Indian weirs, one or more fish ladders. In the Soane weir there are four separate fish ladders, one at the end of each of the shore sluiceways and one on each side of the central sluice.

The crest of the weir is 9½ feet above the river bed. The gates by which the sluiceways are closed are each 20 feet long and 9½ feet high. They are separated by masonry piers each 6½ feet wide and 32 feet long. As at first constructed these piers were much smaller, but it was found they would not withstand the jar produced by the manipulation of the gates and their thickness has since been increased. It is

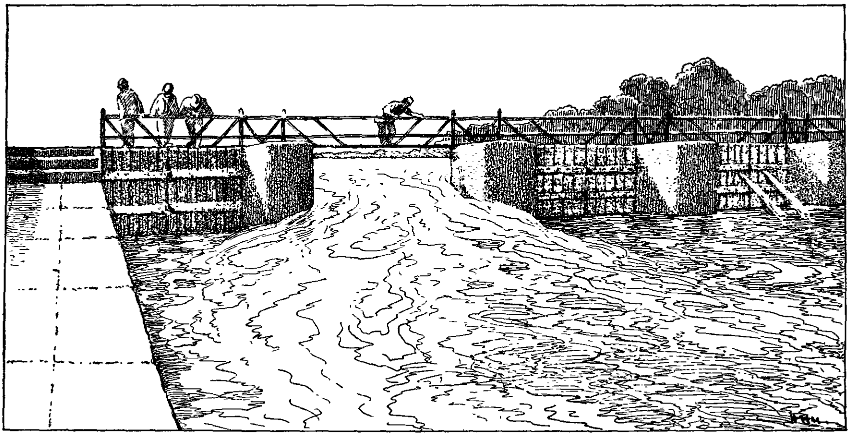


FIG. 19.—Dropping the Soane automatic sluices.

estimated that the velocity of the current through these scouring sluices is about 17½ feet per second. The floor of the sluices is 90 feet wide, parallel to the river channel. As at first designed this flooring consisted of a substratum 4 feet thick of rubble paved with good stone 6 inches thick, but the difficulty of this construction was such that it was abandoned, and the foundations were finally set on blocks. These blocks are 10 by 6 feet, with two well openings each, and were built 3 feet high upon bamboo curbing laid on the surface of the sand, and when the brickwork had set they were sunk until their tops were a foot below water. Concrete was then thrown into the wellholes and around them, and when set in left a solid foundation for the masonry. The ashlar pavement on this solid floor is 15 inches thick in the bottom of the scouring sluices and 9 inches thick over the apron. Twenty-five feet upstream from the sluice flooring is a line of wells sunk 10 feet as a curtain wall to the apron, and the wellholes and interspaces are filled with concrete, as in the foundation of the flooring. The space between the curtain wall and the sluice flooring is packed with large bowlders and covered with pavement 9 inches thick. Twenty-five feet downstream from the flooring of the sluices a line of wells has been sunk 10 feet and formed into a solid wall; the spaces between this wall and the flooring have been tiled and packed with bowlders and stone, and downstream from this point a talus, composed of large bowlders and blocks of stone, stretches 50 feet farther. The whole length of the sluice flooring parallel to the river channel is 200 feet. Notwithstanding the good workmanship of this foundation, the floods of 1874 proved very destructive, and tore away much of the river bed to a depth of 38 feet below the toe of the talus.

The mode of construction and operation of the sluice-gates themselves is as follows: These gates (fig. 25) are constructed of wood, well

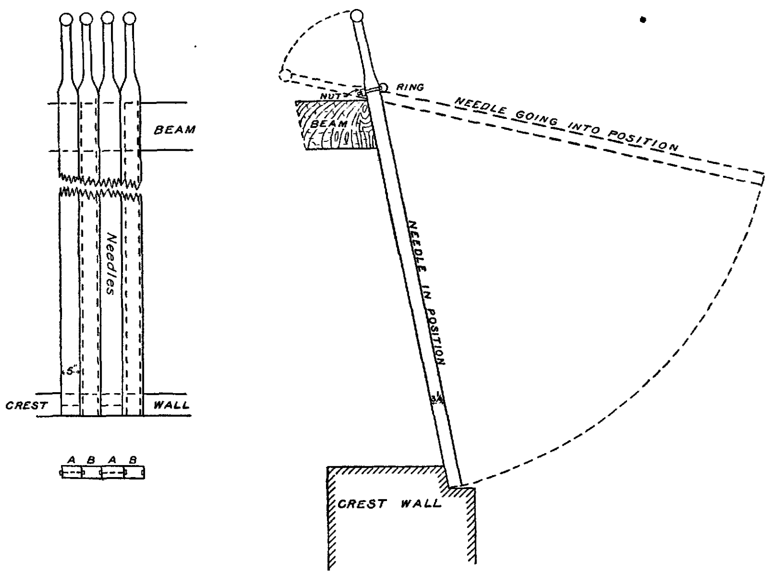


FIG. 20.—Details of Sidhnai weir.

braced, and there are two for each opening. For each alternate pair of piers on the downstream flooring a low masonry wall 1 foot high is built out, which holds 1 foot in depth of water, thus forming a water cushion on which the lower gate falls and relieving the piers of a portion of the shock. The upper gate falls upstream, being hinged to the floor at its bottom, and abuts against a series of six struts, hollow iron cylinders with small vent holes in which pistons work, so that when the gate is raised by the water under it the impact against the struts is relieved by the pistons plunging in the water in the cylinders. The downstream gates fall downstream (fig. 19), and are supported by four iron rods hinged to their upper face below the center of gravity, and when in position are held upright by chains attached to the piers. If both gates are open and it is desired to close the lower one, so as to cause it to dam the water up, the operation is performed in this manner: The lower gate is first relieved by pushing aside the catch which attaches it to the floor, and is raised a little by means of a hand lever, whereupon the force of the water on the under surface brings it up slowly for a short distance, when it comes up with a jar against its cylinder struts.

The pressure is now relieved from the lower gate, which is then raised by hand levers and chained in an upright position to the piers. The upper gate is again lowered, now falling chiefly by its own weight through the water, and is fastened down. The lower gate, now acting as a dam, is prepared to be released at a moment's notice.

The needles used on the Sidhnai weir (fig. 20) are an improvement on a very ordinary form of gate found in most of the simpler and older structures. At the heads of many old canals, and in some sluiceways, gates are found closed by two classes of needles, the simpler consisting of planks or flashboards let horizontally into grooves in the piers and raised or lowered, one at a time, until a sufficient number have been removed or introduced to regulate the discharge of water. The needle is formed by inserting these planks vertically between timber guides or abutments laid horizontally between the piers, the water being regulated by the removal of as many as may be desired. The needles employed on the Sidhnai weir are made of hard wood, of such weight as to be manipulated by a strong man, each needle weighing not over 40 pounds. They are $7\frac{1}{2}$ feet by 5 inches by $3\frac{1}{2}$ inches in size, with a stout handle $1\frac{1}{2}$ feet long ending in a knob.[a]

The most difficult problem when these needles are in position is to make the dam water-tight. Several methods were at first proposed. Grooved needles were found to be unnecessary; ordinary needles, if the interstices between them were filled with wood shavings and chopped straw, were found to be readily made water-tight. After the needles are placed in position they are forced together by being driven horizontally with a crowbar, and a basket filled with shavings, etc., is slipped down in front of the leak to be closed, the calking material being drawn by the current into the openings.

CANAL REGULATORS.

A set of regulating gates is always constructed at the head of a canal. They must afford sufficient way to admit all the water the canal is estimated to carry, and by them the amount admitted can be controlled. Like the scouring sluices, these regulators consist of a set of grooved piers resting on a foundation carried across the canal bed.

The water may be controlled by a set of planks or needles worked by hand in grooves, or, as is more usual, by drop gates raised and lowered by a winch from above. When not under too great a head, each opening is closed by a single gate raised by a hand windlass or winch.

[a] Sidhnai canal project: Selections of Records of the Government of India, No. 248, Calcutta, 1888.

In some cases, under considerable pressure, a double series of gates, one above the other, is used, or else valve gates are employed, which are worked by hand levers and screws from above. It is customary to connect the piers of the regulator by arches, so as to form a bridge across the canal, at the same time affording a convenient platform from which to operate the gates. The bed and banks of the canal at the head are protected by masonry, so as to be safe from erosion when the gates are opened.

In locating the position of the regulating sluices, the principal object is to bring the water in the river through the scouring sluices in such a way that it shall pass directly in front of the regulator, preventing the deposit of silt at its head. This must be so established that the canal will receive the desired volume of water with the least liability of receiving the heavy silt through the regulators or to damage from matter carried by floods. Where this relation between scouring sluices and regulators is such that the least eddy or quiet water exists between the two, there is certain to be a deposit of silt, which is an element of danger and must be removed. At the head of

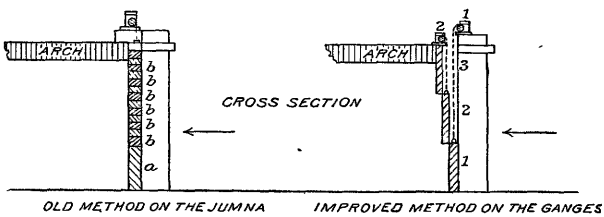


FIG. 21.—Regulating gates, Ganges and Jumna canals.

the Ganges canal the location of the regulating gates is such that heavy deposits of silt are formed. At the head of the Soane canal the face of the regulator is set back 30 feet from the abutment of the scouring sluices, and here also is a heavy deposit of silt. At the Bari Doab head-works the regulating sluices are close to the scouring sluices and the current is so strong that small bowlders and gravel are carried through into the canal. The head-works of the Agra canal are excellently located, and the river channel and canal line are so nearly at right angles to each other that apparently no silting takes place. At the head-works of the Lower Ganges canal little or no silting occurs, owing to the excellent relative location of the various sluiceways.

At Myapur, the head of the Ganges canal, the regulating bridge has 10 bays or openings, each 20 feet wide and 16 feet high, fitted with gates and apparatus for opening and closing. The breadth of the base or platform on which the piers rest is 48 feet, exclusive of the cut-waters, which project upstream 4 feet. The roadway on top of the bridge is 37 feet 9 inches wide between the rear parapet and the row of windlasses on the upstream front. The shutter for closing the regulators, while an improvement on that used on the Jumna canal, is, however, rather crude compared with the modern and improved methods employed on later constructions. The accompanying sketches (fig. 21) indicate the method of arranging the regulators on the Jumna and on the Ganges canals. On the Jumna canal a regulator and drop gate are placed in a simple groove, and sleepers of scantling 6 inches square are dropped in the top of the gate. This has always acted efficiently, but time and labor are required in its manipulation. On the Jumna canals there is no great volume of water to contend

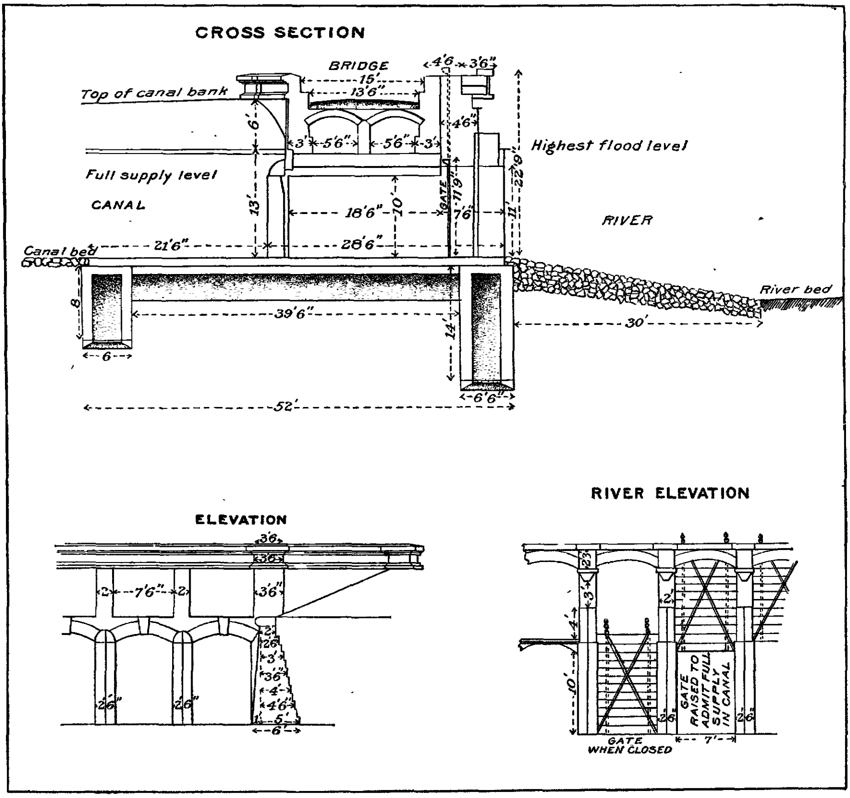


FIG. 22.—Narora weir, Lower Ganges canal; detail of canal sluices.

with, nor is there as large a number of bays as on the Ganges canal. On the latter, as shown by the illustration, the bay is divided into three series of gates, the most advanced one having its sill at the level of the canal bed, and two higher series of gates, each having their sills revetted 6 feet and retrograding toward the face of the bridge. These are operated by separate windlasses over each. The two lower gates are quite independent of each other, the third or upper bay being closed by simple sleepers. The machinery attached to these gates is of the simplest character and readily understood by the commonest laborer, while it is not liable to disarrangement.

From the plan of the relative locations of sluice-head (fig. 23) and regulating bridge it will be seen that the triangle in front of the latter affords an immense backwater or eddy in which deposits of silt must necessarily take place. Designs have recently been submitted for a new regulating bridge which shall be a skew arch, the front face or entrance to the regulators being parallel to the channel of the Ganges and at right angles to the scouring sluices, the rear side being at right angles to the channel of the canal.

An interesting and unique set of regulating gates, because of the great pressure under which they are worked, are those at the head of the Betwa canal (fig. 49, p. 177), and attention is called to them in this

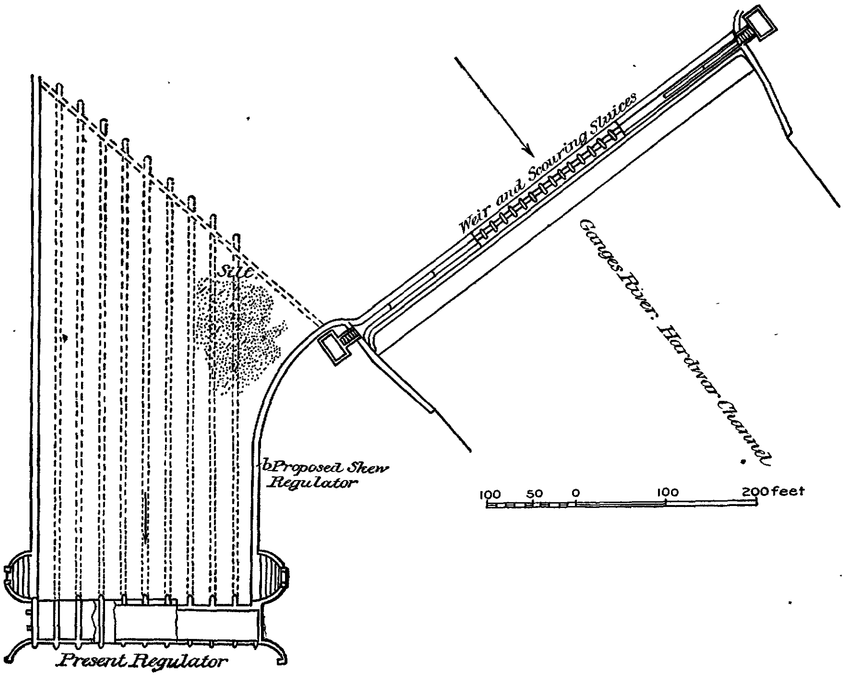


FIG. 23.—Head-works, Ganges canal.

place, though they will be more fully described later on. The regulators at the head of the Soane canal are placed at right angles to the scouring sluices, though they are set back a short distance from the line of the curtain wall leading to the scouring sluices. The floor of these regulators is about 3 feet above that of the scouring sluices. The masonry work in connection with the head-works of this canal is well constructed, but perhaps too elaborate. These regulating sluices are designed to discharge 4,500 second-feet with a head of only 4 inches and a depth of 9 feet of water. They consist of 24 openings, each 6 feet wide, and separated by the solid piers which support the bridge above. There are two shutters constructed of wood, opening vertically (fig. 24). Usually only the upper gate is used, the chief deposit of silt thus taking place in front of the lower gate, where it is easily dredged out, but when the head of water is very low the lower gate is sometimes raised. The silt is thus flushed out and deposited in the canal, where it is still more easily dredged. These shutters are raised by a traveling winch supported on a hand car on rails on the bridge above. The figure shows the mode of raising these gates and of fastening them together when both are to be opened.

At Vir, where the head-works of the Nira canal are situated, the regulating gates are simple, giving a water way through seven separate bays, each 4 feet wide, and operated from a masonry bridge above (fig. 45, p. 170). These are so designed that under the lowest available head of 9 inches the full discharge required will be admitted to the canal.

The regulators at the head of the Lower Ganges canal, like the weir and scouring sluices (Pl. XIII and fig. 22), are founded on two rows

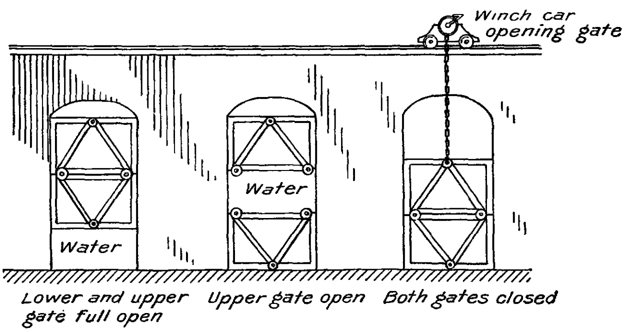


FIG. 24.—Regulating gates, Soane canal head.

of wells. Curtain walls founded on wells are carried along the banks of the river and canal for a short distance. The flooring of the regulators is well paved with substantial masonry from 3 to 5 feet thick, and a rough loose-stone pavement is carried for some distance into the river above the regulators and 100 feet below them, the banks of the canal being revetted for some distance farther. The width at the canal head is a little greater than that of the canal, causing the velocity for a short distance to be diminished, in consequence of which the majority of the silt is deposited at this one place, where it can be most conveniently removed. The total width of the regulators at the head is 282½ feet. There are 30 bays, each 7 feet wide, separated by substantial masonry piers 28½ feet long by 2½ feet wide. The gates closing the entrance to the canal head are of iron and slide vertically. They are each 11 feet high, are raised by a winch traveling on the bridge overhead, and are closed by their own weight. In the piers on the upstream side of these gates are grooves in which planks may be inserted in order to reduce the head on the gates when operating them.

The regulator at the head of the Sidhnai canal consists of four 60° arches of 22.5 feet span, with jack piers 2.5 feet thick in the center, which divide the waterway into eight spans of 10 feet each. The arches

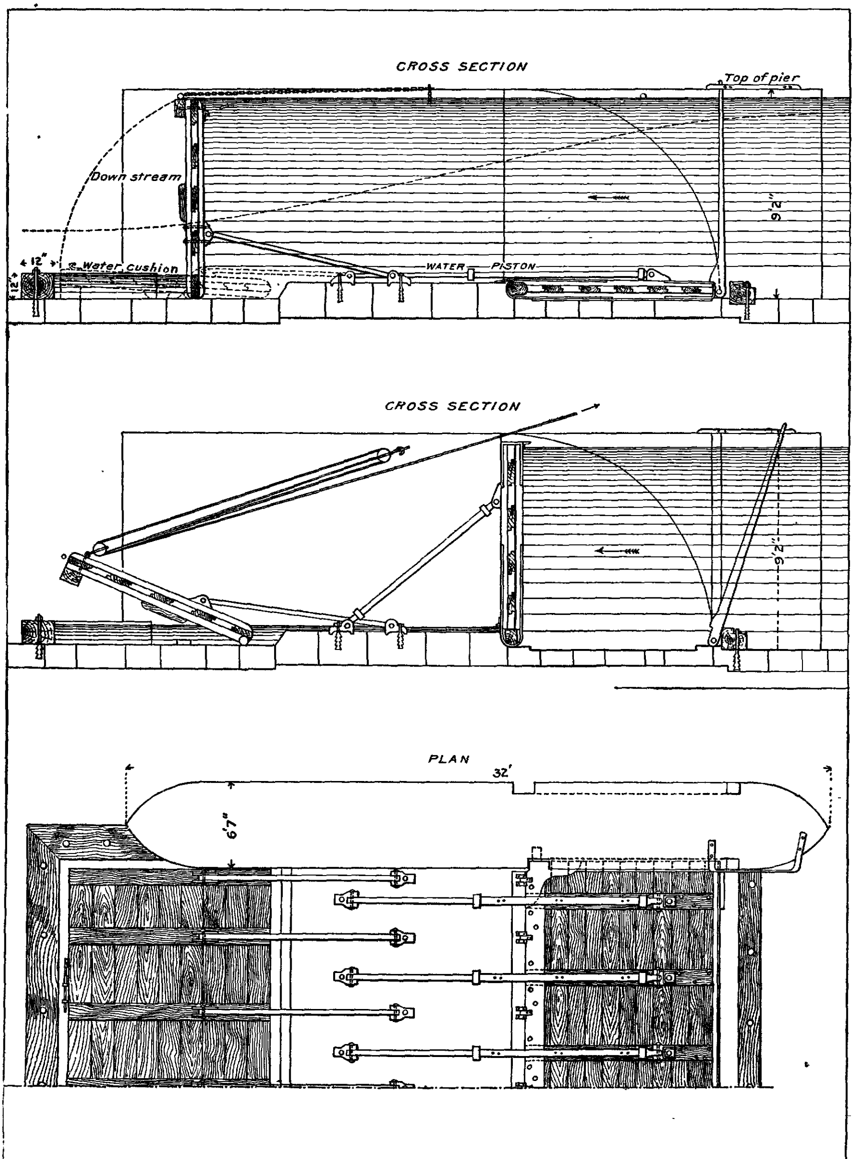


FIG. 25.—Soane canal, automatic sluice gate.

spring from 6 feet above the floor. The floor is 1 foot above the crest of the weir, and as the needles on the top of the latter are designed to hold up $7\frac{1}{2}$ feet of water, $6\frac{1}{2}$ feet can be forced into the canal. There is nothing novel in this regulator, the gates being made of wood bound with iron and sliding in cast-iron grooves. The lifting apparatus is a traveling winch working on rails on the top of the parapet of the bridge, so placed that the drum of the crab winch is centrally located over the gate to be lifted. There is an upstream set of grooves in the piers into which planks can be inserted to relieve the gate from pressure should it jam. Planks are generally used for regulating the supply in the canal, the gates being intended for use only when it is necessary to close the regulator quickly.

WELL FOUNDATIONS.

Wells and blocks may be considered as one and the same form of construction, though perhaps blocks are more properly rectangular wells having one or more well holes in them, while wells proper are circular in plan with a single central opening. They are in reality brick caissons from 6 to 20 feet in diameter, the walls varying in thickness from 2 to 4 feet and of any required height. Blocks are rectangular brick caissons, perhaps 6 by 10 or 12 feet, with 2-foot or 3-foot walls, and subdivided into two or even four vertical passages or well holes. For the piers of the Solani aqueduct the blocks are 20 feet square and divided into four well holes. At the head of the Agra canal they are rectangular, 13½ by 9 feet, and contain two well holes, each 4 by 3 feet. At the head of the Lower Ganges canal they are round, 12 feet in diameter, with walls 2 feet thick.

In sinking wells the water in the part of the river to be operated upon is usually temporarily dammed and the earth removed until the water surface is again reached. Curbing of bamboo of the size of the well is then laid, and on this the well is built up. It is commenced by placing on its lower edge a cutting surface of wood or iron, wedge shaped, with the cutting point downward. Into the top of this the masonry work is built. As the building continues the sand and gravel are removed from within by hand or by dredge, and the well sinks by its own weight. Much difficulty is frequently encountered in sinking these wells, owing to their uneven subsidence or on account of meeting layers of earth of different character, which must be removed or the well so loaded as to cause it to sink vertically. When the well or block is sunk to the required depth it is usually filled with concrete, and thus becomes a solid pillar. The spaces between the walls are then protected by sheet piling, and after the removal of the sand concrete is placed between them, thus forming a continuous wall. This method is simple and not costly. It is particularly effective in deep sand or in quicksand, and may be carried on by workmen with little risk of danger.

The depths to which wells are sunk differ greatly. In the case of the head-works of the Agra canal no wells whatever were made under the weir, as it rested directly on the sand. At the head of the Soane

SINKING FOUNDATION WELLS, NADRAI AQUEDUCT, LOWER GANGES CANAL.

canal the wells are sunk about 10 feet below the base of the weir; and at Narora, at the head of the Lower Ganges canal, they were sunk 20 feet. Wells are built either in single or double rows, the distance between these varying according to the dimensions of the wells themselves. They have in some cases been connected by brick masonry arches, and the interspace below the arch filled with solid brick. This was done in portions of the head-works of the Lower Ganges canal.

The most striking case of the construction of wells as a foundation for a masonry superstructure is that of the wells for the support of the Nadrai aqueduct on the Lower Ganges canal over the Kali Nadi Torrent. The whole structure of the aqueduct, including river and canal wing walls, is founded on wells, the cutting edges of which are sunk 51½ feet below the level of the Kali Nadi Torrent at that point, the average depth of the wells being 56 feet. The wells are of three sizes, being 20 feet in diameter for the piers and canal land wings, 13 feet in diameter for the river piers, and 12 feet for the abutments. There are 102 wells 20 feet in diameter, 44 wells 13 feet in diameter, and 122 wells 12 feet in diameter, or a total of 268 wells on this work. The total linear depth of well sinking amounted to 15,008 feet. Accompanying are given illustrations showing some of the details of these wells (Pl. XIV).

The well curbs were generally constructed of wood, with wrought-iron bolts 1¼ inches in diameter projecting from them and built up into the brickwork. In the 12- and 13-foot wells only one dredger was worked at a time, and the average rate of sinking was 1 foot per day. In the 20-foot wells three or four dredgers could be used at once, and with this number the rate of sinking amounted to 1¾ feet per day. Building and sinking went on alternately in the construction, the brickwork being carried up in lengths of about 8 feet, as the wells sank that much. When 25 feet had been sunk the brickwork was carried up the full height, 47½ feet above the cutting edge, and the sinking continued until clay was reached. On a well showing even the slightest signs of going out of the perpendicular dredges were worked on the opposite side from that to which the well inclined. In extreme cases a "jham" was worked from a windlass on top, which stirred up the silt in the sump less than did the dredger and allowed a deeper hole to be made on one side. Only two or three of the 20-foot wells were 1 in 40, and the majority less than 1 in 100 out of perpendicular when the under dredging was stopped. In the lines of the abutments, where the 12-foot double rows of wells were only 2 feet apart, there was a decided tendency for each pair of wells to lean toward each other and for the curbs to separate. In some cases where the wells got out of perpendicular or failed to sink in the hard clay, it became necessary to load them with railway iron or a temporary superstructure of brick. To test their resistance against subsidence some of the less satisfactory wells, after they had been hearted with concrete, were loaded with a great temporary superstructure of bricks, which in the case of one well weighed 1,451 tons (Pl. XIV). The total subsidence amounted to but $1\frac{1}{4}$ inches. After the well had gone through the blue clay and while dredging in the brown sand was in progress, inblows of the blue sand above the clay were of frequent occurrence. These were generally caused by the dredger being worked awkwardly. Sometimes the inblows were so rapid as to bury the dredger before it could be lifted, and at other times they were extremely gradual. These inblows frequently caused the well to incline from the vertical. When it was found that some of the 12-foot wells inclined from the vertical, advantage was taken of it to make them incline, so that when finally loaded with the superstructure and arch they would be in the best position to receive the arch thrust.

Mr. Beresford, the superintending engineer, in a note on "Frictional resistance to sinking due to lateral pressure of earth on the sides of a well," [a] shows that the pressure Py exerted by earth against a vertical plane per unit of the breadth is

$$Py=\frac{Wx^2}{2}\cdot\frac{1-\sin O}{1+\sin O},$$

where W=the weight of earth per cubic foot, x=the depth the plane is sunk below the surface of the earth, and O=the angle of repose of earth. The values found practially agree very closely with those derived from this formula. From some computations it was found that the value of $Py=\frac{100}{2}\times 58^2\times 0.33\times 63=3,496,878$ pounds=1,562 tons, taking W=100 pounds; O=30° and the coefficient of friction of the masonry on moist clay as given by Rankine=0.33. Therefore the friction F=1,562×0.33=515 tons.

ESCAPES.

In order to establish a complete control over the water in a canal channel, provision is made for disposing of any excess which may arise from sudden rains or floods, or from water not being required for irrigation. This is effected by means of escapes or short cuts from the canal to the river or other natural waterway into which the excess of the water can be discharged. These escapes perform the additional service, in the case of streams carrying much sediment in suspension, of flushing the canal, thus preventing or removing excessive silt deposits. Colonel Cautley, in speaking of escapes and their employment on the lines of distributaries, says:

> In times of flood, opening the heads of the distributaries relieves the main canals, and the former are in turn relieved by the escapes. Hence the distributary heads become the safety valves, and the escapes the waste pipes of the entire canal system.

[a] Gordon, W. B., Notes on Well Sinking, Nadrai Aqueduct, Public Works Department, Northwest Provinces, India, p. 20.

Escapes are provided at certain intervals along the entire canal line, and a double set of regulators are made at the point where the escape is taken off, as in the case of a branch canal or distributary. On the Ganges canal they are projected at every 40 miles, though much depends on the convenience with which they can be made and the proximity of the canal to some water course into which the escape water can be conducted. They are also provided if possible at dangerous points, as above or along lines of heavy embankment where, in case of the bursting of the bank, much damage would ensue. The first main escape is always constructed at a distance of half a mile or less below the canal head, and when it becomes desirable to scour out the silt accumulated between the head and the escape the latter is opened and a large volume of water admitted to the canal. This runs off through the escape carrying the silt with it. It is usual in such cases to decrease the slope of the canal for a short distance below its head to cause the deposit of matter carried in suspension between that point and the escape.

The escape cut must be sufficiently large and have enough fall to carry off the whole body of water which can reach it, so that if necessary the canal below the escape may be left dry for repairs without stopping its running above. The complete control of the canal waters by double escapes consists of the construction of a regulator at the head of the escape, and another one across the canal channel immediately below the escape. These escape heads are similar to the regulating bridges previously described and to the various regulators constructed at the heads of distributaries. When a heavy rain occurs on the line of a canal the irrigators cease to use the canal water, and as the flow can not be immediately stopped at the head-works, great damage would be done by the surplus water but for the escapes, which act as though the head regulator of the canal had been brought so much nearer the point of application.

The Khutowli escape head on the Ganges canal is an interesting example. It is at the sixty-second mile and consists of a channel excavated 60 feet wide and $3\frac{1}{2}$ miles long. The masonry head consists of ten openings, each 6 feet wide, the height from the flooring to the soffit of the arch being $8\frac{1}{2}$ feet. The flooring is 64 feet wide, 40 feet of which forms the tail, and is laid on a slope of 1 foot from the level of the canal bed. The banks of the works are protected by masonry revetments and guards of piling and rubble which protect the floor from the wear and tear of the current.

Colonel Cautley made the following rules to control the location and regulation of escapes on the Ganges canal:

With reference to position, the distance between the escapes is limited to 40 miles, considering that by adapting their capacity to the volume of water contained in this length of canal the facilities for regulation are ample. In the sandy tracts of the canal the number of the escapes is multiplied rather than having their waterway increased. The sites of all escapes are fixed in such a position that the water may be plunged into the bed of the receiving channel and that the high-water mark of the latter shall never interfere with the free discharge of the canal. The escape channel shall, when perfected, have, in addition to the initial slope of 12 inches from the bed of the main channel which is given to the tail of the escape head, a slope of bed equal to 1½ feet per mile.

FALLS AND RAPIDS.

As the natural fall of the country through which a canal runs is usually greater than the slope of the canal, it becomes necessary to compensate for this difference of slope. This is done by concentrating it at a few points where vertical falls or rapids are introduced.

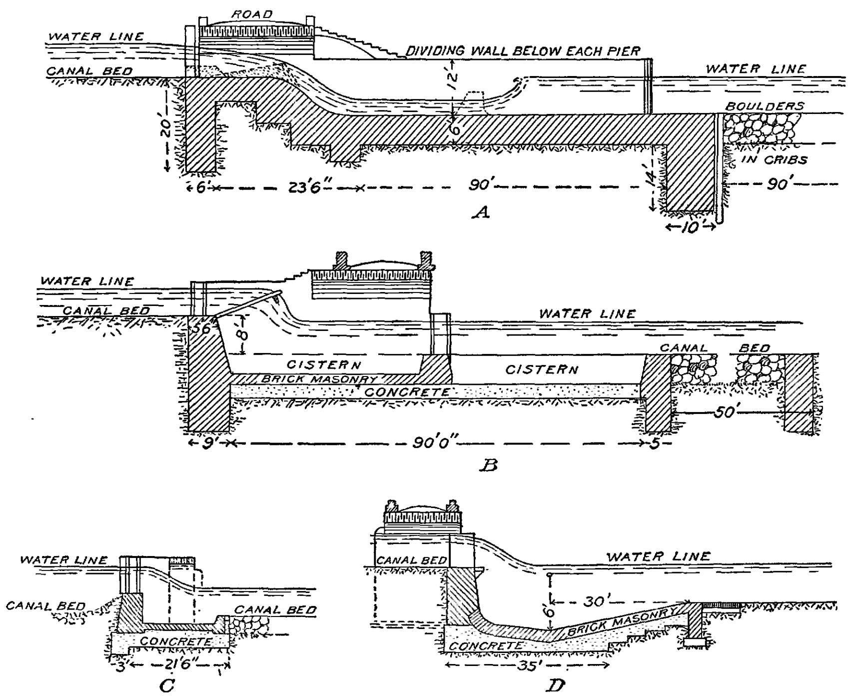
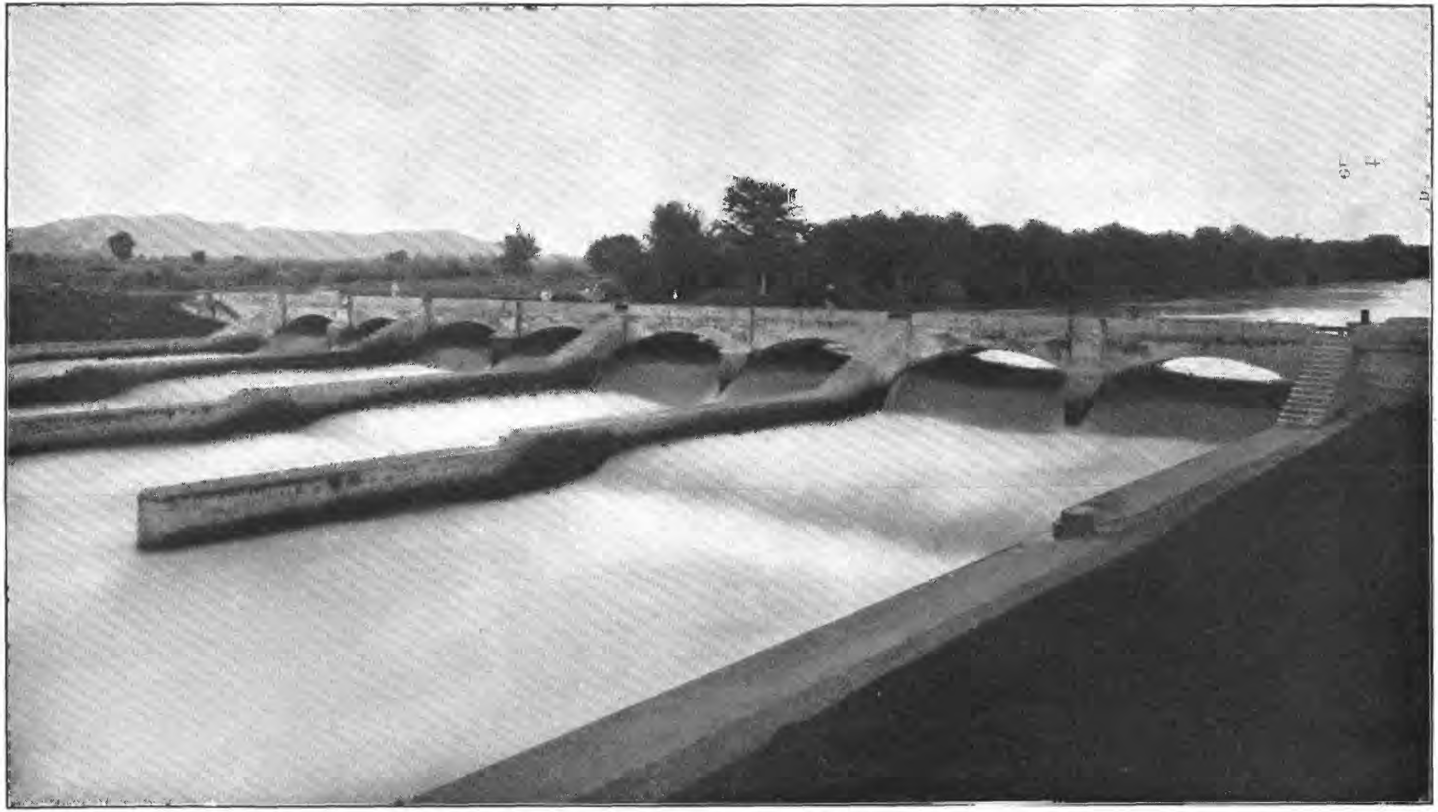


FIG. 26.—Sections of canal falls.

