7_ Tulloch. Major. R.E. "The Water-supply of Bombay." Being a Report submitted to the Bench of Justices of that city. Presented by —

THE ROYAL SOCIETY
FOR THE PROMOTION
OF HEALTH

Founded 1876

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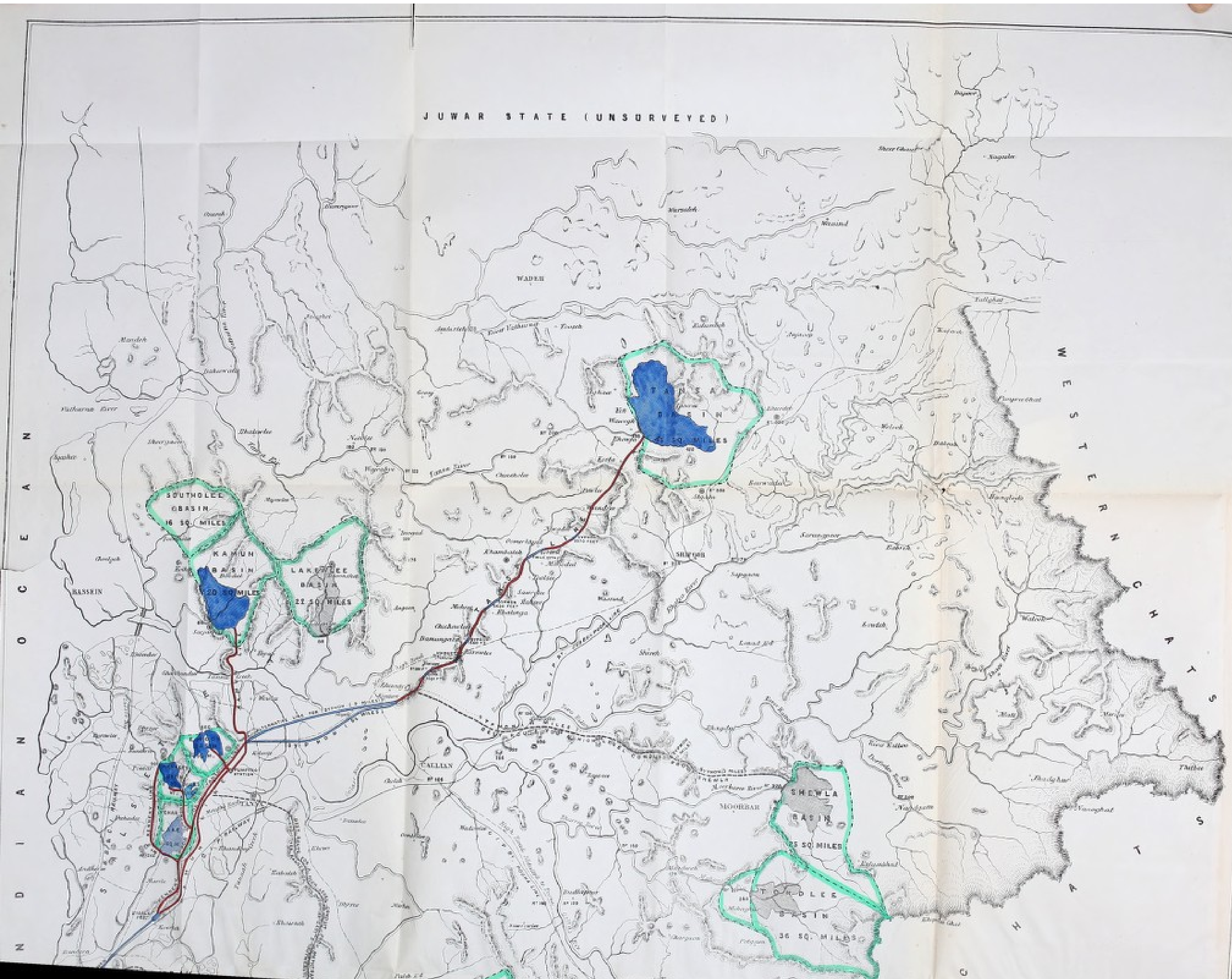
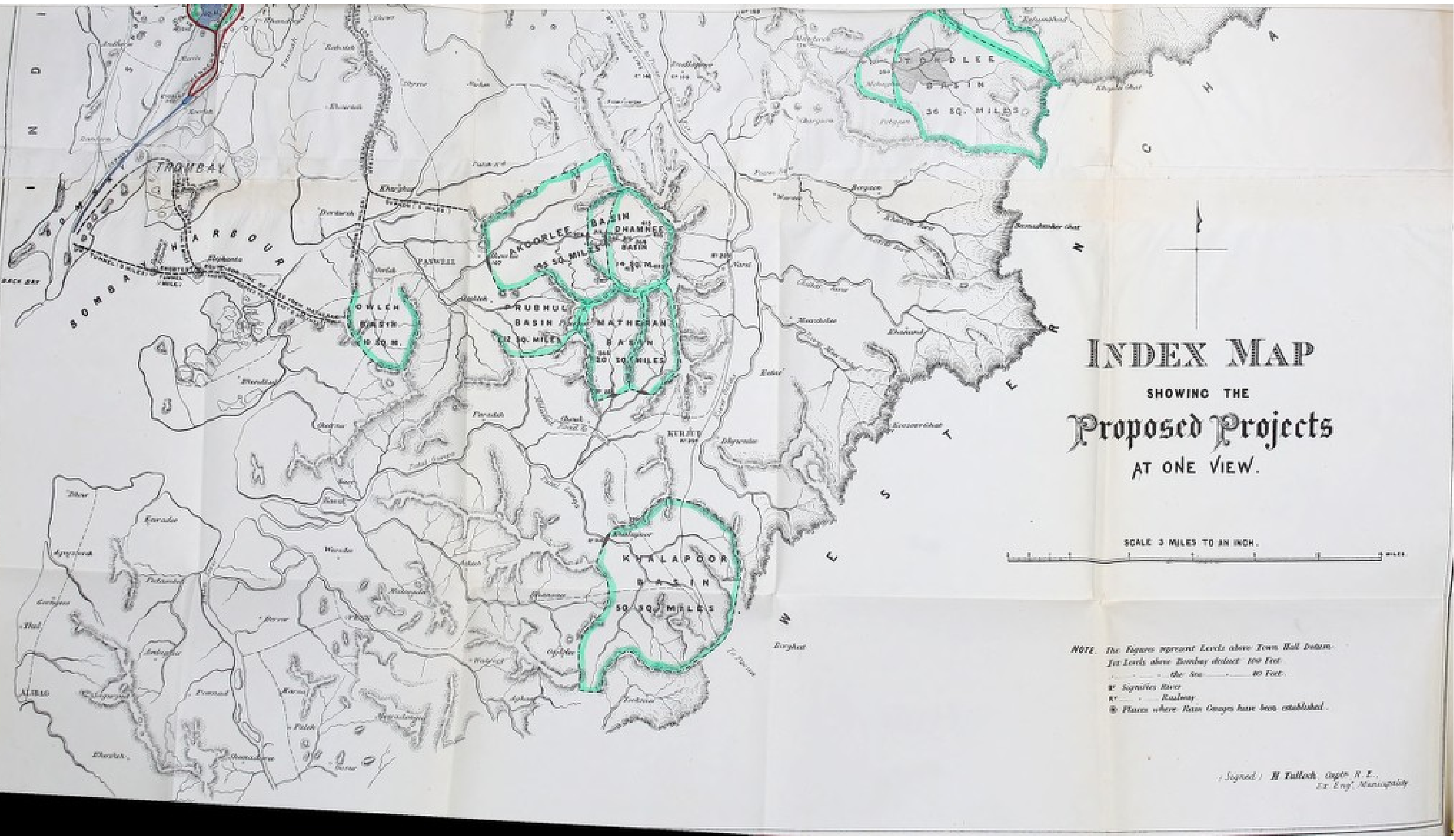

JUWAR STATE (UNSURVEYED)
WESTERN GHATS
INDIAN OCEAN
WADEH
SOUTHOLEE BASIN 16 SQ. MILES
KAMUN BASIN 20 SQ. MILES
BASSEIN
CALLIAN
MOORBAR
SHEWLA BASIN 25 SQ. MILES


INDEX MAP
SHOWING THE
Proposed Projects
AT ONE VIEW.
SCALE 3 MILES TO AN INCH.
NOTE. The Figures represent Levels above Town Hall Datum.
For Levels above Bombay deduct 100 Feet.
the Sea 80 Feet.
Signifies River
Railway
Places where Rain Gauges have been established.
(Signed) H Tulloch, Captn. R.E.,
Ex. Engr. Municipality
TROMBAY
HARBOUR
BACK BAY
PANWELL
AKOORLEE BASIN
155 SQ. MILES
DHAMNEE BASIN
PRUBHUL BASIN
MATHERAN BASIN
20 SQ. MILES
OWLEH BASIN
KHALAPOOR BASIN
50 SQ. MILES
TONDLEE BASIN
36 SQ. MILES
KURJUT
WESTERN GHA

THE

WATER-SUPPLY

OF

BOMBAY.

BEING A

REPORT SUBMITTED TO THE BENCH OF JUSTICES OF THAT CITY

BY THEIR EXECUTIVE ENGINEER,
HECTOR TULLOCH.
MAJOR, ROYAL ENGINEERS.

LONDON:
PRINTED BY W. J. JOHNSON, 121, FLEET STREET.

1872.

LONDON:
W. J. JOHNSON, PRINTER,
121, FLEET STREET, E.C.

PREFACE.

I wish to state at the outset that the present investigation has not been undertaken with any preconceived ideas as to what system of water-supply, whether on the high pressure or low pressure principle, whether through pipes or through masonry conduits, whether by help of pumps or without them, should be adopted. In the evidence which I gave before the Water-supply Commission, which sat in Bombay in 1869, I studiously and repeatedly maintained that I was in favour of no particular system, but that what I recommended was a careful inquiry into every system, so that the Bench of Justices might be able to form their own judgment in the matter. Further on in this Report they will be able to say how far I have acted up to these convictions; that I have endeavoured to do so may be gathered from the variety of solutions of the problem presented to them. For the present I beg they will suspend their judgment altogether and even lay aside any preconceived opinions they may have formed on the subject. There is a large body of facts to be laid before them which it was not possible that any one could be acquainted with previous to the completion of the recent surveys, so that any opinion arrived at before, however correct and logical it might have been on the then known facts, must have been founded on incomplete data. With the new facts before them the Bench will have a better opportunity to form a judgment.

Fortunately, the subject of water-supply is a popular one. It could not well be otherwise. The slightest acquaintance with the town of Bombay must convince any one that a real necessity exists for an additional quantity of water. The supply is so short at present, that all kinds of expedients have to be resorted to in order to let each part of the town share in the distribution from the Vehar Lake. The natives are, if possible, more anxious for an extension of the water-supply than even the Europeans. In such a healthy state of public opinion it will be strange if this opportunity for action is allowed to pass. There is all the greater reason that something should be done forthwith, because the price of the one article which makes projects for water-supply so expensive is steadily rising. Iron pipes two years ago might have been laid down in Bombay for £11 a ton—now they will cost £16! What the price may be in two or three years more it is impossible to say. I have assumed that the Bench are satisfied that steps should be taken to bring more water into the town, and I have endeavoured, as far as possible, to give them the facts necessary to enable them to arrive at a decision on this important subject. I have felt all the greater confidence that a report of this comprehensive nature will meet with the approval of the Bench, because, as they are themselves aware, action has been delayed hitherto only in consequence of the imperfect information which has been laid before them. My impression has always been that the Justices have hesitated to act because they have never felt that they have been in possession of a sufficient body of facts upon which they could form an opinion as to whether any particular project was deserving of their attention. Mr. Aitken's projects were all set aside for want of sufficient information. My project for impounding water in the Toolsee Valley was set aside for the same reason, and I thought at the time that the Bench were acting judiciously not to sanction it without fuller enquiry. But now it is otherwise; that enquiry has been made, and as fully as can reasonably be expected. I have not merely suggested what I think the Bench should do, but I have given them all the facts bearing on the question, to enable them to decide whether my recommendations are borne out by those facts.

It only remains for me now to bring to the notice of the Bench the services of those gentlemen through whose help I have been enabled to submit so comprehensive a report. My acknowledgments are due to Mr. Rienzi Walton, who has, during my repeated absences from Bombay on survey duties, performed all the usual work in the Executive Engineer's Office with great skill and judgment; to Mr. C. B. Braham, for the help he has given me in that part of the investigation which has demanded special engineering and mathematical knowledge; to Mr. Burt and Mr. Grey, for the energy with which they have conducted the surveys under the most trying circumstances; and to Mr. Bhadurjee Framjee, for the tact and firmness with which he has managed the Water Works Department, and the excellent manner in which he has superintended and checked the accounts of the Survey Extension Establishment.

I cannot refrain from suggesting to the Bench that, as soon as it is decided what project shall be carried out, the services of Mr. C. B. Braham should be borrowed from the Government, and that Mr. Burt and Mr. Grey also should be engaged for the new works. These gentlemen are so well acquainted with all the different projects and with the country in which they would have to be carried out, that an immense deal of time, trouble, and expense would be saved by their employment. If new hands are called in, it will take them months to become familiar with the subject, and, without any knowledge on their part of the wild country through which the lines of the conduits will have to be accurately traced, and of the mode of tracing them, which has been adopted after much experience in the previous surveys, the works will be carried on under great difficulties. I sincerely hope the Bench will give this point their careful consideration.

H. TULLOCH.

CONTENTS.

APPENDIX.

PLATES.

THE WATER-SUPPLY OF BOMBAY.

CHAPTER I.

HISTORY OF THE WATER-SUPPLY OF BOMBAY.

First Alarm, 1845.

On the 2nd of June 1845, the Government of Bombay were so alarmed at the deficiency of water in the town, that they passed a Resolution appointing a Committee to report with the least possible delay on the state of the wells in the Island, the quality of the water in them, and the quantity remaining for consumption.

Doctors Graham and Leith on the Water-supply.

The demand for the Report must indeed have been very urgent, for the Committee, composed of Doctors Graham and Leith, submitted their views to Government on the very next day. They acknowledged the great want of water prevailing in the town, and the great distress felt by the people from the deficiency; they pointed out, moreover, that the water was, as a rule, bad in quality, in some instances brackish, and in others, tainted by the drainage from the streets. It will interest the reader to learn that the recommendations they made were: that the use of some private wells in Girgaum should be secured for the public by compensating the owners; that the wells on the Esplanadé where cattle were watered should be reserved for man; and that other wells in the same locality which had been closed should be re-opened. One cannot but be struck by what must seem to us the mildness of the remedy proposed to be applied in those days in so serious a case.

The crisis must have been a very alarming one, for we find that, three days after the Report was sent in by the Committee, the Government passed another Resolution, in which the Chief Engineer of the time was also called upon to report on the subject, and they expressed themselves "most anxious to prevent the recurrence, even during one year, of such a calamity as is now felt."

Mr. Rivett's Project.

So great was the attention which the matter attracted that before even the Chief Engineer, who took ten days only to think over his project, could reply to the demand of the Government, another gentleman, who had been devoting himself to the solution of the problem, stepped in and proposed a remedy for the evil. We find that on the 14th of June a memorandum was prepared by L. C. C. Rivett, Esq., of the Civil Service, "On the practicability of obtaining a supply of Good Water for the Native Town of Bombay."