The location of these is usually fixed by the place where the canal becomes too high above the surface of the ground, while their exact position is made to coincide if possible with that of a bridge or similar work in order to economize masonry construction.

Ogee falls were first adopted on the Ganges canal and are of the shape shown in the accompanying figure, the intention being to break the force of the fall of the water. They were about 8 feet high, but the shock of the fall proved so great that they have been modified to give two vertical falls, the lower of which drops into a water cushion. On the Ganges canal were a number of ogee falls (fig. 26, *A*) 15 feet high. These have been so remodeled as to give an upper fall of 5 feet, then



ASAFNAGAR FALLS, GANGES CANAL.

a short level bench of 10 feet, and a vertical drop of 10 feet, ending in a shallow water cushion (Pl. XV). These falls have a solid masonry floor 4 feet thick. On some falls the action of the water is lessened by making it play over a wooden grating. This reduces the shock by dividing the stream into a number of fine threads. Falls are invariably constructed of substantial masonry laid on a deep and firm foundation. The banks are protected by masonry and paving. The latter is carried for some distance below the fall both in the bed and on the sides, and the flooring terminates in a row of sheet piling. In broad canals like the Ganges the fall is generally divided into compartments by longitudinal dividing walls, so that when repairs are necessary one portion may be laid bare at a time. On the Ganges canal most of the falls are constructed at points where bridges would be necessary, and to the lower side of the bridge the fall is attached. Below this the channel of the canal is widened out, the flooring and sides to the extremity of the cistern in which the fall terminates being carefully and securely paved and revetted.

Experience seems to show that vertical falls with gratings, as used on the Bari Doab canal, and terminating in water cushions, are the best that have been devised (fig. 28). The grating consists of a number of wooden bars, resting on an iron shoe built into the crest of the fall, and on one or more crossbeams, according to the length of the bars. These bars are laid at a slope of 1 on 3, and are of such a length that the full supply water level in the canal is half a foot below their upper ends. The dimensions of the bars used where the depth of the water is $6\frac{1}{2}$ feet are as follows: Lower end one-half inch broad by three-fourths of an inch deep; upper end one-fourth inch by three-fourths inch deep. They are supported on beams 1 foot broad by 1 foot deep. At first these beams were 6 inches apart, but it has since been found best to increase this distance a trifle, and now 18 bars are placed in a 10-foot bay. The bars are undercut from the points where they leave the shoe at the crest of the falls in such a manner as to make each space an orifice in a thin plate.

The effect of a fall at the end of a canal reach is to increase the velocity and to diminish the depth for some distance above the fall. This increase of velocity produces a dangerous scouring on the bed and banks of the canal, and is guarded against by heading the water up at the crest of the fall by means of sleepers dropped in grooves of the piers, thus increasing the height of the fall. The narrowing of the canal banks at the fall produces the same effect. The better method, however, is to raise the crest of the fall by a masonry weir, and the height necessary to raise it is found by the following calculation, given by Colonel Dyas:

$$H=\left(\frac{900\ a^2\ d}{l^2 s}\right)^{\frac{1}{3}}-125.8122\frac{d}{s}$$

in which H is equal to the height of the water above the crest of the fall; a is equal to the sectional area of the open channel; d equals the hydraulic mean depth of the same; l is equal to the length of crest of the fall, and s equals the length of slope to a fall of one in same. When gratings are used these act instead of a weir in checking the velocity of the water, and the method of spacing them is such that the velocity of no one thread of the stream shall be either increased or retarded by the proximity of the fall.

On the Soane canal, where there are many locks, the falls are nearly always introduced at the points where the locks occur (fig. 27). The main line is carried through the locks, and the waste weir or branch channel is carried around them, and in it the surplus water over that which is required for the operation of the lock is conducted. In this branch channel a fall must be constructed. In one case noticed, where there were two locks, with a total lift of 20 feet, the fall was constructed

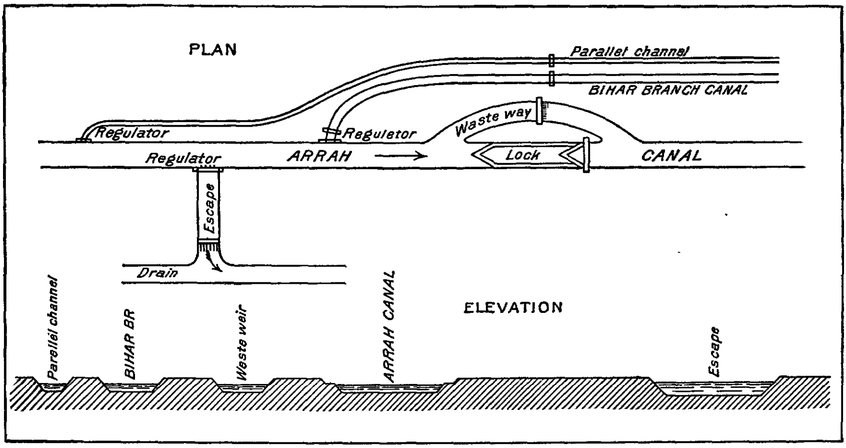


FIG. 27.—Soane canals, Bengal; arrangement of branches and escape at Dunwar.

in three bays. The channel was 40 feet wide and the falls were built of substantial brick masonry terminating in a deep cushion below. On the Agra canal are several interesting falls, perhaps the most elaborate of which is the Kushuk fall, on the Bata escape (fig. 30). This is a masonry fall, or rather two falls terminating in water cushions, the total height of which is 27 feet. The total length of the masonry work is 190 feet, and the depth of the concrete flooring is 3 feet, terminating on a well, on which the toe of the apron rests.

Instead of falls, rapids have been constructed with great success on the Bari Doab canal (fig. 28). The slope of the rapid is paved with loose bowlders, confined by walls of masonry built at intervals of 40 feet longtudinally across the stream. From experience on these rapids it has been found that dry bowlder or rockwork is not to be depended on for velocities over 15 feet per second, and that over this the slope must be modified or masonry be used. On the Bari Doab canal rapids were adopted wherever bowlders were procurable at moderate expense.

Bowlders form the best material for the flooring of a rapid. Brickwork should not be used with currents of high velocity, as the best bricks do not stand the wear and tear for any time, certainly not for service in contact with velocities exceeding 10 feet per second. The bowlders were generally grouted in a good bed work of mortar and small pebbles or shingle, where velocities above 15 feet per second were employed. The tail walls on these rapids are of peculiar construction, for the purpose of turning back the eddies and of protecting the canal banks from the direct action of the water. Beyond a point where the heaviest action occurs and where the greatest width is given the tail-works, the banks incline toward each other so as to direct the set of the stream to the middle of the canal. The tail walls are not kept to their full height throughout, but gradually become lower and lower, till they disappear altogether, where they reach the same level as the bed of the canal. In case no tail works are given, the banks are faced with bowlders or piling for a length of perhaps 300 feet below the rapid. On distributaries and their branches falls and rapids are resorted to, as on the main canals, differing only in details of design.

DRAINAGE WORKS.

In canals where the diversion line is carried along the sides of hills or slopes, great difficulties are sometimes encountered in passing the side drainage which crosses the canal lines. Much can be done by diverting water courses or constructing short drainage cuts emptying into natural drainage lines. When the drainage can not be diverted it may be passed in one of several ways. If the stream is at a lower level than the canal the latter may be passed over it in an aqueduct, which in most cases will involve the construction of some embankments before the stream channel proper is reached. If the canal and stream meet at the same level the latter may under exceptional circumstances be permitted to enter the canal. This will necessitate the introduction of proper regulating works below the canal crossing, and an escape or dam on the opposite side to the inlet. In the case of very small streams entering a canal at level, an inlet only is necessary, the surplus water being passed off through the first escape in the canal channel. If the stream encountered is at a higher level than the canal it is generally carried over the latter in an aqueduct, which is called a superpassage. In the case of nonnavigable canals, less elaborate drainage methods than those described may be employed, and modifications of these methods are used, as when the canal is carried under the stream in an inverted siphon, or a combined siphon-aqueduct has been constructed.

By means of simple diversion of the course of a stream much expense may be saved. An instructive example of diversion is that of the Chuki Torrent on the Bari Doab canal. At the time of the construction of the canal this torrent had two outlets. Just above the crossing of the canal the main channel divided, one channel running into the Beas and the other into the Ravi River. The latter was embanked close to the bifurcation by bowlder dams and spurs protected by masonry revetments. By this means the whole of the water was forced to flow into the Beas, and the expense of the work of crossing the canal was saved. Another instance is that at the head of the Betwa canal. The first 6 miles of this is protected by a drainage channel 15 feet wide at the bottom and 6 feet deep, which runs parallel to the canal and carries the drainage into a small stream whence it is let into the Betwa River. At the Betwa head-works a creek enters the river, and this was blocked up by a large embankment and turned back by a cut, through which it entered the river above the head-works.

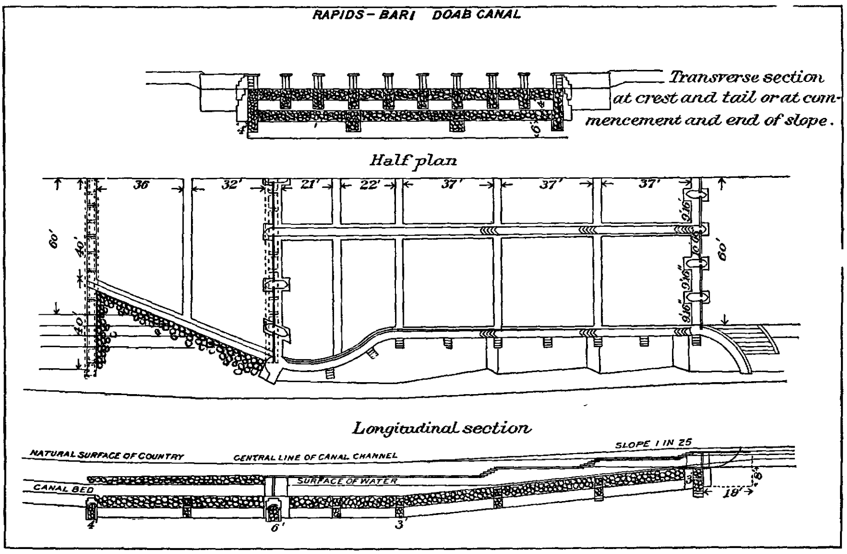
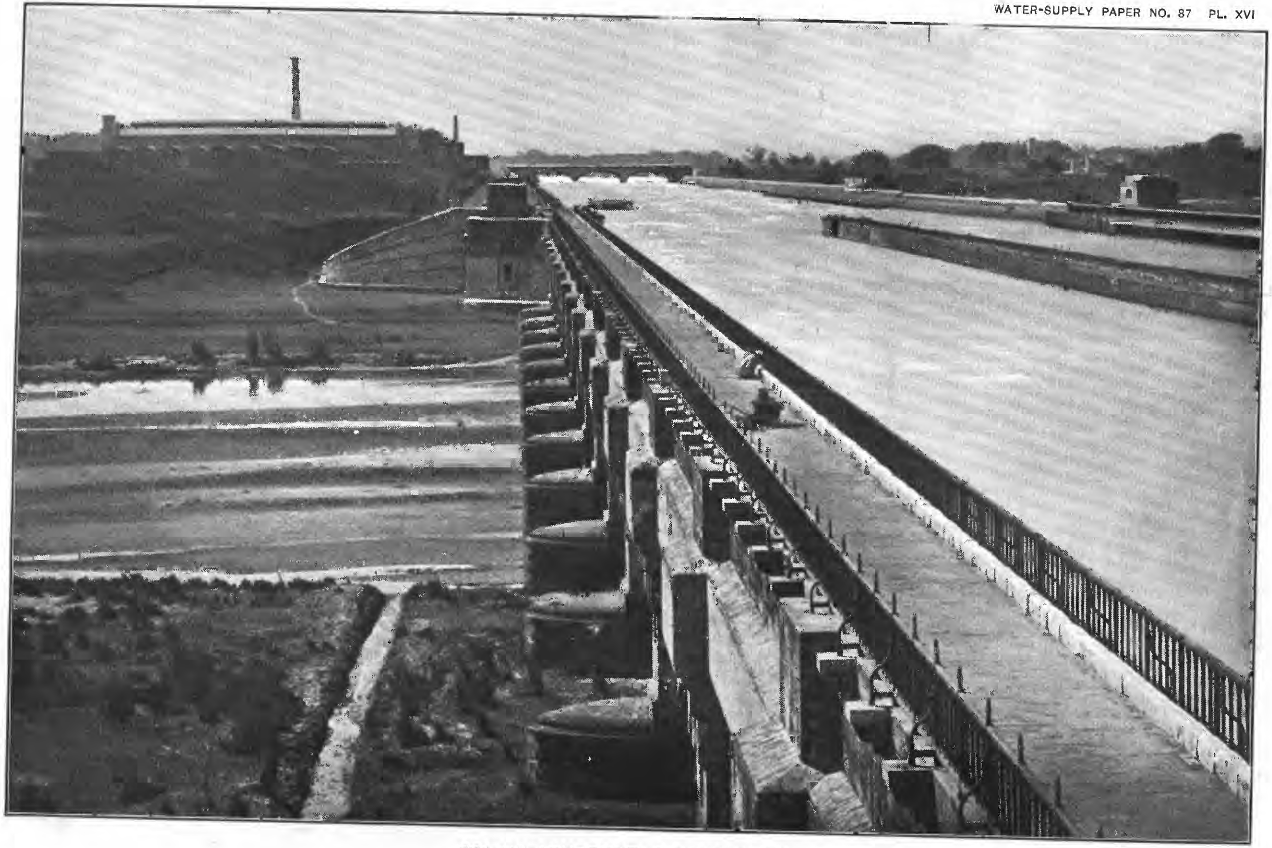


FIG. 28.—Rapids, Bari Doab canal.

Aqueducts differ from bridges only in having to carry a water channel instead of a railroad or roadway. The bridge portion may be of wood, iron, or masonry. In India, masonry is almost exclusively employed because of its relative cheapness and permanency. On the Soane canal are several interesting aqueducts, one of which, across the Thora Nulla, carries the Buxar branch canal on a well-constructed masonry structure (fig. 8, p. 102). This aqueduct is 38½ feet in height and, exclusive of the wings or retaining walls, is 155 feet long, the width exclusive of wings being 54 feet. The waterway of the aqueduct is 42 feet wide on top, 40 feet at the bottom, and 7 feet in depth. The waterway for the torrent beneath the aqueduct is constructed almost as an inverted siphon, the bed having an inverted arch beneath the piers. There are four spans, each 30 feet wide by 20 feet 9 inches



SOLANI AQUEDUCT, GANGES CANAL.

high, the arch above supporting the aqueduct. The height of the piers to the springing of the arch is 12 feet and the rise of the arch is 6 feet. The piers are each $6\frac{1}{2}$ feet wide. The object of the invert is, that should a greater flood occur than is estimated for, the openings may act as siphons. They are estimated to carry 10,000 second-feet.

One of the greatest and earliest aqueducts constructed is the Solani aqueduct on the Ganges canal at Roorkee (Pl. XVI). This consists of an earth enbankment $2\frac{3}{4}$ miles in length across the Solani Valley, and about $16\frac{1}{2}$ feet high, its greatest elevation above the river bed being 24 feet. This embankment, as shown in the sketch (fig. 29), is 350 feet wide at the base and 290 feet wide on top, and on this the canal banks are formed. The outer edges of these banks are 30 feet wide and 12 feet deep, and are lined throughout by masonry or revetments of stone. The exterior slopes of the embankment are 1 on $1\frac{1}{2}$, and have been made with great care. The total length of the upstream revetted channel is 10,713 feet; that of the downstream channel is 2,723 feet, and between these embankments is built the masonry aqueduct, the total length of which is 920 feet, with a clear water

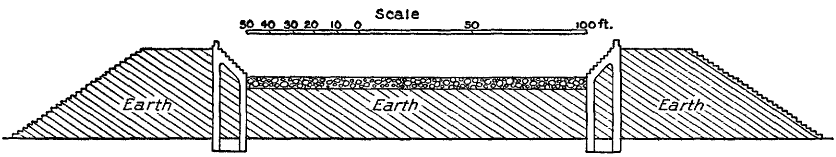


FIG. 29.—Cross section of Solani aqueduct, Ganges canal.

space between piers of 750 feet in length, consisting of fifteen spans of 50 feet each. The breadth of each arch parallel to the channel of the river is 192 feet and its thickness is 5 feet. The arch is in the form of a segment of a circle with a rise of 8 feet, and the piers are raised on foundation blocks of masonry, sunk 20 feet in the river bed. The greatest height of the aqueduct proper above the river valley is 38 feet. The waterway of the aqueduct is formed in two separate channels, each 85 feet wide; the outer walls of masonry are 8 feet thick and 12 feet deep, the aqueduct being intended to carry 12 feet of water. The velocity through the aqueduct is $3\frac{2}{3}$ feet per second.

Perhaps the most magnificent aqueduct yet constructed is that built across the Kali Nadi at Nadrai, which carries the waters of the Lower Ganges canal over that river. The first aqueduct at this place was much smaller than the present one. Before the great flood of 1885 it was calculated to permit the passage of 30,000 second-feet through the five bays into which this water way was divided, and it was founded on the natural channel of the torrent. In 1884 an extraordinary flood occurred which discharged nearly 100,000 second-feet under the aqueduct, and greatly injured it. Repairs were at once commenced and slight alterations made in order to increase the channel. On the 2d of

October, 1884, a flood level was noted on the upstream side corresponding to a reading of 22.2 feet on the downstream gage, the difference of surface level above and below the aqueduct being 3½ feet. The mean velocity of discharge in this flood was about 10½ feet per second. This work had scarcely been commenced when, on the 17th of July, 1885, another and greater flood occurred. This flood is fully described in notes made at the time by the executive engineer, Mr. W. Good.[a]

Early on the morning of the 17th the river began to rise and the water level rose in a wave 4 feet high and carried away part of the revetment. Other waves 10 or 15 feet high surged over it, and the whole of this revetment work and the abutments collapsed. Shortly afterwards the piers were carried away and parts of the aqueduct fell into the stream. The velocity was terrific. The water in the main stream was piled up in waves 20 feet high at intervals of 100 feet apart. By 3 in the afternoon 100 yards of the canal bank had been carried away and all of the aqueduct had been destroyed. From 4 o'clock in the morning to 3 o'clock in the afternoon the level of the water rose to a total height of 23 feet and had a velocity of over 18 feet per second. From estimates made by Mr. Good the discharge of that flood was probably 135,000 second-feet, and during the rain storm (which lasted three days), an average of 22 inches of rain fell on the whole catchment area. The greatest fall occuring in one day, the 16th, was 20 inches on some portions of the basin.

In estimating for an aqueduct to replace the old one, this flood was considered as the greatest which was ever likely to occur, and the new aqueduct as now finished is estimated to discharge under it 140,000 second-feet, with a velocity of 8 feet per second, thus requiring a waterway of 22,430 square feet. This is equivalent to a run-off of 55 cubic feet per square mile of catchment, the total area of which is 3,025 square miles. The waterway for the canal on top of this aqueduct will carry 3,175 second-feet.

The aqueduct (fig. 33) consists of 15 masonry spans, each 50 feet long, supported on wells. The maximum pressure on the foundation wells of the piers does not exceed 2½ tons per square foot. Under the aqueduct is sunk a concrete floor 5 feet in thickness. The total cost of this work was about $1,523,000.

On the Ganges canal are two of the largest as well as the most interesting superpassages constructed in India, one for carrying the Puthri Torrent and the other the Ranipur Torrent over the canal. In the construction of a superpassage especial care must be taken to give its bed such a slope that it shall not be filled up by the deposit of sediment, while the masonry and revetting of the banks must be carried a sufficient distance on each side of the canal up and down stream to protect the foundations of the work.

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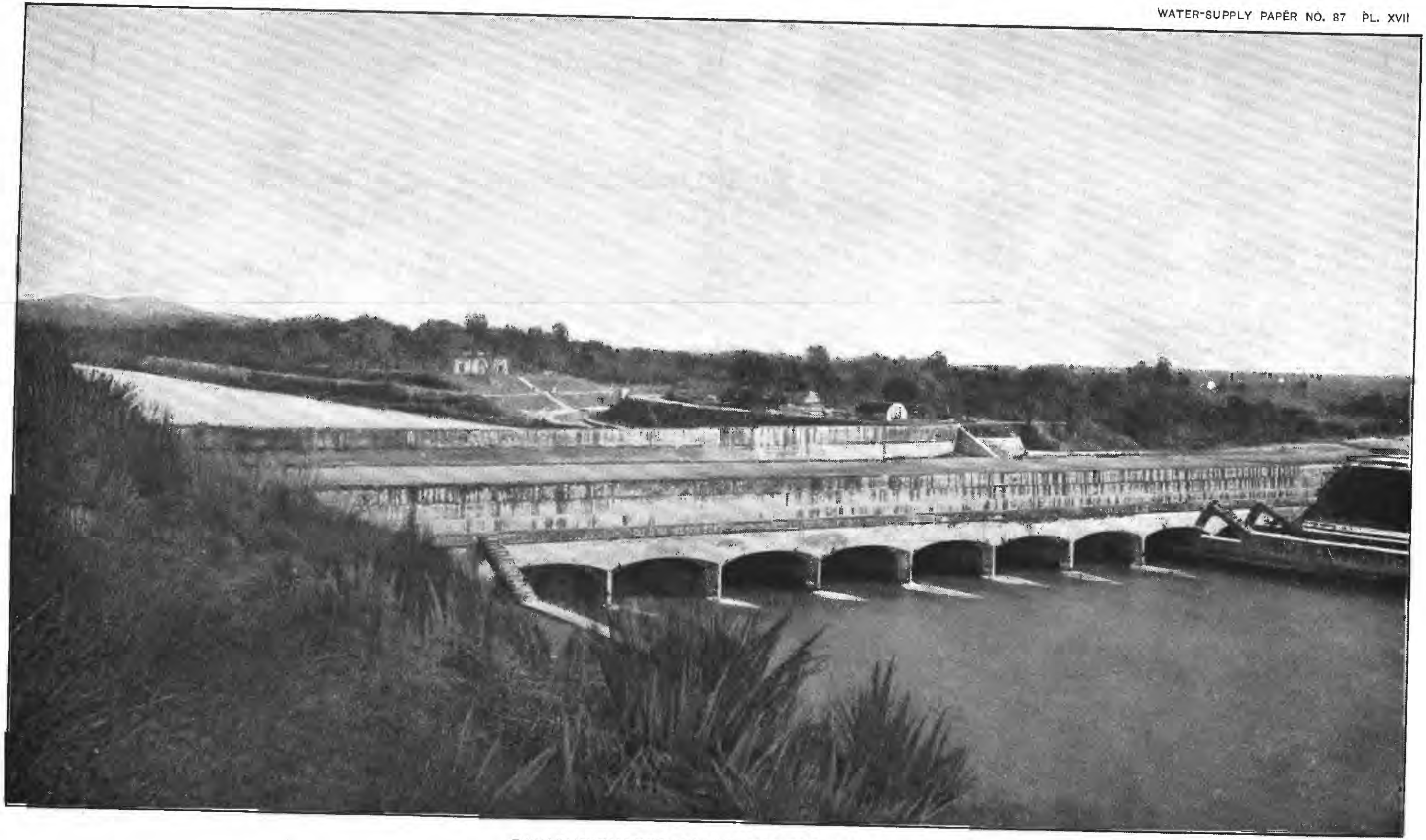
[a] Failure of the Kali Nadi aqueduct: Records of the Government of India, Public Works Department, No. 240, Calcutta, 1888.



RANIPUR SUPERPASSAGE, GANGES CANAL.

The catchment basin of the Ranipur Torrent is about 45 square miles, its average width being 4½ miles and its total length 10 miles. At the point where the superpassage is constructed there is an ogee fall with a drop of 9 feet, the base between the piers supporting the superpassage being used as a portion of the masonry construction of the fall (Pl. XVII). The foundations of the upper and lower levels are protected by lines of piling and box work; the former have a width of 10 feet and the latter of 70 feet. The flooring of the superpassage from the crown of the arches to its bed is in its thinnest place 3 feet thick, and the parapets are 7 feet wide and 4 feet high. These continue inland from the body of the work a distance of 100 feet on each side, expanding outward so as to form wings for keeping the water within bounds. This superpassage is 300 feet long and provides a waterway for the torrent 195 feet wide and 6 feet deep.

At the Puthri superpassage the torrent of that name drains an area of about 85 square miles and discharges a maximum flood of 15,000 second-feet. This superpassage consists of an aqueduct, under which the canal passes in nine bays, each 25 feet wide. The width of the superpassage is 296 feet. This waterway, as it now appears, was made too wide, and accordingly the decrease in the velocity of the torrent at this point, which in the natural channel is 16 feet per second, has caused considerable silting and the superpassage has been constantly filling up. This error has been obviated by decreasing the waterway by the construction of masonry groins projecting from the side parapets of the superpassage out into the stream at right angles to its course. This has nearly remedied the evil, as the silt previously deposited is now being rapidly cut away.

The Sasoon superpassage (fig. 36) on the Sirhind canal, whereby the Sasoon Torrent is carried over the canal, drains an area of 24 square miles. The discharge of this stream is estimated at 7,750 second-feet, and a waterway has been provided 150 feet wide by 6½ feet deep. The difference in level between the bed of the canal and the torrent is 21.9 feet, of which 7 feet are depth of water in the canal, 10 feet headway up to soffit of arch, 3 feet the thickness of the arch, and 1.9 feet brick flooring. The canal channel is spanned by three central arches, each of 45 feet span, and two at the sides, each of 32 feet span. There is an aggregate waterway for the canal of 184 feet, but the mean waterway of the channel is only 177 feet. The side walls or parapets of the superpassage are 10 feet high and 5 feet thick at base. The mode of construction of this superpassage is indicated in fig. 36, p. 149.

An interesting mode of disposing of drainage is by a drainage reservoir, as is done on the Agra canal. Several streams cross the canal at a certain point. They are, however, all disposed of through one channel by constructing an embankment on the upper side of the canal, so that a reservoir is made. The object of this reservoir is not storage, but drainage. The embankment is of earth and about 40 feet high. The bottom or sill of the superpassage, which carries the flood water over the canal, is about 30 feet above the bottom of the reservoir, the object being that the lower 20 feet of the bed of the reservoir can be cultivated and supplied from this water. A large revenue is returned to the government from the lands cultivated in the reservoir bed after the waters have been drawn down through the superpassage. This superpassage is constructed of boiler iron. It is 99 feet long, 30 feet wide, 10 feet deep, cross braced by angle iron on top, and supported by two piers each 5 feet thick. It is well built and supported and the slope is steep, giving a high velocity to the water. The connection between the ends of the superpassage and the abutments is made of heavy sheet lead, to accommodate the changes due to expansion of the iron and to prevent leakage. After flowing through this superpassage the water falls vertically 12 feet, and then 25 feet into the old channel of the River Jumna.

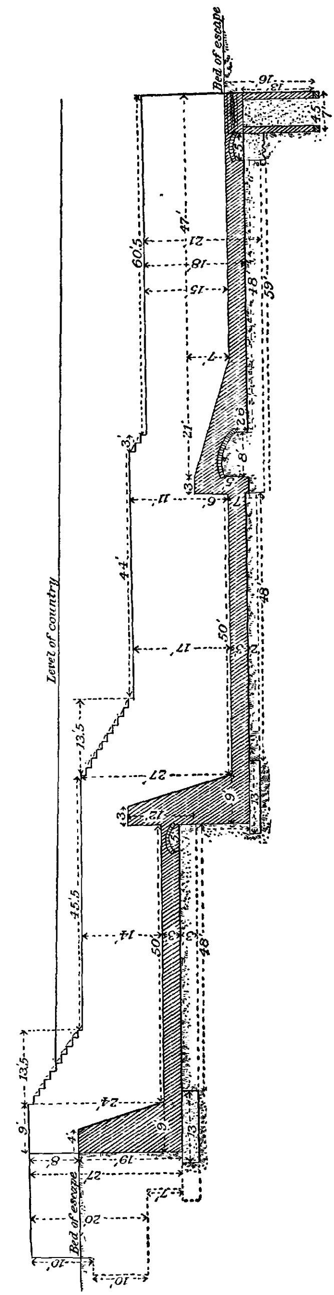


FIG. 30.—Agra canal, cross section of Kushuk Falls.

The Rutmoo Torrent is passed across the Ganges canal by a level crossing (Pl. XVIII). This consists of a simple inlet at the torrent entrance to the canal and of a masonry outlet dam and escape regulator in the canal bank opposite the torrent inlet, while there is another regulating bridge across the channel just below the inlet (fig. 31). By this means the flow of water is easily regulated, the amount admitted to the canal below the inlet being controlled by the regulator in the canal itself and the superfluous water being discharged through the regulating breach or dam in the canal bank. This dam consists of 47 sluice ways, each 10 feet wide, with their sills flush with the canal bed. These are flanked on either side by overfalls of the same width

RUTMOO LEVEL CROSSING, GANGES CANAL

with their sills, 6 feet higher, and on the extreme flanks are platforms 10 feet above the canal bed. These elevated platforms are 17 feet long and connected with the revetment on the canal banks by inclined planes of masonry. This escape dam is practically identical in construction with the ordinary scouring sluices at Myapur and other places. The waterway through the sluices up to the height of 6 feet is 470 feet wide, and between the levels of 6 and 10 feet it is 570 feet wide. Above that it is 800 feet wide. The closing and regulating of the opening in this sluiceway is conducted by means of flash boards fitting into grooves. The sluice gates are dropped rapidly, being constructed on a plan similar to the Soane scouring sluices, but more crude in their method of manipulation. When not in flood, the water in the torrent is carried under the canal and returned to the Rutmoo Torrent below it by means of a little drainage tunnel or inverted siphon about 500 feet long. Owing to the high velocity of the floods in the Rutmoo Torrent, there is no deposit of silt in the canal, the greater part of the silt being carried straight through it by the rush of the flood waters. The torrent in late years has been cutting badly on the downstream, and to stop this retrogression of levels 5 masonry bars have been put across it, each about 200 yards apart. These are composed of cribs filled with bowlders, and have acted as contemplated. The maximum flood anticipated and discharged through the Rutmoo Torrent is 25,000 second-feet. The regulating bridge across the canal below the crossing has 10 waterways, each of 20 feet, and in addition to this there is a roadway over it forming a bridge. There is about a mile of revetment walls, all resting on blocks or wells sunk to a depth of 20 feet below the canal bed. This is protected by numbers of piles and cribs filled with bowlders.

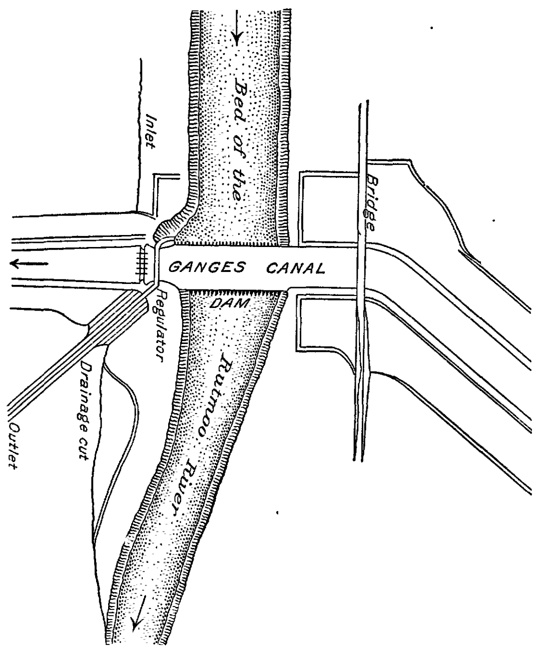


FIG. 31.—Plan of Rutmoo crossing, Ganges canal.

The Kao Nulla on the twenty-first mile on the main western Soane canal is passed by a siphon aqueduct. This torrent is subject to great floods. They are estimated on the basis of 6 inches of run-off on the 57 miles of catchment, and the highest velocity is $8\frac{1}{3}$ feet per second. The siphon passage for the flood provides 1,103 square feet of water way disposed in 20 openings, each of 54 square feet. This work consists of substantial masonry carried well beneath the ground under the bed of the torrent and above ground for the support of the aqueduct, and is only a semisiphon carried under the aqueduct, as indicated in the accompanying sketch (fig. 32). A similar work is

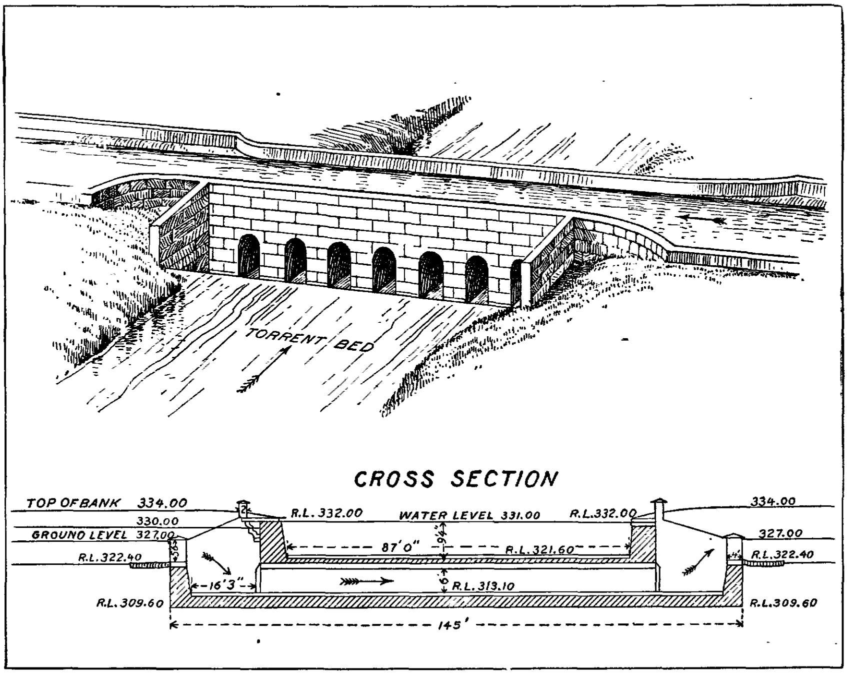


FIG. 32.—Kao Nulla siphon aqueduct, Soane canal.

that of a superpassage and siphon on the line of the Nira canal whereby the torrent is carried over the canal, the latter being in an inverted siphon. This work is indicated in fig. 46 (p. 171).

DISTRIBUTARIES.

Like the main canals, the distributaries or laterals are invariably designed and laid out by and are under the control of the canal engineers. From these the farmers take their private water courses and channels to their fields. Sir P. T. Cautley thus speaks of them in connection with the Ganges canal:

> In our irrigation system the trunk and main canals with their great branches play the part of a reservoir to the distributaries. The latter hold the relation to the main canals of a system of distributary pipes in a town water supply, and the village or private water courses play the part of service pipes.

Distribution from a canal is most economically effected when the latter runs along the summit of a ridge so that it can supply water to its branches and to private channels on both sides of it (fig. 37). This location in the case of a large canal can happen only in occasional instances, but the secondary or distributary branches taken from these principal canals can and should be made to conform to

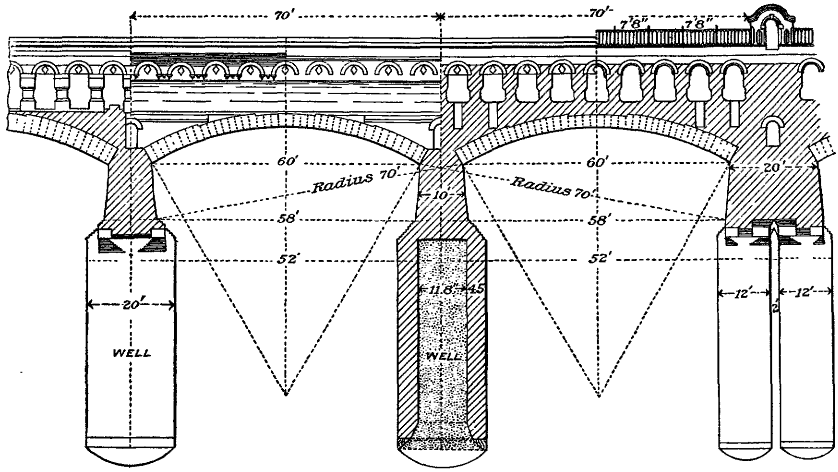


FIG. 33.—Nadrai aqueduct, Ganges canal.

dividing lines between water courses. The capacity of the distributary which then traverses each separate drainage divide is proportioned to the duty it has to perform, the bounding streams limiting the area it has to irrigate.

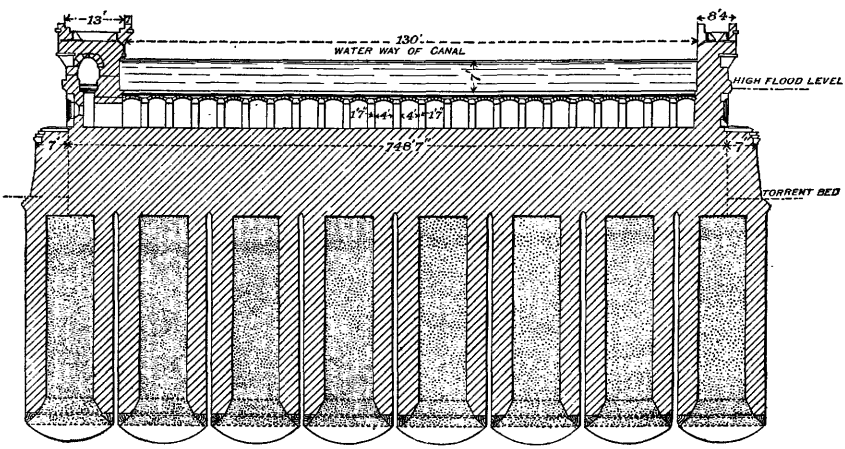


FIG. 34.—Cross section of Nadrai aqueduct, Ganges canal.

For the more complete and efficient distribution of water the engineer treats them as of as much importance as the main branches themselves. Attention is devoted to the character of the soil traversed, to the alignment, to the safe and permanent crossing of natural drainage lines, and to so maintaining the surface of the canal with relation to the ground as to command the largest irrigable area. In all well-designed distributary systems the capacity of the channels is exactly proportioned to the duty to be performed, the cross-sectional area being diminished as the quantity of water to be carried is decreased owing to its diversion by private water courses, though a sufficiently large margin is usually allowed for future possible development.

It is usual to take off the water of a distributary from the main canal as near the surface of the latter as possible. That is, the bed of a distributary should not be on a level with the bed of the main canal, the object being first to get the clearest water possible, which is found nearer the surface, and second to keep the bed of the distributary at as high a level as possible to admit of surface irrigation throughout its length. In level country great care is always taken in designing these distributaries that the natural drainage lines in which they tail shall be sufficiently large to accommodate any flood volume it may be necessary to pour into them, so that the distributary may be rapidly relieved during times of storms and the drainage lines shall not become clogged and flood the surrounding country. The slope of a distributary is usually planned to be as nearly as possible parallel to that of the district it traverses in order to avoid costly embankments and to insure the surface of the water being above that of the country. Falls are sometimes rendered necessary by the profile of the country, as is the case on larger canals, while escapes are introduced every 8 to 10 miles.

Distributaries as designed on the great Ganges canal have been made to conform as far as possible to a general design, which may be outlined as follows: The heads have been constructed at the points where bridges or falls were necessary, in order to economize in masonry construction. This location also insures their better inspection. The beds are generally from 2 to 3 feet above those of the main canal from which they are taken. These heads are designed as mere open gateways with grooves for the introduction of shutters or planks. No further design has been attempted for the regulation of discharge. The distributaries are divided into main lines and feeders. The first or main lines run parallel to the canal on both sides, and these parallel lines are met in their passage downward by feeders coming from the different distributary heads in the neighborhood. This principle of constructing parallel channels to the main canal is one which would not recommend itself for use in the United States, as the chief object, or rather the cause of their employment, has been the navigative character of the main canal. As the main canal must necessarily have a very low slope in order that the velocity will not impede navigation, and as these main canals at their heads below lock are usually sunk some depth beneath the surface of the adjacent country, it becomes practically impossible to distribute water from them, and accordingly the parallel lines have been employed, which, keeping near the surface of the country, facilitate the distribution of the water to other minor channels. Where the canals are not primarily designed for purposes of navigation these parallel channels may well be dispensed with, though they are found on nearly all of the larger Indian works.

According to Major Brownlow, R. E., the greater the amount of water discharged by a distributary the smaller will be the proportion of cost of maintenance, for a channel 12 feet wide discharges more than double that of two channels each 6 feet wide, while the cost of patrolling and repairing the banks will be half that of the two smaller ones. Experience proves that irrigation can be most profitably carried on from channels 18 feet wide at the bottom and with about 4 feet depth of water. On the eastern Jumna canal, during the years from 1858 to 1860, the expenditure on all the distributaries of 12 feet head width and upward was 0.123 of the revenue, while on all those below 12 feet it was 0.223 of the revenue, or nearly double the first. The relative value per cubic foot per annum from the same experiments, on channels of respectively 12, 6, and 3 feet in width, was as 10 : 7 : 4. Increased action of absorption in small channels, with diminished volumes and velocities, accounts for the difference. The depth of water accordingly should be seldom less than 4 feet, and the surface of the water should be kept at from 1 to 3 feet above that of the surrounding country, not only to afford gravity irrigation, but because the loss by absorption is thereby diminished. This was shown in the experiments referred to in the previous part of this paper, under the heading "Duty and absorption."

Indian engineers unite in condemning the practice of raising the water in the channels to the surface of the country by means of dams or stops made by introducing planks into grooves made for that purpose. This practice, they say, converts a freely flowing stream into a series of stagnant pools, encouraging the growth of weeds, the deposit of silt, and an unhealthy condition of the neighborhood; and it is, moreover, extremely wasteful of water, since much of the latter is dissipated because of the loss of head. In designing the canal banks the width of the top of the bank should be sufficient to admit of easy inspection. On moderate-sized distributaries, such as those just referred to, 4½ feet may be taken as the minimum width, and wherever the dimension of the channel will permit it this width should be increased. Should the cutting be so deep that a berm is necessary, it is always well to let the latter slope away from the canal and be drained off through the bank; the top of the bank, likewise, should slope away from the canal, and not drain toward it, as in times of heavy storms much silt may be deposited in the canal from this local drainage.

Ordinarily the water for the village ditches is taken from the distributary by means of hollow wooden or iron pipes let into the banks of the canal and nearly flush with its bed. These are stopped at the outlet by a valve or plug. The heads of the distributaries on the modern canal systems are more carefully designed. They are usually constructed of substantial masonry works let into the canal banks, and closed by a valve or other easily controlled shutter. In the Northwest Provinces a series of standard designs has been prepared, an illustration of which is given (fig. 38). The heads of the minor branches or the private water courses are, like those of the distributaries, usually placed where the existing masonry works occur, as at falls or bridges, while the private channels head in simple wooden or iron

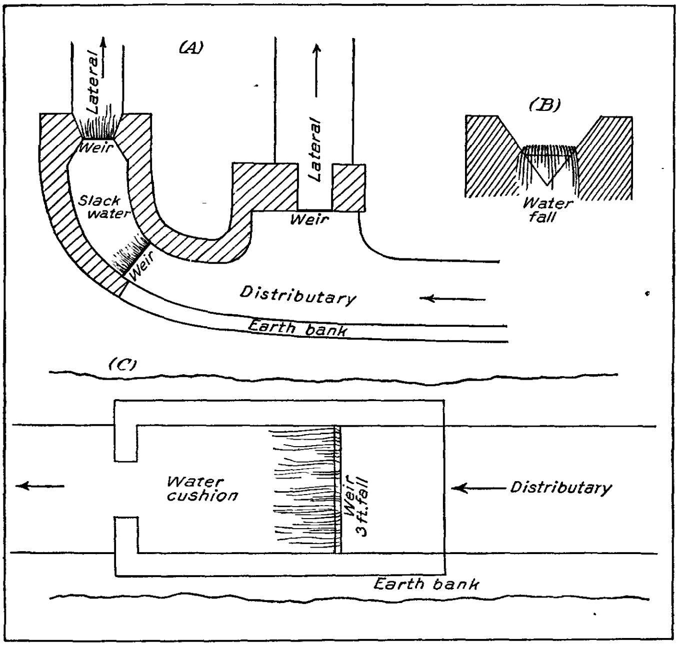


FIG. 35.—Plans of distributing head, Mutha canal, Bombay.

outlets. Substantial masonry falls are constructed at such points as the grade of the surface of the country makes necessary (fig. 35). These are usually simple vertical drops into a masonry well, and the scouring is generally lessened by creating a water cushion at the bottom of the fall.

In the Punjab and elsewhere rules have been laid down for the construction and estimate of the masonry works on distributaries. Among others are these: Siphon barrels shall have a sectional area equal to the bed width plus one-half the full supply. Siphon wells shall have the same area as above, the depth being equal to $1\frac{1}{2}$ times the fall supply. The depth of the cistern at the foot of a fall in order to form a water cushion shall equal one-third of the height of fall, plus the full depth of the water. Thus with a fall 4 feet deep on a canal carrying 5 feet of water, the cistern depth will equal $\frac{1}{3}(4 + 5) = 3$ feet. The minimum cistern length is qual to three times the depth counting from the drop wall to the reverse slope, which latter will be 1 in 5. The width of the cistern must be twice the mean depth of the water in the channel, or twice the bed width plus the full depth.

While the water rate is at present charged in India according to the area irrigated and the crop raised, it is universally conceded that it would be fairer to charge for the water according to the quantity used, as it can make no difference to the canal proprietors what becomes of the water after it has been delivered and paid for. The difficulties in the way of delivering water by actual measurement have been insuperable, chiefly because no practical method of measuring water under

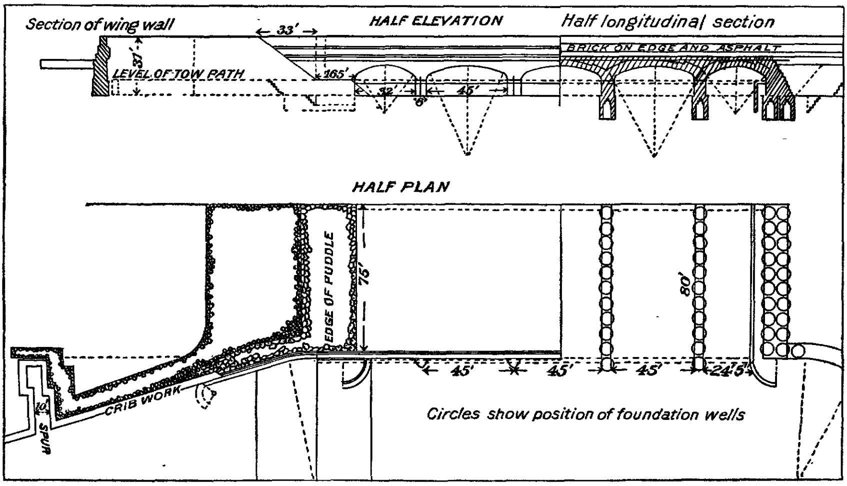


FIG. 36.—Sasoon superpassage, Sirhind canal.

a constantly varying head has yet been devised. On all the older-established canal systems, especially when the supply entering the head of the canal is insufficient for the demand, a system called "tatil" has been established. This may in general be said to consist in a mode of regulating the amount of water given to the irrigators by the canal officers closing their outlets for successive periods of time in regular rotation. Each cultivator is compelled to take the water when his turn arrives, be it in night or day, or else lose his share of water at that time. It is considered the best practice to impose these tateels on long portions of a distributary at once, as short ones have very little effect in forcing water down to the tail of the canal. In their operation an irregular period of rotation is employed. Thus the outlets may be closed in the first length of the canal for four days, on the second portion for three days, and so on, and then this order may be reversed, the period of rotation being such as to change the length of closure along various portions of the canal. One advantage of the imposition of tateels is, that by affording a constant but moderate supply in the distributaries the embankments are kept moist and are thereby less liable to crack, and the growth of weeds is to a certain extent checked.

The measurement of the quantity of discharge into any distributary is made by one of several methods. V weirs are usually constructed at the heads of these if the expense of the masonry will not be too great. Wherever falls or masonry head-works exist, V weirs can be cheaply added to the structure. For smaller channels standard-sized pipes let into the banks of the canal to draw off the water are used, and the discharge through this orifice under a given head is known from experiment. In larger distributaries the volume discharged is usually obtained by measuring a short length of bank, and, knowing the cross section, the velocity is determined by floats on this known length. The methods in use are generally rather crude and unsatisfactory. For, though the sectional area of the outlet is known, little or no attempt is made to regulate the pressure. The majority of these larger outlets are masonry tubes, from 10 to 20 feet long, and the friction in these is considerable. The outlets are rarely so arranged that the pressure on the head can be regulated, as is done in the measuring boxes employed in California and Colorado. The Indian engineers hold that the ordinary Italian module is not applicable to their distributaries because of the fluctuation in the height of the main canal and because of the amount of silt carried in suspension, which closes the tail and impedes the circulation of water.

METHODS OF APPLYING WATER.

There is little that is novel to American irrigators in the modes employed by the Indian agriculturist of applying water to crops. The chief peculiarity which at once strikes the observer is the great care with which each crop is handled and the expense with which the private ditches are frequently aligned and constructed. As India is an old country, and one in which both land and water are valuable, and the various individual holdings being small, each cultivator having but a few acres, rarely over 5, sometimes less than 1, to look after, it is a frequent occurrence to see the cultivators irrigating their crops from their ditches by means of wooden scoops or wicker baskets, with which they toss the water out of the ditch and scatter it over the land. On sugar cane, rice, and the more expensive grain crops the action of gravity is brought into greater play and private channels are so laid out that the natural flow of water will carry it over the crops.

In irrigating from wells the water which is raised is usually emptied into a basin or shallow tank excavated in the earth, which may be lined with puddle, or, as is frequently the case, with masonry. From this basin the water is conducted at first through masonry or well-constructed earth ditches to branch channels, which are ordinary runways roughly excavated in the soil.

Rice is everywhere irrigated by dividing the land into small squares or blocks in an irregular checkerboard fashion. These are usually not less than 20 and rarely 100 feet square, depending largely upon source of supply and slope of country. These blocks are separated by low earth banks about 1 foot in height with cuts opening through them from one block or field to another. Where the slope of the surface is very light extensive fields may occasionally be seen within one block. On hillside country the steeper slopes are terraced by the construction along a contour line of a low embankment about 1 foot in height. These terraces retain the water from floods or storms, submerging the rice crop to a depth of several inches, thus acting as miniature tanks. In the more level rice country the various blocks are flooded from the canals, the rice always being submerged to a considerable depth.

In irrigating sugar cane an effort is usually made to obtain a freer flow of water than can be obtained by the above method, though as in the case of rice cultivation this crop requires a great deal of water and it is permitted to stand to a depth of several inches over the surface of the ground. Wherever the slope will permit, numerous cross furrows are plowed or narrow ditches run throughout the field of grain or cane in such a manner as to permit the water to flow in a thin layer over the soil, that which is not absorbed being caught up and utilized by the next lower ditch. Excepting in the irrigation of rice or occasionally of sugar, the land is almost invariably divided by some method of gridiron work of furrows and ditches as will most conveniently cover the area to be irrigated, excepting in cases where the water is sprinkled by hand.

In an interesting paper discussed by Mr. Baldwin Latham before the Institution of Civil Engineers,[a] he gave a novel description of the circulation of water in soil as shown by some experiments which he had made with the object of discovering the precise difference between the application of water in rice irrigation where it stands stagnant on the land and other irrigations where a constant current is kept moving. The result of these experiments showed that where a surface velocity was created it would promote a circulation of water throughout the soil, a matter of considerable importance, as by that circulation manurial matters were equally distributed while other material was removed which was not required by the plant, and which if allowed to stagnate would produce those ill effects shown when cultivating rice. The experiments were conducted in a water-tight glass tank which was filled with fine silver sand into which was poured a solution of perchloride of iron. Over this a solution of nutgalls was allowed to pass slowly and the course of the circulation could be readily followed, as the point of

[a] Discussion of irrigation in northern India: Proceedings Institution of Civil Engineers, London, vol. 35, p. 172.

contact of the two mixtures produced tannate of iron or ink which portrayed a perfect diagram of every stage of the experiment. The result of the experiment showed, among other things, that where there was an inclination of the surface resulting in the production of natural currents over it, a circulation through the soil took place.

Another tank experiment was made giving the conditions of a rice irrigated field. The same materials were used, but the tank was kept level, and it was found that after six months' contact no discoloration of the sand had taken place to a greater depth than one-fourth of an inch, showing there had been no displacement of the water occupying interstitial spaces in the sand. Mr. Latham said that the circulation of the water through the soil, on all land having an inclination, had a marked beneficial influence on irrigation, as conclusively shown from the practice adopted for generations in the irrigated districts of Piedmont and Lombardy, Italy, where, as the headwaters are left, it is customary to increase the natural slope of the irrigated beds in order to create a greater velocity, and hence a greater circulation through the soil.

CHAPTER VIII.

STORAGE WORKS.

CLASSES OF WORKS.

The employment of storage works in connection with irrigation projects is resorted to in order that an assured constant supply of water of a given amount may be furnished by their aid to any area of irrigable lands during each and every season, regardless of the amount of rainfall occurring and of the question whether it be an abnormally wet year or one of unusual drought. Where great perennial streams flow through land to be irrigated there is never any necessity for the addition of storage works as a protection against the failure of the water supply, but where valuable lands are to be irrigated and the source of water supply is from intermittent or very small streams, it becomes necessary to supplement the perennial flow occurring in these during the irrigating season by the storage of the flood or waste waters lost during the remainder of the year. This end is attained by damming the stream in some place where it will flood a broad valley and create a large artificial lake or reservoir, or by diverting its waters to some depression or other reservoir site where it can be conveniently stored.

Two classes of storage works are generally referred to by Indian engineers—namely, reservoirs and tanks. There seems not to be any set rules for distinguishing the two, as works sometimes called tanks are frequently larger than the largest reservoirs. Merely for purposes of convenience in discussing the subject, the author will adopt the common practice of considering reservoirs as bodies of water retained by a dam constructed wholly of masonry, while tanks are storage works the dams of which are constructed wholly or in part of earth. Reservoirs are usually deeper than tanks and are constructed on running and flood streams, while tanks are generally shallower and are constructed on minor and unimportant streams, the flood discharges of which are so small that all the water can be either stored or safely wasted, thus not endangering the integrity of the dam, or they are constructed in depressions on the plains or interfluves adjacent to the streams from which water is diverted to them.

In general, works for storage purposes may be filled from canals diverted from some large stream or filled directly from the discharge of the catchment basin of the stream upon which they are located.

The location of, necessity for, and probable return from the construction of a storage work is always a subject which receives much careful thought, both from the engineering and financial departments of the Indian government, before the work is finally sanctioned and undertaken. Many different considerations have first to be discussed and weighed in deciding the location. The work should be placed at a sufficient elevation above the lands which it is intended to irrigate to allow the delivery of the water to them by natural flow. The storage work may be so situated that it is immediately adjacent to these lands, in which case a very short canal will serve them, or it may be at some distance from the lands to be irrigated, thus requiring a long line of canal. Again, the storage water may be turned back into the natural drainage channel when required, and be permitted to flow

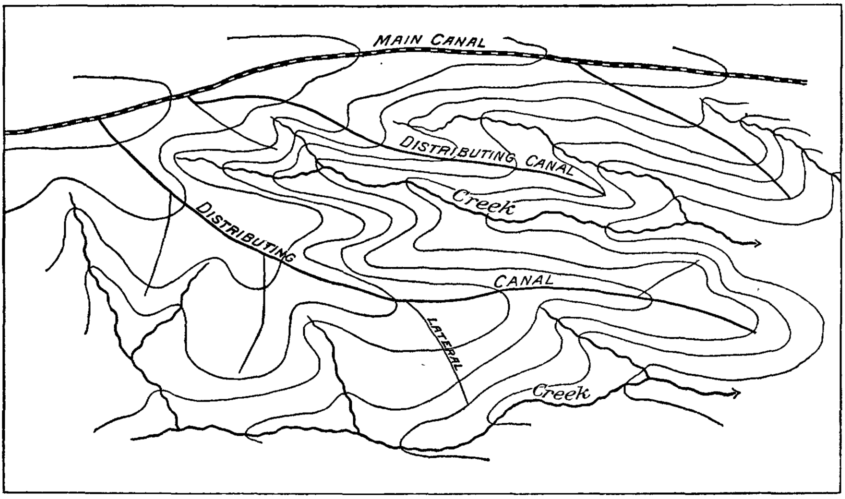


FIG. 37.—Drainage map, showing arrangement of distributaries.

down to the neighborhood of the lands where it will be again diverted for irrigation purposes. The second case mentioned may be very costly if the canal line be long, but the last is invariably the most expensive method, as it is wasteful of water, the loss of which is greater by absorption and evaporation than in a well-constructed canal, while there is incurred the additional expense of a diversion weir at the point where the stream is turned from the natural channel into distributing canals.

Having decided upon the location of the lands to be irrigated, and knowing their area, the first consideration attacked by the engineer is the location of the storage site. This may be discovered after much time has been spent in making trial surveys and investigations. In order that it shall be desirable for its purpose it must be of such a character that the cost of its construction will not be prohibitory. In considering the source of the water supply from which to fill the storage work a thorough hydrographic survey of the catchment basin above the reservoir is necessary, in order to discover the maximum and minimum precipitation, the percentage and rate of run-off, and the total quantity of water available for storage. Stream gagings are maintained for a few years, and all possible effort made to discover the volumes of maximum floods as well as the total quantities of water discharged. To these ends a good topographic survey is first executed, as from the maps thus constructed the relation can best be studied between the irrigable land and the reservoir site and the latter and its catchment area. These maps enable the engineer to measure the areas of the catchment basins and to calculate the discharges from these areas, provided the rate of run-off is known. The Indian government has already constructed over most of its territory a good topographic map, on a scale of 1 mile to 1 inch, upon which the topography and outlines of hills and valleys are indicated in hachures, and numerous elevations are marked at prominent towns, passes, and mountain peaks. In addition to this, much of the more densely inhabited portion of the peninsula has already been surveyed and mapped for revenue purposes, on the large scale of 4 inches to 1 mile. With the aid of the latter map it is possible to determine with much accuracy the various fields and plats of land which are to be served by the irrigation scheme and their general relation to the distributory channels, while the smaller scale maps enable the engineer to solve all the general problems in connection with the catchment basins, streams, general location of storage site, and the general course which the distributing canal or other medium must take in order to conduct the water to the lands to be irrigated. Such maps as these are of the greatest possible service in the designing of any scientific and general scheme for the development of the irrigation resources of a country, and enable the engineer, like the general in command of an army, to muster all his forces, look over and conceive at a glance the problem to be attacked, and decide upon the best mode for the utilization of all the resources at his command for the general good of the whole area to be served.

After the preliminary problems have been solved the more detailed considerations are investigated. In locating the dam site it is necessary, first, to have above it the largest possible basin or valley, with as low or flat a slope as is obtainable, in order that a maximum storage capacity may be had. The site should be so chosen that it shall require the shortest possible dam to close it and yet afford a sufficiently wide waste weir to discharge the maximum flood without injury to the dam. Finally, it must be so located that the geologic formation shall be favorable. The dam must not be founded on a porous formation, and, if of earth, the material of the abutments and foundation must be of suitable quality to afford an impervious connection. If a masonry dam, it should be founded on solid rock. A study of the general geology of the neighborhood in order to ascertain whether the valley which is to be used as a storage site is an anticlinal or synclinal valley, or one produced by simple erosion, is of great importance as indicating the dip of the rock underlying it and the possible value of the same as a nonconducting medium for the water stored in the valley. Material for the construction of whatever class of dam is decided upon must be convenient to the site in order to reduce to a minimum the cost of transportation and construction.

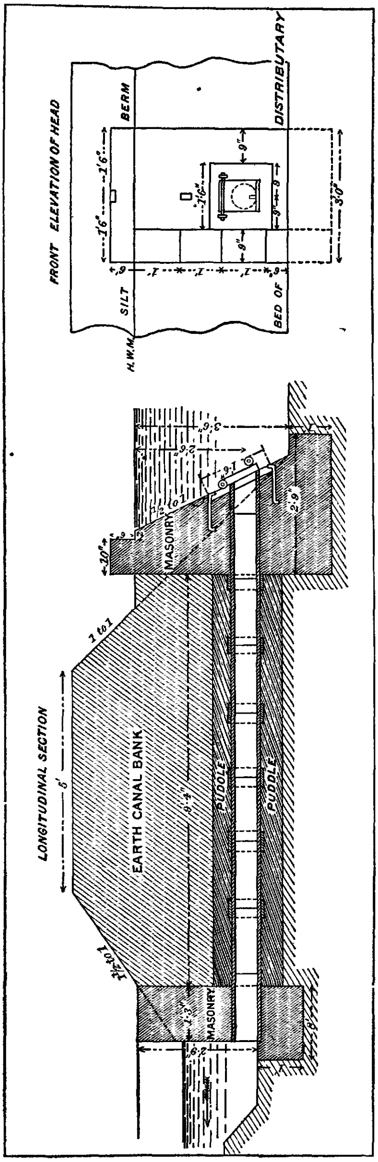


FIG. 38.—Standard masonry outlet for distributaries, Punjab.

In studying a catchment basin the Indian engineer has recourse to a few simple formulas to assist in determining the flood discharge from the area under consideration, and as a check on the results obtained from local observation. The following are two of the formulas most used:

Ryves's formula, $D=C\sqrt[3]{M^2}$,
Dickens's formula, $D=C\sqrt[4]{M^3}$,

in which M represents the area of the catchment basin in square miles, C is a coefficient depending for its value upon rainfall, soil, slope of ground forming the basin, etc., and D is the resulting discharge, usually shown in terms of cubic feet per second. It should be borne in mind, however, that no such formula can be strictly applicable with the same coefficient to areas of varying sizes, even in the same part of the country and under the influence of the same intensity of rainfall, unless the other circumstances, such as the slope of the ground, character of the soil, etc., be approximately similar. The chief difficulty will be found in the selection of a suitable coefficient, and a few of these for different districts in India, which correspond in general characteristics to the arid region of the United States, are here given.

In regions where maximum recorded rainfalls of from 3 to 6 inches in twenty-four hours have occurred, the coefficients for Dickens's formula, which have been settled upon, are about as follows:

Maximum rainfall 3.5 to 4 inches, in flat country, C = 200; mixed country, C = 250; hilly country, C = 300; and for a maximum rainfall of 6 inches C varies between 300 to 350, according to the nature of the country. The corresponding number of inches of drainage for a standard area of 5 square miles from these figures would vary, for the first group between 5 to 7.5 inches, and for the second group between 7.5 to 8.5 inches. For Ryves's formula the coefficient varies between 400 and 500, and for very hilly areas, where the maximum rainfall is high, it may reach as high as 650. The flood discharges are invariably proportionately less for large basins than for smaller ones.

A very interesting paper on this subject of maximum flood discharge from catchment areas was read by Mr. James Craig before the Institution of Civil Engineers in 1884.[a] The details of the argument entered into in this paper are too elaborate to be presented here. In general they are an amplification and discussion of results obtained from variously shaped catchment basins, showing new methods of determining the loss of discharge other than those obtained by the two formulas given above.

In order to show the character of the detail connected with the various investigations and problems to be solved when the value of or necessity for the construction of the storage work is under consideration in India, attention will be called to a few of the questions which the Indian engineer is directed by his superiors to investigate. These points and others not included herein are laid down by General Mullins, chief engineer of irrigation for the Madras government in India, for the guidance of engineers in that presidency.[b] The general circumstances of investigation are whether the valley or drainage area under consideration is partially occupied by tanks or is unoccupied. There will be some prima facie evidence available about particular sites or what the inhabitants suppose would be suitable sites. It may be desired to supply water to a definite area of new land to be irrigated or to land that had a previous supply which has been stopped by the silting up or destruction of existing tanks.

In the preliminary information the average rainfall of the country and its character are obtained from any records which may be in existence. The irrigation duty of the drainage area in square miles or some other unit is ascertained, as well as the quantity of water derivable from this unit of catchment area and the average rates of assessment for irrigable lands. The preliminary investigation includes, as before stated, a study of the atlas sheets of the survey of India and of the revenue survey maps, an examination in detail of the country

[a] Maximum flood discharge from catchment areas: Proceedings Institution Civil Engineers, London, vol. 80, pp. 201-220.

[b] Irrigation Manual, E. F. Spon, London, 1890, p. 55.

in order to ascertain the most suitable reservoir sites, and an examination of the drainage lines thence downward. To be considered, sites usually must be in a valley which has a moderate longtudinal slope, with moderate transverse slopes on either side of the axis of the valley, must admit of a moderate length of dam with suitable abutments at either end, a probable moderate depth of water and corresponding height of dam, suitable material for the formation of the dam, and possess facilities for the disposal of surplus, preferably by wasting over detached saddles through rock soil or subsoil. Land below the site must also be available for irrigation, and there should be an absence of much or valuable cultivation and of villages within the probable area of the water spread. Whether water storage may be obtained on financially advantageous terms will depend largely on the difference between the values of the land when irrigated and when not irrigated. In order to ascertain this difference in value it is necessary in India, as in America, to know what area a given quantity of water can irrigate, what that area will pay for the water, and what the storage and distribution of the water will cost.

In various discussions of storage capacity and water duty, hereafter to be entered into, the author will for convenience use the storage unit employed by the United States Geological Survey, 1 acre-foot. This is 43,560 cubic feet, or the quantity of water which will cover 1 acre in area to a depth of 1 foot. In dealing with large quantities of water, such as those stored in great reservoirs, it is inconvenient and troublesome to speak of capacities in millions or billions of cubic feet, and the much smaller figures which will be dealt with by using the acre-foot as the unit of measure make the subject-matter more intelligible. Likewise the area of land irrigable from a given amount of storage water can be more conveniently considered; that is, the duty of the storage water can be spoken of in more convenient terms if we refer to the duty performed per acre-foot. Thus, in portions of Colorado the duty of an acre-foot, providing the distance which the water has to be carried to the land is not so great as to cause excessive loss by absorption, may be stated as being 1¼ acre-feet per acre.

As an instance of the cost of storing water, the investigations of the Bombay engineers show that in favorable cases where water has been stored in reservoirs of the first class 56,700 cubic feet, or about 1⅓ acre-feet, of water has been stored at an average cost of $1. The cost of the water, however, when served to the field will be considerably above this, as the loss due to evaporation and absorption in the reservoir during storage period and the loss due to the same causes in conveying the water through the canals to the fields to be irrigated must be included in the estimates. In this same locality in Bombay, after considering these losses, it appears that about 38,000 cubic feet of water can be stored at an average cost of $1.

RESERVOIRS.

Before entering into a description of the details of construction of various notable reservoirs employed in India for the storage of water for purposes of irrigation, it will be well first to look at some of the financial results and general statistics relating to these works. In the following table, compiled from the irrigation revenue report for Bombay for the year 1900–1901, are given the principal data in connection with the chief reservoirs of that presidency, namely, Bhatgur and Lake Fife:

Reservoir works, Bombay.

	Bhatgur dam and Nira canals.	Lake Fife and Mutha canals.
Area of catchment .... square miles..	128	196
Average annual rainfall .... inches..	145	32.4
Available contents .... acre-feet..	126,500	75,500
Surface area .... acres..	3,584	3,630
Area commanded .... do....	274,447	94,087
Area irrigated .... do....	113,280	16,800
Height:		
Above foundation .... feet..	127	97.8
Above river bed .... do....	108	....
Main canal .... miles..	100	88
Distributaries .... do....	139	70
Total cost, including canals	$3,138,000	$4,448,000
Area irrigated:		
Summer crop .... acres..	21,602	7,575
Autumn crop .... do....	30,126	629
Total	51,728	8,204
Percentage double cropped	....	8.7
Average discharge utilized .... second-feet..	103	....
Area irrigated, per second-foot of discharge utilized, acres	139	64

The following table gives some of the figures connected with the water supply of the irrigable land served by these two projects for the year 1889:

	Nira canals.	Mutha canals.
Rainfall on irrigable lands .... inches..	15.1	31.5
Duty, autumn (four months) .... acres..	118	60.5
Cost of water measurement per acre .... cents..	1.5	4
Loss of evaporation in tank .... feet..	....	4.5
Maintenance cost per acre irrigated .... cents..	31.0	....

The working expenses on the Nira canal for the year 1900–1901 were $17,000—$170 per mile on the main canal, or 33 cents per acre irrigated and 89 cents per second-foot of discharge at canal head. The returns realized being from plantations of trees on the canal banks were $231, and the water rate charged during the same year was 37 cents per acre irrigated, or $56 per second-foot of discharge at the canal head. The total revenue was $60,000, and the net revenues or profit $27,400, or 1.45 per cent on the capital invested.

On the Mutha canal $960 were realized during the same year from the plantations maintained on the canal banks, while the water rate per acre irrigated was $3.91, or $260 per second-foot of discharge entering the canal head. As will be noticed, the water rate levied on the Mutha canals was very high relatively to that on the Nira, and also very high as compared with that charged on any other canal system in India. The cause of this was the great amount of sugar cane cultivated along the canal, a crop requiring a great amount of water to mature it.

In the following table are given some of the revenues derived from the cultivation of the various crops on the Nira and Mutha canals:

Crop.	Nira.		Mutha.	
	Acres.	Value.	Acres.	Value.
Wheat	3,190	$37,200	2,861	$17,800
Sugar	143	7,100	4,277	649,000
Jowar	10,320	86,000	854	5,300
Bajri	3,038	30,200	1,336	6,000
Beans	783	5,200	440	5,100
Total	17,474	165,700	9,768	683,200

MUTHA PROJECT.

The Mutha canal scheme was first proposed by Colonel Fife, R. E., in 1863, with a view to irrigate a large district in the neighborhood of Poona and to furnish the water supply of that city and cantonment. The Mutha River, a tributary of the Bhima, rises in the Western Ghauts, 30 miles east of Poona. The rainfall on the Ghauts above Poona is seldom less than 200 inches per annum and has never been known to fail. Plans and estimates for the project were finally submitted in 1868, and in the latter part of that year the construction of the work was commenced.

The scheme comprises (fig. 39) a large storage reservoir, Lake Fife, on the Mutha River, 10 miles west of Poona, with two canals, one on each bank of the river. It is the reserve storage supply from this reservoir which assures an unfailing flow of water in the canals, as the rainfall is always more than sufficient to fill the reservoir. The canal on the right bank is 99½ miles long, and is designed to discharge 412 second-feet at the head; however, its usual discharge is somewhat

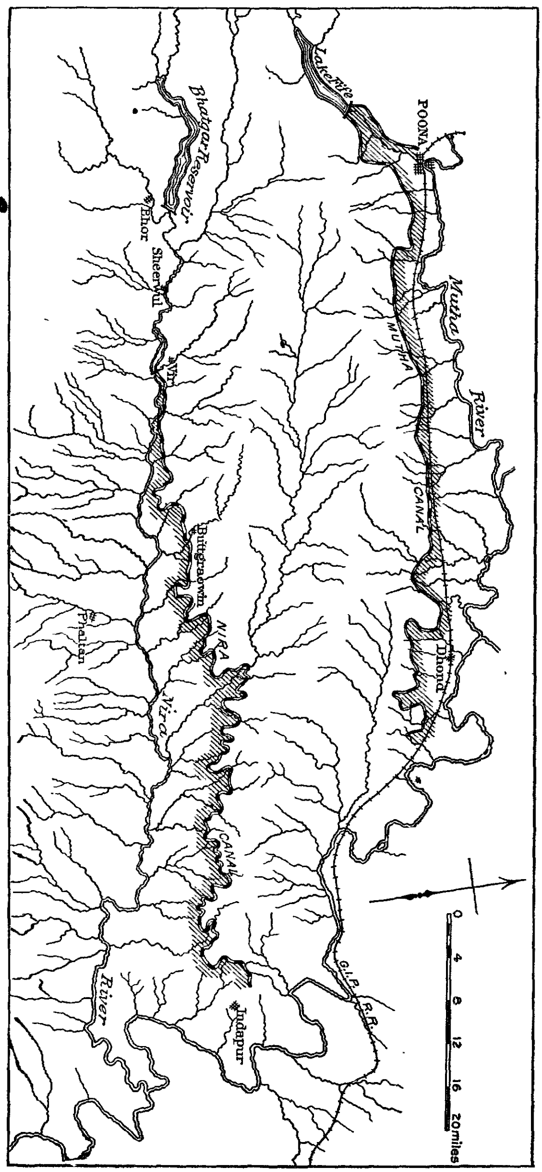


FIG. 39.—Plan of Mutha and Nira irrigation projects, Bombay.

less, while if necessary it can be increased to as much as 535 second-feet. This canal passes through the town of Poona and commands 147,200 acres of land entirely within the dry zone of the Deccan, where the rainfall seldom exceeds 20 inches. In this area the variations in the rainfall and risks of drought are as great as the absolute rainfall is small. The left-bank canal is but 14½ miles in length and extends but a short distance beyond the town of Kirkee. It commands an area of 4,300 acres and the discharge at the head is 38 second-feet.