Mr. Rivett pointed out that it was hopeless to attempt to add to the supply by means of wells; that in order to keep the tanks in the town full up to a certain level during the whole year, the only plan was to collect rain-water during the monsoon; and that the principal desiderata were "an elevated position for a reservoir," "a large surface from which to fill this reservoir," and "facility of conveying the water from this reservoir to the tanks in question." Mr. Rivett wrote: "The principal points which at first sight present themselves for such an object appear to be"—I think the Bombay public will smile—"Nowrojee Hill at the back of the Gaol, the hill above Mazagon, the Chinchpoogly Hills, the hill above Parell, Malabar Hill adjacent to the Parsee Cemetery, and the hill above Colonel Dunsterville's House." How wonderfully the town has grown since then, and how our wants have increased, we can realize by the fact that the idea should at one time have been even entertained that these sources might suffice.

A glimpse of the future Bombay must have been caught by Mr. Rivett even a quarter of a century ago, for, on consideration, he rejected all these sources. Calculating the areas of the important tanks on which the town depended for its supply, Mr. Rivett found they amounted to 672,000 square feet, and he considered it would be necessary to supply each tank with water to the depth of sixteen feet. Proceeding then on the supposition that the rainfall was 6½ feet in the year, and that only half of it could be collected, and assuming that the reservoir should hold a three-years' supply, he found he should require a gathering ground of 240 acres. This would enable him to collect 200,000,000 gallons. As none of the sites above mentioned offered this extent of collecting area, he proposed that a reservoir should be built on a hill standing on the peninsula called "The Neat's Tongue," but which we know better as "Trombay." He said:—

"There is, however, on the peninsula called the Neat's Tongue, a hill which offers all the requisite advantages, and where a reservoir sufficient to supply fifty times the amount above specified (200,000,000 gallons), might be constructed. This hill is certainly 800 or 1,000 feet high; its sides are steep, and there are several spots on it in which the ground, converging towards the nullahs, forms almost a natural crater, admirably adapted for a reservoir. There is here sufficient unemployed surface to collect water for a reservoir of almost boundless extent, and one, the bottom of which would be at least 300 feet above the level of the tanks it would have to supply. On this hill a point might be selected, distant from Sewree in a direct line three miles. The water from the reservoir might be conveyed from the hill by an aqueduct of iron pipes, supported on pillars of masonry, across the arm of the sea (dry at low water) which separates Sewree from the

Neat's Tongue. From Sewree a similar aqueduct would lead the water to the Byculla Tank, in the first instance, and from thence it should be conveyed by underground pipes to the other tanks, or any other point in the native town, which in this manner might be as well supplied with water as London."

The Estimate of the cost of the works was as follows :—

5½ miles of 12-inch pipes from the Reservoir on Neat's Tongue to Bombay........................	£8,800
2 miles of pipes to distribute the water from tank to tank	3,200
Masonry columns to support the 5½ miles of pipes	16,940
Reservoir, about..	40,000
Total	£68,940

Or somewhat less than seven lakhs of rupees.

At this distance of time it is amusing to think that the hill on the Island of Trombay should ever have been considered so extensive as to be able to give us a reservoir "of almost boundless extent." Since Mr. Rivett's day the inhabitants have multiplied to such an extent, that the supply from any reservoir in Trombay would hardly suffice the town for more than a week.

Mr. Rivett's proposition, although it was put forward with great ability, and was really, in my opinion, well worthy of consideration at that time, does not seem to have met with approval. At all events no action was taken upon it, and we may, therefore, conclude it died a natural death.

Colonel Jervis' Project.

Two days after the issue of his memorandum, the Chief Engineer, Lieutenant-Colonel George Jervis, came forward and submitted his remedy to alleviate the thirst of the patient. This was :—

"To provide three reservoirs in the following situations, which afford sandstone strata, which are saturated with water throughout the year—1st, The Dhobee's Tank on the Esplanade; 2nd, some eligible spot to be purchased in the Girgaum Oarts; 3rd, the Cocoanut Oarts of Mahim. The first for the supply of the Fort; the second for the supply of the Native Town, from the verge of the Esplanade to a line running east and west from the Mombadavee Tank; the third for the supply of Parell, Byculla, Mazagon, and the Native Town, north of the line above mentioned. The supply of water in the reservoirs to be obtained by galleries, cut as far as possible in the sandstone stratum. The water to be pumped from the reservoirs by steam-engines and conveyed through iron pipes to the different quarters. The reservoirs to be covered over by the engine-rooms, and other buildings, to prevent evaporation, and to preserve the water pure."

The patient, however, who was complaining not of having too much but too little water in his system, declared his symptoms were not dropsical, and accordingly refused to undergo the operation of tapping on such a large scale, so that the scheme, in spite of its ingenuity, fell to the ground.

On account of this obstinacy on the patient's part, the Government got into a more nervous and fidgetty state than ever, and, having apparently determined that the whole responsibility should not rest with them, they passed a Resolution on the 24th of September 1845, directing the attention of the Court of Petty Sessions to the subject, and requesting them to consider the "measures to be taken for husbanding the supply of water, and for keeping it pure and wholesome."

The recommendations of the Court of Petty Sessions.

The nostrum of the Court of Petty Sessions was an exceedingly mild one. They recommended that, in order to prevent waste, the tanks in the town should be guarded by peons; that a solitary spring, which there was at the Cooperage, should be 'reported' on; that the shipping should be made to water at Elephanta or Salsette; and, of all things in the world, that the Government should issue a proclamation which was practically to the effect that the people should not drink more water than was good for them, and that they were not to spill more in the act of drinking than they could possibly help. The people were to be allowed to carry away as much as they chose, but, having got it into their houses, they were to take great care of it. The Government of those days must have had wonderful faith in human nature, if they supposed that a man, having taken the trouble to convey a certain quantity of water to his house, would be influenced in his use of it away from the surveillance of the outer world and by a proclamation!

Captain Turner's Project. 1846.

However, this advice to the patient not to drink more than was good for him, while all the time he was dying of thirst, was of no use. In spite of the Proclamation, he still cried out for water, and the authorities seem to have considered the cry not an unreasonable one, for, on the 21st March 1846, the Civil Architect of the Presidency, Captain T. M. B. Turner, of the Engineers, acting under the instructions of the Chief Engineer, submitted a new project. This was to intercept the rain falling—1st, on a portion of that side of Malabar Hill which faces Back Bay; 2nd, on the hill near that on which the Parsee Tower of Silence stands; and 3rd, on some ground lying directly north of the Gwalia Tank.* Having intercepted the rain, Captain Turner proposed to lead it into a reservoir 400 feet square to be built close to the Gwalia Tank. The total supply calculated to be obtained from this project, which was probably intended for only a portion of the town, was 29,000,000 gallons, or, as Captain Turner put it, sufficient at the rate of five gallons a day for 62,222 people during 90 days.

But this proved of no use. The attraction of five gallons per head per diem was not enough to reconcile the patient to a sudden death after three months. In fact, the prospect of a short life and a merry one did not suit him at all, for he cried out louder than ever, and so the crisis continued.

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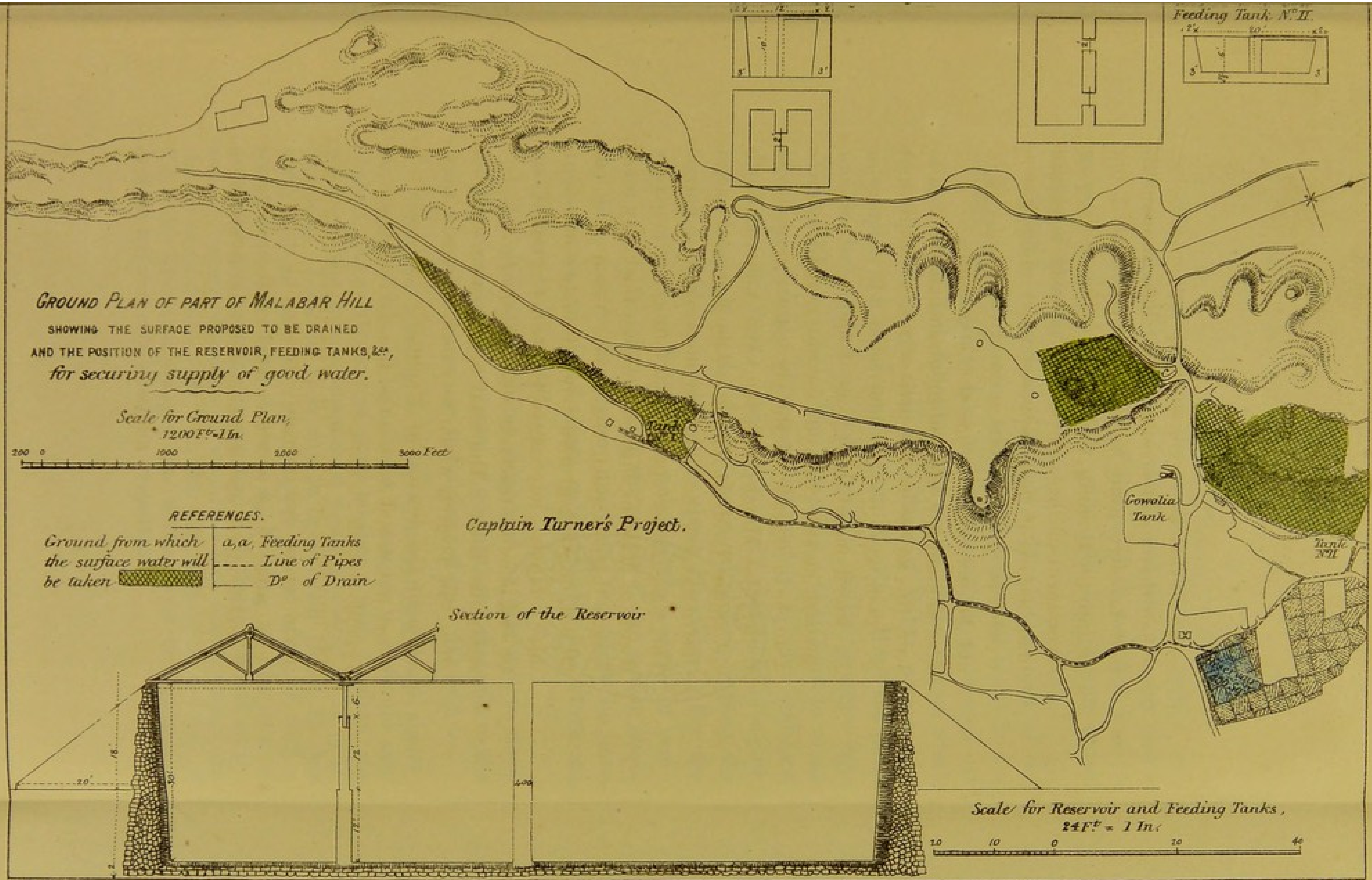
* *Vide* Plate I.


GROUND PLAN OF PART OF MALABAR HILL
SHOWING THE SURFACE PROPOSED TO BE DRAINED
AND THE POSITION OF THE RESERVOIR, FEEDING TANKS, &c.,
for securing supply of good water.
Scale for Ground Plan, 1200 Ft. = 1 In.
200 0 1000 2000 3000 Feet
REFERENCES.
Ground from which the surface water will be taken
a, a, Feeding Tanks
Line of Pipes
Do. of Drain
Captain Turner's Project.
Section of the Reservoir
Feeding Tank No. II.
Gowalia Tank
Tank No. II
Scale for Reservoir and Feeding Tanks, 24 Ft. = 1 In.
20 10 0 20 40
T. M. Rozario.
B.E.S. Press.

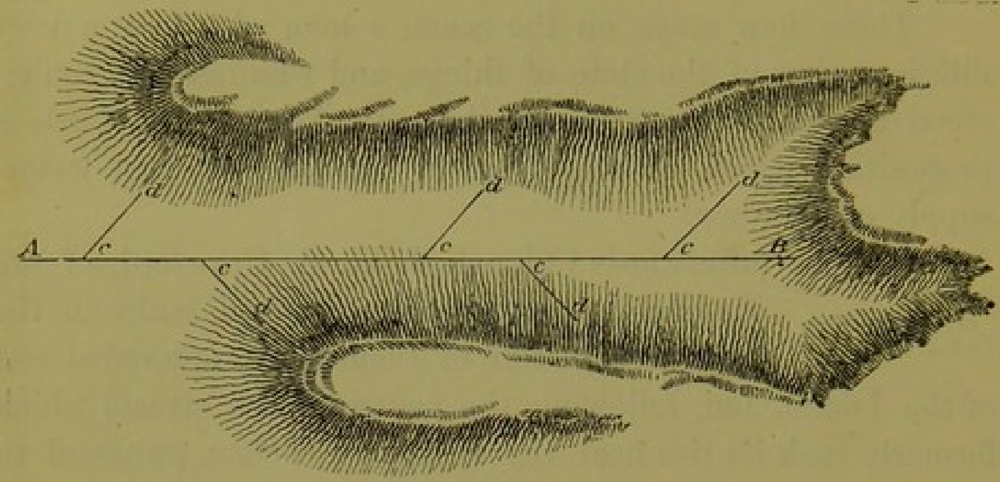
There now steps on the scene a man who took a very different view of the state of things, and who not only understood the alarming nature of the patient's case, but made a proposition which ultimately grew into the present water-supply of Bombay.

Captain Crawford's First Project.

Captain (afterwards Colonel) J. H. G. Crawford, of the Engineers, leaving the wells and tanks in the town to take care of themselves, proceeded out of the Island, and, following the course of the stream which formerly took its rise near the village of Vehar, proposed to intercept it at a point not far from Koorla. Here the water was to be pumped up and brought under pressure into Bombay by iron pipes. The dam was not to be built to retain any large quantity of water, but merely to give sufficient depth to pump from. This supply every year could of course last so long only as the stream continued to flow, or from the setting in of the monsoon up to about December. For the supply of the town during the other months a series of reservoirs were to be formed along the course of the stream above the dam, and, as the stream dried up, the water in these reservoirs was to be led down to the lowest one where the pumps were to be placed.

An alternative scheme suggested by him was to drain the Koorla valley by a system of underground channels to the point where the water was to be pumped up. He said:—

"Suppose a valley, as in the accompanying rough sketch, the nature of the soil being what I imagine it, I should sink a shaft (A) at the lowest point whence I wish to draw my water—in the present instance it would probably be 15 or 20 feet deep. I should then run an open drain (A B) 2½ feet wide, and as deep as circumstances would admit of, with a slight slope downwards towards A, building up the sides if necessary, and covering the surface with flagstones and earth; and at certain distances I would in like manner open the shorter cross drains (*c d*). In this way, looking at the bed of the valley as a vast sponge, the whole would be thoroughly drained without any loss from evaporation."



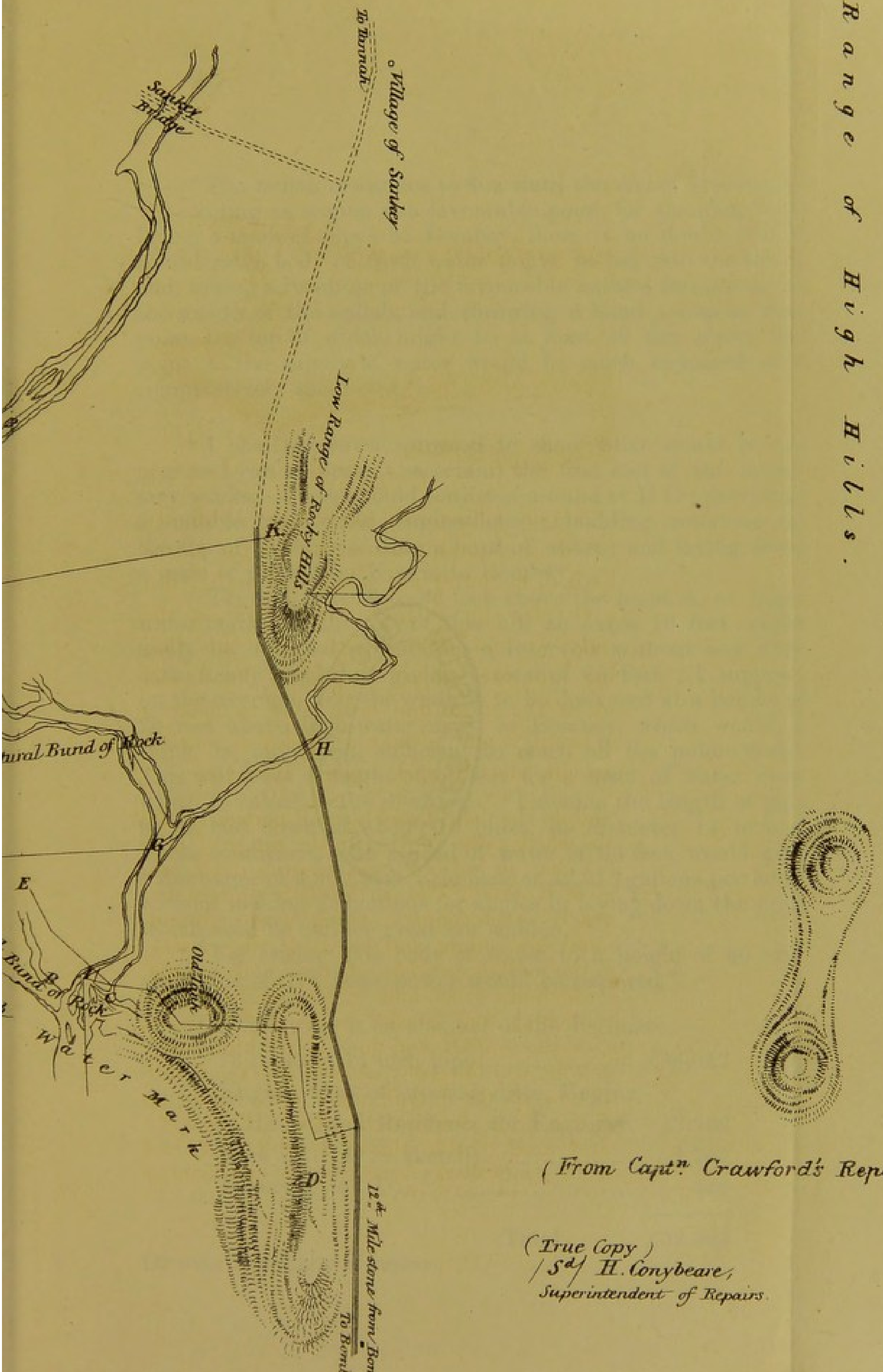
Captain Crawford's Second Project.

Captain Crawford's suggestions evidently attracted considerable attention, for the Board of Conservancy, to whom his letter was submitted on the 16th May 1846, called at once for further information on the subject. Accordingly, we find, three months after this, that another report, going into the subject in greater detail, was prepared. He had in the meantime been able to make a rough survey of the country, and to take a few levels, so that he now had some specific facts to work upon. He wrote :—

"The sketch* exhibits the mouth, and a small portion of the course of the nullah, which takes its rise in the range of hills near the village of Vehar, in Salsette, and empties itself into the sea at the village of Koorla. The portion here represented flows through a nearly level country, partly waste ground, covered with trees and low jungle, and partly of rice cultivation. The bed of the nullah consists of rock and shingle, whilst the banks—which are 8, 10, and 12 feet high—are in places nearly perpendicular, and consist principally of earth. Across the mouth of the nullah, and just above high-water mark (B C), there is a natural bund of rock, which extends into the country on both sides of the nullah, and a little higher up there is another of the same description. The hill D is 70 feet above high-water mark; it is almost a solid rock, and conveniently situated for any works requisite for establishing a head of water.

. . . .

* *Vide* Plate II.



(From Captn. Crawford's Report)

(True Copy)
(Sd) H. Conybeare,
Superintendent of Repairs.

"The nullah continues to flow until the end of December. By erecting an engine at a favourable point for pumping, and laying a main of pipes to Bombay, there is no doubt that a considerable body of fresh water might be led into the town, and, taking advantage of the favourable natural formation, at the mouth of the nullah, and throwing a bund across at that point, the top of which might be at least 20 feet above the point A, the supply of water would be much increased at a comparatively small cost.

. . . .

"I shall, however, proceed to show what would be (as near as I can at present ascertain) the first cost of the necessary works. These would consist of a bund at B C; providing a suitable engine and engine-house; building reservoir on the top of D for procuring a head of water; and laying down a main of pipes from Koorla to Bombay.

"The hill D is 70 to 86 feet above the point A, or high-water mark; on the top of this hill an extra 10 feet might easily be obtained in building a reservoir without any very extra heavy cost, thus giving a total of 80 feet. I suppose, on the average, that the water is to be delivered at a height of 20 feet above high-water mark in Bombay, which would, I think, be more than sufficient to reach all the public tanks. This will leave a height of 60 feet for a head of water upon which to calculate the discharge. I assume the length of pipe to be laid down at about 10 miles, its diameter 14 inches. These conditions, with a head of water of 60 feet, would give a discharge of 6,992,542 cubic feet, or 43,575 gallons per hour, without making deductions for angles in laying down the pipe, which need be neither great nor sudden.

"For raising this body of water to a height of 80 feet, an engine of 176 horse-power would be required."

The following is an abstract of the Estimate:—

13 miles of 14-inch pipe	£36,023
Engine, Cost of erecting ditto, Engine House, and Residence for Engineer.	13,900
Dam (at B C in sketch)..	1,700
Reservoir (at D).............	440
Total.........	£52,063

Or over five lakhs of rupees.

Colonel Jervis resuscitates his Scheme. 1848.

The alarming symptoms which the patient exhibited in 1845 and 1846, must have temporarily subsided, for nothing of importance seems to have been done in 1847. In 1848, however, the symptoms revived, and we accordingly find the public mind again in a ferment. In the month of May the Chief Engineer, Lieutenant-Colonel George Jervis, resuscitated his scheme ot tapping the water-bearing strata in the island, but, before carrying it out on a large scale, he proposed :—

"That Government be solicited to sanction the construction, in some convenient site on the northern boundary of the Esplanade, of a circular cut-stone well or reservoir, with one or two tunnels cut into the sandstone formation of the Esplanade as feeders to the reservoir, 100 yards in length, 6 feet broad, and 15 feet deep, or more if practicable ; the tunnels to be filled to within 6 feet of the surface with loose rubblestone, with a covering of rough stone slabs, levelled to the surface, with the soil excavated."

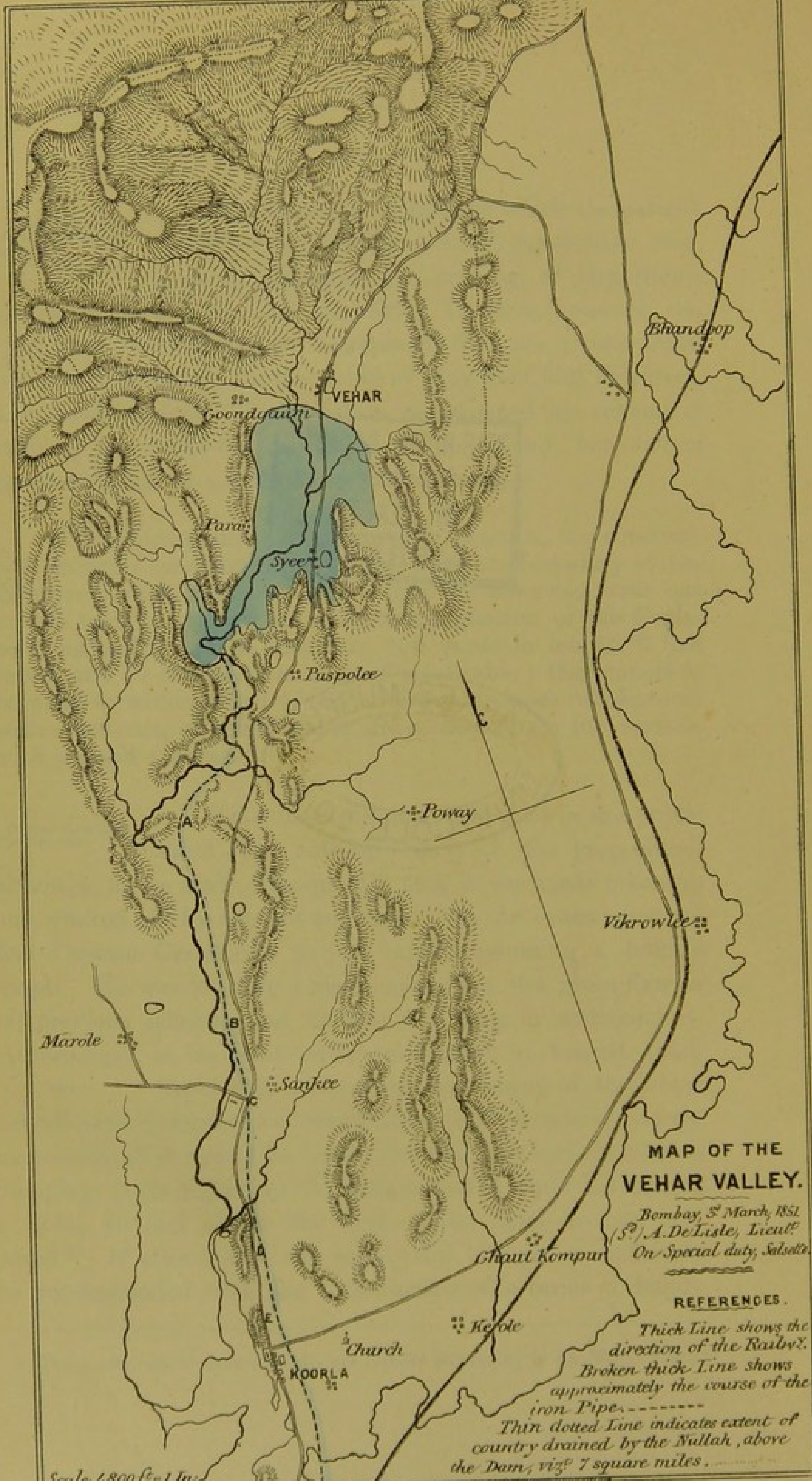
Captain Crawford's Third Project.

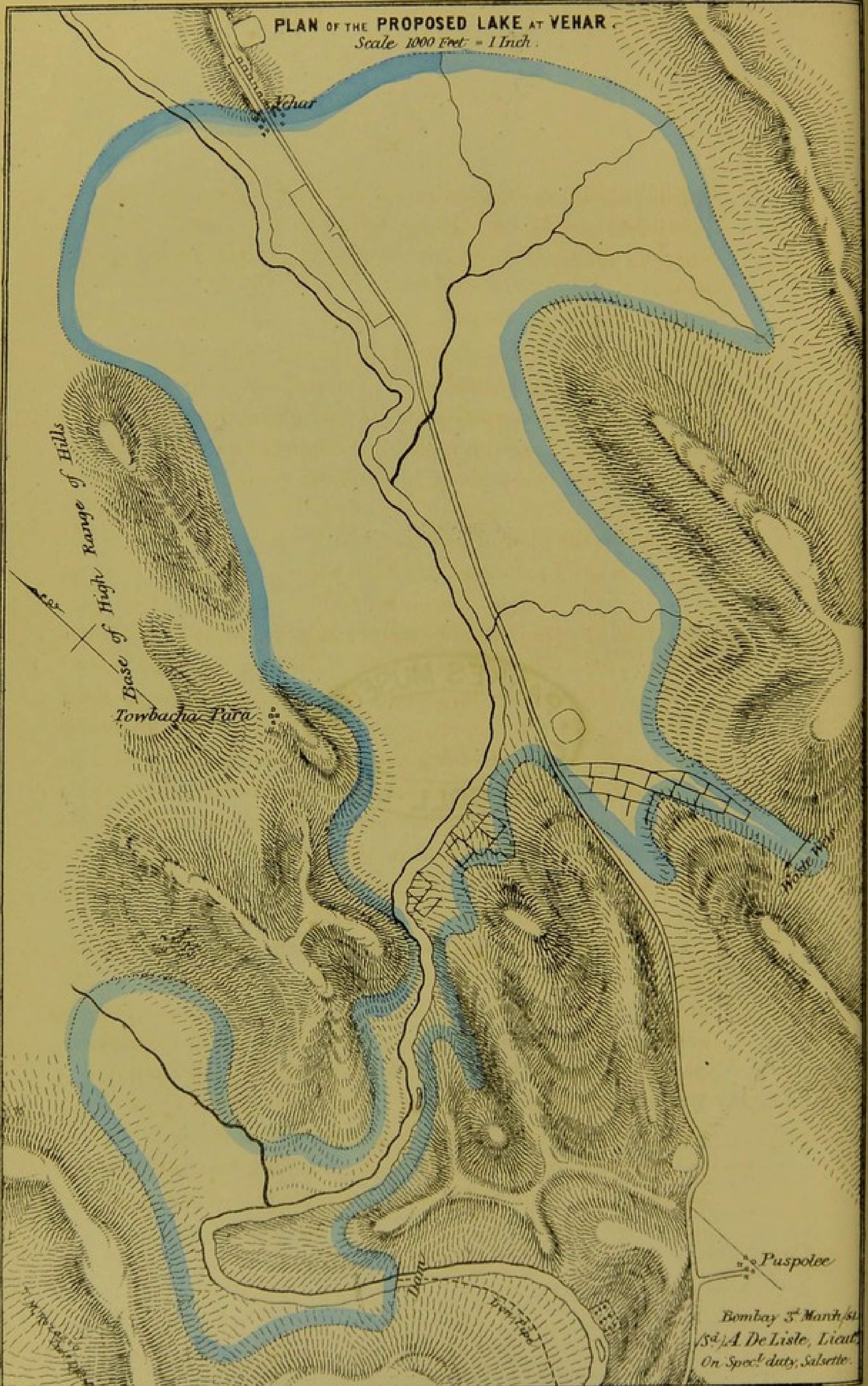
This idea did not take root in the public mind, for nothing came of the proposition, although, as we shall subsequently find, it was again taken up and worked out by another engineer. On the other hand, we find Captain Crawford's project rapidly assuming a definite shape. He was too able a man not to see the great flaw in his previous schemes, and he was not long in rectifying it. Accordingly, in his next report, submitted in August 1850,

1850.

instead of advocating the raising of the water near Koorla by mechanical contrivances to the height of 80 feet, he considered it would be better, in order to avoid the cost of pumping, to go higher up the stream and to build his dam at a point 80 feet above the level of the bund he first proposed.* If after a time the supply did not prove sufficient, he recommended that the construction of a series of bunds

* The reader will observe that we are rapidly advancing to the Vehar Lake.