The reservoir is formed by a masonry dam founded on solid rock. This dam is constructed of uncoursed rubble masonry. Its total length is 5,136 feet, of which 1,453 feet are used as wasteway. Its height above the river is 98 feet, while its maximum height above the foundation level is 108 feet. The crest of the wasteway is 11 feet below the top of the dam, thus giving a maximum storage depth of 87 feet. The dam backs the water up the valley a distance of 14 miles. The available contents of the reservoir are 75,500 acre-feet, and the area of water surface exposed is 3,681 acres. In order to command a sufficient elevation the beds of the canals are taken off at an elevation of 59 feet above the river bed or bottom of the storage reservoir. Thus the available depth of storage is but 29 feet. The river above the reservoir has a catchment area of 196 square miles, over which the rainfall is so great that only one-sixth of the whole discharge of the river is used. The design of the dam is unquestionably crude. As at first constructed it was 14 feet wide on top, with straight slopes on either side of 2 on 1 downstream and 20 on 1 upstream. The dam soon showed signs of weakness, and to strengthen it a great bank of earth 60 feet wide on top and 30 feet high was piled up against its lower face. The line of the dam is built in several tangents, with changes of top width for each, according to the height of that portion of the dam, the points of juncture of the various tangents being backed up by heavy buttresses of masonry. The cost of this structure was about $1.75 per cubic yard, and its total cost was $630,000. While under construction a temporary wall of masonry was erected at some distance below the main dam in the river bed, which was built up to a height of 50 feet. The object of this was to form a temporary water cushion for the floods to fall on, so that they should not undermine the main dam while the wasteways were being prepared.

The discharge of water from the reservoir into the right-bank canal is regulated by ten sluices, each 2 feet square. These sluices are closed by iron shutters and are operated by means of capstan and screw from the top of the dam. There are in addition eight circular sluices, each 2 feet 6 inches in diameter, which are 1.33 feet lower than the canal sluices and are designed to supply water to turbines for mill power. These latter discharge into the canal through the turbine chamber. Three sluices of a similar pattern to the canal sluices mentioned are at the opposite end of the dam, for the supply of the left bank of the canal.

The right-bank canal has a bottom width of 23 feet and depth of 8 feet, though its usual supply of water is about 5 feet. Its fall is 4 inches per mile to Poona, at which place there is a drop of 2.8 feet, which is utilized by means of an undershot water wheel to drive pumping machinery for the supply of water to the town. The canal is carried through Poona in a tunnel excavated in rock. At the fifty-first mile the canal supplies Matoba tank, which is constructed as a relief work and commands an area of 8,550 acres of irrigable land.

The Mutha project was designed and has been operated as a productive work, and was constructed from borrowed capital. As originally estimated for, the total cost of the work, including land compensation, was to have been $2,664,000. The estimated revenue, including the revenue from mill power and water supply to the city of Poona, was to have been $207,000, or 7.78 per cent on the capital outlay. The total cost of this work to the end of 1889 has been $2,082,000. The working expenses were, in the year 1889, $2.08 per acre irrigated; the gross revenue from irrigation was $37,000, and the total net revenue was $72,000, including the revenue from all other sources, or 3½ per cent interest on the capital invested.

NIRA PROJECT.

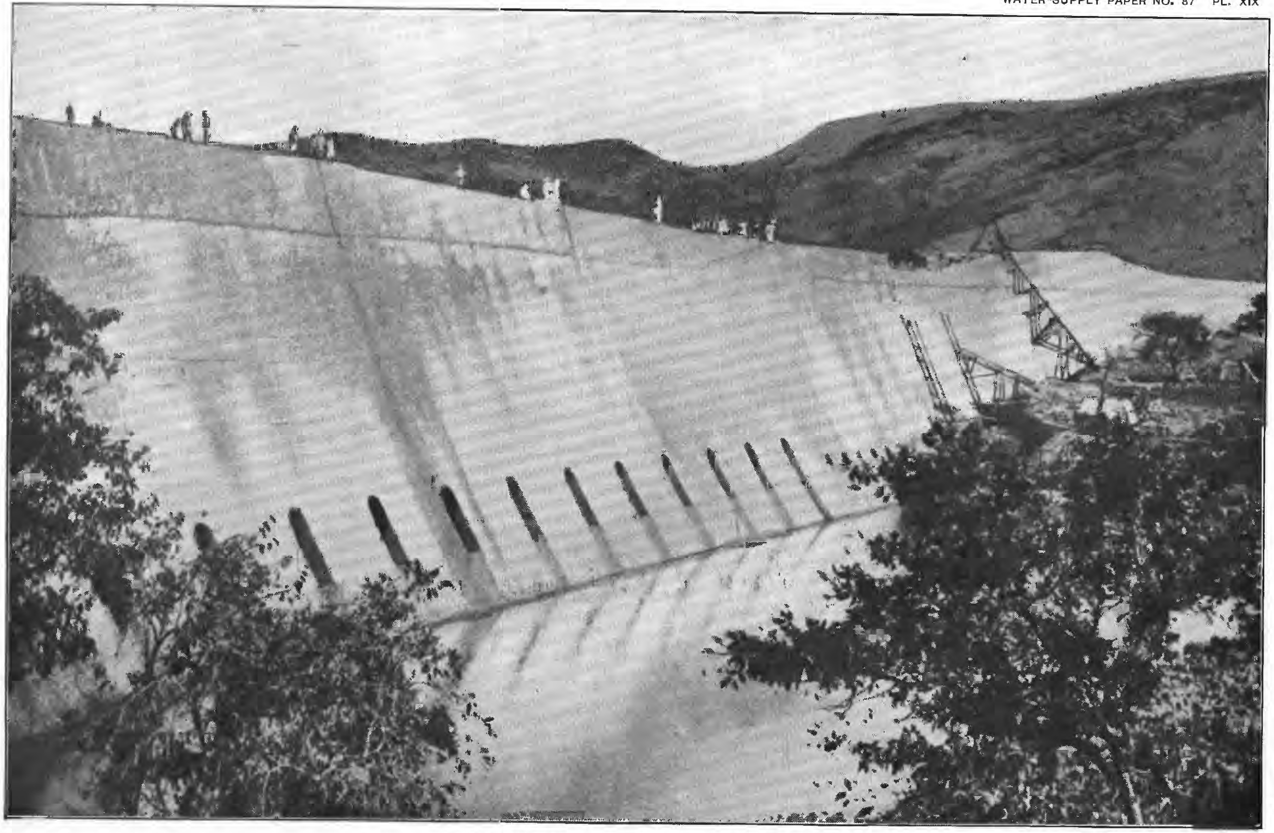
Bhatgur reservoir is located in the Presidency of Bombay, about 40 miles south of Poona, on the Yelwand River just above its junction with the Nira. The topography of the country thereabouts, in its physical characteristics, its climatology, and the appearance of its vegetation is very similar to that in northern Arizona in the neighborhood of Peach Springs or Hackberry. It consists of high mesas or table-lands, terminating in abrupt and nearly perpendicular rock slopes, and cut into by deep canyons, which open out rapidly onto broad bottom lands and valleys, leaving the mountain masses standing out boldly like the ruins of great old fortresses.

The frequent failure and the general uncertainty of rainfall in the portion of the Poona collectorate through which the upper Nira River flows caused Colonel Fife to turn his attention to devising some means for supplying this district with water for irrigation. Surveys made under his direction in 1863 showed that the system of small tanks which had been generally considered applicable to this region was, financially speaking, impracticable, as the slopes of the smaller valleys are as high as from 30 to 50 feet per mile. The result of the detailed surveys then made was that these tanks at best afforded but a limited area of irrigation, while a tolerable site for a tank was almost invariably occupied by gardens irrigated from wells, thus rendering the land expensive.

Preliminary surveys for the Nira project were made in 1864, but were soon discontinued. They showed that the canal must commence near the town of Shirwal. In 1868 a committee was appointed to investigate this scheme further, and the result was that it reported the district to be drought stricken, and said it would be advisable to have surveys made at once for the construction of a reservoir on the Nira River, with a canal from the same. Surveys were resumed in the same year under Lieutenant Buckle, R. E. These were continued for some time, and were finally taken up by Mr. J. E. Whiting, C. E., under whose direction the project was finally constructed. Mr. Whiting's observations and surveys proceeded until 1871. They included the examination of several different sites and comprised detailed surveys not only of these sites, but of river-gaging and rainfall observations, and the cross sectioning of the valley along the canal line. The scheme as finally submitted, and as now constructed, consists of a reservoir on the Yelwand River and of a canal heading at Vir, on the Nira River, 19¼ miles below the reservoir site, the canal being 129 miles long and discharging 945 second-feet at the head (see fig. 39).

The catchment basin above the dam site has an area of 128 square miles, and the fall of the river bed within the reservoir limits is 5 feet per mile. The water in the reservoir is backed up the valley a distance of 15 miles, and its total capacity is 126,500 acre-feet. The dam is 4,067 feet in length, and is composed of the best uncoursed rubble masonry laid in hydraulic cement. It is 127 feet in height above its foundation and its crest is 8 feet above high-water mark. Its extreme bottom is 74 feet wide, and the top is 12 feet, and is intended to be used as a roadway. The dam is designed on a modern cross section, by a formula very similar to M. Bouvier's (fig. 40). When full the pressure on the toe is 5.8 tons per square foot, or 90.8 pounds per square inch, and when empty is 6.7 tons per square foot on the heel of the dam. The water supply is such that this reservoir can be filled eight times in the year. Accordingly, it is evident that there is an immense volume of water to be wasted. The alignment of the dam curves in an irregular manner across the valley so as to follow the outcrop of rock on which it is founded. These foundations are excavated to a depth of 2 feet in the solid rock, which has required an excavation sometimes as deep as 30 feet in order to reach homogeneous material. The greatest flood over the dam may be 50,000 second-feet, and this is passed off by 2 wasteways and 20 undersluices. The wasteways are constructed at either end of the dam, in the body of the dam itself, and are arched over so that the roadway is continuous above them. Their total length is 810 feet, and the flood may pass 8 feet in depth through them. The northern wasteway, that on the left bank, consists of 45 arches of 10 feet span each which can be closed by automatic falling gates. The wasteway at the south end consists of 36 arches, with the same dimensions and construction as the others. Jutting out from the main dam on the downstream side, in such a manner as to inclose these wasteways, are constructed walls of masonry which guide the discharged flood water into separate channels, which carry it into the rivers below the main dam.

Of the undersluices (Pl. XIX), 15 are constructed in the center of



BHATGUR DAM, NIRA SYSTEM, BOMBAY.

the dam at its deepest point and are placed 17 feet apart, each being 4 by 8 feet in dimensions, with their sills 60 feet below the high-water line. With this enormous head these undersluices will discharge 20,000 second-feet, which is an average maximum flood, and they have successfully withstood several years of flood without injury to the joints of the ashlar masonry with which they are lined. Under full head the velocity through these sluices is 36 feet per second. Above this row of 15 undersluices, and near the surface slope of the valley, are two others of the same dimensions, one 2 feet above the main row and the other 50 feet above the main row. These sluices are constructed, as are the main sluices, with a lining of the best ashlar

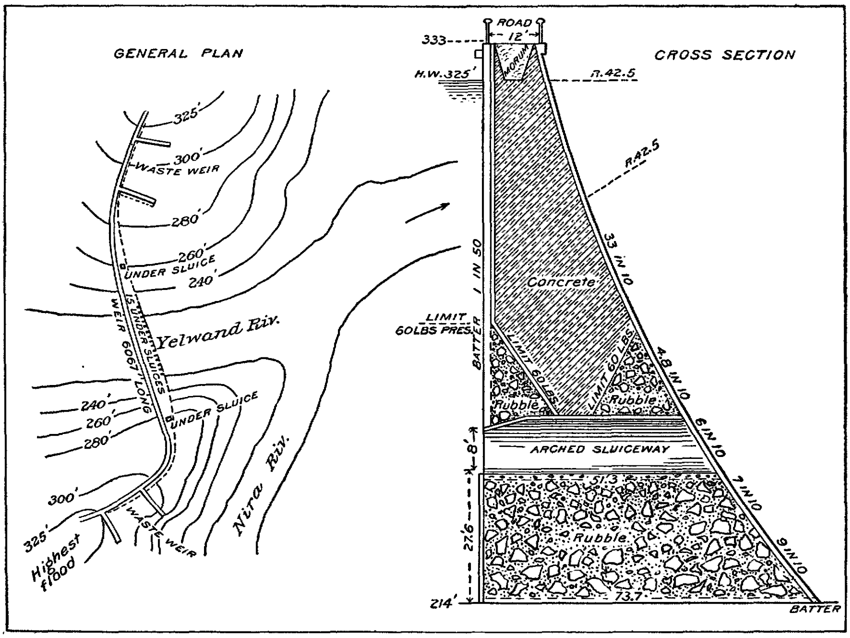


FIG. 40.—Plan and cross section of Bhatgur dam, Nira system, Bombay.

masonry, with pointed joints. They are closed by iron gates, which slide vertically. These gates weigh 2 tons each, and are operated by steel screws worked from above by a female capstan screw operated by hand levers. The gates are protected from injury by floating objects by means of stout gratings of wood on the upstream entrance. There is 30 feet of idle space below the undersluices, and this is expected to fill up with silt.

The object of these sluices is primarily to discharge the water of the reservoir, which then flows for nearly 20 miles down the Nira River to the diversion or pick-up weir at Vir, which turns it into the head of the Nira canal. Fewer sluices would have accomplished this end, but additional ones were constructed with the object of keeping the reservoir above them free from sediment. This can be accomplished only by leaving the sluices open when much sediment is carried in suspension, and it is very doubtful if they would clean the reservoir of silt if it were once permitted to fill up.

Mr. A. Hill, superintending engineer, says of the scouring effect of these sluices:

Scouring sluices have little effect unless the area of the openings is great compared to the area of the floods. To remove silt already deposited they are useless, as has been proven by the manner in which they have silted up at Lake Fife and at Vir and other places where their area is small compared with that of the area of the floods. At Bhatgur they are intended not to remove silt deposited already, but to prevent its deposit by carrying it off while in suspension. If the dam is

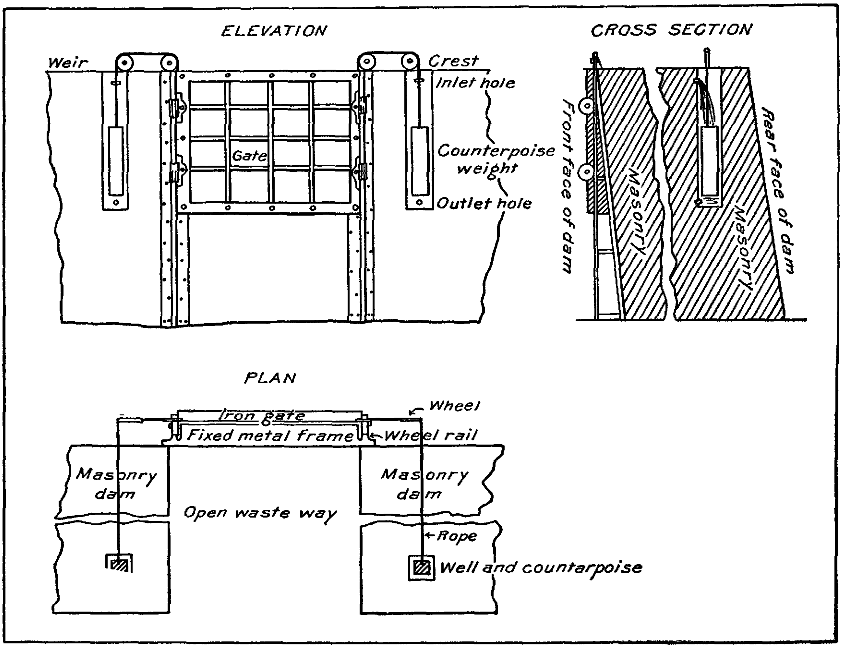


FIG. 41.—Diagram of Reinold's automatic weir gate.

high and the discharge of the undersluices will keep the flood level below the full supply level, then they will be efficient. If the dam is low and the sluices will not keep the flood level below full supply level, they will have little effect.

Experience on the Betwa reservoir and elsewhere bears out these conclusions, with the addition that their scouring or preventive effect is felt a very few feet to either side of the sluices, and silt will deposit close to their entrance. In other words, they do little more than keep an open channel above them.

The automatic sluice gates which are to be used on the wasteway of this dam are peculiar, and are well worth describing. They are patented by Mr. E. K. Reinold, their inventor, and their object is that when the flood reaches its maximum height, 8 feet below the crest of the dam, the gate shall be entirely open, and as the flood subsides the gate shall automatically rise until it is entirely closed, thus adding to the reservoir capacity by the depth of the wasteweir. The gates are 8 by 10 feet, and they thus increase the depth of this reservoir by 8 feet. Where water is valuable such an expedient may be of the greatest financial importance.

These gates have been in successful operation since about 1892, or for ten years, and have worked admirably. So much so, in fact, that similar gates are being placed on the Lake Fife dam, and have been

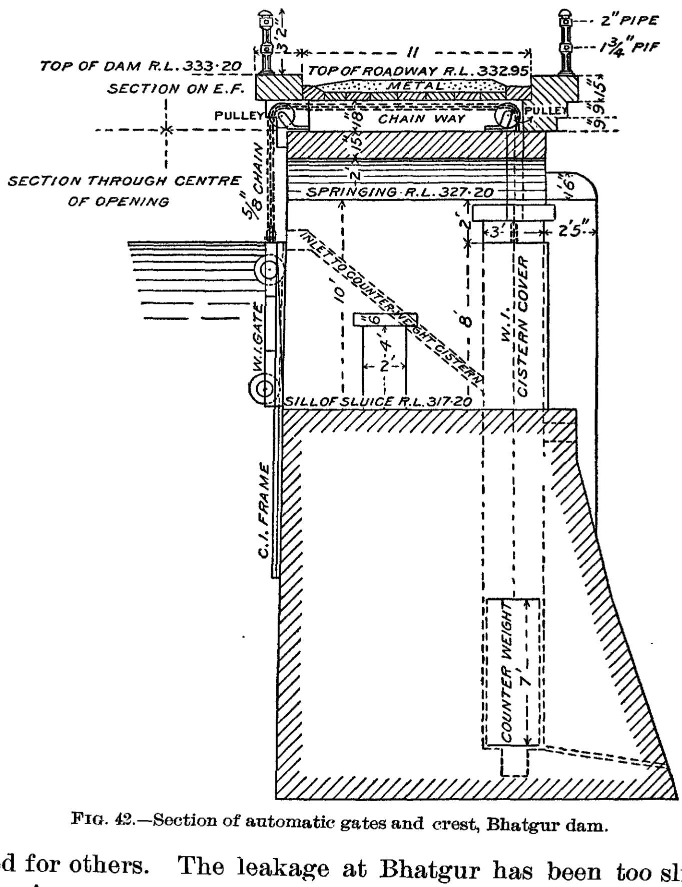


FIG. 42.—Section of automatic gates and crest, Bhatgur dam.

planned for others. The leakage at Bhatgur has been too slight to be taken in account.

The gate has two contact surfaces, one on the standard face against which it presses, and one on the face of the gate. These surfaces slide parallel to each other and are the surfaces of inclined planes. The gate rests on wheels running on rails and the axes of these wheels are parallel to the line of rails and at a slight angle to the contact planes, so that the latter do not touch until the gate is fully raised or closed, thus permitting by leakage a large amount of the flood water

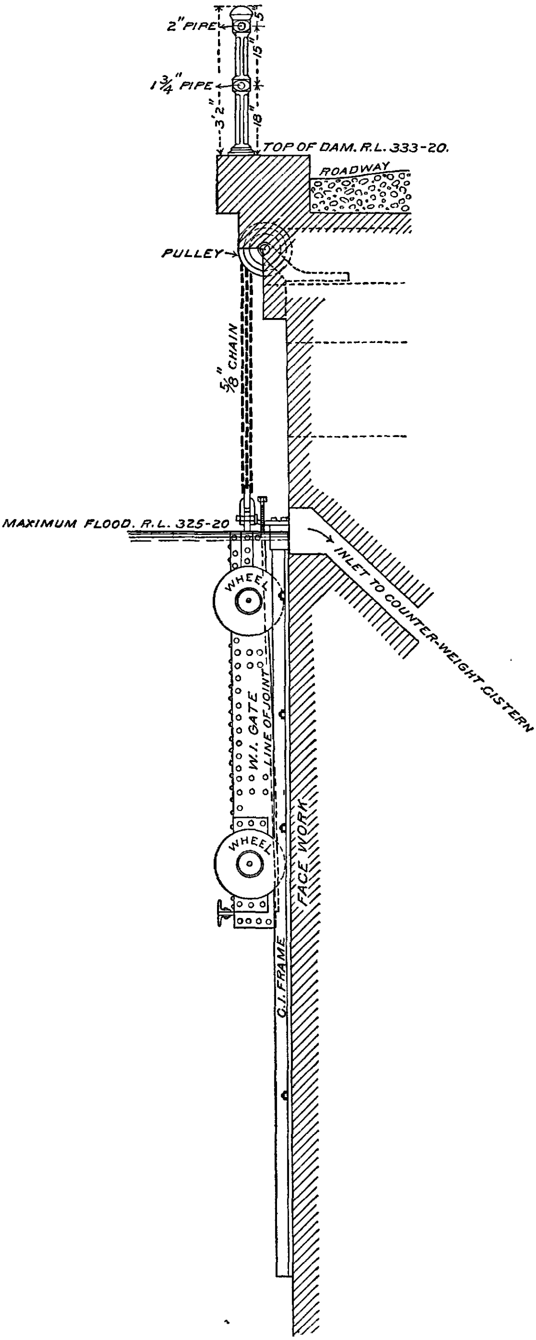
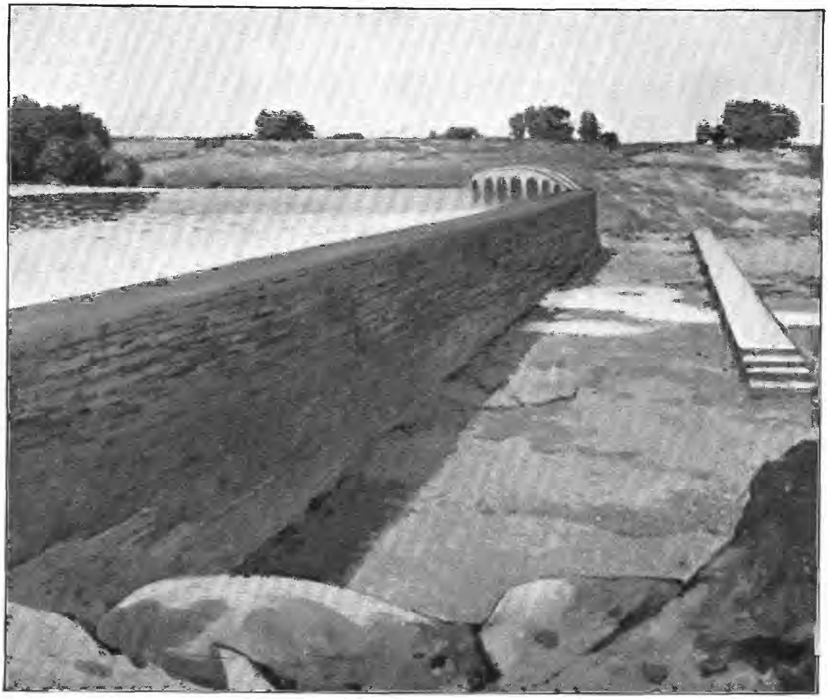
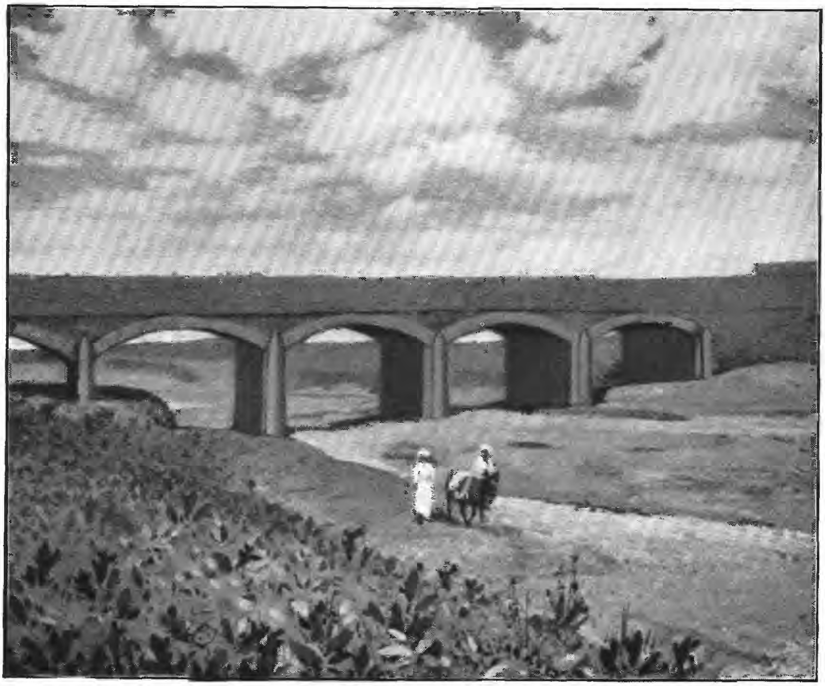


FIG. 43.—Detail of automatic gate.



A. VIR HEAD-WORKS, NIRA SYSTEM, BOMBAY.



B. KURRA AQUEDUCT, NIRA CANAL.

to run out of them until the last moment. The accompanying illustrations (figs. 41–43) explain the operation of the gate. It is automatically operated by means of counterpoises balanced in water cisterns, the weight of which exceeds the weight of the gate by a little more than the amount of the friction, and they act by displacing their volume in water in the cisterns in which they plunge, thus lessening their weight by that of this volume of water. As the water flows over the top it flows simultaneously into the cast-iron boxes in which the counterweights hang, through inlets placed on a level with the gate top. This water entering the cisterns reduces the weight of the counterpoises, and the gate then, being the heavier, sinks, opening the waste-

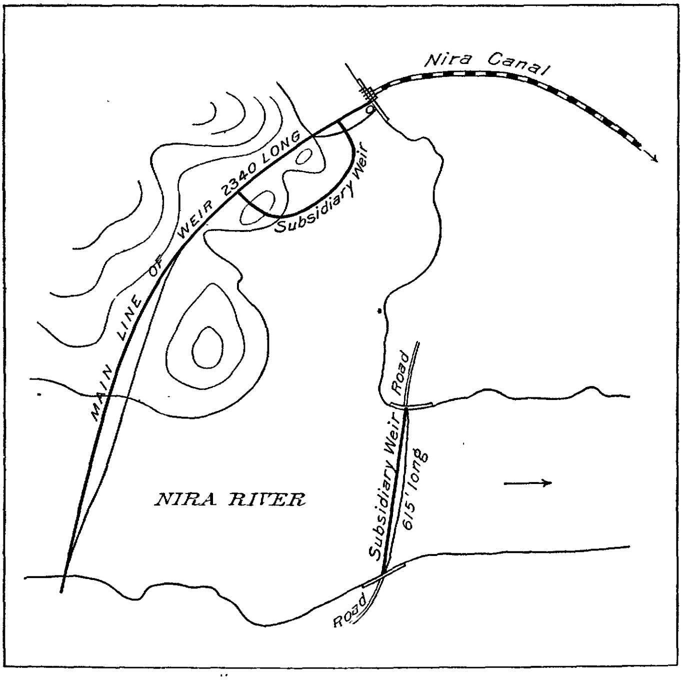


FIG. 44.—Plan of head-works, Nira canal, Vir.

way. When the water ceases to enter the boxes, owing to its having fallen below the level of the inlets, it soon runs out from holes at the bottom and the counterweights then become heavier than the gate and lift the latter. Giving the proper weight to these counterpoises is one of the important details of the apparatus.

The Nira canal heads at Vir, 19¼ miles below the reservoir (Pl. XX, A). The river bed between these two points being of a rocky character little or no loss from absorption takes place. The pick-up or diversion weir is constructed across the Nira River at its junction with the River Vir, and it crosses both of these streams and the point of land between them (fig. 44). The total length of the weir is 2,340 feet, and its greatest height above the foundation is 43½ feet. The dam is constructed of uncoursed rubble masonry and is 9 feet wide on top (fig. 45). The rear slopes are 8 feet on 1 for 20 feet, and 6 on 1 for the remainder or lower part. The upstream face has a uniform batter of 20 on 1. At no place is the mean thickness less than half the weight of the dam. The main weir consists of two straight portions connected by a curved wall over which the water will not flow. This wall extends through the point of land connecting the two rivers, and a channel 126 feet in width is excavated below it, connecting the rivers. The weir is founded on solid rock throughout, but to form a water cushion and break the force of the great flood which passes over

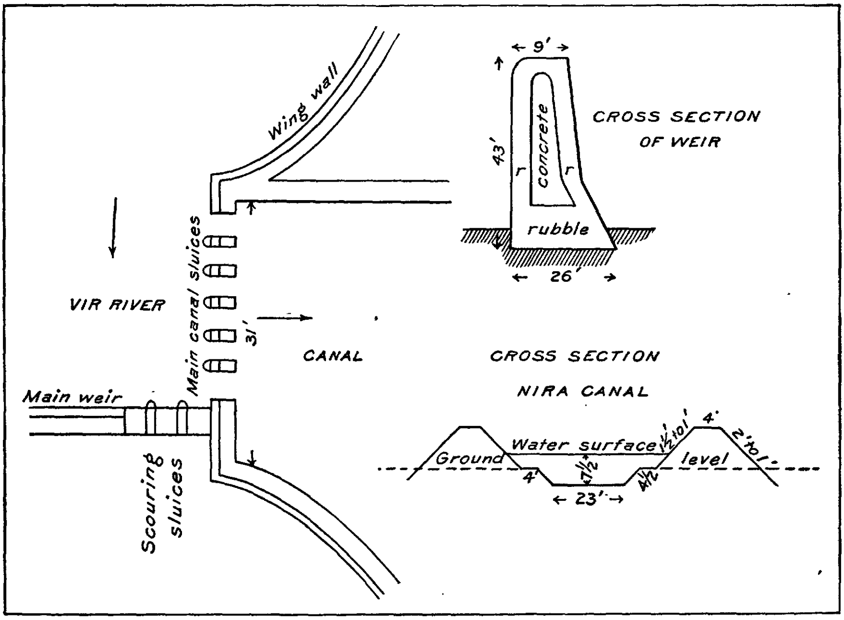
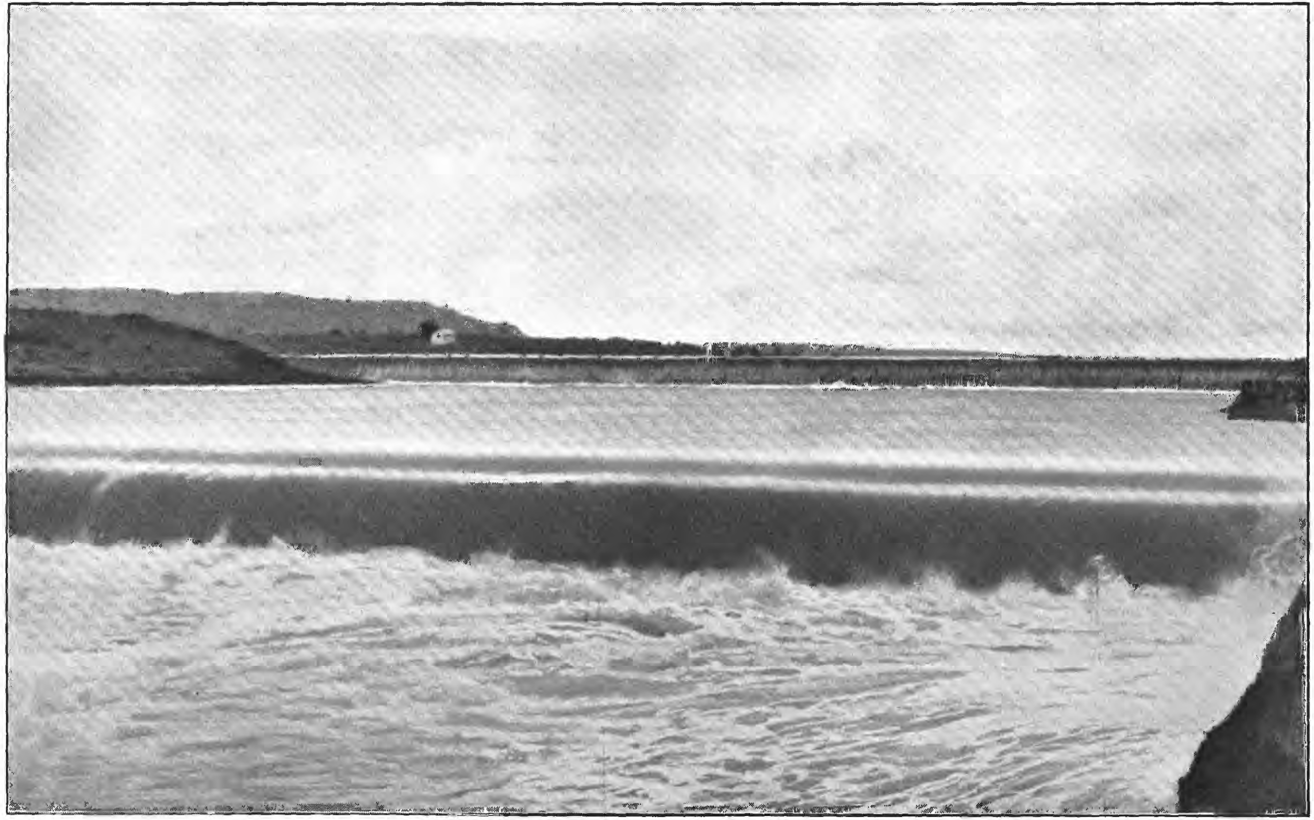


FIG. 45.—Plan of regulator head and cross-section of weir and canal banks, Nira canal.

it, a subsidiary weir, situated 2,800 feet below the main weir, is provided. The total length of this subsidiary weir is 615 feet, and it is 24½ feet high, with its crest 20 feet lower than that of the main weir. It thus forms a permanent water cushion 20 feet deep below the main weir. Like the main weir, this subsidiary weir is constructed of the best uncoursed rubble masonry, and has a roadway on top. During a maximum flood, it is estimated that the cushion will be 32 feet deep when the overfall will be only 8 feet deep.

The catchment basin above this diversion weir is 700 square miles and the greatest flood estimated to pass over it is 158,000 second-feet, corresponding to a run off of nearly half an inch per hour. The greatest flood which has occurred rose 8 feet over the crest of the main weir and 13 feet in depth over that of the subsidiary weir (Pl. XXI).



MAIN CANAL AND SUBSIDIARY WEIRS, NIRA SYSTEM. VIR IN GREAT FLOOD.

The main weir backs the water up the Nira River a distance of 12 miles to Shirwal and impounds about 1,400 acre-feet, or sufficient to afford a reserve supply for the canal for a few days. It is expected, however, that this basin will silt up in the course of time. The canal heads from the left bank of the river at right angles to the River Vir (fig. 44), and in a portion of the weir just below this head it has been found necessary to construct a second subsidiary weir of trifling dimensions which catches the direct flood from the Vir on a water cushion (Pl. XX, *A*).

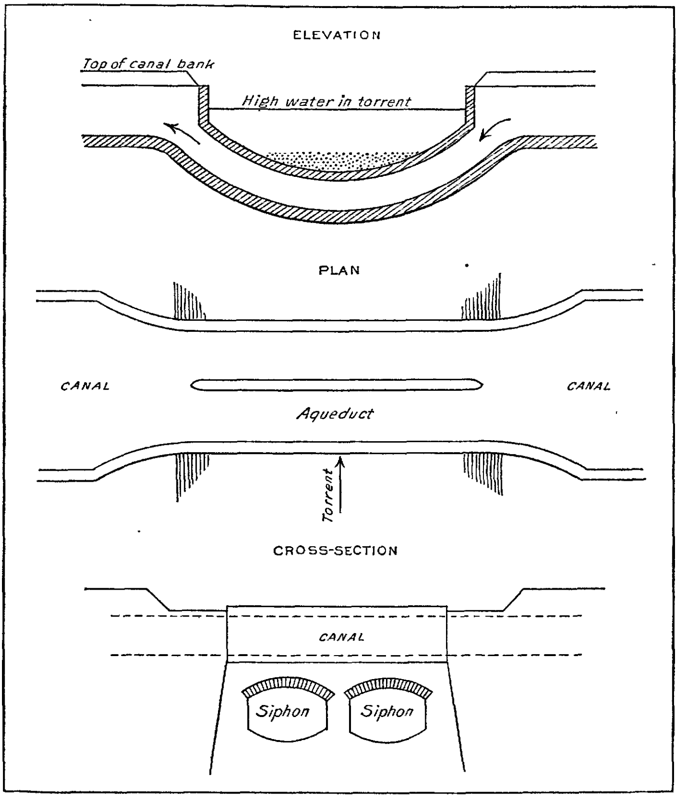


FIG. 46.—Nira canal; superpassage at siphon for Jewhar Torrent.

The canal after leaving the head-gates makes a long sweep through a low ridge, curving until it is parallel to the river. In the cut through this ridge, which is 400 feet in length, the average depth of excavation is 50 feet. The velocity in the canal averages 1.8 feet per second. The regulating sluices (fig. 45) at the canal head are 7 in number, each 4 feet wide and have an available head of 9 inches. In the weir adjacent to the head regulators are a set of two scouring sluices which have not a sufficient area to remove silt which may deposit, but which act as all other scouring sluices in keeping open a clear channel past the head of the canal. At its head the bottom width of the canal is 23 feet, the depth of water $7\frac{1}{2}$ feet, and the discharge ordinarily 470 second-feet, while the fall is 6 inches per mile. As at present constructed the main canal is 103 miles long and controls an irrigable area of 300 square miles. There have been constructed 175 miles of distributaries commanding a portion of this area. The slope of the canal increases to 3 feet in a mile in rock cuts with a corresponding cross-sectional area. In earth where the canal cross section is small the greatest fall is 18 inches in a mile. The accompanying fig. 45 is a cross section of the canal showing the way in which the berms and banks are formed.

Numerous cross drainages are passed in the line of the canal, the largest works being aqueducts over the Kurra River and the Wargaon and a superpassage over the Jewhar Torrent. The Kurra aqueduct (Pl. XX, *B*) consists of 20 arches of 30 feet span each. The discharge of the river is estimated to touch the crowns of the arches at a velocity of 9 feet per second through them. The superpassage for the Jewhar Torrent is novel (fig. 46) and has an advantage over weirs, as the silting of the canal is avoided. This structure differs from an ordinary superpassage in being in solid rock, thus acting as a weir; also in the canal being carried under without any great drop or fall. The canal clears the arching to avoid loss of velocity; in this it differs from siphons. There is extra velocity and consequent narrowing of the waterway. Regarding the aqueducts, it may be observed that, like the superpassages, the object has been to make them as narrow as possible without sacrificing too much fall, and the narrowed channel is smoothly paved and grouted. It is estimated that the acceleration along this steep incline, together with the original velocity of approach, gives the requisite speed before the water enters the aqueduct. An inclination is given along the aqueduct sufficient to maintain this velocity and carry the water across, but directly the passage is cleared the canal is gradually widened and gets its regular fall per mile.

The total outlay on the Nira project to the end of the year 1888 was as follows:

Total outlay on Nira project to end of 1888.

Canals, distributaries, etc	$526,000
Bhatgur reservoir (uncompleted)	355,000
Twenty-three sluice gates and the subsidiary weir	32,000
Canal head-works at Vir	125,000
Nineteen aqueducts	140,000
Two siphon superpassages	22,000
Seventy-five small weirs	92,000
Hydrants, turbines, etc	40,000
Compensation for land	116,000
Total, including sundry others	1,448,000

To the close of 1901 the expenses, exclusive of the Bhatgur reservoir were: For main canals, $630,000; distributaries, $68,000; head-works, \$706,000; establishment, \$342,000; tools and plant, \$41,000; total, \$1,787,000. The revenues to end of 1901 had been: Water rates, \$362,000; plantations, \$3,000; rent of buildings, \$1,600; total, including miscellaneous, \$367,000.

BETWA PROJECT.

The first proposal for the construction of a canal from the Betwa River was made by Major-General Strachey in November, 1855. The question was again considered after the mutiny in 1859, but nothing was done until 1867, when Lieutenant Home, R. E., was directed to conduct the inquiry.

Lieutenant Home made examinations in 1867 and 1868, and submitted a preliminary report which showed that it was practicable to utilize the waters of the Betwa River for irrigating a tract in Bundelcund, in the Northwest Provinces, lying between the Rivers Jumna, Pahuj, and Betwa, whereupon more complete investigations were ordered. The examination was continued by Lieutenant Bagge and estimate submitted. Further examinations were made later, in 1869, by Mr. Anderson, under the general direction of Colonel Greathed, chief engineer, and the conclusions arrived at by him were that Parichi was the best position for a diversion weir; that for four or five months of the year 1,000 second-feet could be depended on even during years of minimum rainfall, but that final further examination was advisable. In November of the same year Lieutenant Bagge submitted a detailed project and estimate of the Betwa canal, including a provision for water storage. The estimates were so high that the project was shelved, especially as there was no prospect of the enterprise realizing more than from $3\frac{1}{2}$ to 4 per cent interest on the expenditure. Finally, in November, 1873, the Government sanctioned the estimates, restricting the canal to wet-weather irrigation without provision for navigation and without being supplemented by storage.

The works of the canal were designed and carried out under these general plans, but were afterwards modified so as to include a storage reservoir and irrigation throughout the year. Various sites were discussed for the location of the storage works, that at Khoord being the most favorably considered for some time, but finally Paricha, a site previously decided upon for the diversion weir, was accepted as the best location.

The area covered by the Betwa canal system is about 1,500 square miles. The surface formation of the bench land covered is very peculiar. The highlands border on the valleys of the Pahuj and Betwa rivers, while the lowlands occupy the central part, being drained by two separate channels which unite as they approach the River Jumna. Owing to the irregularity of the rainfall and the excessive fertility of the soil on this area of land, it is difficult to make a canal project remunerative without supplementing its perennial discharge with storage water, since during the ordinary season of the year, when the river flows an abundant stream of water, the rainfall on the irrigated area is sufficient for most of the needs of the agriculturist. The site chosen for the diversion weir is an excellent one, the unusual width of the river bed at this point affording an ample wasteway for the great floods which may be expected during certain periods. It was necessary to design the storage dam as an overfall weir throughout its entire length, as the maximum flood to be discharged amounts to 750,000 second-feet. A rocky barrier or ledge runs across the bed of the river at this point and forms an excellent foundation for the weir. The river has a straight run between good stiff banks, and there is a plentiful supply of good building stone in the neighborhood.

For the first 20 miles the canal runs in a direct line, and is in an excavation varying in depth from 5 to 40 feet. This portion of the line is fortunately in earth and may be considered as purely diversion line, being too deep for purposes of flow irrigation. The first 6 miles of the canal are protected by a drainage channel parallel to it, which catches the discharge from the various small streams crossing it at right angles to the direction of the canal. Through this first portion of its length the cross section of the canal is 20 feet at the bottom with a depth of 12 feet of water. The first 3 miles below the head are revetted both on the banks and the bed of the canal. This revetment consists of a paving of loose stones carefully laid by hand. No silting of any importance takes place in the canal, as the water is admitted to it only during the season of moderate discharge in the river, and as it is taken from the storage reservoir most of the sediment has been previously deposited. The growth of weeds, however, is rather excessive, owing to the low slope of the canal, and the latter is periodically closed in order that the weeds may be cleared by hand.

One of the principal branches—the Hamirpur branch—is designed with a bottom width of 15 feet for the first 30 miles and a depth of water at head of 6 feet, its slope being 1 in 3,000, which gives a velocity of $1\frac{3}{4}$ feet per second and a discharge of 340 second-feet. From this point on, the branch diminishes gradually in dimensions and carrying capacity, the slope being continually altered so as to give an average velocity throughout of about 3 feet per second. Another main branch, called the Kathund branch, has a bed of 30 feet and a depth of 6 feet, and is designed to carry 500 second-feet of water.[a]

The local drainage met in the first few miles is disposed of by means of a parallel drainage canal having an inlet into the canal, and by another channel near the canal head discharging into the Betwa River. There are two drainage siphons, one in the seventeenth mile and one on the Hamipur branch. The siphon on the main canal will discharge 1,300 second-feet and is provided with five vents of 30 square feet, which head the water up $1\frac{1}{4}$ feet and discharge it with a velocity of $8\frac{1}{2}$

[a] The Betwa Canal Project in the Northwest Provinces, Records of the Government of India, Calcutta, 1877.

feet per second. The falls along the lines of the canal and the bridges are of the usual pattern described elsewhere.

The minimum discharge of the river may be taken as about 50 second-feet, while the maximum discharge may be as great as 750,000 second-feet. The average rainfall over the irrigated lands is 39 inches. The gross area of land commanded is 522,800 acres and the culturable area is 348,586 acres, while the area irrigated at present is 180,000 acres. The expenditure on the works, including all charges to the year 1893, was $1,435,000. These works include 19 miles of main canal, 163 miles of branch canals, and 380 miles of distributaries. The duty performed in 1887 during the fall crop was 67 acres per second-foot of the discharge at the head, or 76 acres per second-foot

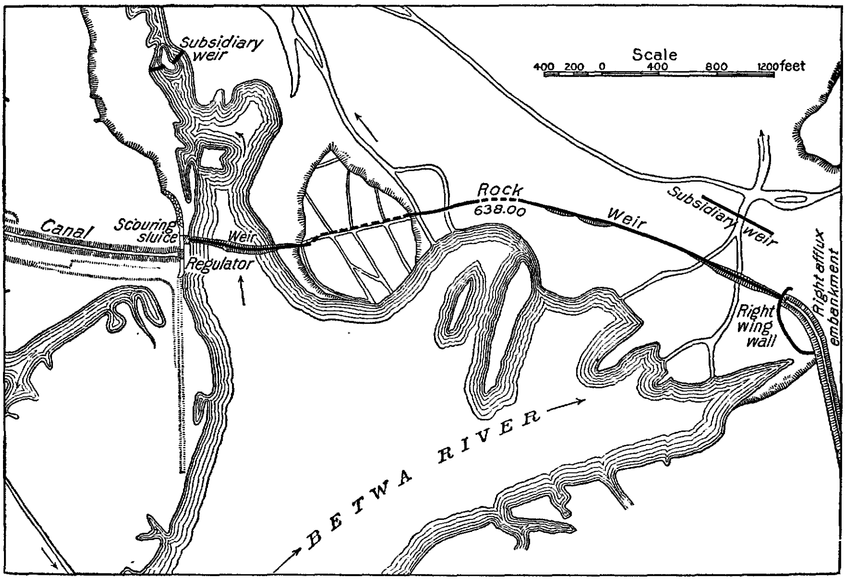


FIG. 47.—Betwa project; plan of dam and head-works.

of the discharge utilized. The principal crops raised were wheat and barley, with a small amount of pulses, indigo, and opium.

The weir alignment has been skillfully located so as to make the most of the rocky barrier which crosses the river at the point where it is constructed (fig. 47). The weir is placed on the ridge of this reef, which curves away from the left flank and is convex upstream, so that the water will be thrown toward the middle of the channel. The height of the weir above the river bed varies between 0.4 of a foot and 60 feet, except on the left bank, where the rock was higher than the sill and had to be cut down. The total length between the steps on either protected bank is 3,296 feet and it is calculated to produce an afflux in extreme flood of 6.5. The cross section of the weir as at first proposed is a trapezoid with sides of equal slope, viz, 10 horizontal to 25½ vertical, the top width being 10½ feet. The chief engineer, Colonel Greathed, did not approve of this cross section, but decided that the downstream face of the weir should be nearly vertical in order that a 6-inch film of water passing over the weir would fall clear of the toe, and in order to increase the stability of the weir it has been extended upstream somewhat. The upstream edge has been rounded in order that driftwood may pass over without obstruction and injury to the masonry, and a curve has been given to the upstream face, instead of a batter, in order to facilitate the passage of water and drift.

The accompanying section of the weir (fig. 48) is for the highest part. Fifteen feet has been adopted as a convenient and uniform width for the top, which is coped with ashlar 18 inches thick, the upper blocks being not less than 15 inches wide and weighing about 1 ton each.

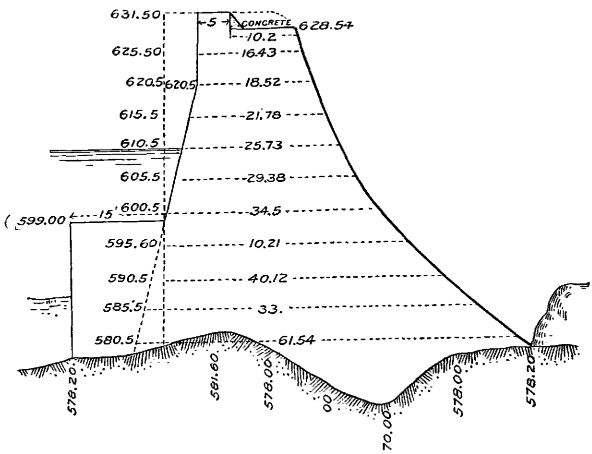


FIG. 48.—Cross section of Betwa weir.

The body of the weir is built of rubble masonry coursed on both faces, the minimum dimensions of the stones being 9 inches long, 8 inches wide, and 6 inches high, with a due proportion of bond stones. The ashlar is set in Portland cement and the rubble in native hydraulic-lime cement. The body of the weir appears to be unnecessarily thick and heavy; especially is this true of the great block of masonry which is placed at the toe. The cross section, however, was considered by the engineers to be necessary, owing to the steepness of the slope of the river and the magnitude of the floods which it discharges.

As shown by the accompanying plan of the river and of the weir crossing it (fig. 47), the latter is constructed in three different lengths, separated by a large island, on which it abuts in one place and by a rock which projects above the surface of the water in another place. The deepest portion of the channel is adjacent to the left bank, and the greatest height of the weir at this point, including foundations, is somewhat over 60 feet. At the toe of the weir on the downstream slope is built out a great block of masonry from 15 to 16 feet in width, which is intended to receive a portion of the jar caused by the impact of the flood water passing over the weir. Adjacent to the left bank a row of undersluices, four in number, are constructed in the weir itself, the object of which is to give a scour past the canal head, thus keeping the latter free of silt. The canal itself heads just above these undersluices, the regulator consisting of five openings, arranged with a double tier of gates, one above the other, in such manner that either the upper

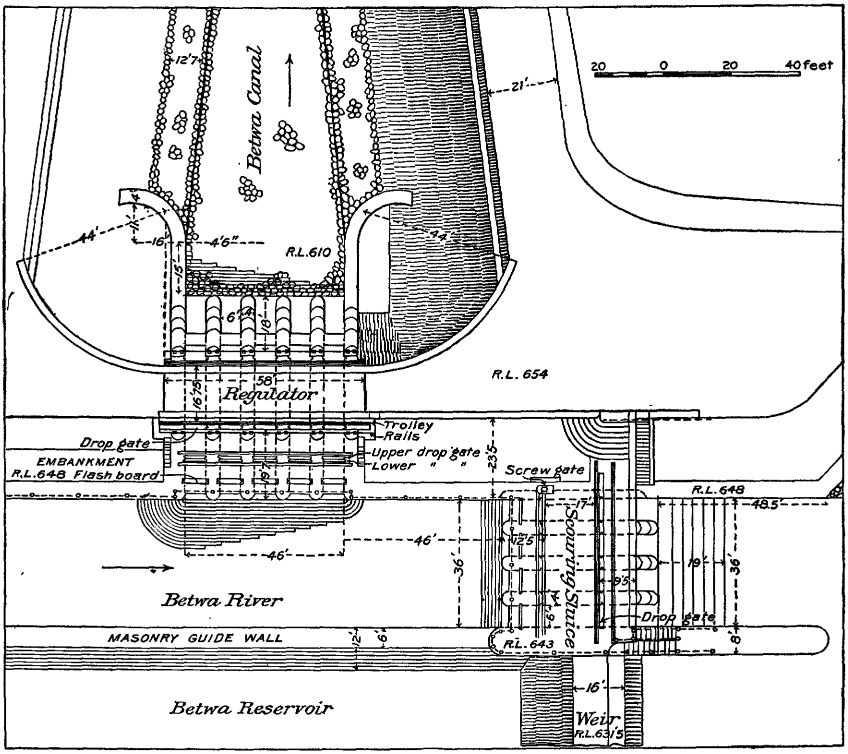


FIG. 49.—Betwa project, plan of regulator and scouring sluices.

or lower series may be used at will according to the depth of water in the reservoir.

Below the portion of the weir across the main channel is constructed a subsidiary weir at a distance of perhaps 1,400 feet, the object of which is to back the water up against the main weir, thus producing a water cushion on which the floods shall fall. The extreme height of this subsidiary weir is about 18 feet and the height of overfall from the main weir to the water cushion formed by it is 21½ feet, though in time of flood this will be reduced to 8 feet. The top width of the subsidiary weir is 12 feet, and its walls are nearly vertical on the downstream side with a slope of about 10 on 1 upstream. The main body of the weir between the island and the narrow right-bank channel is very low and the overfall is onto a solid rock bed. It was accordingly not necessary to construct a subsidiary weir below this portion of the weir, but across the right-bank channel, where the height of the weir nearly approaches that at the extreme left bank, a secondary subsidiary weir has been constructed at a distance of about 200 feet below the main weir, and with the same object and same crest level as the subsidiary weir just described.

The available net storage depth of the reservoir is 21½ feet, and its capacity above the canal bed is 36,800 acre-feet, though it has been found that the lower 6 feet of depth is of little service, as the head above is not enough to force the water into the canal with sufficient freedom to make it practically available.

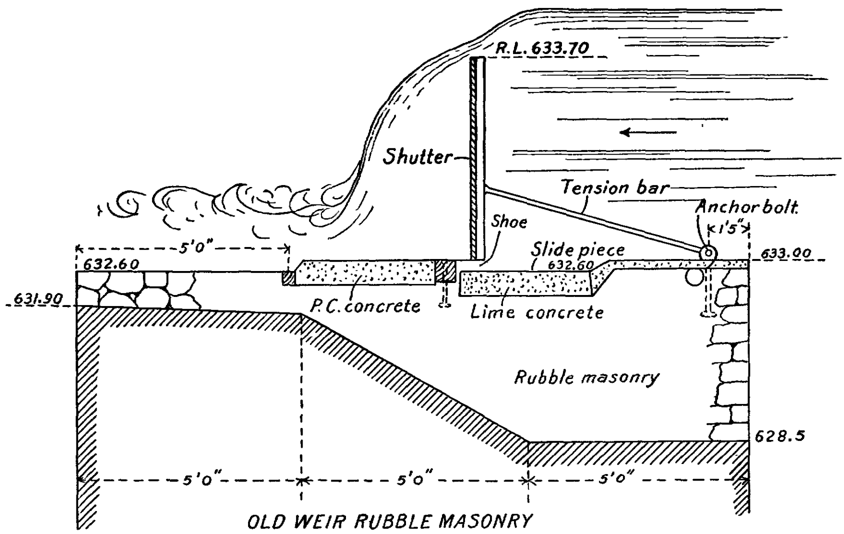


FIG. 50.—Automatic drop shutters, Betwa dam.

In 1897 the subject of increasing the storage capacity of this dam by adding automatic drop shutters on its crest was considered, and the plans for carrying out this work were finally approved and carried to completion in 1901. These works consist of two parts, namely, the building up of the weir crest by the addition of 1 foot in height of the best rubble masonry, and of shutters 6 feet high placed on top of these, thus making the total increase in height to which the water can be raised amount to 7 feet (fig. 50). By this means the gross increase in storage capacity of the reservoir with the shutters raised was 1,800 acre-feet, which is equivalent to an additional nine days' flood supply of the canal.

The shutters are illustrative of the latest Indian practice in the design of automatic drop gates. Moreover, they were subjected to the unusual test on completion, in 1902, in the form of an extraordinary flood of 970,000 second-feet volume instead of the greatest maximum anticipated, of 750,000 second-feet. This flood passed over the crest of the dam to a maximum height of 16.4 feet, when it had been designed only to stand a previous known flood height of 6.5. Fortunately, the shutters worked successfully and rapidly, and neither weir nor shutters sustained any material injury. These shutters are each 6 feet high and 12 feet long, and as the length of the weir crest is 3,600 feet there are 300 such shutters. They are made entirely of

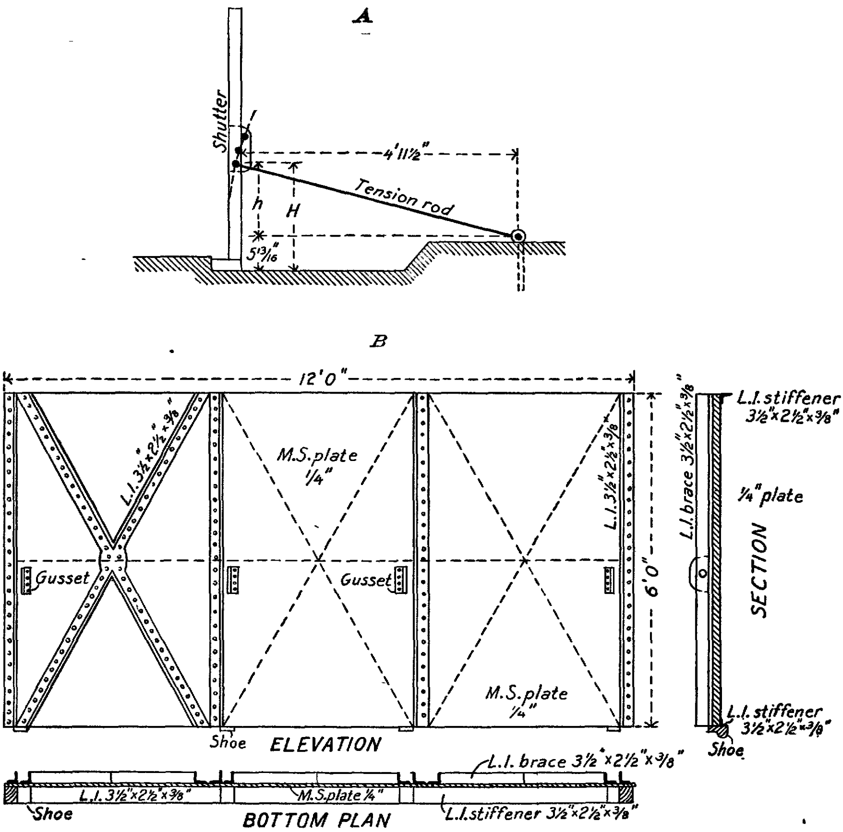


FIG. 51.—Shutter gates, Betwa dam.

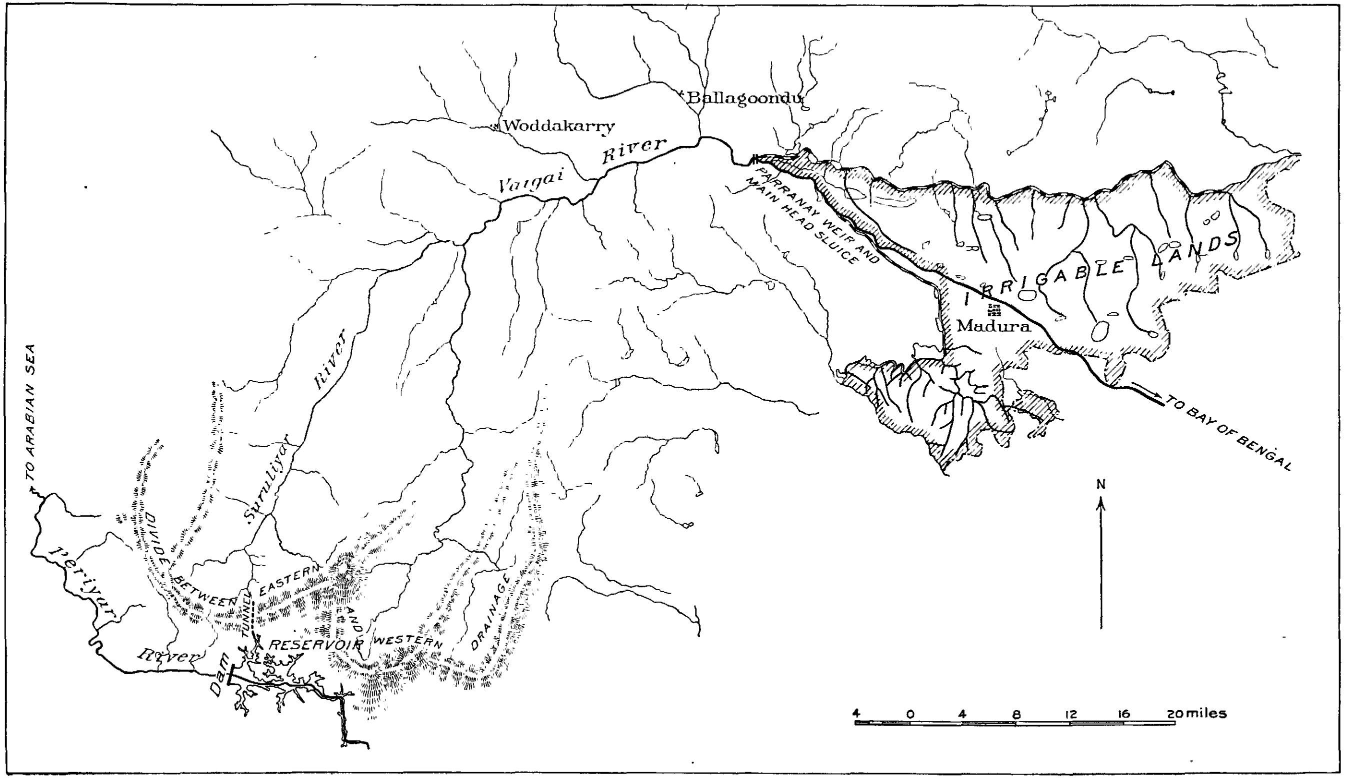
steel, consisting of two one-fourth inch plates joined along their middle and stiffened both longitudinally and laterally by angle iron 3½ by 2½ by ⅜ inches (fig. 51). To the flanges of the vertical stiffeners are pivoted 1¾-inch tension bars. The other end is similarly attached to anchor bolts built 2 feet into the masonry crest of the weir. There are four such tension bars to each 12-foot gate. The point of attachment of the tension bar and shutter is so designed that the gates fall automatically with a given depth of water passing over them, thus securing safety in case of excessive floods. The bottom of each gate is supplied with four steel shoes which rest upon sliding plates built into the weir crest, thus reducing the frictional resistance when the gates fall (fig. 51). Wooden boulks, 4 feet by 4 inches, are fixed to the ends of the shutters, which have a space of 1 foot separating them, which is calked when the gates are raised.

If the 300 shutters were to fall together, the shock would unduly strain the weir and the flood volume submerge the river banks below. Hence the attachment of the tension bars has been so arranged that each third gate falls under different depths of water. The first third fall with a depth over top of 2 feet, the next with 3 feet, and the last with 4 feet. Thus after the first third fall the released water reduces the flood depth, and the latter must increase considerably to top the second third, and so on. It was not anticipated that all the shutters would ever fall, yet this occurred in the flood above mentioned.

Careful calculations were necessary to determine the point of attachment for each group of shutters, and as a fraction of an inch would make a great difference in upsetting the gate careful experiments were made with a model gate to determine the exact point of attachment of the tension rods. So as to have uniformity of length of the latter, the pivot holes in the shutters were arranged in an arc of circle at the required height from the bottom of the shoe (fig. 51, *A*).

Hole.	H.		Depth required to upset.
	Ft.	*in.*	*Feet.*
1	2	$0\frac{3}{4}$	2
2	2	$1\frac{3}{4}$	3
3	2	$2\frac{3}{4}$	4

The undersluices which are constructed in the main body of the weir opposite the canal head are placed at right angles with the face of the canal regulator in order to give sufficient scour along the canal head to prevent the deposit of silt. The height of the face wall is given a margin of 6 feet above the calculated afflux level. The undersluices consist of four vents, the bottoms of which are on a level with the sill of the canal and are each $16\frac{1}{2}$ by $16\frac{2}{3}$ feet in dimensions. The piers of the undersluices are 5 feet thick in order to support the great superincumbent weight of masonry. The abutments, piers, arches, cut-waters, etc., are of ashlar, the rest of the work being of rubble masonry, the upstream face being pointed with Portland cement. A peculiar curve is given to the upper face of the piers between the sluice vents, forming a venar-contractor in such manner as to pass the water with the least friction through the sluiceways. The sluices are each closed by a series of two plain drop gates, the upstream set of gates being operated by a screw by means of hand levers from above,



PLAN OF PERIYAR PROJECT, MADRAS.

the lower openings being closed by slash boards let into grooves in the piers.

The gates of the regulating sluices of the canal are of such cross-sectional area as to admit 1,000 second-feet of water. The number of openings in the regulator is five, each 6 feet in width by 5 feet in height, and, as before stated, are two decks in height, being closed by separate gates in such manner that either the upper or lower series of gates may be opened at will, according to the depth and pressure of water in the reservoir. Below the main regulator gates, which are operated by screws by means of hand levers worked from above, are a set of two safety drop gates, which are raised by means of a traveling winch. The accompanying drawings (fig. 49) illustrate some of the details of construction of the regulating and flushing sluices. These regulating gates, like those of the flushing sluices, are constructed of the best rubble masonry, finished with ashlar. The total cost of the head gates and flushing sluices was $100,000, while the main weir, inclusive of the subsidiary weirs, cost only $160,000.

The left flank of the river is protected up and down stream by a wing wall, the former 140 feet long and the latter 75 feet long. The whole length of the wing walls is founded on rock, and, excepting the parapet, they are constructed chiefly of rubble masonry. In order to avoid inundation by the afflux caused by the weir, embankments have been constructed on both sides of the river. The top width of these is 20 feet and the center of each is hearted with a puddle wall 3 feet thick.

The Betwa project was sanctioned as a protective work. The total expenditure on it up to the end of 1901 was $1,500,000, the total revenues from irrigation were $9,300, and the total working expenses were $30,000; while the net revenue account showed a deficit over all receipts, including those from irrigation, of $20,000. This work has been in operation but a few years and the revenue has been constantly increasing in amount relative to the working expenses.

PERIYAR PROJECT.

The Periyar project for the irrigation of the Vaigai Valley, in Madras Presidency, is probably the most interesting illustration of the combined storage work and irrigation canal system to be found in India, especially as it was sanctioned as a protective work. The project (Pl. XXII) includes the construction of a dam to close the valley of the Periyar River to store 300,000 acre-feet of water, of which 150,000 acre-feet are above the sill of the outlet tunnel and are thus available for irrigation; the construction of a tunnel through the watershed dividing the valley of the Periyar from that of the Vaigai River for the purpose of drawing off the water from the reservoir, with the necessary sluices and subsidiary works for controlling the passage of the supply of the Periyar down the valley of the tributary called the Sooroolly, by which it reaches the Vaigai; and finally, the construction of the works necessary for the regulation and distribution of this supply for the command of 107,650 acres of land in the Vaigai Valley, of which 76,445 acres were irrigated in 1898–99. As the waters of the Periyar flow westward into the Arabian Sea, they are thus diverted across the peninsular divide, the Ghauts, to the eastern coast of India, where they enter the Bay of Bengal.

The area of country which is irrigated by this project was described by Major Ryves, R. E., in his early report on the project in 1867, as being about 1,200 square miles in extent, with a population of nearly half a million. Up to the present time irrigation has been practiced from native tanks, most of which, however, have become very shallow, and from which the waste of water by evaporation is at least 30 per cent. In very good years the water supply from the Vaigai itself is sufficient to irrigate 20,000 acres. Agricultural operations in this region are rarely rewarded by a good crop, although the land where water can be provided is of the most fertile character. During the famine of 1876 as much as $600,000 was expended in relief in this district.

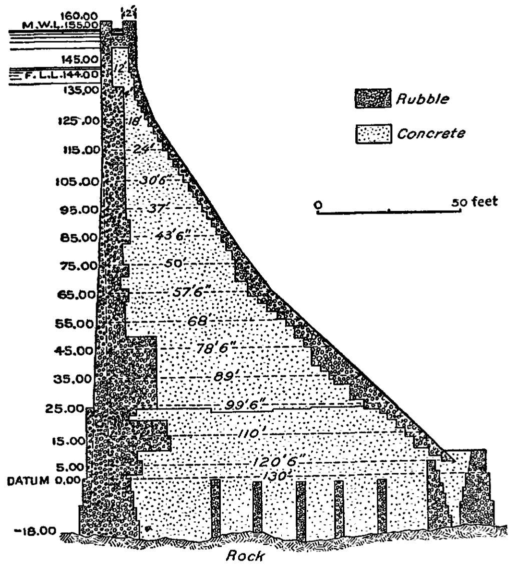
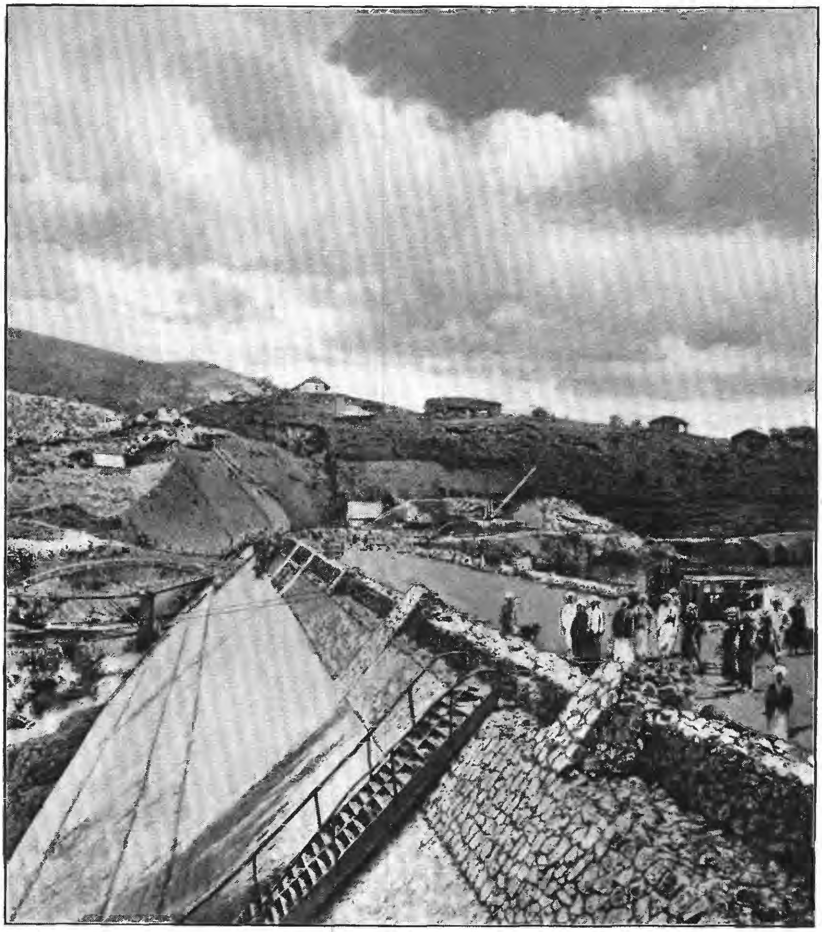


FIG. 52.—Cross section Periyar dam.

The idea of utilizing the water of the Periyar for the irrigation of the Vaigai is an old one. It was first reported in 1808 by Sir James Caldwell, who condemned the project as decidedly chimerical and unworthy of further regard. The subject was occasionally discussed from time to time, but it was not until 1867 that it was practically brought forward by Major Ryves. Major Ryves's proposals included an earth dam 162 feet high, with an escape crest 142 feet above the river bed, and the water was to be diverted into the Vaigai Valley by a cutting having a maximum depth through the watershed of 52 feet. Other examinations were made, and finally a project was submitted by Mr. Smith in 1872, which included a dam 171 feet in height, to be constructed by the silting process and having an escape of 400 feet in length blasted out of the saddle at the right bank.

The final project, and that which has been adopted, was the out-



PERIYAR DAM DURING CONSTRUCTION.

come of further examinations made by Mr. Smith and Major Pennycuick, though to the latter are due most of the later details, and under him is being conducted the construction of the works. It was in this report that Major Pennycuick submitted the first proposals for the substitution of a masonry dam for one of earth. These final proposals were submitted in 1882, and included the construction of a dam (fig. 52), located at the same point as that chosen by Mr. Smith, 7 miles below Major Ryves's site, the height to be 155 feet above the bed of the river, and the summit surmounted by a parapet 5 feet high and 4 thick. The dam proper is 12 feet thick at the top and 114¾ feet at the lowest part. It is constructed throughout of concrete composed of 25 parts of hydraulic lime, 30 of sand, and 100 of broken stone. The front face is covered with a plaster composed of equal parts of lime

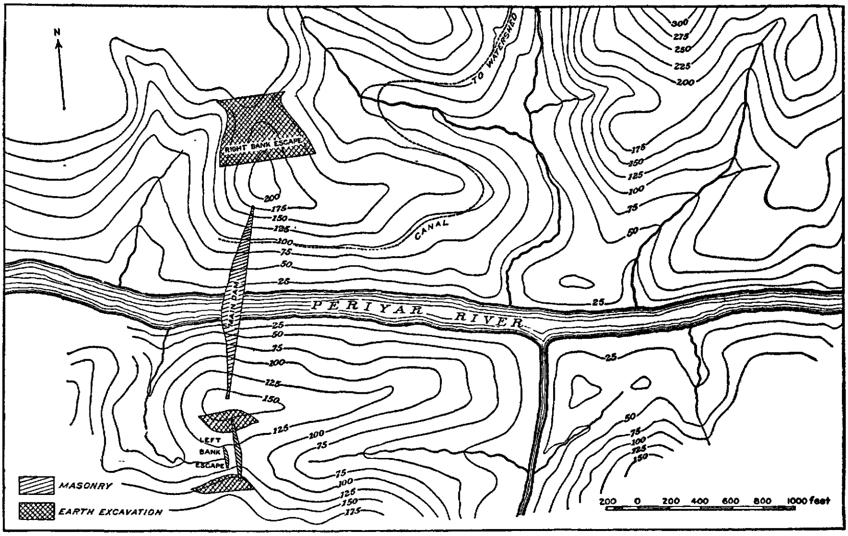


FIG. 53.—Periyar head-works, plan of dam and escape.

and sand. A temporary dam 30 feet in maximum height was constructed above the main dam and a similar dam 10 feet high below the main site, in order to enable the latter to be completely cleared and the foundation trenches blasted out before the main dam was begun.