VEHAR
Goondgaum
Para
Syee
Puspolee
Poway
Bhandoop
Vikrowlee
Marole
Sankee
Chaul Kompur
Kerole
Church
KOORLA
A
B
C
D
E
MAP OF THE
VEHAR VALLEY.
Bombay, 3rd March, 1851.
(Sd) A. De Lisle, Lieut.
On Special duty, Salsette.
REFERENCES.
Thick Line shows the direction of the Railwy.
Broken thick Line shows approximately the course of the iron Pipe.
Thin dotted Line indicates extent of country drained by the Nullah, above the Dam, vizt 7 square miles.
Scale 4,800 ft = 1 In.
Mile 1 3/4 1/2 1/4 0 1 Mile


PLAN OF THE PROPOSED LAKE AT VEHAR.
Scale 1000 Feet = 1 Inch.
Vehar
Base of High Range of Hills
Towbacha Para
Waste Weir
Dam
Puspolee
Bombay 3rd March/51.
Sd/ A. De Lisle, Lieut.
On Specl. duty, Salsette.

still higher up the stream should be undertaken, and, if even this failed to meet the demands of the town, then that the water in the lower part of the valley should be utilized by the help of pumps.

And now we find associated with the originator of the present water-supply of Bombay another able man to whom Captain Crawford entrusted the working out of his ideas. So satisfactory indeed was the manner in which Lieutenant (now General) De Lisle prepared the scheme, that not only did Colonel Crawford speak of him in high terms, but, finding his own original idea open to objection, he at once and finally abandoned the plan of pumping the water at Koorla.

Lieutenant De Lisle's Report on Captain Crawford's Project. 1851.

It is in Lieutenant De Lisle's Report, submitted so far back as March 1851, that we first meet the proposition distinctly put forward to construct a reservoir at Vehar. The accompaying plans,* which are copies of portions of two of those submitted with his Report, cannot fail to convince the reader that the present works are merely the embodiment of Captain Crawford's ideas. Here we have the lake not covering exactly the area occupied by the present one, but covering the greater portion of it. Here we have the dam not precisely in the position of the present main dam, but close to it. And here we have the line of iron pipes connecting the lake with the town.

Lieutenant De Lisle's reservoir with a dam about 50 feet high was to impound in round numbers 1,000,000,000 gallons, and he proposed, in the event of this supply not proving sufficient, to raise the dam ten feet higher, and thus to obtain double the above quantity. He assumed a yearly rain-fall of 76 inches, of which 16 inches would be lost by evaporation, absorption, &c., and of which the remaining 60 inches would be available over an extent of gathering ground of seven square miles. On these data the quantity of water flowing

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* *Vide* Plates III and IV.

into and falling on the lake would amount to 6,000,000,000 gallons, or six times the quantity required to be impounded by the 50-feet dam. The water was to be brought into the town under pressure by a cast iron pipe 24 inches in diameter and 14½ miles long. The cost of the works was calculated thus :—

Pipes	£102,080
Dam, Waste Weir, Delivery Reservoir, and Conduits......................	15,000
Contingencies, &c........................	2,920
Total....................	£120,000

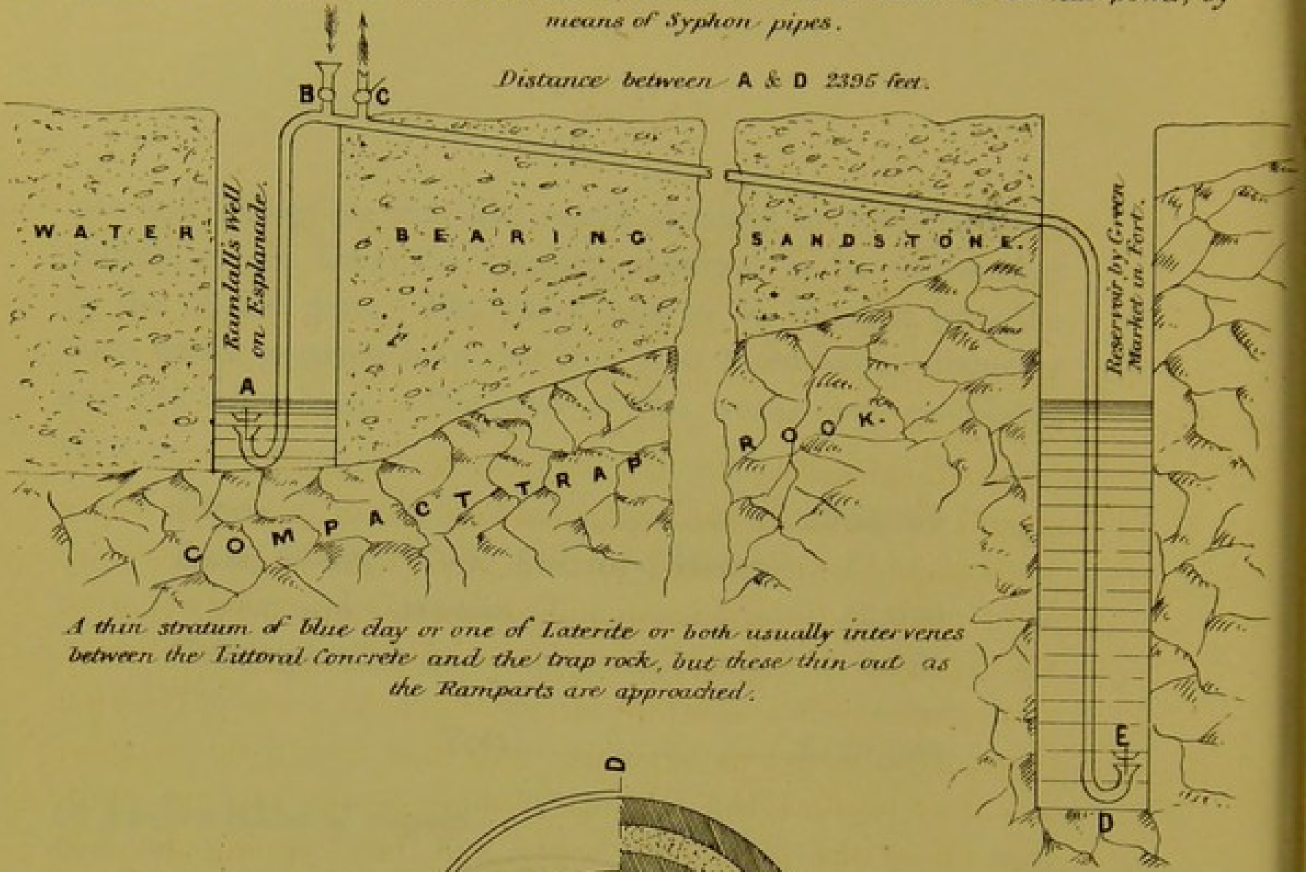
Or twelve lakhs of rupees.

In a Resolution passed on the 26th April 1851, the Government thanked Captain Crawford and Lieutenant De Lisle in handsome terms for their labours, but called for more information on certain points.

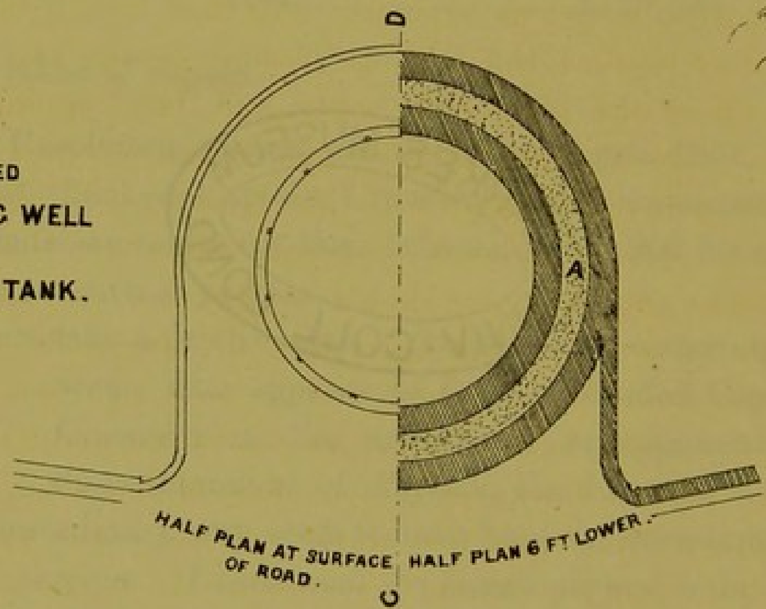
Mr. Conybeare's First Project. 1852.

We now take a further step. Another man comes on the scene, who appears to have succeeded Captain Crawford in the anomalous appointment of Superintendent of *Repairs*, the duties of which in some extraordinary way seem to have been the investigation of *original projects*. Lieutenant De Lisle's papers were forwarded to Mr. Henry Conybeare for report, who, in December 1852, submitted a carefully prepared memorandum on the subject. Although admitting that Lieutenant De Lisle's surveys had demonstrated the practicability of ponding up in the Vehar valley a body of water apparently sufficient for the supply of Bombay at the rate of 20 gallons per head per diem, he was of opinion that, owing to the preliminary nature of these surveys, no sufficient data existed for determining the cost at which the supply could be made available to the town. He recommended that accurate surveys should be made, but at the same time he put forth a scheme of his own which the

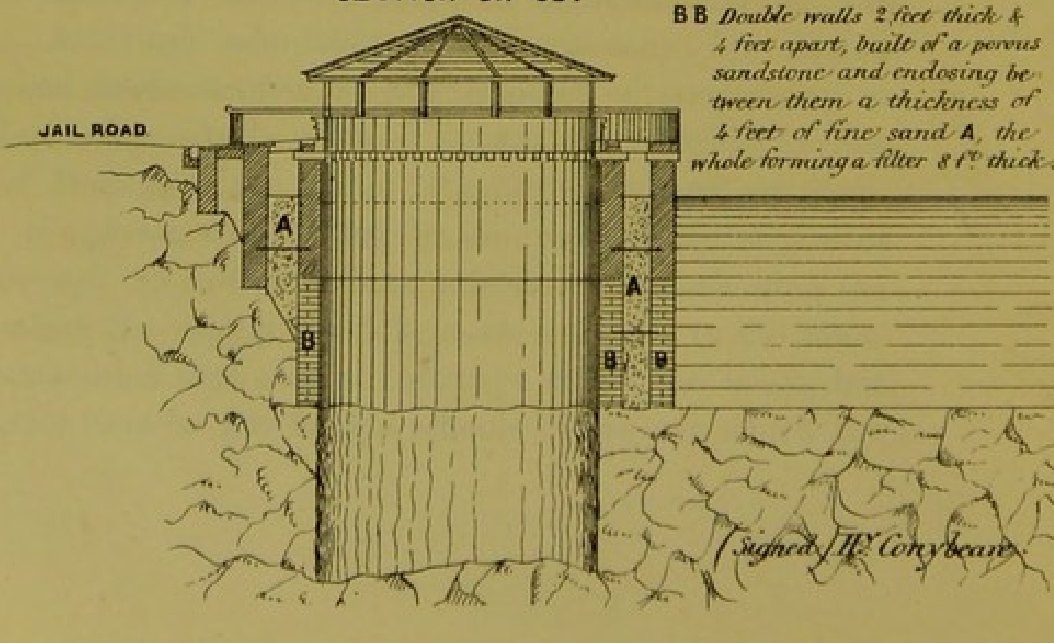
DIAGRAM *of arrangement by which the water of the Sandstone or Littoral Concrete formation might be transferred to distant and waterless localities, without the use of Steam or animal power, by means of Syphon pipes.*



PROPOSED
FILTERING WELL
IN
BABOOLA TANK.



SECTION ON CD.



reader will recognise as similar in its main idea to that suggested years before by Colonel Jervis.

Mr. Conybeare was of opinion that, water obtained from surface collection being unfit for drinking until filtered, the springs in the littoral concrete formation in the Island should be made available to the town. He proposed that wells should be built in the water-bearing strata, and that these wells should be connected by iron pipes with large reservoirs to be made in the solid trap underlying the superficial deposits. He thought that these reservoirs would be kept filled with water running in a constant stream from the wells. The iron pipes were to act as syphons. All that would be required would be to start the syphons by first closing the two ends, then filling the pipes with water, and then opening the ends again. The accompanying sketch,* which is copied from some of the plans submitted with his Report, will illustrate the project. Mr. Conybeare proposed, moreover, that many of the tanks and reservoirs should be roofed over, and that they should be supplied with water from filtering wells. The sides of these wells were to be "double walls two feet thick and four feet apart, built of a porous sandstone, and enclosing between them a thickness of four feet of fine sand, the whole forming a filter eight feet thick." Besides the supply to be obtained from the littoral concrete in the Island of Bombay, Mr. Conybeare also suggested that the spring-bearing strata in Salsette should be thoroughly examined before recourse was had to surface collection.

The Board of Conservancy on the Water-supply of Bombay. 1853.

Fortunately this old idea was not carried out. The Board of Conservancy, in forwarding Mr. Conybeare's Report to Government, took an altogether different view of the subject. They expressed doubts as to whether a sufficient quantity of water could be obtained in the Island in the

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* *Vide* Plate V.

manner proposed by him, and they added that, even if it could be so obtained, it would require to be sent into the town at great expense and from many sources. They were of opinion also that none of the water in the public tanks excepting only one "could be considered wholesome—that they were all more or less filled by drainage, at the best of times impure and subject to the taint of a large town." They pointed out, moreover, that late in the season the quantity of water in many wells was not a quarter of what it was at the beginning, and that Mr. Conybeare had made a mistake in supposing that so many wells were available to the public, the fact being that a great number of those which he had mentioned for use were private property. Regarding the proposition that the spring-bearing capabilities of Salsette should be investigated, the Board said that "any water which might be derived from springs would be found to be, if not below high-water mark, at so low a level that the water would require to be forced up by machinery." They were "of opinion that a great additional supply of water was required for the health and comfort of the inhabitants, and that such supply could be best obtained from the valley of Gopur, and in the manner proposed by Captain Crawford and Lieutenant De Lisle.

The letter from the Board of Conservancy had its effect.