For the formation of wasteways two saddles are utilized, one on each bank (fig. 53). The one on the right bank has solid rock at a minimum level of 154 feet above the river bed, and will be cut down for a length of 420 feet to a level of 144 feet. On the left bank the solid rock is at a level of 104 feet, and the saddle will be built across with similar material to that of the main dam to the same level, 144 feet. The wall thus formed has a length on its crest of 403 feet and a further length of 97 feet in excavation, making 500 feet in all. The aggregate length of the two wasteways is thus 920 feet. At a distance of 60 feet from the escape wall on the left bank is built a subsidiary weir 10 feet in height, with its crest 30 feet below the upper wall, thus forming a water cushion. In the side of the valley tributary of the Periyar, just above the dam, a cutting was started at a height of 113 feet above the river bed running down toward the watershed, 21 feet wide at bottom, with a fall of 1 in 440. The depth of the cutting in rock is 50 feet at a distance of 5,400 feet from the starting point, where it is replaced by a tunnel with an area of 80 square feet and a fall of 1 in 75. At its lower end the tunnel will communicate with the bed of a small stream by a cutting similar to that at the south end, 160 feet in length, the total length of the tunnel being 6,650 feet.

The rock in the river bed and on the watershed ridge is a hard syenite free from fissures and suitable both for a foundation for the dam and for material for its construction. Most modern dams of any magnitude have been built of uncoursed rubble masonry. Major Pennycuick argues that "concrete is nothing more than uncoursed rubble masonry reduced to its simplest form." As regards resistance to crushing or to percolation the value of the two materials is identical; he further says, "unless it be considered as a point in favor of concrete that it must be solid, while rubble may, if the supervision be defective, contain void spaces not filled with mortar. The selection depends entirely upon their relative cost, the quantities of materials in both being practically identical." At the site of the Periyar works skilled labor is abnormally expensive and difficult to procure, while the facilities for the use of labor-saving machinery which can be largely used in the manufacture of concrete are unusually great. Accordingly, after full discussion, it was decided to adopt concrete as the material for the construction of the dam. Excellent sand is procurable from the bed of the river in numerous places above the dam.

The section of the escape dam (fig. 52) on the left bank is designed so that the lines of pressure shall be within the middle third when a depth of 12 feet of water is passing over its crest, and so that the water shall have a clear fall to the surface of the water cushion below. As before stated, at a distance of 60 feet from the upper escape dam is constructed another dam 10 feet in height, with its crest 30 feet below that of the former. The depth of water passing over this dam will be about one and one-half that passing over the upper one, so that the fall from surface to surface will vary from 24 to 30 feet, and the depth of water cushion from 10 to 28 feet. The length of the right bank wasteway is fixed by the quantity of stone required for the dam. This quantity is 3,600,000 cubic feet, of which 1,400,000 are brought from the watershed cuttings, the cost of conveyance being less than that of quarrying at the dam site. The balance after the material has been supplied from other convenient sources is 1,600,000 cubic feet, to be obtained from the right bank waste way. It is contemplated that a great flood will raise the water to a level of 153.1 feet, while it would take several times this discharge to raise it to 155 feet. The maximum flood recorded occurred in 1869, and amounted to 65,500 second-feet; being 131,200 acre-feet in twenty-four hours, and 7,100 acre-feet in an hour.

From the mouth of the watershed tunnel the water of the Periyar passes by minor tributaries into the Sooroolly River (Pl. XXII), and is controlled by numerous regulating works along the course of the various tributaries of the Vaigai. These works consist chiefly of sluices of simple form, their object being to pass the Periyar water around the different weirs which have been constructed by the natives or Government in past times for the utilization of the water of the local drainage basin. None of these old works are provided with head-sluices. Accordingly, the regulating sluiceways which are planned in connection with the Periyar project are designed to discharge the maximum amount of water which that project will furnish when the surface level of the stream above each weir is flush with the bed of the existing channel.

In 1898 a Stoney patent free-roller gate was erected at the tunnel head to replace the equilibrium shutters which were found unworkable. It works in a cast-iron frame built in a masonry sluice chamber 15½ by 15 feet in plan, the sill being 49½ feet below the top of the platform and 37 feet 3 inches below the full lake level. The gate is 12 feet 9 inches high and 9 feet 6 inches wide and is supported on 20 pairs of cast-iron rollers. It is of ¾-inch steel plate, suitably braced, is worked by a screw-lifting gear and winch and is balanced by a counterweight to two-thirds its weight.

From the mouth of the tunnel to the junction of the Sooroolly with the Vaigai is about 46 miles, and for a further distance of 40 miles the water is conveyed by the latter river, no works being required in connection with it until it reaches the Peranny, at which point the distributive works begin. The Peranny weir is a substantial structure already existing and requiring but little improvement, the only alterations made being the closing of the undersluices, the leveling of the crest 5 feet above the floor of the latter, and some slight additions to the wing walls, apron, etc. Two main distributive canals have been planned, passing close under the foothills surrounding the plains about Madura. These and their branches all terminate in natural drainage channels. The quantity of water designed to be carried by the southern main canal is 1,500 second-feet at its head, where the depth is 6 feet, and it is designed to irrigate 75,000 acres of land. The existing or northern main canal is to have a head-sluice of 20 vents, all of 5½ feet span. The steepness of the Vaigai Valley necessitates the construction of numerous drops or falls in both the main and branch channels. For the passage of cross drainage there are in all 26 inlets and 32 level escape outlets on the main canal, besides 2 aqueducts and 6 culverts, 3 inverted siphons, and other works. The head and regulating works for the main canal and a secondary channel called the

Vedacunay channel, are only 1,460 feet apart. It is necessary, however, that both works be built, for the ground between the two is unfavorable for an open channel. There 36 miles of main canals and 164 miles of distributaries.

The water supply is derived from the Periyar, the drainage area of which is 300 square miles, and is undoubtedly sufficient. The estimated rainfall in the Periyar Valley varies between 65 and 200 inches

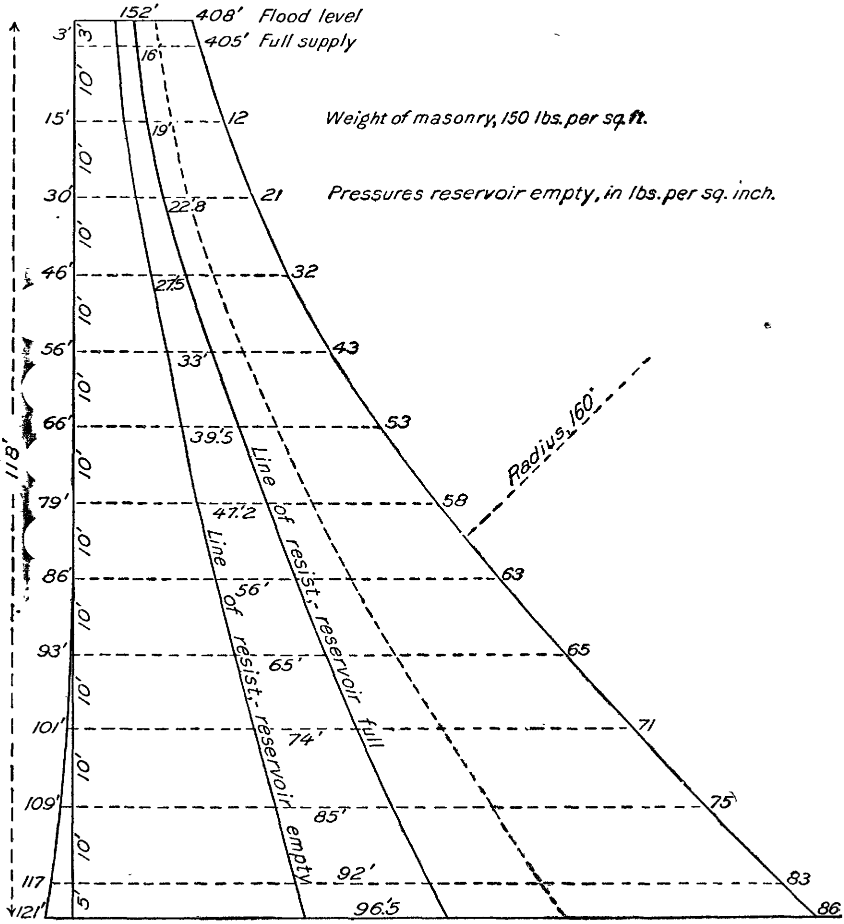


FIG. 54.—Tansa dam, Bombay.

per annum and averages 125 inches, while the depth of run-off from the catchment basin is 49 inches. The estimated discharge of the river available for storage is 760,000 acre-feet, while the loss by evaporation in Periyar Lake and in the beds of the Sooroolly and Vaigai rivers is 70,000 acre-feet, leaving a balance available for irrigation of 680,000 acre-feet. The amount of water required for the irrigation of the lands in the Vaigai Valley is 600,000 acre-feet. It is estimated that

A. FOUNDATION, TANSA DAM.

B. CARRYING STONES TO BUILD TANSA DAM.

not over 7,500 acre-feet will be required to fill the beds of the rivers down which the waters of the Periyar will be passed.

While the maximum storage capacity of the Periyar reservoir is estimated at 300,000 acre-feet, the total available storage capacity above the sills of the discharge sluices is but 150,000 acre-feet. It was estimated that the total cost of this work, including the latest additions to the project and interest charges, would amount to $2,894,000, and this sum has been expended. The works were completed within six years from the time when they were commenced, and the irrigation was expected to be fully developed within ten years after their completion. The gross revenues are estimated to be $350,000 and the working expenses and collection charges $62,000. In 1898–99 the gross revenue was $157,000, the working expenses $49,000, and the net revenue $108,000.

TANSA RESERVOIR.

This reservoir is designed not for irrigation, but for supplying water to the city of Bombay for domestic uses. It is, however, constructed upon the general principles involved in water storage for purposes of

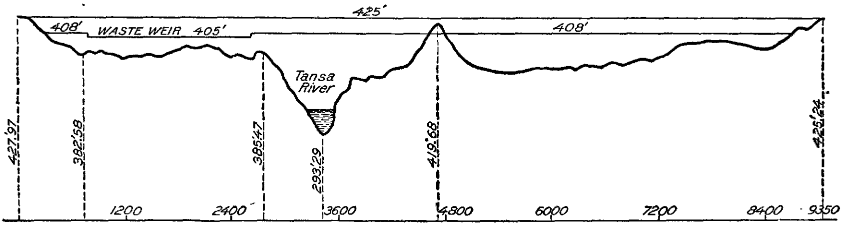


FIG. 55.—Tansa project, longitudinal section of dam.

irrigation, and the dam which forms it is of such great size and excellent workmanship and design that a description of it here will at least be instructive. The project for the construction of the great reservoir on the Tansa River for the storage of water for the supply of the city of Bombay was first brought prominently forward by Maj. Hector Tullock about 1870. The plans of the reservoir and dam as at present constructed were worked out and the construction undertaken by Mr. W. Clerke, chief engineer of the water supply of Bombay.

The Tansa River heads near the summit of the Western Ghauts, where the rainfall is great, ranging from 150 to 200 inches per annum. The area of the catchment basin above the dam site is but 52½ square miles, but the slopes are so steep and the precipitation so great in amount that the discharge is estimated to be about 8,000,000 cubic feet per day. The area of the reservoir is 5.5 square miles, at full supply level 405 feet elevation, and the maximum available depth of water above the sills of the discharge sluices is 20 feet. Its net available capacity is 59,000 acre-feet, less 18,000 acre-feet, which is equivalent to a loss of 6 feet in depth by evaporation and absorption, leaving 41,000 acre-feet. The gross storage capacity of this reservoir is far greater than the figures given above, and much more water could be utilized if it were needed for purposes of irrigation by taking off the discharge sluices at a lower elevation.

The dam (figs. 54 and 55) is constructed of the best uncoursed rubble masonry, laid in hydraulic mortar, which is made near the dam site. The total length of its crest is now 8,800 feet, but may finally be 9,350 feet, of which 1,650 feet are utilized as a wasteway at the south end of the dam. It is constructed in two tangents in such a manner as to get the shortest line on a bed-rock foundation. These tangents meet near the center of the dam in a sharp rocky hillock, which projects a little above its crest. The top of the wasteway is 3 feet below the maximum flood height of the dam, and the volume of flood which will have to be wasted is estimated to be 25,000 second-feet.

The total cost of this work was about as follows:

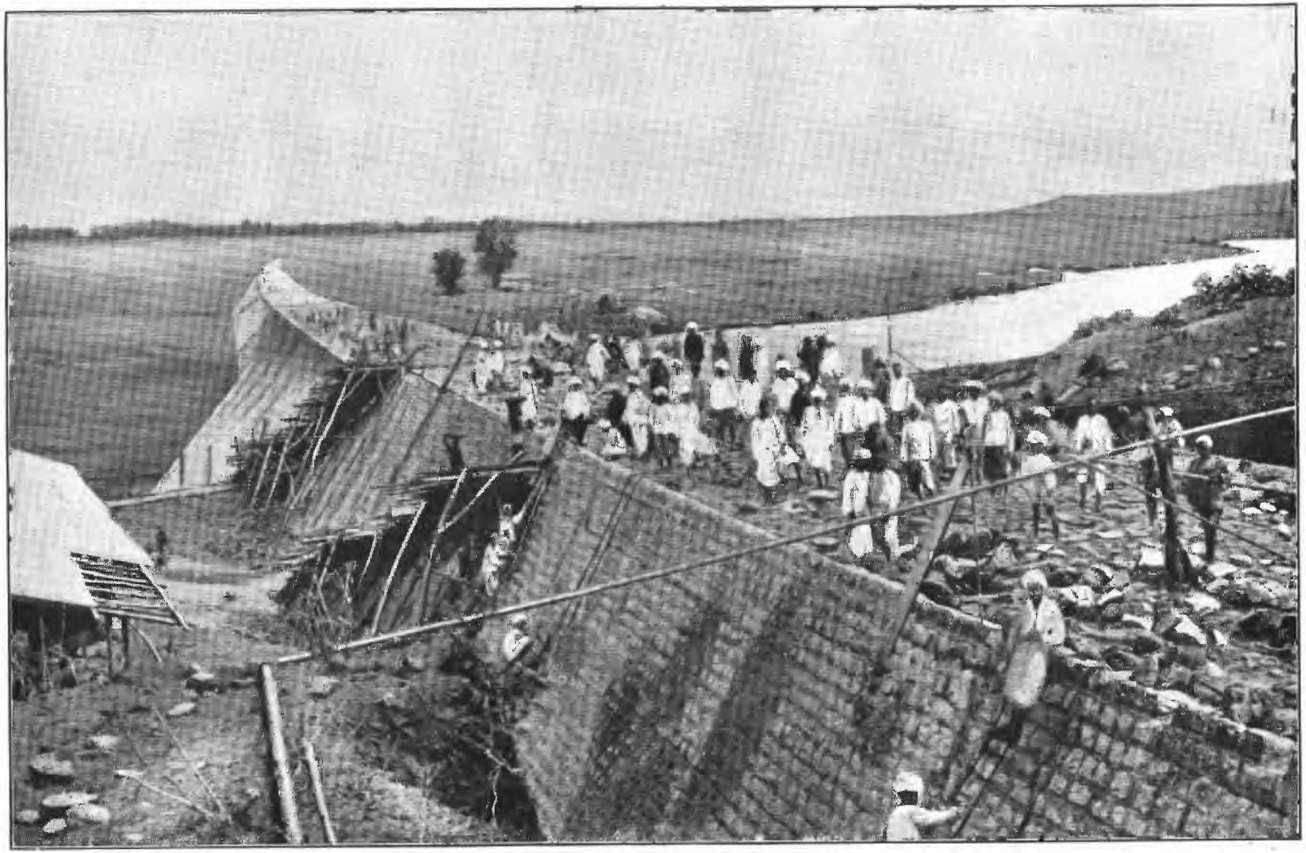
Cost of Tansa reservoir.

Compensation for land, etc	$40,000
Excavations for foundations, 4,000,000 cubic feet, at 30 cents per cubic yard	44,000
Rubble for masonry for the dam, 10,000,000 cubic feet, at $3 per cubic yard	904,000
Total	988,000

MASONRY DAMS.

It may be generally said that all of the masonry dams constructed by Indian engineers in recent times have been designed according to the most approved modern formulas and the material of which they have been constructed has been almost uniformly uncoursed rubble masonry. The Tansa dam (Pl. XXV) is the most logical instance of the use of uncoursed rubble masonry throughout without any coursed work either in the facing or coping, thus giving an almost homogeneous wall. Mr. W. Clerke, chief engineer of this work, holds that the strains due to shrinkage and settlement in a dam thus constructed are uniform throughout its mass and have little or no effect to rupture it. Whereas in other dams, such as those at Betwa and Bhatgur, where a deep layer of coursed stones has been laid outside of the central core of uncoursed rubble or concrete, the homogeneity of the whole may be destroyed, owing to unequal shrinkage or settling, thus diminishing the effective cross section of the dam by the amount of the coursed facing.

The Periyar dam is the most logical example of a dam constructed throughout of concrete without any facing or other material to destroy the homogeneous character of the material of which it is constructed. The great dam at Bhatgur is an example of a com-



NATIVES BUILDING TANSA DAM, BOMBAY.

bined structure; all of the upper portion of this dam above the lines where the limit of pressure exceeds 60 pounds per square inch is constructed of concrete faced with coursed rubble masonry. Below the point where the limit of pressure of 60 pounds per square inch is reached, the material used throughout is uncoursed rubble masonry, faced, however, as is the upper portion, with coursed stones. In building up this structure the coursed facing and the interior hearting of concrete were run up simultaneously in layers, and the various thicknesses of concrete were bound together by the insertion in them of great irregular stone blocks which projected above each layer of concrete as laid. The upper 10 feet of this structure above the high-water line is composed entirely of a filling of spoil from the foundations and this is inclosed between the coursed facing.

The same general mode of construction, a combination of concrete and rubble, was used in the great diversion weir at Vir. The great weir dam at Betwa is constructed of uncoursed rubble masonry coursed on both faces; in addition to this the coping is of the best ashlar. The coursed facing is laid with headers not less than 2 feet long and stretchers, two of which equal in height that of the headers. The material used in the rubblework is a kind of igneous granite, very hard and excellent for the purpose. The ashlar work, however, consists of hard sandstone. In a few cases brick has been used for the construction of low weirs. A notable instance of this is the great diversion weir at Narora, at the head of the Lower Ganges canal, which is constructed almost throughout of brick. This material has proved entirely satisfactory, as the Narora weir is not very high and has to withstand but moderate pressures. The material used in the construction of the Tansa and Bhatgur reservoirs is a heavy trap or greenstone.

The cement used almost universally in the construction of works in India is of local manufacture, being made from dirty nodules of limestone which are found in the clay soil distributed very generally throughout the country. These limestone nodules are called kunkar, and when burned in a kiln produce an excellent hydraulic lime nearly equaling the best cement in hydraulic properties and resistance to pressure. Ordinarily these limestone nodules are comparatively small. The best hydraulic cement made from these is that produced near Vir, at the head of the Nira canal. The nodules used for this are scarcely ever bigger than a man's fist. In other places they are much larger, notably in the Ganges Valley, where the material used in the construction of the Lower Ganges head-works was found in lumps and blocks weighing some hundred of pounds each. For the manufacture of hydraulic cement the limestone nodules are burned in a common kiln with coke, charcoal, and cinders to hydraulic consistency. This hydraulic lime is then slaked and crushed, usually by means of the "churus," big stone wheels drawn by oxen, though occasionally in modern mortar mixers, and is then mixed with the proper proportion of sand, either in the native mortar machine or more usually now in an iron mortar mixer.

The stones used in the construction of uncoursed rubble masonry are rarely larger than can be carried conveniently by two men, as almost all labor is manual, and rarely is carrying machinery used. The method of quarrying the stone and of transporting it by means of tramways is similar to that employed in America and Europe. The following are a few extracts from notes made by Mr. A. Hill, superintending engineer on the Bhatgur dam, on the masonry construction of that work:

In the facing the masonry is laid in courses, each of which does not exceed 9 inches in depth, as large stones are too troublesome to handle. The stones are wetted and the mortar and stones are well rammed. The stones for the rubble are as large as can be conveniently handled by two men, while the smaller stones are broken up for metal to be used in making concrete. In uncoursed rubble the stones touch along their whole sides, not at points or edges merely, and small chips are used to fill in spaces between the larger stones. All awkward projections are knocked off and the stones are well rammed into the bed of mortar in which they are laid, and which must be at least 1 inch in thickness. The average weight of these stones is perhaps 100 pounds.

The concrete is made of broken metal and river gravel, the former 3½-inch gage, the latter one-eighth to 3 inches; the proportions used are, metal, 16 parts, gravel 16, mortar 12. The concrete is laid in two layers, each 4½ inches in thickness, and rammed for twenty minutes and one hour, respectively, and is kept constantly wetted for at least two weeks, that it may set properly. The concrete is mixed both by hand and machine, the hand mixing being done on a floor with a hoe; the machine mixing in iron barrels or mixers. The stone and gravel are wetted before being mixed. Briquets of concrete used on this work, 15 by 10 by 10 inches in dimensions, after six months' setting ruptured under a crushing weight of from 400 to 800 pounds per square inch.

In making mortar only sharp, clear, river sand is used. The lime, after being burned to hydraulic consistency, is slaked for five hours, stirred and ground for three hours more, and then clean wet sand is added in the proportion of 1 to 1 and stirred again for two more hours. For testing, this is made into 2-inch cubes or briquets, which are kept damp and are allowed to set for forty-eight hours, after which they are placed in water until tested.

The folowing are average tests of mortar made in this way at Bhatgur:

Average tests of mortar at Bhatgur.

	Pounds.
Age 12 months, crushing weight per square inch	815
Age 9 months, crushing weight per square inch	600
Age 6 months, crushing weight per square inch	500
Age 3 months, crushing weight per square inch	300
Age 1 to 3 months, crushing weight per square inch	250

Some briquettes stood as high a crushing weight as 1,100 pounds per square inch when one year old. The hydraulic mortar used at Vir gives even better results. Several briquettes of mortar made there and mixed in proportion of 1 to 1 and from eight months to one year old required a crushing weight of 1,500 pounds per square inch to rupture them. Vir mortar mixed with 2 of sand to 1 of hydraulic lime breaks at 800 pounds pressure per square inch. The mortar used in the construction of the Tansa dam showed an average crushing strength of 800 pounds per square inch, though numerous specimens stood a test of from 1,500 to 1,800 pounds per square inch.

At the head of the Ganges canal in the Northwest Provinces, the concrete blocks used for groins in retaining works and for dams are of a peculiar composition, as hydraulic lime is scarce. They are composed of 1 part quicklime to 3 parts of broken stone (about 1-inch gage) and 2 parts of brick dust. These blocks are not very strong nor hydraulic. At this place the blocks which are used under the water and subjected to the greatest pressure are composed of hydraulic lime, 2 parts; sand, 1 part; broken stone, 3 parts. The Periyar dam, which, as before stated, is constructed throughout of concrete, is designed to withstand a limit of pressure of 9 tons per square foot. The quantities of material have been estimated on the supposition that every cubic foot of concrete will require 60 cubic feet of solid stone, plus 10 per cent for wastage, to 25 cubic feet of unslaked hydraulic lime.

DESIGN OF DAMS AND WEIRS.

As stated in speaking of reservoirs and storage works, the Indian engineer designs the cross section of the dam on some theoretic profile which will be most stable and economical. All of these are similar to the profile which has recently been discussed and described by Mr. Edward Wegmann in his treatise on the "Design and construction of masonry dams." Modified formulas, based on Rankine, Delocre, Krantz, or Bouvier, are generally used. Little value has been given to methods sometimes adopted of constructing the dam on a plan curved horizontally. None of the high dams seen in India were sufficiently short to have been curved in this manner. A formula for the design of cross sections which is generally employed by Indian engineers is that which was worked out by Mr. Guilford L. Molesworth in 1883, and is as follows:[a]

$$Y=\sqrt{\frac{.05\,x^3}{\lambda+(.03x)}}\,;\quad Z=\left(\frac{.09\,x}{\lambda}\right)^4$$

A vertical line being drawn from the top front edge of the dam to the base, Y is the width from this line to the rear face and Z the corresponding width from the line to the front face at any distance from the surface of the water or from the top of the dam. Y is further equal to $0.6x$ as a minimum; λ is the limit of pressure of the masonry in tons per square foot; H=top height of dam; a=Y at $\frac{H}{4}$ from the top; B=top width=$\frac{a}{2}$.

[a] Roorkee Professional Papers, Roorkee, India, 1883.

The accompanying diagram (fig. 56) shows how this formula is applied. It is intended to secure the requisite stability at the front face when the reservoir is empty and at the rear face when it is full. This formula of Mr. Molesworth's, which has created considerable discussion among Indian engineers, is considered an excellent empirical formula for general use. Major Pennycuick, who designed the Periyar

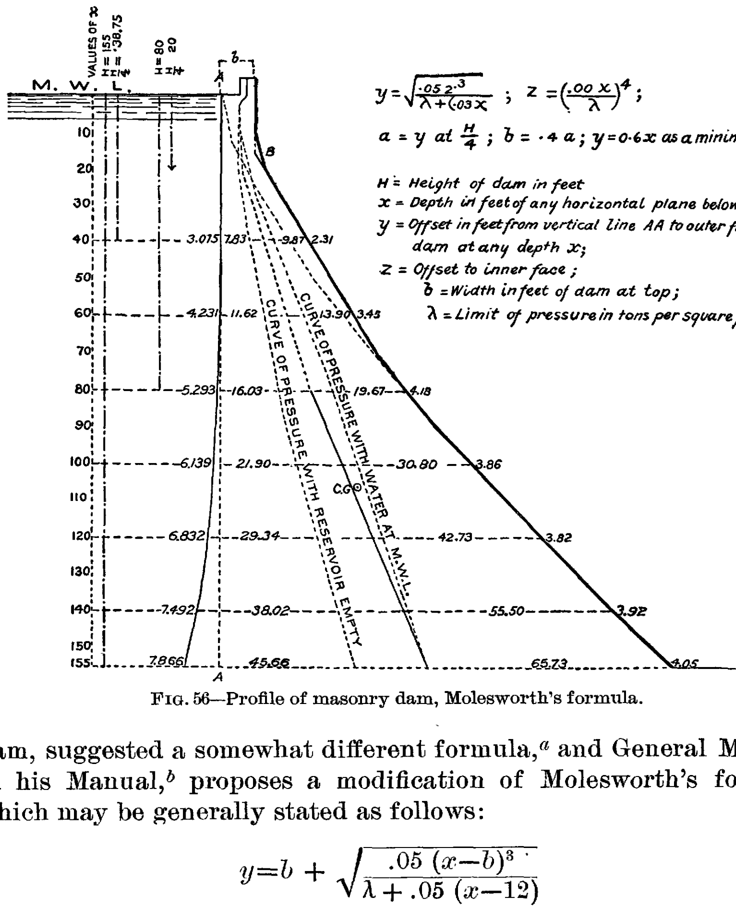


FIG. 56—Profile of masonry dam, Molesworth's formula.

dam, suggested a somewhat different formula,[a] and General Mullins, in his Manual,[b] proposes a modification of Molesworth's formula, which may be generally stated as follows:

$$y=b+\sqrt{\frac{.05\,(x-b)^3}{\lambda+.05\,(x-12)}}$$

with $b=12$, or for smaller top widths.

$$y=b+(12-b)+\sqrt{\frac{.05\,(x-12)^3}{\lambda+.05\,(x-12)}}$$

and adjusting the part above $x=12$ to the top width selected.

For weirs with water cushions the depth of the latter is sometimes determined from the formula $D=c\sqrt{h^3}\sqrt{d}$ in which D represents the depth of the cushion below the top of the retaining wall; c is a coeffi-

[a] Periyar project. Records of the Government of India, No. CCXV, Calcutta, 1886.

[b] Mullins, Lieut. Gen. J., Irrigation Manual, E. & F. N. Spon, London and New York, 1890.

cient, the value of which is dependent upon the description of the material used for the floor of the cushion, and varies between 0.75 for compact stone and 1.25 for moderately hard brick; h is the height of the fall, and d is the maximum depth of the water to pass over the weir crest. The width of the floor of the cushion will depend somewhat on the section of the weir, which need not exceed $8\sqrt{d}$, and should not be less than $6\sqrt{d}$. For works with a vertical drop and a horizontal apron on the same level as the retaining wall, this masonry apron should be formed of fairly regular blocks of stone or of Portland cement concrete, the width varying as just given, and the thickness or depth of stone from one-fifth to one-fourth of $h+d$.

It is difficult to find any set rule for determining the depth of the water cushion by the height of the fall and the volume of water. At the Gairsoppa Falls, in the Western Ghauts, the Rajah Fall has a clear drop of 825 feet in height, and the pool into which it falls is 138 feet deep at low-water stage. The greatest depth of the hole formed by the waterfall in the new outlet of the Mudduk Masur tank is 24 feet. In ordinary states of the river the general depth of the water cushion is to the height of the fall as to 3 to 4 where the greatest action takes place and 1 to 2 in other places. An experimental fall on the Bari Doab canal had a height of 6.9 feet and depth of well of 9 feet, and 3.6 feet on crest, which gives the depth of the well to the height of the fall as 3 to 4. The water had no injurious effect on the bottom of the well. The subject of water cushions is one which is not very well understood, though these are very extensively used in India. They appear to be a most effective and interesting addition to nearly every weir where they are placed, greatly increasing its stability and firmness.

COST OF LABOR AND MATERIAL.

It has generally been held that owing to the great relative cheapness of labor in India, compared with that employed in the United States, few lessons, especially of a financial character, could be drawn from a consideration of the results of Indian irrigation works. The reports on the returns derived from Indian works, the percentage of profit gained or loss incurred, are not of the most encouraging character. A thorough examination of this matter, both in the field and in the reports, has, however, allayed any doubts which I had on this subject, and leads me to believe that yet better results may be obtained in the United States, even in comparatively uninhabited regions.

As was shown in the earlier part of this report, the returns derived in India from works constructed with borrowed capital on such works as the perennial canals of the Northwest Provinces show profits varying from 4 to 20 per cent per annum. It was also shown, however, and this is the least promising phase of the investigation, that in scarcely any case had storage works been profitable. The loss in most cases on this class of works has been trifling, while in several cases a profit has been gained. Moreover, the older works of this class are rapidly becoming more popular. The value of irrigation is becoming better appreciated, even where a constant rainfall occurs, and such works are annually increasing in value.

It was soon seen that any attempt to ascertain the relative value, both cost and return, of works constructed in India by comparison of the rates of labor paid in that country and in America, was altogether futile. Notwithstanding the remarkable cheapness of all classes of native labor, the relations of the laborer to the government, the character of the laborer, and the exhausting heat of the climate, all tend to make his day of labor a relatively short one, both in time and in work done. Few or no mechanical appliances are yet used in the construction of Indian works. It is claimed by some that the seeming cheapness of the labor seduces the engineer. This in most cases is not true. The average engineer appreciates the value of labor-saving machines, but has contended so long with the carelessness of the native laborer and his lack of interest in learning new ways that he has finally given up the struggle of trying to teach him to use modern appliances, feeling convinced that the native cooly achieves as good results in his own way as he could with better apparatus which he would misuse or fail entirely to avail himself of.

The long time required in the excavation of works, in filling, carrying, and emptying a little basket which holds perhaps a shovelful of dirt, tends decidedly to make the native labor expensive. The slow mode employed of carrying comparatively small stones for the construction of great dams, consisting of tying ropes around the stones, attaching them to poles, having them lifted onto men's shoulders with the aid of assistants, then making a slow, plodding journey from the stone pile to the top of the dam, all tend to increase the expense of the labor employed (see Pl. XXIV, *B*). In the construction of such works in the United States, machinery would dig the canals in great part, and a vigorous, skilled workman, using with intelligence labor-saving appliances, would in a day accomplish many times the amount of work that is done by the Indian cooly. In every individual operation is seen the slowness of native methods. If it be grinding mortar, oxen walk in a circle drawing a large stone wheel attached to a wooden beam, which laboriously and slowly grinds the mortar as the old Mexican arrastre grinds the quartz. Occasionally a modern mortar mill is seen operating beside the native churus and doing in a few minutes the work which the latter take hours to accomplish. In the blacksmith shop half a dozen men are needed to perform the work of one. The forge is blown by a boy, who pumps air through a couple of leather bags beneath his arms, taking much more time to create the same degree of heat than a modern blacksmith's bellows would require.

The works constructed in India are invariably of the most substantial masonry and will last for centuries. Along the roads and railways the smallest bridges and culverts are constructed of stone and brick. On the canals the least important regulator, aqueduct, or bridge is likewise constructed of the best masonry for all time. In our construction of such works, iron and timber would be extensively used for bridges and aqueducts, or, as we call them, flumes, and for many parts of the head-works and works along the canal lines, thus greatly reducing the cost.

Another great expense incurred on Indian works has been the effort to combine navigation with irrigation. This effort has been comparatively unsuccessful if viewed from the light of the modern requirements of a country possessing good railways and wagon roads. As before stated, in order to make the canals navigable their expense is greatly increased by the construction of locks throughout the whole length and of parallel canal channels; of bridges of greater headway, in order to admit boats to pass under them; and of expensive aqueducts or similar works, instead of the cheaper contrivances which might be used if navigation were not practiced. Above all, navigation entails great loss of water.

In the neighborhood of Poona labor is perhaps as cheap as anywhere in India. It is performed by all classes, ages, and sexes, the more skilled laborers, as masons, carpenters, and blacksmiths, usually being grown men. Most of the burdens, as gravel, sand, mortar, and materials which have been excavated, are carried away on the heads of women and children. Common labor is paid about 8 cents per day. Masons and carpenters get from 16 to 20 cents a day, while a laborer with a team of bullocks gets 25 cents a day. On the Bhatgur dam donkeys and bullocks were frequently used as pack animals for carrying stones and earth. A donkey will carry a cubic foot of stone per trip and earns 6 cents a day. Common laborers were paid 8 cents, women and children 4 cents, and skilled laborers 20 cents per day. It was estimated that 8 skilled masons could lay and dress 3 cubic yards of masonry per day on this work. Owing to the slow mode in which the work was conducted it was necessary to employ a great number of laborers at one time, so many in fact, that a large portion of them were frequently idle through interference with one another. About 2,000 men, women, and children were engaged on small portions of the dam at once and the daily rate of progress was about 5,000 cubic feet of rubble and concrete work and 1,000 cubic feet of course masonry facing.

At Tansa the work was done by contract, and the prices paid were a little higher than elsewhere. Rubble masonry cost $3 per cubic yard. On Lake Fife and Bhatgur the same class of good uncoursed rubble masonry cost but $2 per cubic yard. On the Tansa dam over 5,000 people were at work at one time. On the Betwa canal earth excavation in deep cuts, not exceeding 40 feet in depth, cost but $6\frac{2}{3}$ cents per cubic yard; surface excavation in earth with short haul cost 3 cents per cubic yard; uncoursed rubble masonry cost $2.30 per cubic yard; coursed rubble masonry, $6.25 per cubic yard, and dressed ashlar work $22.50 per cubic yard. On the Periyar works the ordinary price of unskilled labor was 12 cents per day; for special work, such as feeding machinery, etc., the coolies were paid 20 cents per day; while head coolies, artisans, etc., were paid from 30 to 60 cents per day.

All kinds of material other than those found in the country itself are most expensive in India. Coal is usually brought from England at a cost never below $20 per ton. Iron, steel, and machinery are relatively very expensive, as is Portland cement and wood of every kind. In fact, masonry work is generally cheaper than wood, and iron is always dearer than masonry. The great cheapness of masonry is owing to two causes—cheapness of labor, and cheapness of the hydraulic lime which is manufactured in the country almost invariably near the site of the work which is being constructed. On the Periyar work drilling cost $10 per hundred running feet of drill hole, and the labor of quarrying, including plant, boring, dynamite, and all other expenses, amounted to about 85 cents per cubic yard, or as much as it would in the Western States of America. On the same work in tunneling, the heading cost $6.50 per cubic yard, and for enlarging the tunnel $2.60 per cubic yard was paid; lime cost $1.30 per cubic yard, sand 40 cents per cubic yard, and concrete cost $1.70 per cubic yard laid in place. Of minor items, the removal of earth or cutting cost $6\frac{1}{2}$ cents per cubic yard, steel 15 cents per pound, and wrought iron 8 cents per pound. On the Sidhnai Canal, in the Punjab, concrete cost $1.80 per cubic yard, rubble masonry $2.16 per cubic yard, and brick 95 cents per hundred laid in lime mortar. Earth excavation cost $4\frac{1}{2}$ cents per cubic yard, and the best hydraulic lime cost $2.50 per cubic yard to manufacture.

TANKS.

Tanks were constructed in great numbers by the natives of India many centuries ago, and in some places, notably in central and southern India, in the Deccan, Madras, and Mysore, there are immense numbers of them. These old tanks were usually rude in construction, little care having been taken to economize in labor, and as a consequence the dams constructed were usually made much heavier in cross section than was necessary. In recent years the British engineers have constructed several very large tanks, though many of the higher dams have masonry cores. The conditions controlling the location of a tank are similar to those before described for reservoirs. The water supply must be adequate to fill the tank, the location must be such that a suitable dam can be constructed at a reasonable cost, and an ample wasteway must be provided. In the location of the wasteway for a tank, even more care must be exercised than is necessary for a reservoir; for if the water be permitted to rise too high on the dam—or much worse, if it is allowed to discharge over it—it will speedily cause its destruction if it is built of earth.

It is desirable always to allow waste water to flow off by a side channel, which may be closed by a low rock or crib-work weir, or may consist only of an open rock cut. By such means there is no danger to the dam of having the shock of water falling over it. It may, however, be necessary to have a masonry wasteway constructed in the dam itself, but this is not advisable and is generally avoided. Such a wasteway is usually made by constructing a portion of the dam of masonry, the top of which is a few feet lower than the rest of the dam. When the catchment of the tank is small it is possible to provide for wasting flood waters through an outlet or discharge channel in the dam itself. Such a discharge sluice is necessary in order to draw off the water for irrigation, and must be of sufficient capacity to empty the tank in the shortest irrigating season. The level of the sill of this outlet sluice is generally that of the bed of the tank, but there are occasionally constructed one or more higher outlets to irrigate lands which lie above that level. These sluices are expensive works, and require a well-constructed masonry or iron conduit to be carried through the dam, emptying into the canal at one end and receiving its water supply at the other end through a well or water tower from which its admission can be controlled. It is usual to make the outlet tunnel of good masonry, and it must not be smaller than 2½ feet high by 2 feet wide, in order to permit a man to go through it to examine, clean, or repair it, if required.

One cause of the frequent breaching of Indian tanks is that great numbers are often constructed in one valley, the bed of one beginning where the cultivation of that of the next above it ends, so that the breaching of one often results in the destruction of a succession of those below it. Regarding the depth of tanks, if they be shallow a great loss of the stored water is sustained through evaporation. Shallow tanks are never intended to hold more than water enough for one crop. In India aquatic plants which grow from the bottom in shallow tanks are injurious, while those which spread on the surface, like the lotus, diminish the loss by evaporation. When water is not deeper than 7 or 8 feet the rays of the sun can penetrate to the soil, and growth of aquatic plants is the consequence. In the smaller tanks, intended to cultivate limited areas of land immediately below them, the most economical height for the dam on gently undulating ground where there is a natural and long slope to the rear has been found to be from 10 to 25 feet.

In the construction of modern tanks the same precautions are usually taken and the same detailed investigations made as for a reservoir project. The catchment basin, the discharge of the streams, the rainfall, and other physical phenomena are carefully studied; the lands to be irrigated are examined and their relative position to the location of the tank and catchment basin is surveyed and mapped. Careful surveys are made for the reservoir site to determine its capacity, and of the dam site in order to choose the best and most economical location and to ascertain the cost of the works.

The interior and exterior slopes of earth dams are usually considered as planes, forming together an angle of not less than 90°, and the figure should be so formed in order to increase its stability, that lines of pressure passing from the interior faces at right angles may fall within its base. Upon the calculation that 1 cubic foot of rammed earth weighs 99 pounds and 1 cubic foot of water $62\frac{1}{2}$ pounds, and supposing that the earth would stand at any slope, we find that the base of the prism resisting the lateral thrust of the body of water does not require to be more than two-thirds the depth of the column it supports, so that all quantities above that are due to the natural slopes, the stability of the dam, and the prevention of percolation. Consequently, when large works are projected it is a subject of close calculation which is the more economical, those exclusively of earth or those whose inner slopes have retaining walls of masonry.[a]

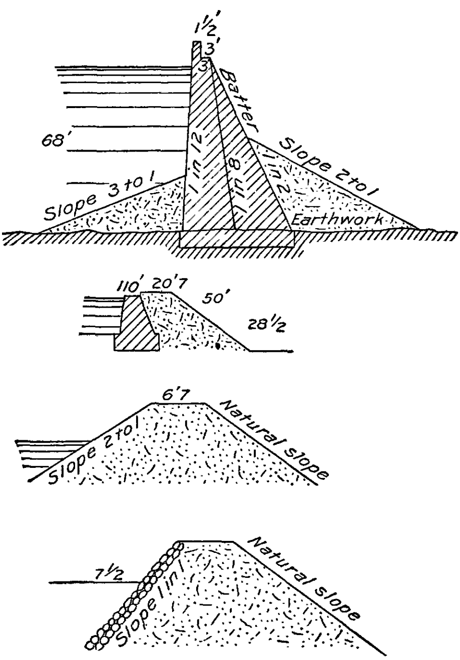


FIG. 57.—Cross sections of earth and combined dams.

As constructed in India, the width of the top of the dam depends not so much on the pressure of water it has to sustain as on the prevention of percolation. The usual width now allowed is from 8 to 12 feet, thus giving room for a roadway. The top of the dam is made sufficiently high above the highest line of flood over the sill of the wasteway to prevent its being topped by waves. On a large spread of water a strong breeze forms waves sometimes 3 feet high, which on a long slope may be raised to 5 feet. The dam must be of such height that water can not pass over it, as the latter would quickly scour away the back slope until the thickness was sufficiently reduced to cause the dam to give way. Additional security against

[a] Victor, H., Notes on irrigation in the Bombay Presidency: Roorkee Professional Papers on Indian Engineering, Roorkee, India.

such an accident is obtained by raising a low masonry parapet on the outer edge of the slope, paving the top, and giving it a slight dip inward to prevent the settlement of water.

The number of disused tanks is remarkable. Many are not breached, but the discharge sluice is left open so that no water is collected. In many cases this is probably owing to the bed of the tank having been gradually raised by silting and thus converted into so productive a soil that it yields as much as or more than could be obtained by means of a diminished quantity of water applied to the comparatively barren soil below. An example of one of these old tanks thus abandoned, but capable of restoration, is the Madag Masur tank, believed to have been constructed about four centuries ago. It was formed by an embankment rising from the sides of a narrow gorge through which the Choardy River passed, and was supplemented by two dams in saddles on a range of hills, that on the east bank 1,350 yards and that on the west 760 yards from the main dam, the length of the latter being 1,650 feet. The inside slope of 1 on 2½, in some parts 1 on 3, was revetted with large stones up to a cubic yard in bulk. This dam is from 945 to 1,100 feet wide at the base and is now from 91 to 108 feet high. There was a sluice under the dam at the east end above the level of the ground. The material of which the dam is constructed is a strong red earth with a considerable mixture of gravel, and was taken from the sides of a hill in the neighborhood. The east supplemental dam has its base 74 feet above the sluice in the main dam, and had also a sluice under it at the ground level. The west supplemental dam, the breaching of which destroyed the tank, was of similar construction to the others, and its base was 60 to 70 feet above the bed of the tank. There was no trace of any wasteweir, and it is probable that the want of this was the cause of the ruin of the tank. From the heights of the dams and the levels of the sluices it is probable that the depth of the tank was 90 to 95 feet, and at that level its area would have been 40 square miles and its contents about 870,000 acre-feet of water.

Another variety of tanks, constructed not on main drainage lines or streams but in depressions in a flat country, are usually closed by a different form of dam. There were many of these, and large numbers are breached or abandoned and their beds now cultivated. The embankments of these flat-country tanks are often of great length, not unusually 1 or 2 miles; that of the Veeranum tank is 12 miles long, and the ruined bank of the Puniary tank in the Trichniopoly district is said to be 30 miles long. The height of these is generally inconsiderable, being in many hundreds of cases only sufficient to hold from 6 to 10 feet of water. A few of these works, however, are 20 or 40 or even 50 feet in depth. The inner slope is generally revetted with stone and has an inclination sometimes of 1 on 1, oftener of 1 on 2 or more. The height of the bank above the water level varies. For instance, the Nundyal tank has a dam at one place 18 feet high, 2 feet above the water level, 16 feet wide on top, with an inside slope of 1 on 1 and an outside slope of 1 on 2. The Kolevoy tank, in the Nellore district, has a bank 36 feet high, extending 9 feet above the water level, a top width of 12 feet, and equal slopes inside and outside of 1 on $1\frac{1}{2}$.

As the accumulating alluvial deposit made year after year gradually raises the beds of tanks, these would become filled up were not some expedient adopted from time to time, such as adding to the height of the dam. This, however, generally involves an enlargement of the cross section as well as the raising of the wasteweirs and the construction of new sluices at higher levels than the one occupied. One expedient frequently resorted to successfully is to have the mud stirred up by hand at the beginning of the rainy season when the flood waters are permitted to carry it off through the discharge sluices. This, however, is only partially effective, like the scouring of the undersluices in a reservoir.

In central India there are many tanks; their history is rather modern and is very interesting. In 1820 the Mairs, a tribe occupying Marwar, Meywar, and Ajmere, were banditti living in the hills, constantly fighting and making raids on the Rajputs and other neighboring tribes. The Mairs lived chiefly by levying blackmail on isolated hamlets and on travelers. Col. H. Hill subjugated them, and by the establishment of a government, police, etc., caused them to live more peaceably and to commence the pursuit of agriculture. In 1835 Colonel Dixon succeeded to the charge of the Mairs and arrived at the conclusion that the lack of water, rendering agriculture impossible in a country whose rainfall was below 20 inches, was the cause of their predatory life. Their history from this time was similar to that of the nomad and bandit tribes which occupied the country now irrigated by the Sirhind Canal in the Punjab. Colonel Dixon commenced by causing the construction of terraced irrigation lands by means of retaining dikes, and of tanks by means of earth or masonry dams.

Having been furnished with an abundant water supply for fertilizing the crops, the Mairs have, owing to this enlightened policy of Colonel Dixon, now become peaceful and industrious cultivators. The small tanks furnish water for irrigation below them and water for wells near them, and when the water is drawn off their beds are cultivated, and, being very fertile and moist from the deposition of sediment, produce excellent crops. These tanks now support a large population and produce considerable revenues.

The following table exhibits the principal dimensions of some of the Mairwara tank embankments and weirs:[a]

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[a] Smith, R. Baird, Italian Irrigation, William Blackwood & Sons, London, 1855, vol. 1, p. 420.

Dimensions of some of the Mairwara embankments and weirs.

Name.	Length of embankment wall or weir.	Breadth—		Depth of foundation.	Height above foundation.	Spread of water.	Area irrigated, including cultivation in bed.	Cost.
		In foundation.	At upper surface.					
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Acres.*	*Acres.*	
Kabra	620	27	10	9	24	182	204	$3,125
Juwaja (escape weir added to ancient embankment)	251½	28	....	6	16	218	364	1,890
Roopana weir	522	10½	3¼	0	18	25	36	1,100
Kalee Kuncur	3,369	42	6	0 to 10	28	182	437	8,275
Gohana	460	25	4¼	10	28	94	250	2,135
Burar weir, upper	240	30	7	8	36	72	109	2,000
Lower	343	12½	6½	10	20	72	29	1,280
Loosanee	575	29	....	20	24	218	273	810
Cheela Bura	954	5	3⅓	6	14	36	83	....
Dewatan	1,333	21	....	19	16	145	328	....

The following table exhibits the results of some of the works detailed above, showing the increase in number of families, of wells, and of village tanks, etc., during eleven years preceding the preparation of Colonel Dixon's report, 1835 to 1846:

Results of Mairwara embankments.

Name of village.	Increase in number of—			Increase in revenue.
	Families.	Wells.	Village tanks.	
Kabra	38 to 133	3 to 46	0 to 31	$235 to $1,030
Juwaja	25 to 122	8 to 28	0 to 15	125 to 895
Kalee Kunkar	0 to 118	0 to 25	0 to 14	0 to 545
Burar	70 to 440	131 to 301	....	1,925 to 4,425

The following table shows the whole number of tank embankments constructed in Mairwara up to the date of the report:

Tank embankments in Mairwara.

Districts.	Number of embankments and weirs.	Spread of water in bed.	Area irrigated, including cultivation in bed.
		Acres.	*Acres.*
Ajmeer Mairwara	158	6,323	10,557
Mewar Mairwara	120	3,077	3,960
Marwar Mairwara	12	275	309
Total	290	9,675	14,826

From the above it will be seen that between the years 1835 to 1846 the increase in the number of wells was from 2,230 to 6,150, or 3,920. The increase in the number of tanks was from nothing to 2,065; the estimated population increased 60,000 (from 40,000 to 100,000), and the revenue increased from $48,000 to $105,000, or $57,000. The estimated sums expended under the sanction of the government in all Mairwara during the same period of years was $125,000, while the aggregate increase in land revenue for the same period amounted to $320,000.

Lieutenant Home, in 1868,[a] reported on six principal tanks in Mairwara the average capacity of which ranged from 920 to 2,400 acre-feet. The total outlay on these to the end of the year 1866 was $40,000. The net income to the end of the same year was $2,000, or a net gain varying between 1 and 12 per cent. The results of Lieutenant Home's inspections showed that not only have Colonel Dixon's works enormously benefited the country, but they have returned the government 150 per cent on the expenditure incurred. The whole of the six tanks especially mentioned paid nearly 10 per cent on the capital invested.

In Mysore in southern India there are 37,000 tanks, of which Sir Robert Temple says:

> Wherever there is a depression in the land an embankment with a wasteweir and a sluice is thrown across it. The water is held up above it, and below it a few acres are sown with rice and sugar cane, and irrigated by means of sluices. A few yards lower down the depression comes another, and so on, increasing in size as they go on until a series of tanks may consist of more than one hundred all connected together, the overflow from the wasteweir of each being the chief feeder of the one below it and the stream that issues from the wasteweir of the bottom one being a river in magnitude. The tanks at the top of the series are mere ponds and those at the bottom are often good-sized lakes, and the area irrigated by these is frequently very large.

In Madras Presidency, including Mysore, there are said to be about 75,000 tanks. All of the smaller tanks are repaired either by the villages or by the landowner. The smaller tanks are used during the rainy season chiefly in order to keep up a constant supply of water for the fields during the intermission of the rainfalls. The larger tanks contain water supply sufficient often for one year and sometimes for several years. In Mysore, early in 1866, Major Sankey[b] reported that the percentage of the whole area of Mysore under the tank system was 59.7, while the total area of the state is 27,300 square miles. Unless under exceptional circumstances, none of the drainage of 60 per cent of this area or 16,300 square miles is allowed to escape, or rather should, with proper attention, be allowed to escape, were all existing works in their normal condition. To such an extent has the principle of storage been followed that it would now require some ingenuity to discover a site within this great area suitable for a new tank. In 1854 Major Sankey said that "one-third of the tanks then existing in Mysore

[a] Home, Lieut. F., R. E., Tank irrigation in Ajmeer and Mairwara: Roorkee Professional Papers, No. 229, Roorkee, India.

[b] Sankey, Maj. R. H., R. E., Irrigation in Mysore: Roorkee Professional Papers on Indian Engineering, Roorkee, India.

were large irrigating reservoirs." He found about one tank to the square mile and one village to the same area; the average quantity of cultivation was about 10 acres to a tank. In this area there are some great tanks, such as the Mudduck and Nuggar tanks mentioned elsewhere.

The ordinary Mysore tank is, however, a much smaller description of work, usually closed by a low and long dam; an average one being about 12 feet broad at top, 60 feet wide at bottom, and 18 feet high. In this description of tank the sluice is usually a large, substantial, and not infrequently expensive work. It consists of a square brick or stone cistern, 2 yards each way and 1 yard high, to keep off the sand at the entrance of the sluice, with one or more valves or plug holes in a stone at the bottom, from 6 inches to a foot in diameter each. The valve is attached to a long pole which is held in an upright position by 2 or 4 vertical stone pillars, to which horizontal projections are attached, one at top and another midway down, through a hole in the center of which the valve rod works. The pressure of the water upon the top of the valve keeps it sufficiently tight when lowered into the valve hole to prevent the escape of water. At the rear of the dam another cistern of about the same dimensions, and usually of brick in mortar, is built, three sides of which are furnished with square openings and shutters to permit the water being turned off. The two cisterns are connected by a tunnel, the length of which depends upon the cross section of the dam through which it is laid.

Most tanks receive their supply from the high ground in the neighborhood; but there are exceptions to this, as numerous tanks are partly supplied by channels, either from water courses or canals, which wind around remote hills and catch the rain flowing down their sides and convey it to the tanks. A single tank may possess several feeders of this kind. Many old tanks which had failed during the early native government have been restored by the British engineers; others which were decayed have been repaired, and a few which were tolerable have been put in perfect order. None of these irrigation works have deteriorated since the British took possession, and their condition on the whole has been greatly improved. Judging from various reports the works are probably now in a more effective condition than at any other time of which we have a record, and the increase in efficiency has apparently kept pace with the increased liberality in the expenditure, taking no account of the great rise in labor rates of late years.

In the Madras Presidency mainly, exclusive of Mysore, there were reported in 1882 to be 53,000 tanks, having about 30,000 miles of embankments and 300,000 separate masonry works, weirs, escapes, etc., yielding a revenue of $7,500,000 per annum, and having invested in them a capital of $75,000,000. In 1882 the area irrigated for first or wet-weather crop amounted to 2,525,790 acres, and the area of autumn crop irrigated in the same year by tanks amounted to 675,400 acres. Some of these Madras tanks are, as before stated, of immense size.

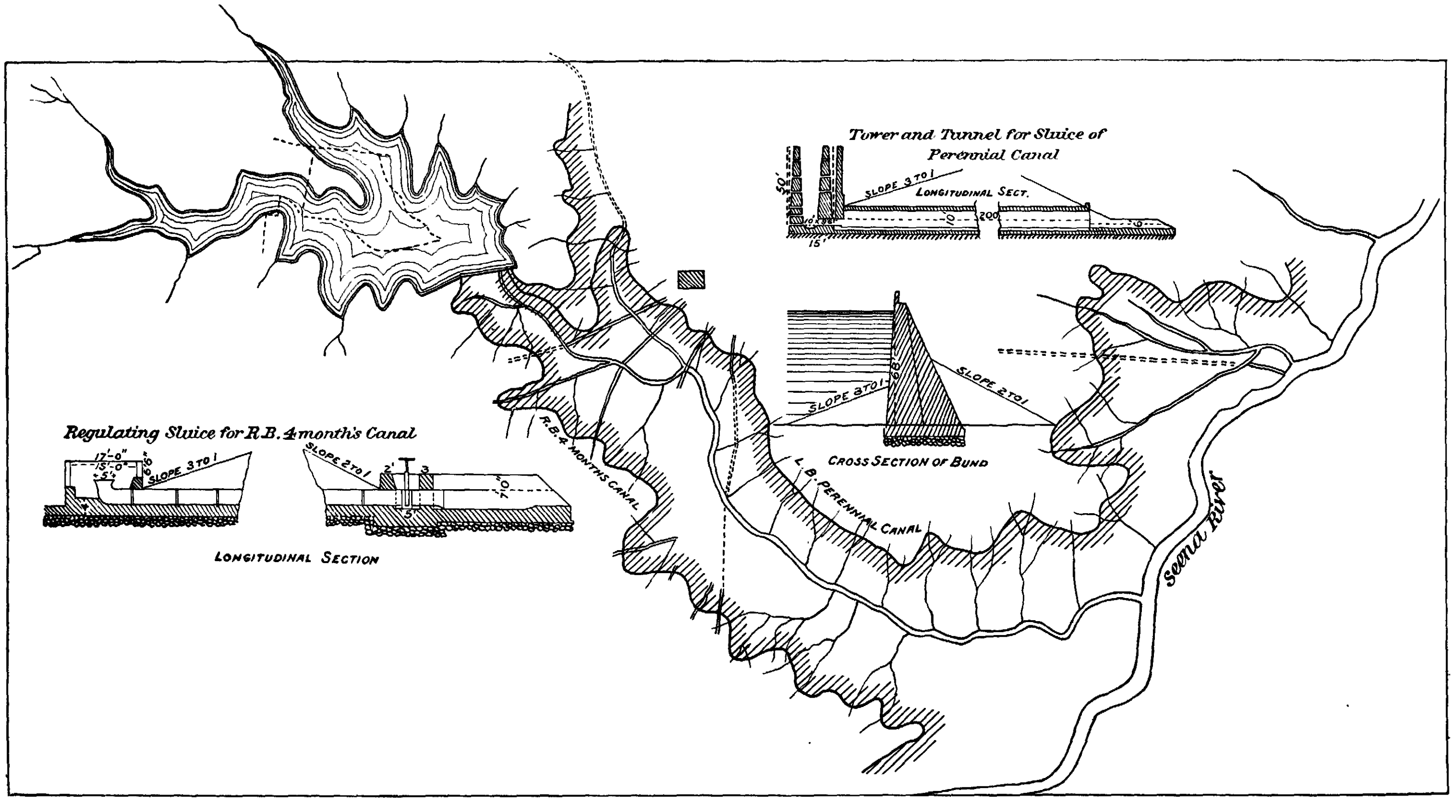
The Virainum tank, which is a very ancient work, has an area of 35 square miles and an embankment 12 miles long. It is still in full operation and returns an annual revenue of $57,000. The Chembrambaukam tank in Chingliput is so large that it resembles a great natural lake. Its embankment is more than 3 miles long, and its wasteways have a total length of 676 feet of escape. Its gross capacity is 63,780 acre-feet, its surface area is 8.95 square miles, or 5,730 acres, and it irrigates of wet-weather crop 12,760 acres, and of autumn crop 3,200 acres. The dam which closes this reservoir ranges from 9 to 28 feet in thickness at the top, and from 16 to 28 feet in height, and is constructed of earth. It supplies irrigation to the fields by means of ten separate sluiceways. In 1882 the capital invested in this work had reached $312,000, and the revenue for that year amounted to $16,300.

Some of the most interesting tanks to be found in India, because they are the most modern, are several of the great tanks recently constructed in the Bombay Presidency, which are more truly reservoirs than tanks, as the latter term fails to convey a proper idea of their magnitude and importance. Of these, the more important and interesting now in operation are the Ekruk tank near Sholapur, and the Ashti tank, also in the Sholapur district, and constructed on the Ashti River.

The following table gives some of the more important data connected with these tanks, and is derived from the Bombay revenue report for 1900–1901:

Tanks in Bombay Presidency.

	Ekruk.	Ashti.	Mhaswad.
Area of catchment ... square miles	159	92	480
Average annual rainfall ... inches	30.7	26.7	22.8
Available contents ... acre-feet	76,130	32,660	62,500
Surface area ... acres	4,551	2,380	4,014
Area commanded ... do	17,152	17,882	129,045
Area irrigated ... do	16,941	11,780	24,800
Main canal ... miles	48	27	66
Distributaries ... do	....	2	33
Height of dam ... feet	76	57.7	79.8
Total cost ... dollars	953,000	278,000	1,175,000
Area irrigated:			
Autumn ... acres	1,620	989	4,947
Summer ... do	1,355	1,440	9,414
Total ... do	2,975	2,420	14,361
Percentage double cropped	1.2	6.3	18
Discharge utilized ... second-feet	33.3	9.2	65
Area of autumn crop irrigated per second-foot of discharge utilized ... acres	40.8	155.8	106


Tower and Tunnel for Sluice of Perennial Canal
50'
SLOPE 3 TO 1
LONGITUDINAL SECT.
10' x 8'
15'
10
200
9
SLOPE 3 TO 1
68
SLOPE 2 TO 1
CROSS SECTION OF BUND
L. B. PERENNIAL CANAL
R. B. 4 MONTHS CANAL
Seena River
Regulating Sluice for R. B. 4 month's Canal
17'-0"
15'-0"
5'
6'
SLOPE 3 TO 1
SLOPE 2 TO 1
2'
3
5
7.0
LONGITUDINAL SECTION

EKRUK TANK.

EKRUK TANK.

The catchment area of the Ekruk tank is 159 square miles, on which the annual rainfall averages 24.7 inches and the run-off 41,400 acre-feet, or 4.87 inches per square mile. The rainfall on the irrigable lands served by this tank averages 22.8 inches per annum, the duty of the water supplied during the four months' autumn crop was 76 acres per second-foot, and the water rate charged on the land served during the year 1888 was 86 cents per acre irrigated or $73 per second-foot of discharge at the canal head. The crops raised in 1888 were distributed about as follows:

Crops raised on land irrigated from Ekruk tank.

Crop.	Acres.	Value.
Wheat	337	$3,100
Sugar	260	17,300
Millet	344	2,307
Beans	537	2,700
Total, including all others	2,976	38,000

This work was undertaken by the Indian government and is situated 5 miles northeast of the town of Sholapur. The scheme, drawn up in 1863 and sanctioned in 1866, comprises a tank formed by an earthen dam and supplying three canals for irrigation. It receives its water supply from the River Adhila, a tributary of the Lina, the fall of which is 7 feet per mile, and its greatest flood discharge is 37,000 second-feet. The dam which forms the tank has a total length of 7,200 feet, including 2,730 feet of masonry, of which 1,400 feet is at the northern end and 1,330 feet at the southern end. The maximum height of the earthwork above the bed of the Adhila River is 72 feet, or 7 feet above the highest flood line. The height of the masonry portion is 3 feet above the highest flood, exclusive of 3 feet of parapet above that. When full the maximum depth of the tank is 60 feet, and its contents 41,700 acre-feet of water, the surface area of which is 6⅓ square miles. The wasteway is at the northern end of the dam, and consists of a channel 250 feet wide carried through a spur and discharging into a side drainage course. The calculated maximum velocity over the wasteway is 10 feet per second, and its capacity of discharge is 250 by 5 by 10 = 12,500 second-feet. The depth of evaporation during eight months is 7 feet, and the loss amounts to 17,250 acre-feet.

This tank has three discharge canals. The accompanying Pl. XXVI gives some details of this work. The lowest or perennial canal is 28 miles long, and its sill is 20 feet above the level of the bottom of the tank. Its discharge amounts to 44 second-feet and it covers an irrigable area of 25 square miles. The next canal above this is intended to provide a four months' supply of water; it is 18 miles long, discharges 42 second-feet, and covers an irrigable area of 21 square miles of land. The highest canal is also calculated for a four months' supply, and is 4 miles long and discharges 21 second-feet of water. The discharge of one of these four-months' canals is compensated for by the supply of rain received during the rainy season. The lower perennial canal is taken from the left bank, the second canal from the right bank, and the higher canal from the left bank. The discharge sluice at the head of the perennial canal consists of a masonry tunnel through the canal bank, with a substantial masonry inlet tower on the water side. The diameter of the tunnel through the dam is 12 feet, and its total length is 200 feet. The discharge sluices for the four-months' canals consist of an iron pipe 145 feet in length and 5 feet in diameter through the dam, which is closed at the lower side by means of a valve worked by hand gear from above.

According to the revenue report for 1900–1901, the total outlay on the Ekruk tank to the end of that year amounted to $953,000, the total receipts from irrigation during the year were $3,040, and the gross receipts from all sources amounted to $8,030; the total working expenses amouted to $2,660, showing a net revenue of $5,370, equivalent to 1.2 per cent on the capital outlay. As originally designed, this work was estimated to yield a net revenue of 9 per cent on the capital expended. Its failure to do this is largely due to the small demand for the water, owing to the natural rainfall on the district served being ordinarily sufficient to raise crops without irrigation.

ASHTI TANK.

The catchment area of this tank is 92 square miles, and the rainfall over this area averages 24.1 inches per annum; the run-off amounts to 8,000 acre-feet per annum, or 1.62 inches per square mile. The rainfall on the irrigable lands served by the tank averages 19.8 inches per annum. The project comprises a tank on the Ashti River, formed by an earthen dam 12,709 feet long and 58 feet in maximum height, having a total storage capacity of 34,500 acre-feet of water. There are two discharge canals, one on each side of the Ashti River, which extend to its junction with the Bhima River and command 25,270 acres of irrigable land.

This work is situated in the Sholapur district, about 16 miles southwest of the town of Madha. The project was originally prepared by Capt. C. B. Penny, R. E., in 1869. In 1876, when the great famine was imminent and the prosecution of relief works was urgently called for, this was one of the first works undertaken for that purpose. The project (fig. 58) was then thoroughly revised and complete plans and estimates prepared by Mr. Charles T. Burke[a] under the orders of Col.

[a] Burke, Charles T., The Ashti tank: Proceedings of the Institution of Civil Engineers, vol. 76, part 2, 1883, London.

C. J. Merriman, R. E., chief engineer. The available capacity of the tank is 32,660 acre-feet, and to furnish this quantity a run-off of 6.3 inches per annum would be required from the catchment basin. The run-off during an average season is but 6 inches, or 4.87 per cent of the available capacity of the tank. The features of the ground, however, do not admit of the capacity of the tank being reduced, as the level of full supply was regulated by the only saddle available for the wasteway. Had that been lowered the quantity of rock excavation necessary would have cost more than the earthwork required to raise the dam, besides which there is manifestly an advantage in making the reservoir of large capacity if it can be done without increased expense.

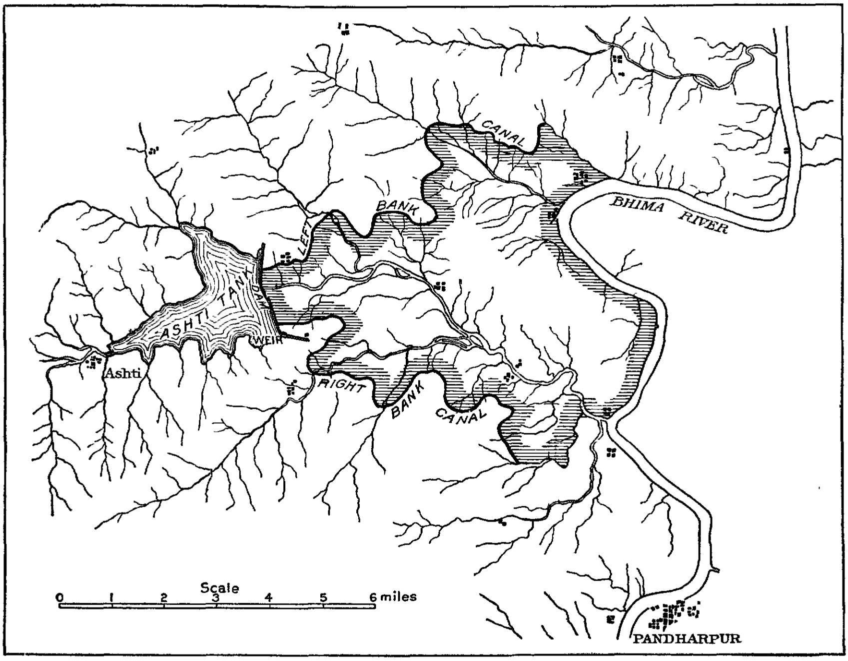


FIG. 58.—The Ashti tank and canals.

The loss by evaporation, absorption, etc., was estimated at 4 feet in depth on half the area at full-supply level. From actual experiment after the completion of the work it was found that the loss from evaporation in 1880 during the six winter months of dry weather was 3.8 feet; deducting this quantity the net supply of water available for irrigation is 25,300 acre-feet.

The total length of the dam is 12,709 feet. Its top breadth is 6 feet, its breadth at full-supply level is 42 feet; the side slopes above this point are 1 on $1\frac{1}{2}$ below it, the inner slope is 1 on 3, and the outer slope 1 on 2. Previous to its construction the site of the dam throughout was cleared of vegetable and loose material, and the sand and silt were removed from the entire area forming the site of the dam in the river bed. Thus the dam throughout rested upon a sound and firm foundation. There is no puddle wall, but a puddle trench, the filling of which rises 1 foot above the ground surface, extends throughout the whole length of the dam, and is 10 feet in width, and has been excavated down to a compact impervious bed. Its composition is 2 parts sand and 3 parts of black soil. The central third of the dam is built up of selected material of black soil, extending, as shown in the accompanying illustration (fig. 59), in a triangular section, from the dam crest, where it is 6 feet wide, to the base, where it is 60 feet wide. Outside of this are two triangular sections composed of the brown soil of the country, and this is faced outside with from 1 to 15 feet of puddle of sand and black soil, while a similar puddle on the inner slope is paved with 6 inches of large stone pitching to enable it to resist wave action. Across the river bed a trench 5 feet in width was excavated along the entire length of the dam down to the rock and extending 100 feet into the banks of the river. On each side this was filled with concrete and was connected with the puddle trench. The puddle trench was curved around the concrete wall and continued across the river at a distance of 20 feet from the concrete wall on the upstream side.

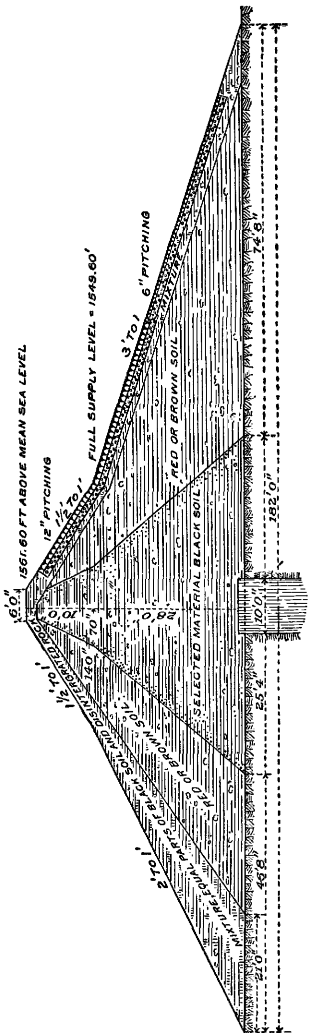


Fig. 59.—Ashti tank dam.

The following procedure was adopted in completing the foundation of the dam in the river bed. The puddle trench and concrete wall having been finished during the dry season, measures were taken to utilize the floods of the ensuing rainy season to assist in clearing away the sand, silt, etc., from the site in the river bed. Piers of loose rubblestone were disposed in rows upon the upstream side of the site; these were about 5 feet in diameter and were placed about 40 feet apart. During breaks in the wet weather the sand to be removed was plowed and thus more readily acted upon by the scouring action of the floods, which flowed with a high velocity through the contracted water area between the piers and caused the removal of a large quantity of sand from the site at a small expenditure. A low dam of dry rubble work was then constructed across the river about 100 feet above the site to prevent it from again being silted up, and during the dry season the work was carried up in the ordinary manner.

The pitching given to the inner slope of the dam was calculated as follows:

The thickness of the pitching depends upon the greatest height of the waves to which the dam is exposed, and the maximum height of the waves depends upon the "fetch" or distance from the shore where their formation commences and was determined by Stevenson's formula

$$x=1.5\sqrt{F}+(2.5-\sqrt[4]{F})$$

where x = the height of wave in feet, F = the fetch in nautical miles. Again, Rankin states that where an embankment of loose stone is exposed to the action of waves it must be faced with blocks set by hand, the least dimension of any block in the facing being not less than two-thirds of the greatest way height. From these two considerations the thickness of the pitching was deduced.

The cross section of the Ashti dam is considered to be amply strong in every way, yet Mr. Burke deems it well to consider whether in works of such magnitude the adoption of a more liberal cross section would not be advisable. He says that the Ekruk tank dam has a top breadth unnecessarily great and not uniform, as it is diminished in proportion to the height. This does not improve the appearance of the dam, is unnecessary under any circumstances, and involves an increased outlay. The top breadth of the Ashti dam is too narrow, for, although sufficient in strength, Mr. Burke considers it objectionable for various reasons. A dam of this kind would warrant, if but for appearance alone, as well as for the convenience afforded by a roadway, a small outlay to increase its top breadth sufficiently. In preparing the plans of the Pangoan tank which was subsequently designed by Mr. Burke, the top breadth was increased to 8 feet, and even this appears insufficient for a dam 77 feet in height. Mr. Burke recommends the following as a minimum top width for works of this nature in India: For earthen dams 50 feet in height and over, top breadth to be 10 feet; under 50 feet in height, 8 feet. In the course of time settling may occur in dams constructed wholly of earth, rendering repairs and renewals necessary. In the first ten years after the completion of the Ekruk dam, $2\frac{1}{2}$ feet in depth of new material was added to its top, and this could not have been properly rolled solid if the roadway had not been sufficiently wide for compression by a heavy roller.