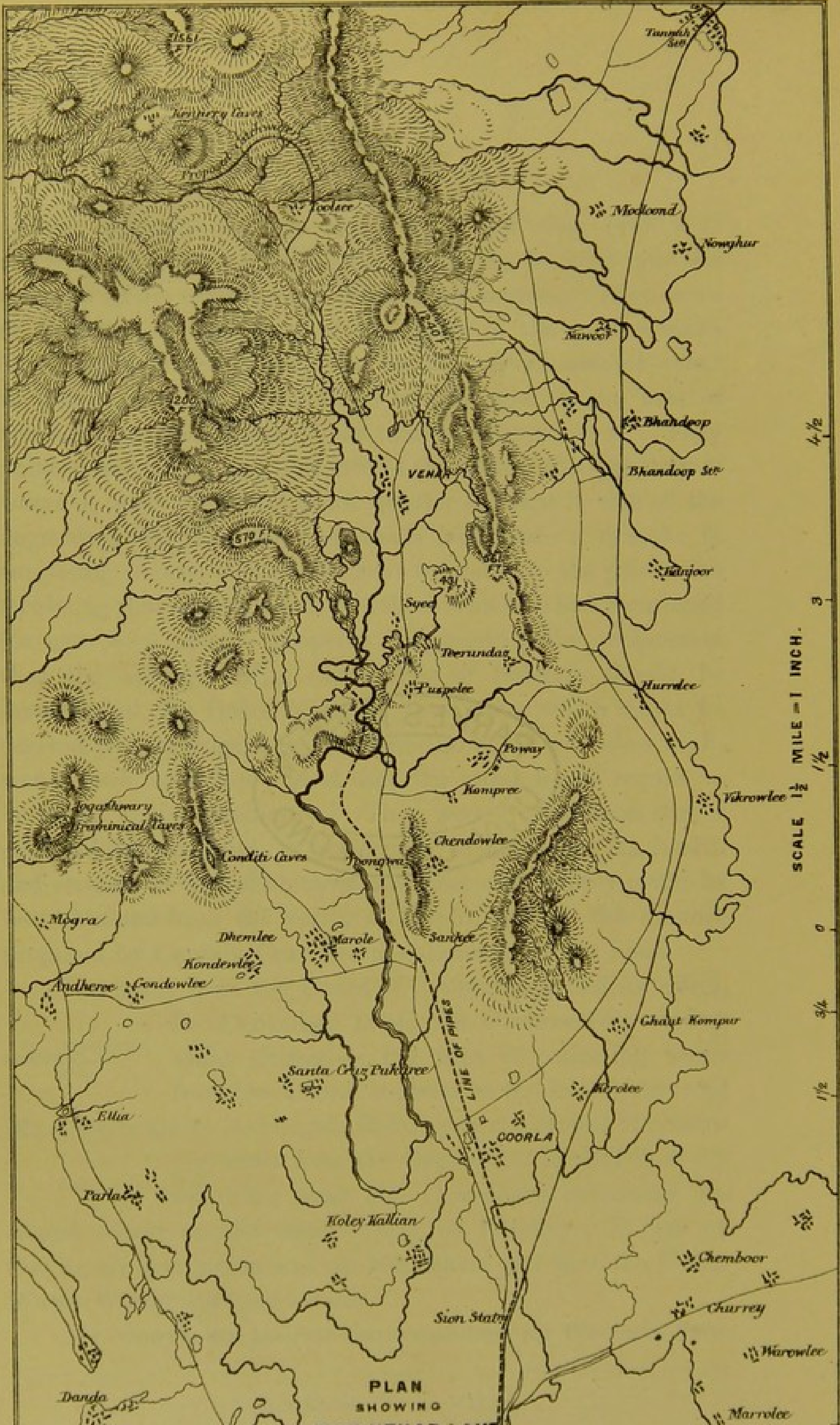
Mr. Conybeare's Second Project. 1854.

In December 1854, the Government, setting aside altogether the idea of collecting water from the littoral concrete in the Island, directed Mr. Conybeare to investigate thoroughly the project of obtaining water from the Gopur, and in March of the following year Mr. Conybeare submitted his second report on the water-supply of Bombay. It was on this report that action was at last taken, and that the Vehar Water Works were carried out.

1855.

Mr. Conybeare pointed out two sites* for the main dam,

* *Vide* Plates VI. and VIII.



T. M. ROSARIO, LITH. DRAFTSMAN

one of which is identical with the site proposed by Lieutenant De Lisle, and the other higher up the valley, where in fact the present main dam stands. As no observations regarding the rain-fall in the Vehar valley had ever been taken, he was compelled to approximate to it from the rain-fall at the Colaba Observatory and at Tannah, which town is 5½ miles only from Vehar. On these data he reckoned that certainly 100 inches at least fell yearly on the gathering ground, and possibly as much as 124 inches. He assumed, moreover, that six-tenths of this would be collected. The following facts may be gathered from his report :—*

	Area of gathering ground.	Six-tenths of 100 inches on gathering ground.	Six-tenths of 124 inches on gathering ground.
	Acres.	Gallons.	Gallons.
Small Reservoir	3,948	5,358,737,260	6,644,834,187
Large Reservoir	4,682½	6,355,211,091	7,880,461,734

* Mr. Conybeare's levels of the contours of the lake and of the embankments were referred to what he called "Puspolee Datum"—*i.e.*, the bed of the Gopur stream at the site of the lower dam. All the levels below this point were referred to the "Poydonee Datum"—the kerbstone of the platform of the Poydonee reservoir in the heart of the native town in Bombay. The Puspolee and Poydonee Datums with reference to Town Hall Datum are 171·83 and 89·83 feet respectively.

Mr. Conybeare says in his report that Poydonee Datum is 92 feet below Puspolee Datum, and he adds that it is 3·11 feet above high-water mark. Several careful series of levels show that Puspolee Datum is 171·83 feet on Town Hall Datum. This is correct to within six inches, probably correct to within one. Poydonee Datum therefore should be (171·83—92) 79·83 feet on Town Hall Datum. But this, so far from being 3·11 feet above high-water mark, as mentioned by Mr. Conybeare, is a little below mean sea level. I feel persuaded that 92 is a misprint in Mr. Conybeare's report for 82. If it is, then Poydonee Datum would just be about 3 feet above high-water mark.

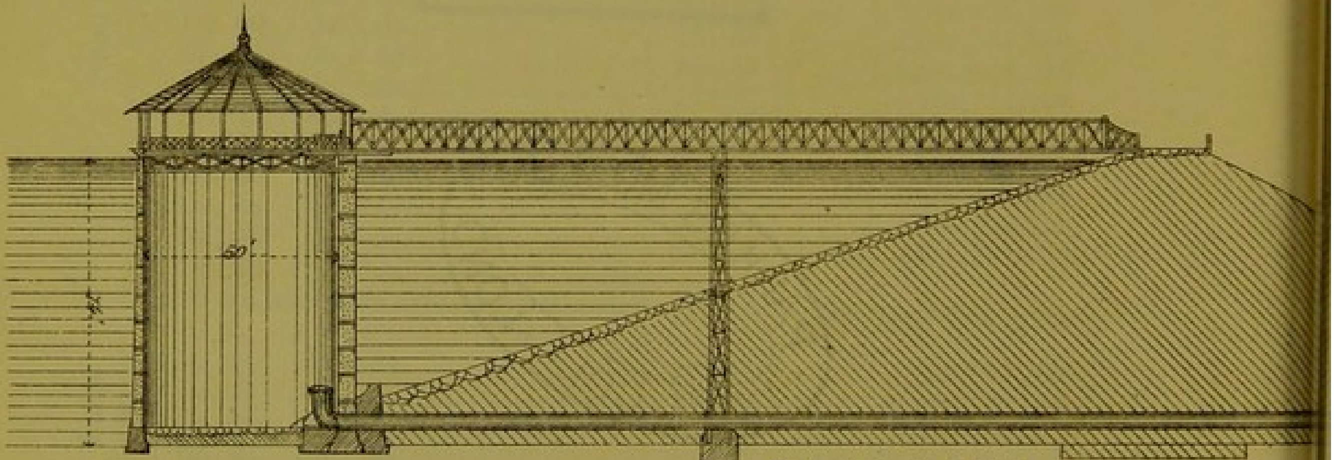
It has cost me days of labour to ascertain what should be clear from the working drawings, but these contradict each other, and the original bench-marks are lost, so that I have been compelled to investigate the subject for myself. I mention these points because they have so much interest for the profession, and I wish to save my brother engineers, should they ever have occasion or the wish to consult the original plans, all the labour I have gone through.

		Reduced to Town Hall Datum.	Area of Lake in Acres.	The Reservoir contains in Gallons.
Small Reservoir.	Up to 32 feet above Puspolee Datum (about four inches above the level of the lip of the lowest inlet pipe—*i.e.*, about the lowest level at which water could be drawn from the lake).	203·83	..	168,713,974
	Do. 36 do. do.	207·83	...	298,285,505
	Do. 40 do. do.	211·83	...	497,701,627
	Do. 44 do. do.	215·83	...	779,737,068
	Do. 48 do. do.	219·83	...	1,159,660,328
	Do. 52 do. do.	223·83	...	1,641,860,106
	Do. 56 do. do.	227·83	...	2,215,687,185
	Do. 60 do. do.	231·83	...	2,881,141,640
	Do. 64 do. do.	235·83	...	3,632,668,316
	Do. 68 do. do.	239·83	...	4,464,711,984
	Do. 72 do. do.	243·83	...	5,377,272,680
	Do. 76 do. do.	247·83	...	6,391,022,435
	Do. 80 do. do.	251·83	1,102	7,526,633,254
	Do. 84 do. do.	255·83	1,214	8,784,105,511
	Do. 85 do. do.	256·83	1,242	9,117,514,470
	Do. 90 do. do. (about 8 inches below the level of the present waste weir)	261·83	1,400	10,800,000,000*
Large Reservoir	Do. 31 do. do.	202·83	...	353,000,000
	Do. 72 do. do.	243·83	...	6,950,132,838
	Do. 80 do. do.	251·83	1,319	9,553,421,335
	Do. 84 do. do.	255·83	1,440	11,051,351,036

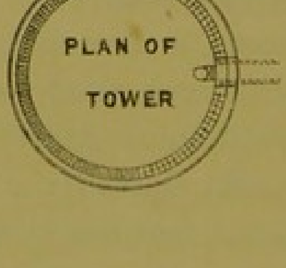
Mr. Conybeare recommended the higher site for the reservoir—that the main dam should be where it now stands—and that it should impound 85 feet depth of water. The advantages of the lower site were that it afforded both a larger extent of gathering ground and a greater storage capacity, but these could not have been secured without the construction of four dams, two of which would have been very expensive works. The upper site, although offering a somewhat less extent of gathering ground and less storage capacity,

* This last capacity, which is the most important of all, is not given in Mr. Conybeare's Report, but is taken from a paper read by him before the Institution of Civil Engineers. *Vide* Vol. 17, page 560, *Proceedings of the Institution of Civil Engineers.*

METHOD PROPOSED BY MR. CONYBEARE
FOR FILTERING, AND DRAWING OFF, THE WATER
FROM THE VEHAR LAKE.



Scale 60 feet = 1 Inch.



necessitated the construction of but three dams, one of which only was a heavy work.

Mr. Conybeare pointed out that, if more gathering ground were required, it might be obtained by running open catch-water channels "along the western slopes of the hills both on the west and on the north of the reservoir." *

He also discussed the question of earthen and masonry dams, and decided for the former chiefly on the consideration of cost.†

For the escape of the surplus water he proposed a waste weir 340 feet long situated alongside of the main dam (the site of the present weir).‡ The water was to be delivered by cast-iron pipes under pressure from Vehar, and the size of the main he proposed was 48 inches in diameter.

Mr. Conybeare recommended that the water should be filtered, and the accompanying sketch,§ with the following description of the filter, taken from his report, will explain the subject clearly:—

"The arrangement I propose . . . consists of a filtering tower 50 feet diameter inside, rising from the foot of the inner slope of the dam to the same height as the latter. It will be built of a highly porous littoral concrete, found along the west coast of the Island of Bombay and Salsette, and at many other localities along the Malabar Coast. At intervals of six feet there will be bond courses of Porebunder stone pavement in two thicknesses, breaking joint with each other. The floor of the tower will be paved with stone, and thence the main conduit pipe will take its course, its inlet being closed at will by a single sluice. Directly this sluice is opened, the level of the water in the tower will sink till the pressure is sufficient to force the water through the porous sides of the tower. I calculate that two or three feet difference of level will be sufficient for the purpose." ||

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* *Vide* Plate VI.

† This subject is fully treated in this Report, *vide* Chapter III.

‡ *Vide* Plate X. § *Vide* Plate VII.

|| It is fortunate that this plan was not carried out, for it is perfectly certain that a filter constructed on these principles would have stopped work

Forming part of Mr. Conybeare's Project was a Distribution Scheme for carrying the water by iron pipes to nearly all parts of the town. In most of the districts the delivery was to be on the "constant service" system, with all the modern conveniences of fire-plugs, stand-pipes, &c. The outlying villages were to be supplied by means of draw wells kept constantly full by small stoneware pipes or masonry conduits, in which the water was to be admitted from time to time through sluices in the main pipe so arranged as to deliver the water without pressure. Mahaluxmee, Malabar Hill, and Walkeshwar were to be supplied on the "intermittent system" during the night.

The cost of the works was estimated as follows :—

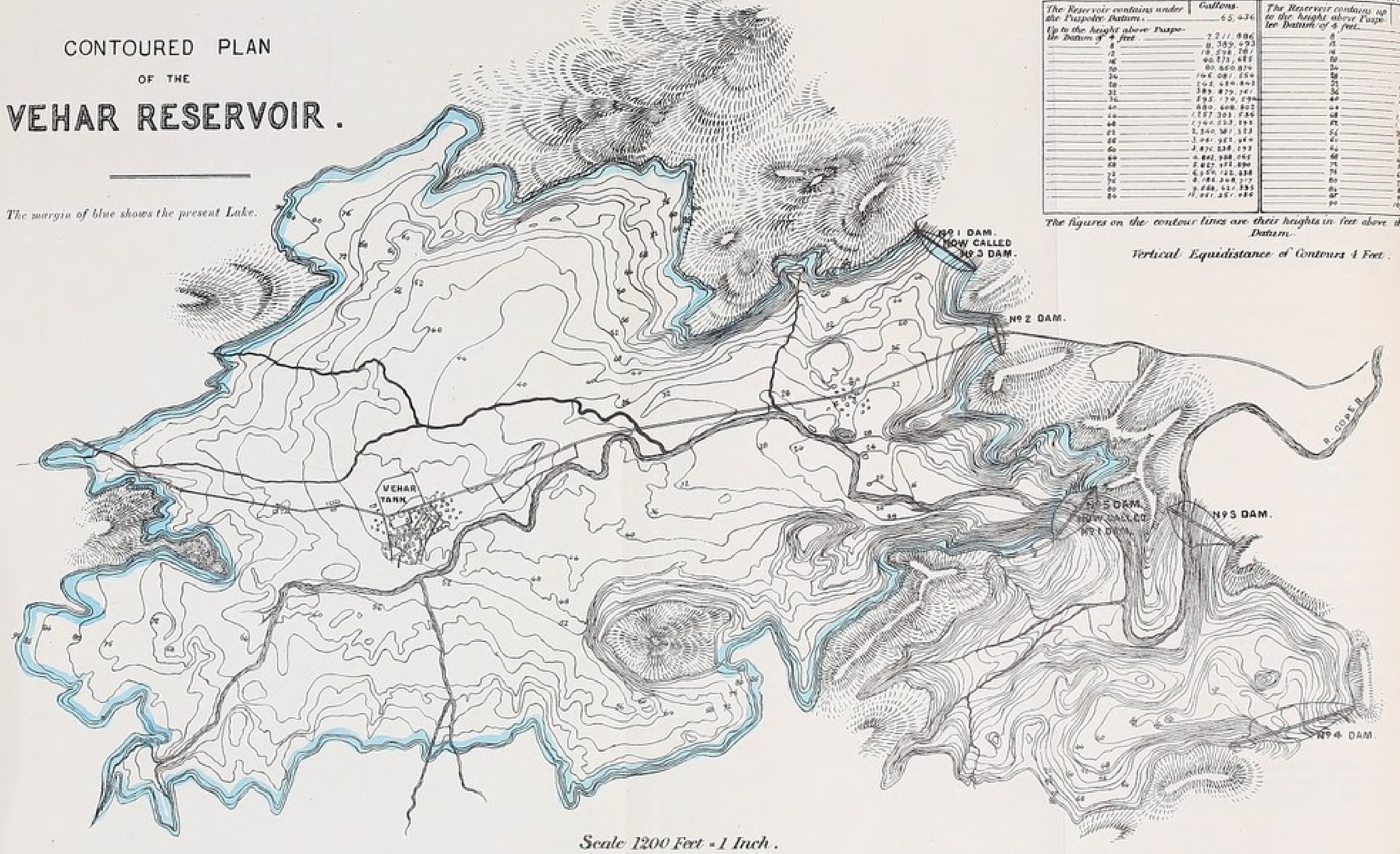
Dams and Waste Weir	£17,411
Catchwater Channel for extending the area of the gathering ground........................	5,000
Filters and other Works at Reservoir.........	4,302
Main Pipe	159,320
Town and Village distribution	48,173
	£234,206
Contingencies at 5 per cent.	11,710
Total...	£245,916

After Mr. Conybeare's project had been prepared, it was submitted to Captain (now Major) Crawford, and he, on the 20th April, 1855, gave his general approval to the proposed works. Mr. Conybeare was then despatched by the Government to England, where the designs for the Outlet Works were altered and some modifications were made in the plans. The pipes were selected and sent out under his directions. He never returned to India again. The contract was drawn

ing in a very short time from the pores of the stone becoming choked up. Every one who has used self-filtering goglets made of porous stone knows how admirably they answer at first, but how soon they lose all power to filter the water.