The change of inclination from 1 on 2 to 1 on $1\frac{1}{2}$ of the outer slope of the Ashti dam is undesirable. As regards the inner slope, the inclination of 1 on 3 up to the level of the estimated maximum flood appears to be good. This should then change in tanks to 1 on $1\frac{1}{2}$ to the top of the dam. It is a matter for consideration whether the upper part should not be 1 on 1, rather than 1 on $1\frac{1}{2}$. It would probably be an advantage, Mr. Burke thinks, that waves should be reflected rather than broken on the slope, and on the authority of Mr. Scott Russell it appears that a slope of 1 on 1 will reflect waves, while on flatter slopes they are broken. The cross section recommended by Mr. Burke for general adoption in India is as follows: The height of the dam above the full-supply level, or the crest of the weir, is $h=d+x+c$; in which d = the depth of water in the tank above the weir-crest level when a maximum flood is flowing over the weir; x = the height of the top of pitching above the surface of the maximum flood in the tank, found by the formula previously given; and c = a constant of the value of 2 or 3 feet according to circumstances—that is, the vertical height of the top of the dam above the top of the pitching.

The wasteway of the Ashti dam consists of a channel having a clear width of 800 feet excavated through a saddle in the high ridge constituting the western boundary of the tank. The bed of this channel, which is excavated in rock, is level for a mean length of about 600 feet and then falls away, with a slope of 1 in 100, toward the Rapla Torrent, into which the flood waters are discharged, and thus pass into another valley distinct from that draining the tank. The discharge capacity of this wasteway is 48,000 second-feet, which will cause the water to rise 7 feet above its sill, or within 5 feet of the top of the dam. The discharge capacity of the wasteway was calculated as follows:

L=width of channel=800 feet.

d_2=the depth of water in the channel=3.5 feet.

The surface slope of the channel being 1 in 100, the mean velocity is as follows:

$$v=92.26\sqrt{\frac{h}{e}\times d_2}=17.25 \text{ feet per second}$$

and the corresponding discharge is 48,300 second-feet. The head of water in the tank necessary to cause a discharge of this volume was determined by the formula

$$D=C_d\,L\,d_2\sqrt{2gd}+\tfrac{2}{3}C_d\,Ld\sqrt{2gd}$$

where d_2 is the depth of the channel and the constant C=75.

The Ashti tank was designed as a minor productive work, the total outlay on which to the end of 1901 amounted to \$278,000. The revenues from irrigation in that year amounted to \$1,780 and the gross revenues to \$2,040. The working expenses during the same time amounted to \$14,500. This excess expenditure, however, was largely due to additional works. There was earned, in fact, a net revenue of 1.46 per cent on the capital outlay.

TANK DAMS.

General Mullins in his Manual of Irrigation[a] lays down some different rules for the top width and various dimensions of an earthen dam from those above quoted from Mr. Burke. He says that the top width of an earth dam should not be less than $4\frac{1}{2}$ feet anywhere, and while that width will suffice for the ends of dams of comparatively shallow tanks, the width at the deeper part of these should be increased to 6 feet. From 9 to 12 feet will be a proper top width for larger dams, and for very large ones one-fourth of the depth of the water is the prescribed minimum for the deeper parts and 8 feet at the ends. The top of the dam, the upstream slope of which is revetted, should always slope toward the rear edge, so that the rainfall may flow off down the rear slope and not on the revetment, with the risk of washing out the back of the latter; 1 on 16 for earth and 1 on 24 for gravel will be suitable grades for this top slope. The grade of the interior or front slope will depend upon the description of protection against wash to be provided, revetted slopes ranging from one-third to $1\frac{1}{3}$ on 1; for shingle, slopes of 1 on 2 or $2\frac{1}{2}$ are suitable. The gradient for the exterior or rear slope will vary according to the nature of the soil from 1 on $1\frac{1}{2}$, which is the steepest allowable, to 1 on 3.

In southern India at or near the center of the dam is considered the best position for a puddle wall. It is of primary importance that the wall should not crack during the considerable periods of each year that the tanks are either dry or the water in them is at a low level. The material most used for puddle walls in Madras is clay of the description used for tile making. It is well tempered and a puddle made not too wet. Any excess of moisture beyond that needed to allow of the entire wall being worked into a homogeneous mass increases the risks arising from settlement. The top width given to puddle walls, whatever their height, is about 2 feet, and the top level is made from 1 to 2 feet below the level of the top of the dam. Batters of from 6 on 1 to 8 on 1 are given to the faces of the puddle wall. The thickness of the wall at the base, that is, at the ground level, is usually found by the formula $2+\frac{2h}{b}$ in which h is the height from the ground to the top of the wall and b is the batter. The foundation of the wall is frequently of concrete down to an adequate depth below the ground surface, viz, to 1 foot at least in clay or impervious soil and to 4 feet in more or less pervious soils. The cross section of the foundation trench is made as wide at top as the base of the puddle wall and somewhat narrower at the bottom, being cut with side slopes of 3 or 4 on 1. In revetting water slopes of dams a suitable backing of small stone and gravel is always placed beneath the revetment of uncemented stone.

[a] Mullins, Lieut. Gen. J., Irrigation Manual, E. & F. N. Spon, London and New York, 1890.

In designing the surplus weirs or wasteways the quantity of water to be gotten rid of must first be ascertained. The length of weir required is usually ascertained in Madras either from tables or by calculation with the formula for weirs:

$$D=L\times\tfrac{2}{3}cd\sqrt{2gd}$$
$$=L\times\tfrac{2}{3}c\times 8.02\sqrt{d^3}$$

which, with $c=.6075$ (a value applicable to very many tank works) becomes $D=3.25\,L\sqrt{d^3}$, in which D is equal to the discharge in second-feet; c is a coefficient, the value of which varies with the form of the weir, but seldom exceeds 0.65; d is the maximum depth in feet of water to be allowed to pass over the weir, and $2g$ is a consonant representing the force of gravity.

As of interest, showing how even earthen dams which are constructed in a most substantial manner may slip or subside from some unexpected cause, the following is a description of the slips which occurred in the Ekruk and Ashti dams. The full-supply level of the Ekruk dam has a thickness of 91 feet, and at the maximum calculated flood level its thickness is 41 feet. From the date of its completion in 1869 until September, 1872, the dam was perfectly sound and in good order, but in that month excessive rain fell all over that part of the country in which the dam is situated. From 9 to 14 inches of rain were gaged at different places in the catchment area between the 19th and 23d. The water on this occasion rose to 6 feet over the crest of the waste weir and at the same time three slips occurred in the rear slope of the dam. Colonel Fife, the chief engineer, at once visited the tank and reported that the slope of the embankment where the earth had slipped or been washed down was not vertical, but was about 45°, and this for about 10 feet only, after which it became flatter. No leakage whatever was observed through the dam. Prior to this accident dry stone drains had been constructed at an angle down the rear slope to carry off the rains and prevent scouring of the embankments; it was thought that these drains at the site of the slips had become choked or had sunk, owing to the saturated condition of the soil, and had thus allowed the water to accumulate and escape, washing away the earth below. These drains on the slope were accordingly done away with, the dam was carefully made up to its original section, berms were constructed to weight the toe of the dam at the sites of the slips, and surface drains were cut to carry off the slight leakage under the dam.

No further accident occurred to this dam until the summer of 1883, when another slip took place, coincident with heavy rain on the catchment basin. The position of this slip was directly in continuation of one of the slips of 1872, the rear half of the dam having for an average length of 188 feet subsided vertically about 8 feet. This portion of the embankment was founded principally on black soil which had become saturated, resembling a pulpy mass, and had been forced upward by the pressure of the dam. To remedy this a dry stone retaining and draining wall was constructed at the toe of the dam at the side of the slope. This wall was sunk 8 feet into the ground and was 10 feet wide at the bed; cross drains were also cut to drain this in the direction of the creek below the bank, and a counterfort or berm 45 feet wide and 10 feet in height was raised on the toe of the embankment to counteract, by its weight, the tendency to bulge upward.

Early in November, 1883, owing to excessive rains, the water in the Ashti tank rose 1 foot over the crest of the wasteweir; shortly after a small horizontal crack about 40 feet in length was observed in the pitching on the front slope, and it was immediately repaired by removing the stones, tamping the bank, and relaying the pitching. About a week later a crack 3 inches wide and 4 inches deep was found in the rear of the slope. This crack had a horizontal length of about 60 feet and ran down the slope to a level of about 10 feet below full-supply mark. It was at once repaired, but on the following day it reopened, when a settlement at the top of the dam was observed. From this time for several days the top continued to subside and the ground at the toe of the dam to bulge upward. Equilibrium was not established until a week later. The total settlement of the top of the dam amounted to 16 feet, bringing it 4 feet below the full-supply level of the tank; the pitched slope, however, remained intact up to about 4 feet above this level.

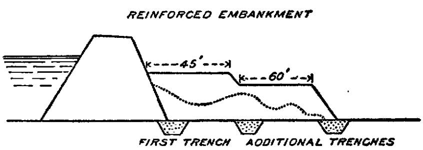


FIG. 60.—Ashti dam slips.

The causes of the slips resemble in a measure those of the slips at the Ekruk tank. A considerable length of the dam is founded on a clay soil, with nodules of dirty lime in it, and generally contains a quantity of alkali which causes it to become semifluid when soaked with water. It is probable that at the site of the slope the excavation for the puddle trench had not been made quite deep enough to prevent leakage of water under it. The length of the slipped portion at the top was 155 feet. The dam at this point is 44.3 feet in height and at the time of the accident the water was standing 31.7 feet deep at this point.

The permanent corrective measures adopted after the cessation of the movement were the digging of a trench at the toe of the rear slope which was filled with bowlders and broken stone (fig. 60), as was done for the Ekruk dam, heaping the excavated material and other earth on to the bulged-up ground to counterbalance the lifting action, remaking the dam to its original section, and adding earth and broken stone to give additional weight to the rear slope. The drainage trench has been extended along the slope wherever the foundation was thought to be treacherous and this has been supplemented by additional drains, similar in character and running parallel to it, and two counterforts or berms have been added to the slope all along the rear portion of the dam, about 700 or 800 feet in length, to weigh the toe.

COMBINED STORAGE AND CANAL SYSTEMS.

Several combined storage and canal systems have already been described in their proper places. The Nira project, the Betwa system, the Periyar system, and the larger tanks just described are all combined systems of storage works and irrigating canals. There are two other combined systems which differ from these in their general characteristics and should be described as of peculiar interest. One is the Palar anicut system in Madras, whereby the water from the Palar River is furnished to a number of tanks by means of main and branch supply channels and is stored in these tanks until wanted for purposes of irrigation. The other is the Zhara Karez irrigation scheme in Beluchistan, by which a number of small detached tanks situated in the bottom lands adjacent to the Machka Torrent are filled by a tunnel intercepting the subsurface flow and by channels taken from the torrent to the tanks during portions of the year when there is running water in the stream.

PALAR ANICUT SYSTEM.

The Palar anicut or wier was originally designed to give an improved supply to old channels which fed a series of old native tanks. It is situated on the Palar River, 4 miles below the town of Arcot, and has a catchment basin above it of 3,974 square miles, the maximum flood discharge from which is 25,000 second-feet. Anicut is a Tamil word which means literally wier, and the Palar anicut is a simple diversion wier constructed across the Palar River whereby water is diverted on both banks of the river into the supply canals which head above the wier.

The irrigation which commenced in 1853 with an area of 9,000 acres of wet-weather irrigation and 700 acres of dry-weather irrigation extended until 1882, when there was an area of 66,700 acres of wet-weather and of 20,600 acres of dry-weather irrigation. The net revenue derived from the system previous to the end of 1882, including the enhanced land revenue, was $290,000 or 36.5 per cent on the amount of direct charges. The amount of interest charged to the same date, however, was $670,000.

The weir itself (fig. 62) is 2,634 feet in length between wing walls and 7 feet high with a vertical fall, and is founded on a suitable row of circular wells. There are three aprons, the first of cut stone in mortar 36 feet wide, and the third of dry rubblestone 30 feet wide. The under sluices on the north side of the river consist of 22 vents of 5 by 5 feet each, those on the south side of 10 vents of the same dimensions. The weir was breached for a length of 1,015 feet by the floods of October, 1874, previous to its final reconstruction. The channels on the north are the Mahendravadi channel supplying the tank of the same name, and the main channel which branches into two supply channels, one at 3 miles from the head and the other at 21 miles from the weir. From this last channel other branches are taken off which terminate in various tanks. On the south side are three channels. The project has not realized the anticipations originally formed because the supply in the river bed was overestimated, besides which there were considerable defects in the channels themselves as originally laid out.

The water records show that on an average there are 273.7 days yearly on which no water is registered. The northern channels

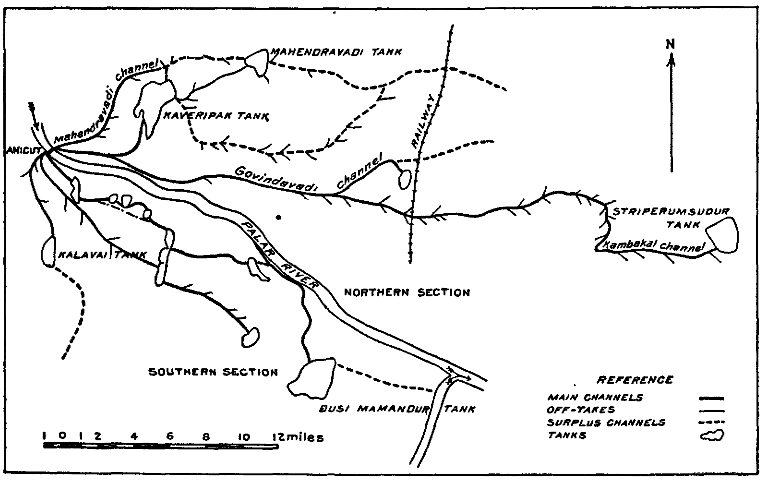


FIG. 61.—Palar anicut system, showing main channels and offtakes.

receive a full supply when there is $5\frac{1}{2}$ feet on the sill of the weir under sluices, and the southern channels not until there is 7 feet on that side.

The Palar River rises on the Mysore plateau and runs into the ocean after a course of about 220 miles. There is extensive irrigation from it by means of river channels, which are chiefly provided with masonry heads. The weir supplying the system here described is built at the one hundred and fifty-second mile, and is situated about 4 miles below the famous town and fort of Arcot. The drainage basin of the river to this point is about 3,974 square miles, the maximum flood discharge about 25,000 second-feet, and the maximum depth of flow passing over the weir 6.75 feet, as before stated.

There is little or no direct irrigation from the main or branch channels. In almost every case the water is first let into the tanks in which it is stored. These are frequently of large size, as the Kaveripak tank on the northern and the Dusi Mamandur on the southern side, which irrigate 5,870 and 3,050 acres, respectively. As at present constructed, the system contains on the northern side 127 tanks irrigating 38,260 acres, or about 300 acres per tank; and 74 tanks irrigating 14,750 acres, or nearly 200 acres per tank, on the southern side. Only a portion of these, however, are filled by river water, many of them receiving large supplies from the local drainage, which is conveyed to them by various channels.

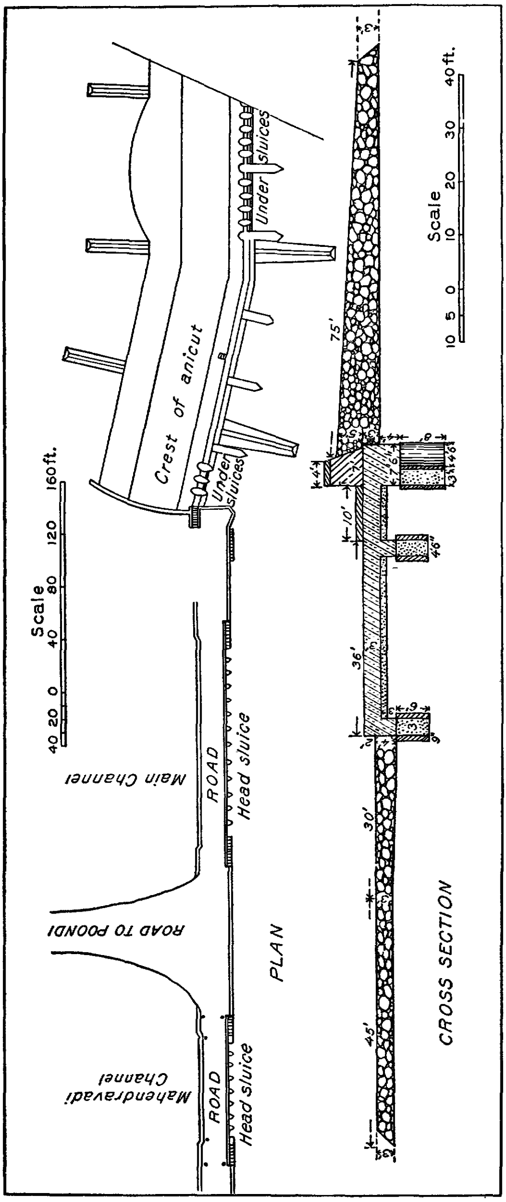
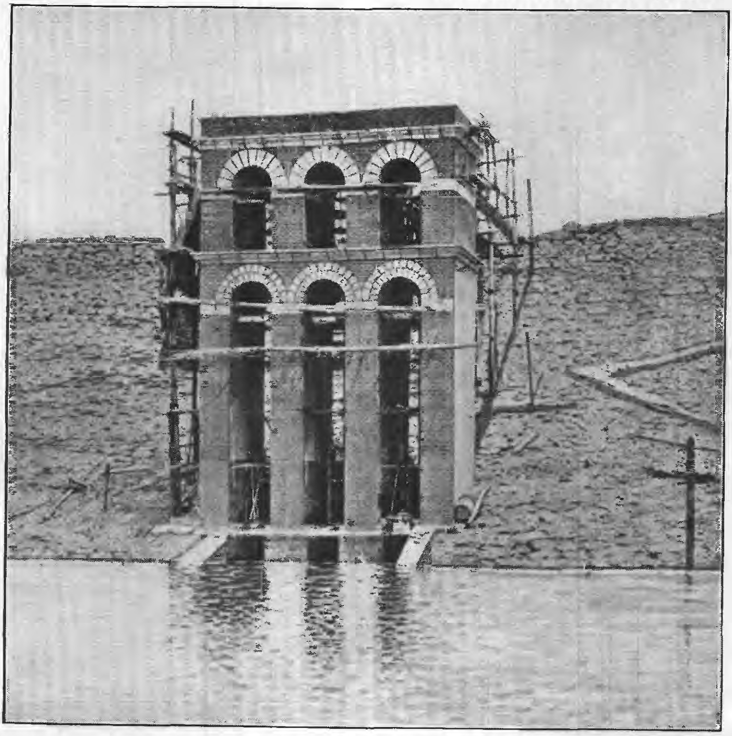
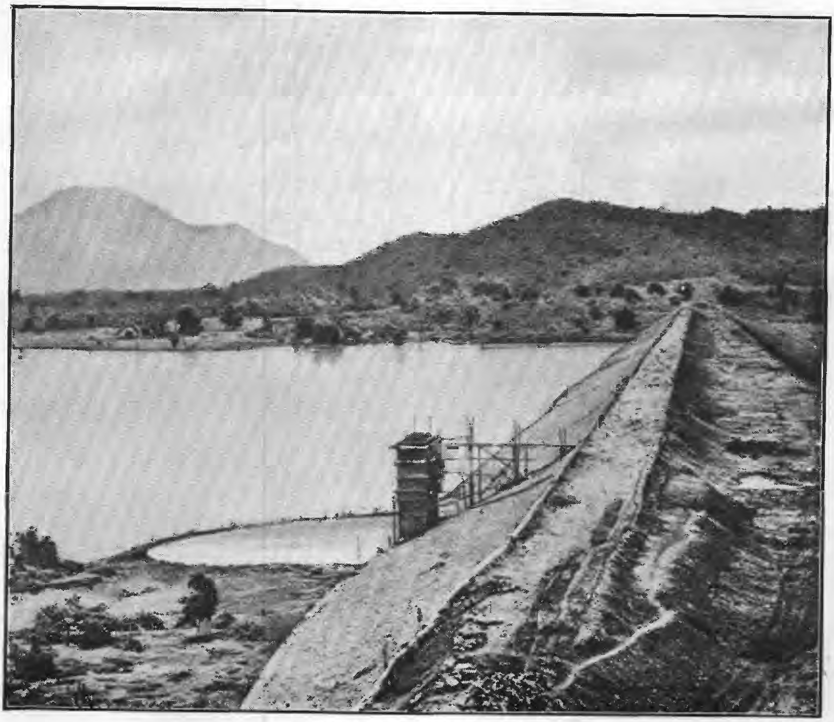


FIG. 62.—Plan and cross section of Palar anicut system.

The Palar River is an extremely objectionable one for the supply of a large irrigation system. The northern head sluices receive a full supply only during an average of 22.6 days in each year, as the latter are $1\frac{1}{2}$ feet above the sills of the northern sluices. The carrying capacity of the northern main canal is not more than 3,140 second-feet. It is 215 feet wide, carries 4 feet in depth of water, and has a fall of 3 feet per mile. The southern main canal is 113 feet wide, carries 4 feet in depth of water, and has a fall of 6 feet per mile with a discharge of 2,300 second-feet. Combining these results with the number of days during which the water supply is available it will be seen that the northern channel carries 140,000 acre-feet during the period of full supply and the southern channel 65,000 acre-feet. These are assumed as the volumes which determine the area capable of being irrigated.



A. RUSSELLKONDA HEAD SLUICE.



B. RUSSELLKONDA DAM.

RUSSELLKONDA TANK, RUSHIKULYA PROJECT.

The Rushikulya irrigation system consists of two canals drawn from the Rivers Mahánadi and Rushikulya, which are tapped by anicuts built at the heads of those canals, and the supply further supplemented from two reservoirs, the Russellkonda and Suradá. The Russellkonda is formed by damming up a valley in the basin of the Mahánadi and supplying it by an anicut and channel from the Gulleri River, one of the affluents of the Mahánadi. The Suradá reservoir is constructed across the Pathama River, one of the affluents of the Rushikulya. The length of the Mahánadi canal is 19 miles, while that of the Rushikulya to the Chatrapur-Berhampur road is 57 miles.

The dam (Pl. XXVII, *B*) is entirely of earth, carefully worked in layers with a puddle wall through the center and carried up to within 25 feet of the top of the bund, as it was considered essential to continue it above a point where there was less than 15 feet of water pressure at F. T. L. The front slope is carried up on an average of two-thirds of the height of the dam at a slope of 2:1 and from that point at a slope of 1:1, and revetted with stone-pitching $2\frac{1}{2}$ inches in thickness. The rear slope is $2\frac{1}{2}$:1 up to the same height and then is brought up in the ratio of $1\frac{1}{2}$:1. The rear slope is turfed throughout with a berm varying from 10 to 50 feet wide at the point where the break in ratio of slope occurs. The settlement throughout has been perfectly uniform, and no slips or dangerous percolation have as yet occurred. The maximum height of the dam is 75 feet and depth of water 58 feet. Its contents at F. T. L. will be 2,295 millions of cubic feet, and it can be supplied from the Gulleri River in thirty-eight days.

The head-sluice (Pl. XXVII, *A*) is built of table-molded bricks and ashlar string courses and ashlar vents. The vents, three in number, are closed by cast-steel shutters worked from a platform by ordinary screw gearing with ball-friction bearings, and can be raised without difficulty by six men against the maximum head of 42 feet of water. The anicut is of the usual form adopted in the Madras Presidency, with a clear drop wall 6 feet in height, with an upper masonry apron, and longitudinal retaining walls, all founded on wells, with a packed rough stone and an adjustable loose-stone apron below.

The Mahánadi canal head-sluice and scouring sluices in juxtaposition thereto are built of random rubble and pointed with surki mortar. The sluices are fitted with shutters and screw gearings. The Janamalli anicut, built at the rear of the Rushikulya canal, across the river of the same name, consists of a main body wall and a sloping talus of rough stone, with one longitudinal retaining wall and an adjustable loose-stone apron below. The water from the Mahánadi canal, being passed into the Rushikulya, is arrested by the anicut and diverted through the Rushikulya canal head-sluices, twelve in number. The Godahallow aqueduct, consisting of 15 arches across the river of that name, is 40 feet wide and will carry a maximum depth of 8 feet of water. The side walls are of random rubble in surki mortar and the arches of brick in surki mortar. A depth not exceeding 3 feet has been passed over it, sufficient for present requirements of the irrigation below.

ZHARA KAREZ IRRIGATION PROJECT.

This scheme proposes to store in detached small tanks the water supply which runs in the Machka Torrent for a month or so in spring. The site of the scheme and the catchment basin of the torrent are in

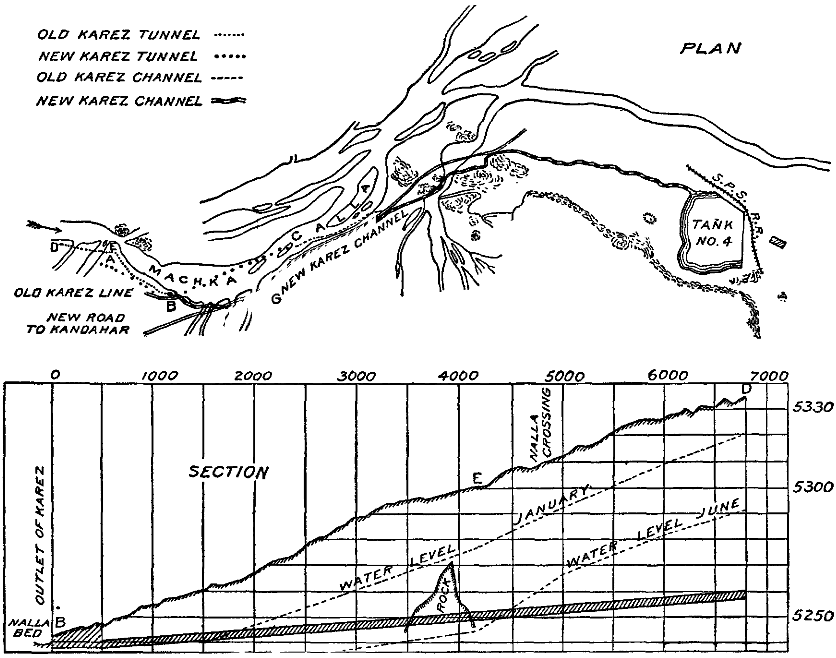


FIG. 63.—Zhara Karez irrigation project, Beluchistan.

Beluchistan, in the neighborhood of Khojak Pass. In the winter a good snow generally falls on the hills and after melting filtrates through the shale and runs off in springs lower down. The bed of the torrent has a slope seldom less than 1 in 70 where it leaves the hills; a short distance lower down its bed deepens until it is about 30 feet below the surface of the plain. There is no possible site for a large reservoir and accordingly five small sites for tanks were selected. About six of the last twenty years there has been no winter supply in the stream. In summer there are occasional heavy showers, but the floods last but a few hours and little or none of their water can be stored. The tanks are to be filled by small water courses leading from the stream (fig. 63), and the water will then be utilized about the 1st of May in giving a final watering to rain-sown wheat crops, as the spring rains are generally sufficient up to that time. When empty, the beds of the tanks will be utilized for small crops without irrigation. There are no distributing canals, as in no case is anything larger than a large private water channel necessary.

The tanks are all on a comparatively small scale, the maximum depth having been fixed at 12 or 14 feet. As no clay was available for making puddle, the top of the bank is 3 feet above the full supply level, and the inside slopes are either pitched with bowlders or planted with willows. The outlet sluice is a simple concrete wall with numerous holes 0.8 of a foot in diameter placed at various depths and closed by wooden plugs, which can be opened by hand from a movable ladder resting on top of the well. From the bottom of the well a culvert leads under the embankment with stop walls on the outside. There is scarcely any local drainage to any of the tanks, and hence no large escapes are necessary. As a precaution the top of the well is only carried up to the full supply level.

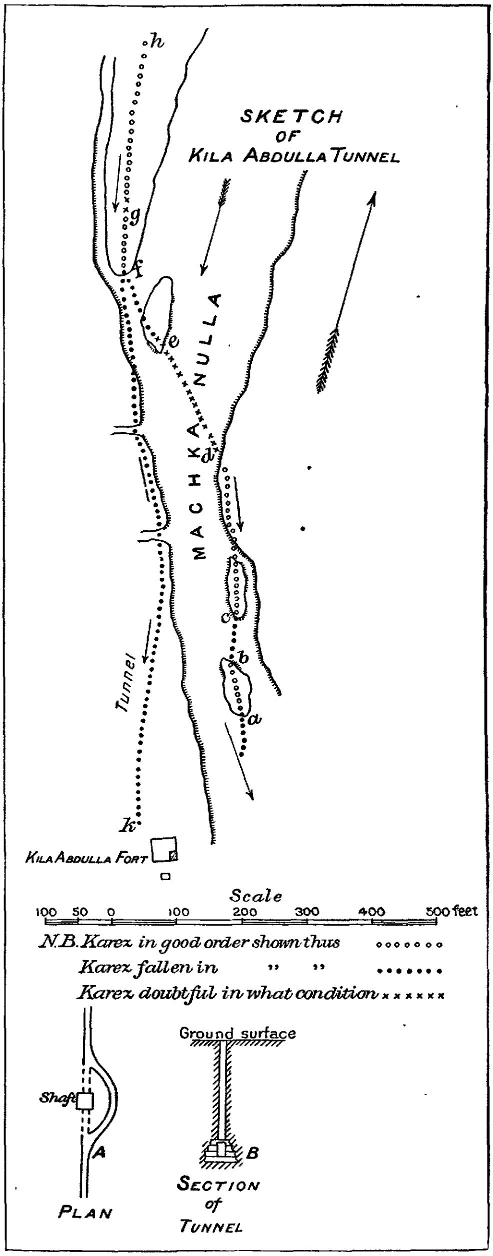


FIG. 64.—Machka Nulla Karez.

The total amount of water available in the tanks for purposes of irrigation, after deducting losses by absorption, will be 1,550 acre-feet, and this is estimated to be sufficient to irrigate 2,570 acres; from which deduct about 30 per 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 insure 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. 63). 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 9 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, 150 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 Ganges 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

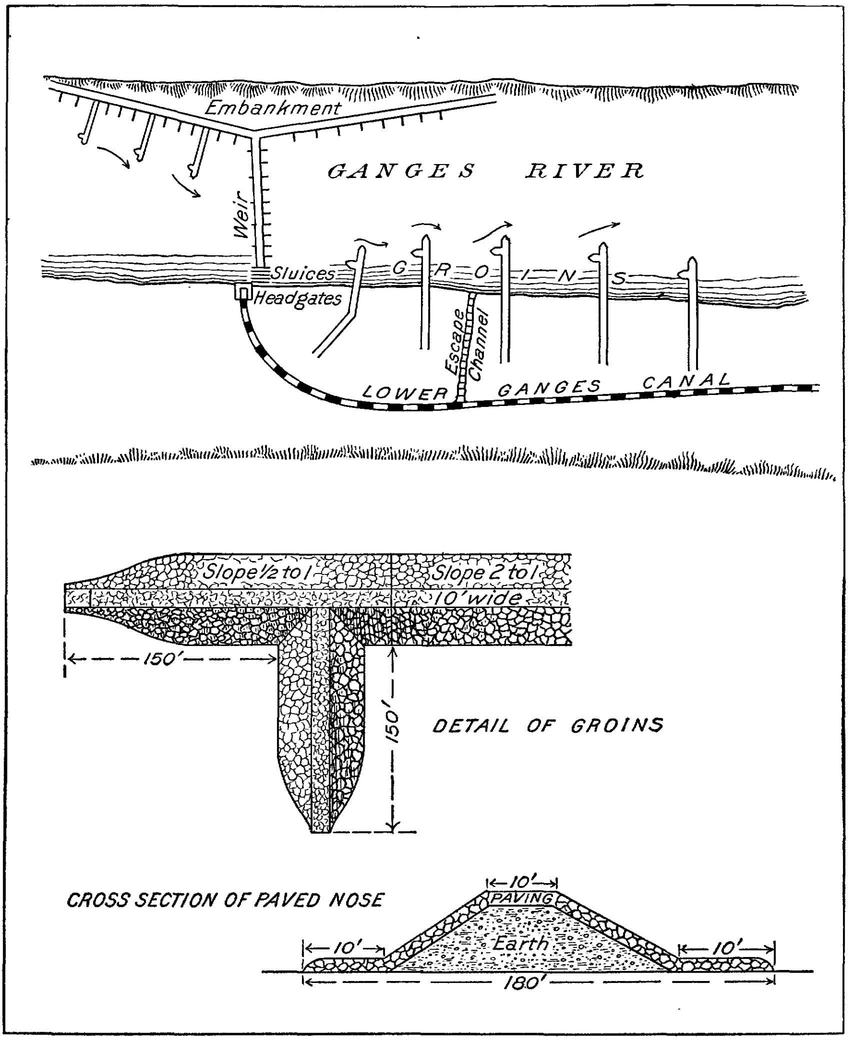


FIG. 65.—Training works, Lower Ganges canal, Narora.

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. 66) and parallel to the course of the river. These works are known as "alli-

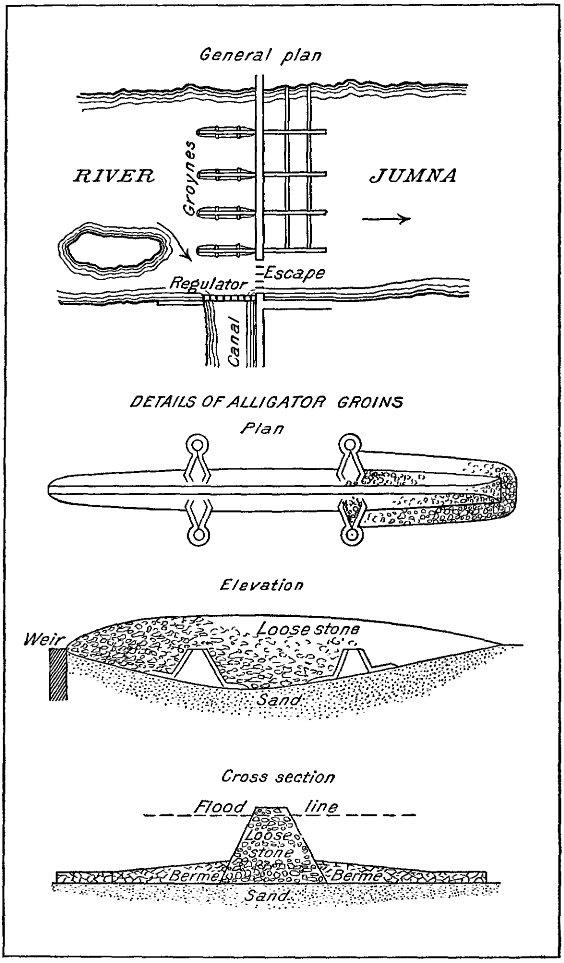


FIG. 66.—Training works, Agra canal, Okhla.

gator 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 prosecuted in India with as much zest as is the construction of canals or storage works.

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The following papers also relate to this subject: Underground waters of Arkansas Valley in eastern Colorado, by G. K. Gilbert, in Seventeenth Annual, Part II; Preliminary report on artesian waters of a portion of the Dakotas, by N. H. Darton, in Seventeenth Annual, Part II; Water resources of Illinois, by Frank Leverett, in Seventeenth Annual, Part II; Water resources of Indiana and Ohio, by Frank Leverett, in Eighteenth Annual, Part IV; New developments in well boring and irrigation in eastern South Dakota, by N. H. Darton, in Eighteenth Annual, Part IV; Rock waters of Ohio, by Edward Orton, in Nineteenth Annual, Part IV; Artesian well prospects in the Atlantic Coastal Plain region, by N. H. Darton, Bulletin No. 138.

SERIES P—HYDROGRAPHIC PROGRESS REPORTS.

Progress reports may be found in the following publications: For 1888-89, Tenth Annual, Part II; for 1889-90, Eleventh Annual, Part II; for 1890-91, Twelfth Annual, Part II; for 1891-92, Thirteenth Annual, Part III; for 1893 and 1894, Bulletin No. 131; for 1895, Bulletin No. 140; for 1896, Eighteenth Annual, Part IV, WS 11; for 1897, Nineteenth Annual, Part IV, WS 15, 16; for 1898, Twentieth Annual, Part IV, WS 27, 28; for 1899, Twenty-first Annual, Part IV, WS 35-39; for 1900, Twenty-second Annual, Part IV, WS 47-52; for 1901, WS 65, 66, 75; for 1902, WS 82-85.

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The following papers also relate especially to irrigation: Irrigation in India, by H. M. Wilson, in Twelfth Annual, Part II; two papers on irrigation engineering, by H. M. Wilson, in Thirteenth Annual, Part III.

All communications should be addressed to

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