CONTOURED PLAN OF THE VEHAR RESERVOIR.

The margin of blue shows the present Lake.



Scale 1200 Feet = 1 Inch.

The Plan exhibits two alternative sites for the principal Dam across the Goper. One/Nº 3/ at Puspolee, the other/Nº 5/ at Syee. The contents of the Reservoir in each case would be as follows.

The Reservoir contains under the Puspolee Datum.	Gallons. 65,436	The Reservoir contains up to the height above Puspolee Datum of 4 feet.	Gallons.
Up to the height above Puspolee Datum of 4 feet	2,211,886	8	
8	8,389,493	12	
12	18,598,781	16	
16	40,873,685	20	[illegible]
20	80,850,874	24	[illegible]
24	106,081,554	28	[illegible]
28	243,490,843	32	[illegible]
32	389,879,761	36	[illegible]
36	595,170,59[illegible]	40	[illegible]
40	880,600,802	44	[illegible]
44	1,257,303,586	48	[illegible]
48	1,740,553,195	52	[illegible]
52	2,340,387,323	56	[illegible]
56	3,041,952,964	60	[illegible]
60	3,876,238,193	64	[illegible]
64	4,802,988,065	68	[illegible]
68	5,827,478,890	72	[illegible]
72	6,956,122,838	76	[illegible]
76	8,186,248,917	80	[illegible]
80	9,884,417,395	84	[illegible]
84	11,061,257,486	88	[illegible]
		90	[illegible]

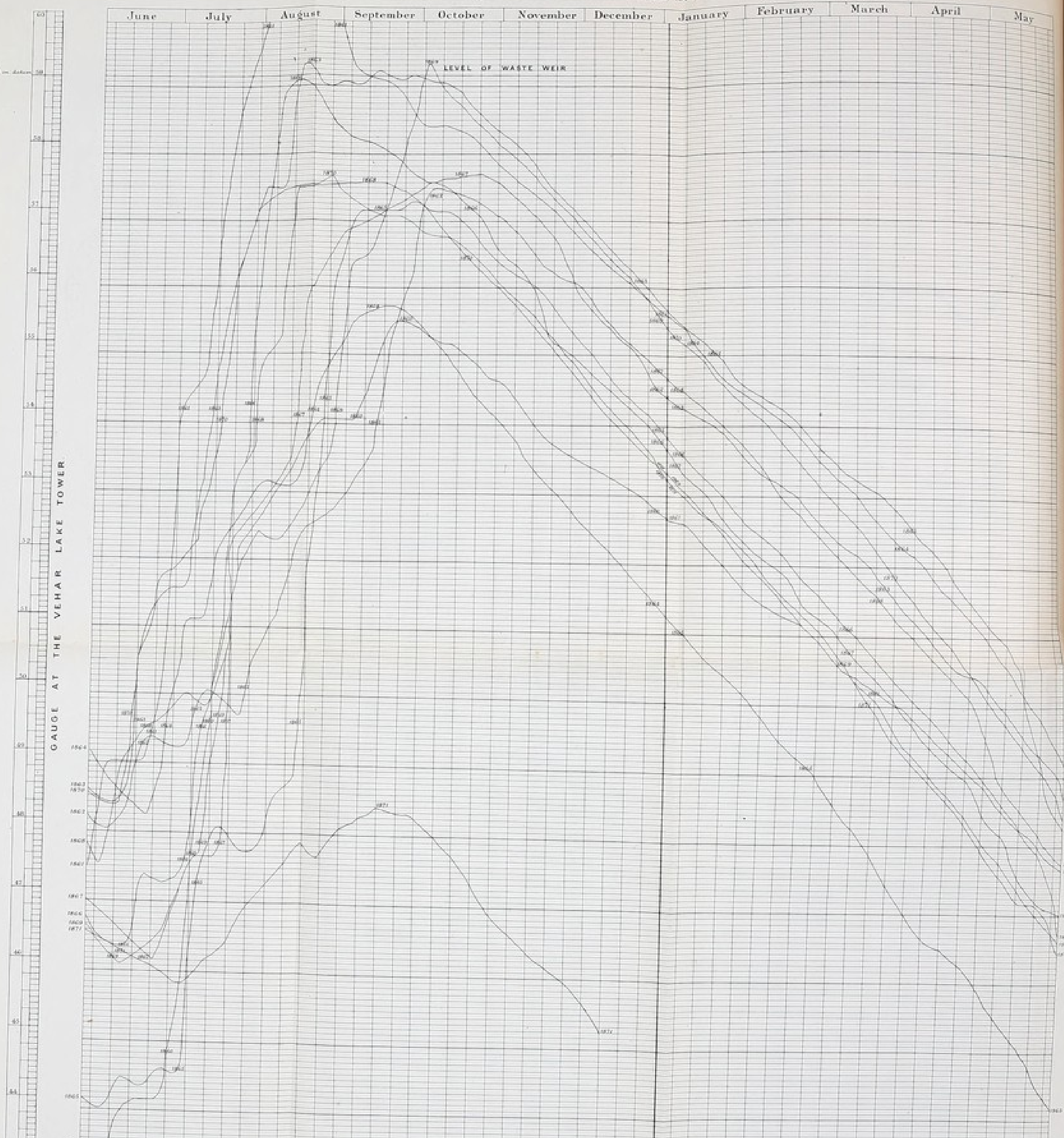
The figures on the contour lines are their heights in feet above the Puspolee Datum.

Vertical Equidistance of Contours 4 Feet.

VEHAR LAKE.

DIAGRAM SHOWING HEIGHTS OF WATER IN LAKE FROM JUNE 1860

Reservoir was completed in 1859 and overflowed in 1861, 1863, 1866 & 1869.



The Zero of Gauge, is the Lip of the lowest Inlet Pipe of the Water Tower which is 209 on Town Hall Datum.

This is taken from the plate in Mr Walton's report on the Toolsee Valley.

Kell Bros Lith., London.

out in England by the Honourable the Court of Directors, and was given by them to Messrs. Bray, Son, and Champney, of Leeds. Mr. Walker was appointed Resident Engineer, and Mr. Conybeare was made the referee for all disputes between the Government and the Contractors.

We now pass from the region of discussion to that of action. The Vehar project from an idea grows into a fact. It is necessary that I should describe the works as they were carried out.

The Present Water Works of Bombay.

The Vehar Lake,* covering an area of about 1,400 acres, and with a gathering ground, exclusive of the area of the water surface, of about 2,550 acres, is formed by three dams. Two of these were rendered necessary to prevent the water escaping over ridges on the margin of the basin, which were lower in level than the top of the main dam. The quantity of water supplied yearly by the reservoir falls considerably short of Mr. Conybeare's estimates,† and may be taken at about 8,000,000 gallons a-day, or at the rate of nearly ten gallons per diem per head of the present population. The level of the surface of the water when the lake is full—*i.e.*, the level of the top of the waste weir, is 262·50 on Town Hall Datum, and the average depth to which the surface sinks yearly is about 11½ feet or down to 251·00. The surface has sunk as little as 9 feet, as in 1863, and as much as 12 feet 9 inches, as in 1867. Last year (1871) there was a failure of the monsoon, and the consequence

* *Vide* Plates VI. and VIII.

† No blame should be attached to Mr. Conybeare for this. The yearly rain-fall at Vehar was unknown, and all he could do was to approximate to it from the only data at hand—viz., the rain-fall at Bombay and that at Tannah. It is remarkable that although most people would have argued as Mr. Conybeare did, and concluded that the rain-fall on a height like the Vehar Valley would have exceeded that at Tannah, still this is not the case. Mr. Conybeare, although of the above opinion, yet, to be on the safe side, took, as already mentioned, 100 inches as the average rain-fall at Vehar, 124 inches being that at Tannah. Even this moderate quantity is probably above the actual one—90 inches as well as I can make it out from the records. The records, though, are unreliable.

was that the level of the water fell in December to 248·50 on datum, six feet lower than it has ever been in that month.*

The arrangements for drawing off the water admit of this being done down to a depth of 59 feet, or to 203·50 on datum.† The total quantity of water contained between the level of the surface of the lake when full and the lowest level at which the water can be drawn off may be taken in round numbers at 10,650,000,000 gallons, and, as about 3,000,000,000 are used in the year, the quantity that would remain for use in the lake, supposing a failure of the monsoon, would, at the present rate of delivery, and allowing for evaporation, soakage, &c., be equivalent to about a two-years' supply.

All the Vehar dams are made of earth, and in form they are similar to those ordinarily built in England.‡ They have an exterior slope of 2½ to 1, and an interior slope of 3 to 1. The main dam, with a width at top of 24 feet, has a puddle wall along the middle. The other two dams were built without puddle walls.§ The surfaces of all the dams are

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* *Vide* Plate IX.

† It is difficult to say at what level *exactly* the mouth of the present inlet pipe is, but I take it to be at 31·67 on Puspolee Datum or 203·50 on Town Hall Datum. I come to this conclusion thus:—

There is a letter on record written by Mr. Mylott, the Resident Engineer's Assistant, who was on the spot, and who says in it that the water at 3 o'clock P.M., on the 24th June, 1857, was "six inches over the 32 feet-contour (Puspolee Datum), thereby flowing ten inches over the top of the lower inlet." Ten inches, or ·83 of a foot deducted from 32 feet 6 inches gives us 31·67 as the level of the inlet on Puspolee Datum. Now the waste weir I have ascertained by careful levels to be 262·50 on Town Hall Datum, and when the lake is full, the gauge fixed to the tower shows that there is 59 feet of water above the mouth of the inlet. The mouth of the inlet therefore must be (262·50 − 59) 203·50 on Town Hall Datum.

I should add that if, as I think, the inlet is 31·67 feet on Puspolee Datum and the waste weir is 59 feet above it, the waste weir must be at 90·67 on Puspolee Datum. All the working drawings show the waste weir at 90·00 on Puspolee Datum. I believe, therefore, that the weir was built about eight inches higher than was intended. I prefer to go by the emphatically distinct statement in Mr. Mylott's letter than by working drawings which, even if drawn correctly, might not have been rigidly adhered to.

‡ *Vide* Plates X. and XI.

§ It is in consequence of this chiefly, I suspect, that the repairs done to these dams in 1871 were required. In the working drawings puddle walls are shown in No. 2 and No. 3 Dams, but I have the best reasons for doubting whether what appears as puddle in them was so. *Vide* my "Report on the Vehar Lake Dams."

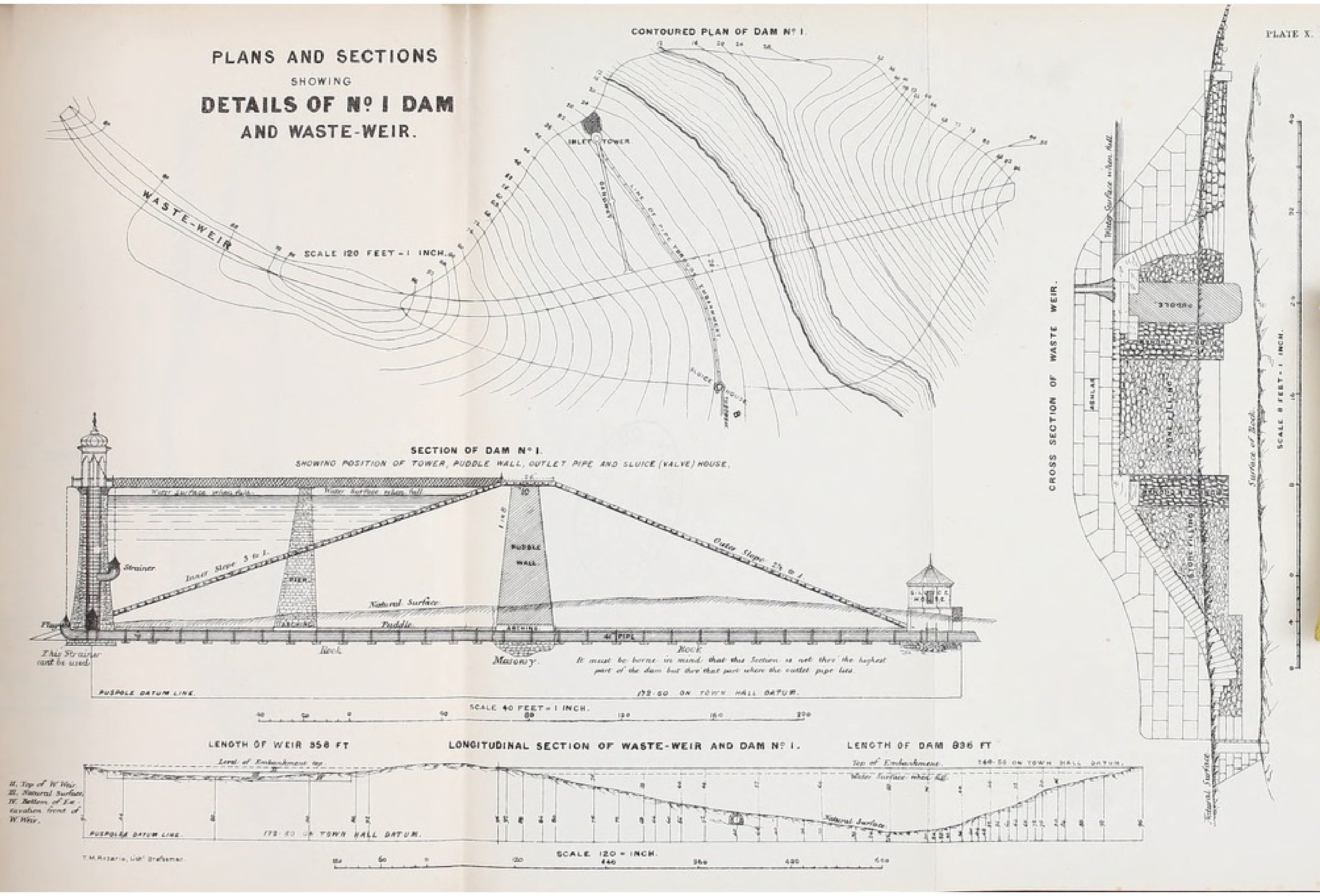


PLATE X.
PLANS AND SECTIONS
SHOWING
DETAILS OF Nº I DAM
AND WASTE-WEIR.
CONTOURED PLAN OF DAM Nº I.
WASTE-WEIR
SCALE 120 FEET = 1 INCH.
INLET TOWER
SLUICE HOUSE
SECTION OF DAM Nº I.
SHOWING POSITION OF TOWER, PUDDLE WALL, OUTLET PIPE AND SLUICE (VALVE) HOUSE.
Strainer
Inner Slope 3 to 1.
PIER
PUDDLE WALL
Outer Slope 2½ to 1.
Natural Surface
Puddle
ARCHING
Rock
Masonry
This Strainer can't be used
It must be borne in mind that this Section is not thro' the highest part of the dam but thro' that part where the outlet pipe lies.
PUSPOLE DATUM LINE.
172·50 ON TOWN HALL DATUM.
SCALE 40 FEET = 1 INCH.
LENGTH OF WEIR 356 FT
LONGITUDINAL SECTION OF WASTE-WEIR AND DAM Nº I.
LENGTH OF DAM 836 FT
Level of Embankment top
Top of Embankment
Water Surface when full
Natural Surface
SCALE 120 = INCH.
T. M. Rosario, Lith^r Draftsman
CROSS SECTION OF WASTE WEIR.
ASHLAR
PUDDLE
STONE FILLING
Surface of Rock
SCALE 8 FEET = 1 INCH.

PLANS AND SECTIONS SHOWING DETAILS OF No. 2 AND 3 DAMS.

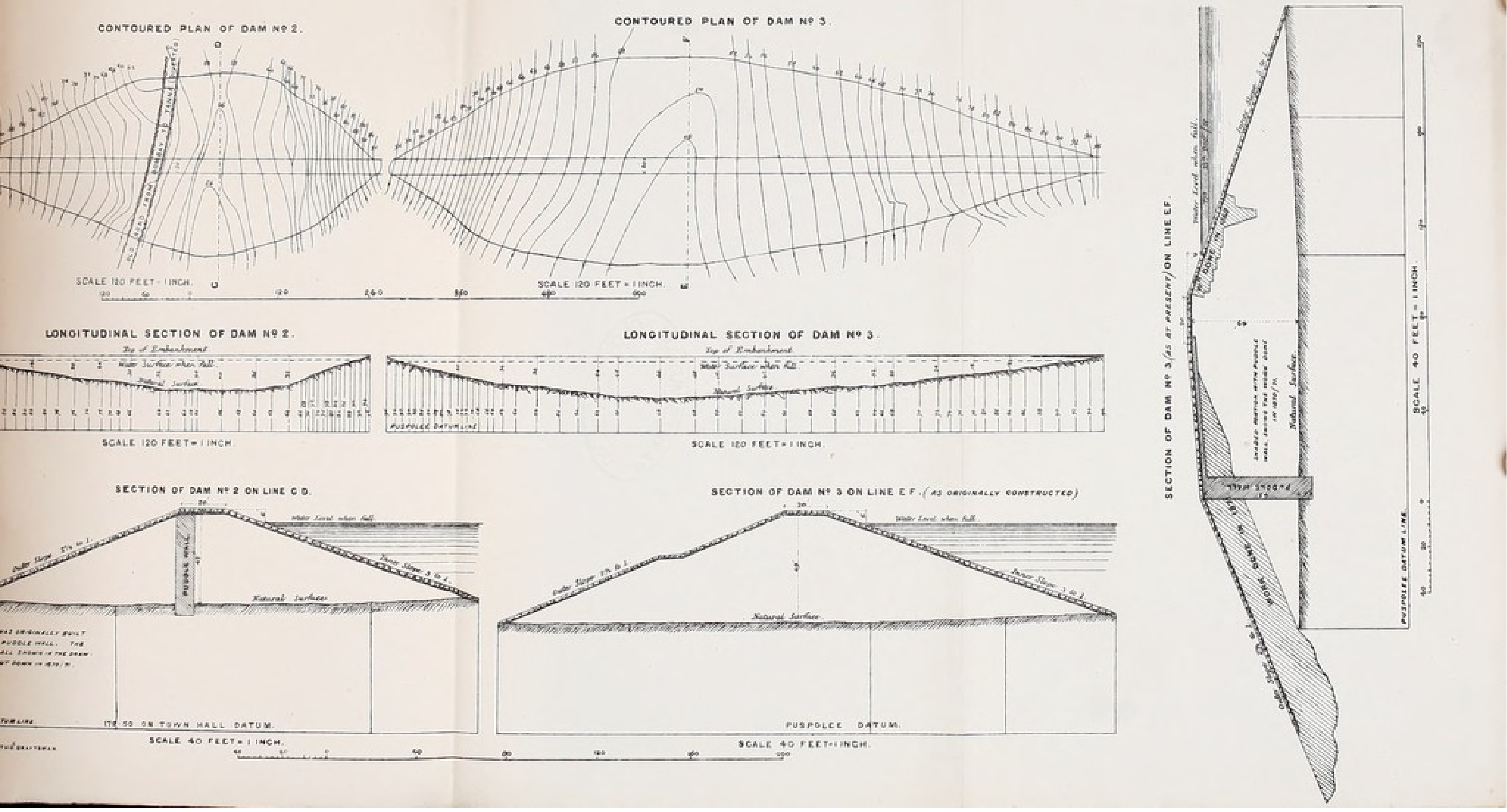
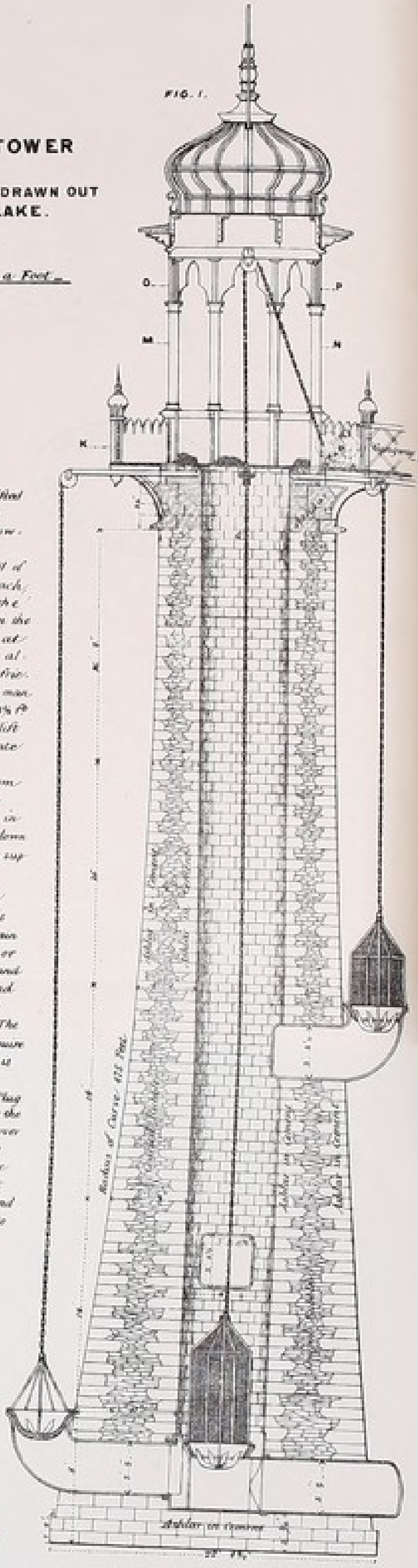


FIG. 1.

DETAILS OF TOWER
SHOWING
HOW THE WATER IS DRAWN OUT OF THE VEHAR LAKE.

Scale: ⅜ of an Inch to a Foot.



The Plugs and Strainers are lifted by means of a moveable Crab which is shown in the Drawing.

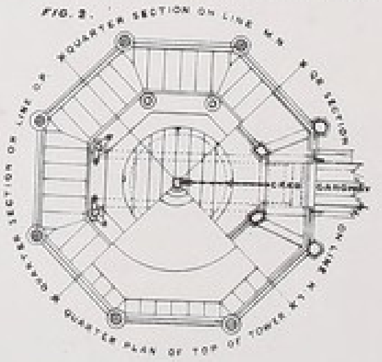
The Plugs and Strainers in Well of Tower weigh about 1450 lbs each; and as the Crab multiplies the power thirty two times 80 lbs on the crank axle will give 2560 lbs at the drum thus giving ample allowance for weight of chain & friction. And as the work of one man turning an axle is 80 lbs at 3½ ft per second, he will be able to lift either Plug or Strainer at the rate of at about 8 ft per minute.

To lift the Strainer at the bottom of the Well the Crab has to be moved into the position shown in figs 1 & 2 and is there held down by bolts attached to the beams supporting the gangway.

To lift the Strainers outside the Tower and the Plugs the Crab is moved over the end of the chain that is fastened to the plug or strainer required to be lifted, and the end of the chain is wound round the drum of the Crab until it has sufficient gripe. The Crab in these cases does not require fastening as the pull upon it is downwards.

When a Strainer is to replace a Plug at any of the inlets to the tower the strainer is brought in a boat over the inlet and the plug having been raised by the man at the Crab it is taken into the boat and the strainer fixed to the end of the chain and lowered into its place.

FIG. 2.



(Signed) H. Conybeare, C.E., F.G.S.

pitched with stone. No. 2 Dam has a top width of 20 feet, and No. 3 Dam had the same width when constructed. But in consequence of the repairs carried out in 1871 to stop the leaks discovered in this work, the form of No. 3 Dam has been altogether changed, as will be seen by reference to Plate XI.*

The following is a table of the quantities of the different kinds of work in the three dams, as calculated by Mr. Conybeare:—†

Dams.	Extreme height.	Extreme length at the top.	Earth-work.	Puddle.	Tot. earth-work and puddle.	Broken stones under pitching.	Rough stone pitching.
	Feet.	Feet.	Cubic yds	Cubic yds	Cubic yds	Cubic yds	Square yds
No. 1	84	835	255,706	30,910	286,616	997	26,993
„ 2	42	555	43,617	10,332	53,949	327	8,827
„ 3	49	936	106,743	14,717	121,460	659	17,797
Total ...	...	...	406,066	55,959	462,025	1,983	53,617

The arrangements for drawing off the water from the lake are shown in the accompanying plan.‡ The water is first strained through sheets of extremely fine copper gauze fixed to cages placed over the mouths of large pipes which pass into a masonry tower. In the bottom of this tower is fixed the mouth of the outlet pipe (41 inches in diameter) which passes under the dam, and conducts the water to Bombay. Two strainers are ordinarily sufficient to supply the tower with water as fast as it is drawn off by the outlet pipe, and, as the purity of the water in the lake is in proportion to its nearness

* In the working drawings the main dam is shown as completed to about eleven feet, while it now stands about six and a half in the middle, and seven feet on the sides, above the weir. If the drawings are reliable, it follows that the dam has settled down from 4 to 4½ feet. I can give no information regarding Nos. 2 and 3 Dams, as these works have undergone repairs, and it is impossible now to say what their heights previous to the repairs were.

† *Vide* his paper on the "Bombay Water Works," Vol. XVII., Proceedings of the Institution of Civil Engineers.

‡ *Vide* Plate XII.

to the surface, the upper pipes are those always in use, the lower ones being kept closed with iron plugs.*

The outlet pipe ($1\frac{3}{4}$ inches thick) under the embankment rests on a firm foundation of rock or masonry, but, over it, I am told, there is only puddle. On issuing from the dam it bifurcates into two branches, each 32 inches in diameter, and on each branch is a sluice worked by a capstan arrangement. One branch goes on to Bombay, while the other stops with an open mouth about 200 yards from the sluice. The latter was intended for another main, when it became necessary to extend the water works.†

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* In 1865 the lowest inlet was kept open. The water from the bottom of the lake proved to be of a reddish brown colour, and great complaints were made of its unwholesomeness. Some time after its delivery in the town, cholera broke out in various parts, and when the cause was suspected and the lower inlet closed, the epidemic at once disappeared.

Those who were in Bombay in April and May, 1871, will remember a sudden discolouration to a dirty brown tint of the Vehar water supplied to the town in those months. As the Department was engaged at the time in repairing some of the strainers, I was under the impression that the discolouration arose from unstrained water passing through the upper pipes; but, as the discolouration continued even after the repaired strainers had been put down again, I was quite at a loss to account for the fact. Remembering, however, what took place before, it occurred to me that water was probably being drawn off from too low a level. On inquiry, I found that three inlets were open. I closed the mouth of the lowest one, and, in a few hours, the water in the town resumed its usual transparency. It is quite clear, therefore, that the lower the water from the surface of the lake, the more impure it is, and that, for the proper supply of the town, the water near the surface only should be used.

It will be seen further on (page 28) that this statement is contradicted by my friend Dr. Lyon's analysis. I believe, however, that he is not himself satisfied that an analysis of the water taken in the dry months would be the same in character as that which he has made of the water in the monsoon.

† The present sense of the Bombay community seems to be that the town should not be dependent on the Vehar lake alone for its supply, so that this branch line will probably never be laid down. It would be useless to do so without bringing more water into the lake from the Toolsee gathering ground, as the quantity of water now used yearly in Bombay is almost exactly that which the present gathering ground affords. The lake has overflowed only three times in thirteen years—twice to an insignificant—but once (1861) to a considerable extent. This overflow, though, was due to the fact that the distributory system in the town was at that time incomplete, and that much less water than the present quantity was being drawn off. Practically, all the water that has ever fallen on the gathering ground has been collected. The idea which has been put forward from time to time in the local news-

The line of pipes to the town is 14 miles long, and, excepting where it crosses streams, is placed under ground a few feet from the surface. The action of the earth on the metal tends to corrode the pipes very much. Layers of the oxide of iron three-eighths of an inch thick may often be removed from the surface.* The pipes are each 12 feet long, of the spigot and faucet kind, and the joints are run in with lead. The thickness of the iron was intended to be from one to one and one-eighth of an inch, but there are many pipes not even three-quarters of an inch thick. The consequence is that we have numerous bursts of the main, when the town has sometimes to go without water for hours together.†

The greatest theoretic pressure of the water in the mains is about 180 feet, but the pressure actually registered varies between fifty and a hundred and forty feet. The "pull" begins at 4 o'clock in the morning with about 250,000 gallons per hour, and the consumption steadily increases till at 6 o'clock it

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papers, that more water might be obtained by a better system of distribution, is not correct. As all the rain which falls on the gathering ground is collected, and as, practically, none goes to waste over the weir, we must be using all we gather. If we were not, the surface of the lake would steadily rise year after year. But it does not. On the contrary, it keeps at one average level, or, if anything, it has a tendency to fall. At this present moment (April, 1872) it is lower than it has ever been in this month since the construction of the lake.

* Occasionally, pipes are taken up in the town reduced to a state of graphite. The iron can be cut like the softest lead pencil with an ordinary penknife. This state of things is no doubt due to the action of saline matter on the metal. Some of the soils about Bombay are impregnated with salt. This is one among other reasons why I advocate that all pipes should in India be placed above ground. In England it cannot be done on account of the frost. If this difficulty could be got over there by jacketing the pipes, I am certain it would result not only in their better preservation, but in an enormous saving of water. All leaks would be immediately discovered, and could therefore be at once stopped.

† Some of the pipes were shockingly badly cast. There is part of one in the Municipal Office, not more than about $\frac{1}{8}$th of an inch thick, and with a large hole in it through which for years a great quantity of water must have leaked. It was situated close to a sewer, so that the water escaped into the latter and did not make its appearance as it usually does on the surface of the road.

attains a little over 400,000 gallons an hour. Up to about half-past ten there is no great variation, but about this time the consumption imperceptibly declines to a little under the above quantity. About 4 P.M. it begins again to increase, but very slightly, till half-past five, from which hour it declines steadily up to midnight, when only about 240,000 gallons an hour are used, and this rate of consumption continues till four in the morning. To put it in other words, the consumption begins at four A.M., reaches its maximum at six, continues at its maximum all day long, begins to decline at six in the evening, reaches its lowest at midnight, and continues at its lowest till four again the next morning.

The accompanying plans* show the arrangements of distribution in the island. During the day no valves are closed. The entire system of pipes throughout the island is open to the flow of the water, but the practical effect of this is that those parts of the town close to the mains and lying at a low level monopolize the supply. In order to render the distribution fair, certain valves are closed at night, so that the districts far from the mains and situated at a high level may obtain their supply. This plan leads to great waste. Cocks are kept open all night, and thousands of gallons are lost to the public.

Originally the Vehar water was exceedingly pure, but I believe it has, during the last few years, deteriorated to some extent. Even now, however, I doubt whether there are many towns in England which can boast a purer supply. The cause of deterioration is the great increase of vegetable matter in the lake, which is filled with myriads of plants of a low form of aquatic life, probably of the *Protococcus* class, one of the *Confervoid Algæ*. It does not merely float on the surface, but apparently thrives at all depths, and it consists of a minute

* *Vide* Plates XIII. and XIV.

PLATE XIII.

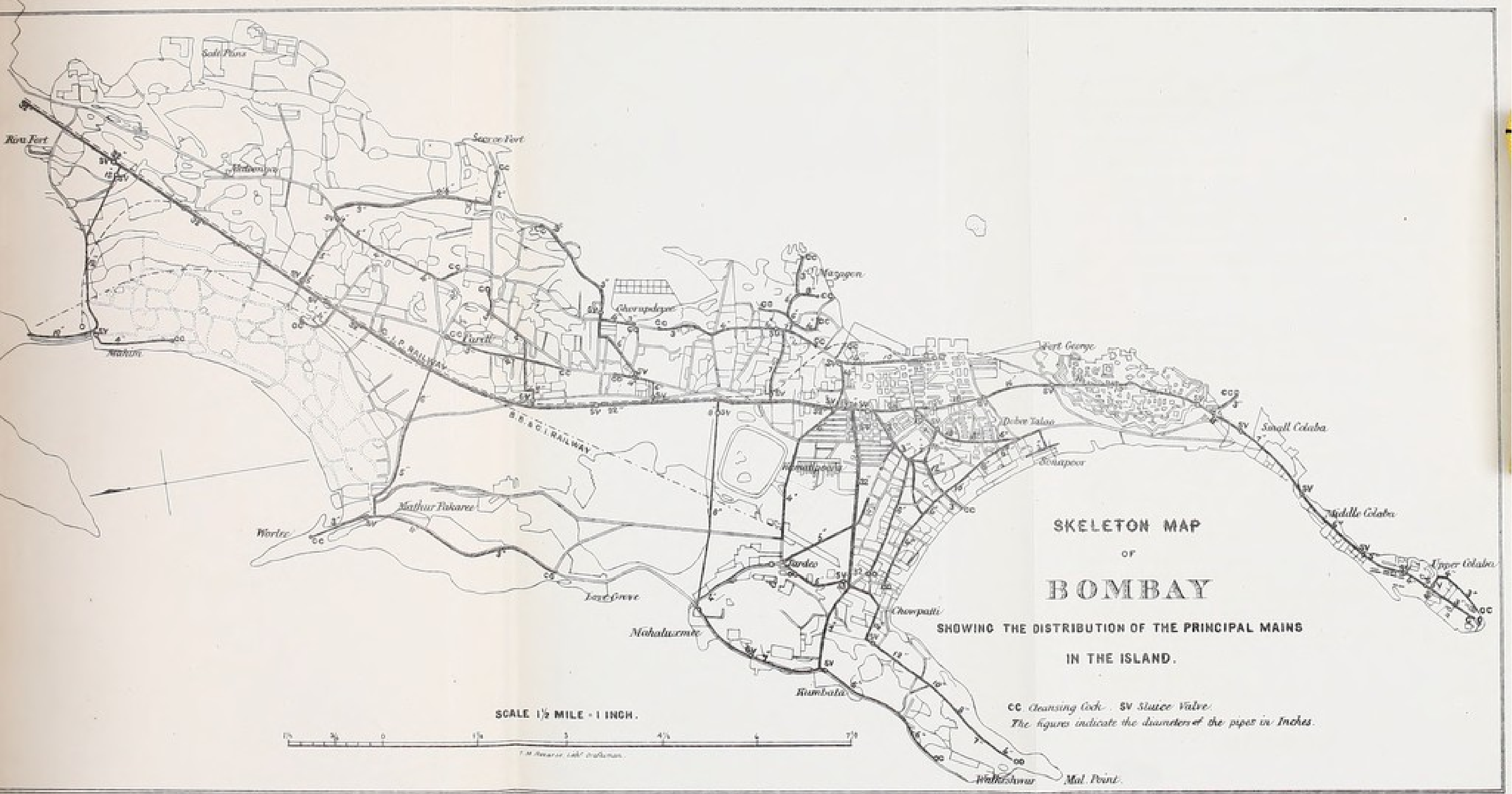
SKELETON MAP
OF
BOMBAY
SHOWING THE DISTRIBUTION OF THE PRINCIPAL MAINS
IN THE ISLAND.
CC Cleansing Cock. SV Sluice Valve.
The figures indicate the diameters of the pipes in Inches.
SCALE 1½ MILE - 1 INCH.
Salt Pans
Riva Fort
Sewree Fort
Mazagon
Chorupdeyne
Parell
G.I.P. RAILWAY
B.B. & C.I. RAILWAY
Mahim
Worlee
Mathur Pakaree
Love Grove
Mahaluxmee
Tardeo
Chowpatti
Kumbala
Walkeshwar
Mal. Point
Fort George
Dobee Talao
Sonapoor
Small Colaba
Middle Colaba
Upper Colaba


PLATE XIV
PLAN
OF THE
FORT & NATIVE TOWN
SHOWING THE
STREET SERVICE.
FORT
NATIVE TOWN
TO THE FORT AND COLABA
ARTHUR CRAWFORD MARKETS
MAIN FROM VEHAR
TO MALABAR HILL
TO COLABA
JAMSETJEE JEEJEEBHOY HOSPITAL
Sluice Valves ● Cleansing Cocks ○
TOD STREET
CHURCH GATE ST
HORNBY ROW
ESPLANADE
SCALE 12 INCHES = 1 MILE

sporule which is sometimes as small as the point, and seldom larger than the head of a good sized pin.*

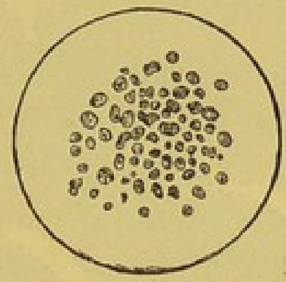

DIAGRAM No. 1.

Protococcus, magnified 350 diameters, from a sketch by Doctor Gray, of the Bombay Medical Service.

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* From my own observations I am led to believe that unless some steps are taken to destroy these plants, they will go on increasing to such an extent as will at last render our water-supply comparatively impure. To what cause they are due it is perhaps impossible to say. I cannot help thinking, however, that it may be necessary in a hot climate like India, where the generation and increase of all forms of life are so rapid, to empty our reservoirs at times. This appears to me the most effectual way of destroying the vegetation which poisons the water. Under present circumstances we could not empty the Vehar Lake, but this might be done if we constructed another reservoir.

It is remarkable that for some months before the monsoon, and until it sets in, the water in the lake is almost discoloured by these sporules, but immediately the monsoon breaks they disappear as if by the wand of the magician. In August, 1871, I had difficulty in procuring even the few specimens from which the accompanying sketch was drawn. The obvious inference, of course, is that the influx of the fresh water destroys the sporules, but why so small a quantity of rain should produce such an effect it is impossible for me to say.

Regarding the deterioration of the water in the Lake, I should mention that the subject has occupied the attention of the Executive for some time past. Doctor Blaney, than whom no one in Bombay takes a deeper interest in the sanitary welfare of the town, and to whose intelligent exertions and disinterestedness the town owes so much, made what might have proved a valuable suggestion some time ago, but I regret to add that there is little hope of any success following its adoption. Doctor Blaney recommended that the plant "*Anacharis Alsinastrum*" should be introduced into the lake. The matter was referred home by us for any information that could be obtained regarding the effects produced by this plant on impure water. The London Water Companies, not being advocates for the employment of the plant, one of the very highest authorities in England was consulted on the subject. The following is Dr. Frankland's opinion :—

"In reply to your inquiries I have to say that, in my opinion, no beneficial results would ensue from the introduction of '*Anacharis*' or any other plant into the Reservoir or Lake. Living plants are of great use in ameliorating very foul waters, such as sewage, but they have very little effect upon

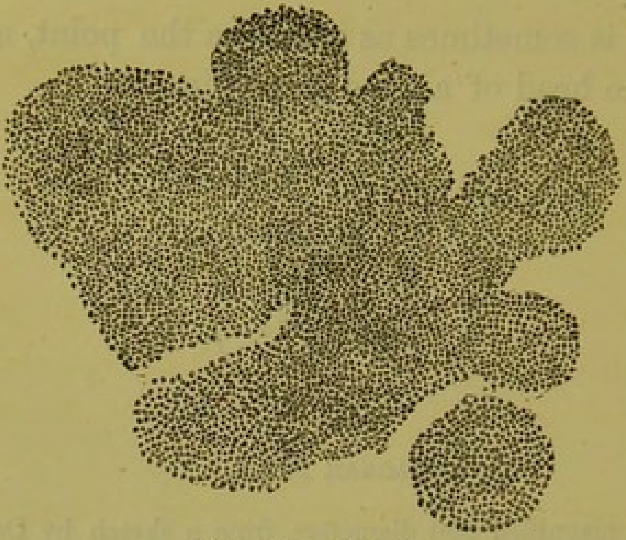

DIAGRAM No. 2.

Appearance of one of the sporules under a microscope, magnifying 250 diameters, from a sketch made by myself.

In order to convey clearly to the reader the actual size of the sporule examined in the last case, I may say, it was about half the size of one of the minute dots in Diagram No. 2.

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moderately impure water like that contained in the Lake in question; moreover the continual decay of the older portions of the plant would necessitate the frequent cleaning of the reservoir, otherwise the quality of the water would become seriously deteriorated. Filtration through sand (5 or 6 feet thick if possible) is the most efficient means of purification of all foul water, on a large scale, hitherto discovered. It is desirable, however, that the filters should be allowed to run dry at least once a week, so as to allow the pores of the sand to become filled with air. Thus filtered and afterwards kept in covered reservoirs, the water of the Vehar Lake could not fail to be rendered good and palatable. I have read the memorandum by the Army Sanitary Commission, which was enclosed, and I entirely concur in the four recommendations of the Commissioners."—August 10, 1871.

And again :—

" I have carefully perused the copy of Dr. Thomas Blaney's letter which you forwarded to me, and whilst I agree with the writer that plant life tends to purify water, so long as the plants and their leaves are alive and healthy, yet when the plants or their leaves die and decay, a serious pollution of the surrounding medium takes place, and the balance of effect produced is deterioration of the water unless the latter be originally excessively polluted. Moreover the *Anacharis* grows so luxuriantly and spreads from canal to canal with such rapidity as to become a serious nuisance and a source of considerable expense in the keeping open of canals and watercourses. Its introduction into India would consequently be a matter for grave consideration. Since its introduction into this country I have never heard of any beneficial effect which it has produced; on the other hand, the inconveniences which it causes are constantly being complained of.

" I do not therefore find anything in Dr. Blaney's letter which would

Every now and then the water delivered through some particular pipe becomes exceedingly foul, and, when this is the case, the cause generally turns out to be some dead animal matter in the pipe. Fishes and eels often pass into the pipes, and, dying there, poison the supply. Whether they escape in the form of spawn through the strainers, and subsequently develop to full size in the distributing pipes, or whether they escape after development in the lake through crevices in the tower, I cannot say, but at times they are found of a great size.*

The following is an analysis of the Vehar water.† As the subject of its impurity below the surface has attracted much attention, the analysis is of samples taken at four different levels—at the surface, and at fifteen, thirty, and forty-five feet below the surface.‡ The water might fall to the fifteen feet level in the month of May or June after a total

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cause me to modify the opinion I have expressed in my former letter."—October 10, 1871.

I should mention here that the difficulty of a sand filter, as recommended by Dr. Frankland, is, that in our case it entails a loss of pressure in the pipes and consequently a smaller delivery of water in the town. If the Bench were prepared to go to the expense of pumping the water on to a sand filter above the level of the Lake, to which there is no engineering objection, as the filter could be easily constructed, the water would be rendered pure with no deficiency in the supply. Or if the town were willing to do without filtered water in the event of a failure of the monsoon, then the filter might be put just below the level to which one year's consumption reduces the surface of the Lake. The loss of head of about fifteen feet would not entail a great reduction in the quantity of water delivered in the town, and practically, except for one year in ten or twenty, all the water used by the inhabitants would be filtered.

* Fishes have been found 4 feet long and 12 inches round the body. Only the other day a dead eel was taken out of a pipe 4 feet 8 inches long, and 12 inches in girth.

† It has been made for me as a *personal* favour by my friend Doctor Lyon, and because I could not obtain the information elsewhere. Those who attach importance to the good quality of our water (and who does not) as one of the great agents, if not the principal one of all, in maintaining the health of the inhabitants, and thus keeping down the death rate, will no doubt appreciate the value of this analysis as it deserves to be appreciated.

‡ The surface of the lake when the water was taken from it for analysis stood at twelve feet below high-water mark—*i.e.*, at 250·50 on Town Hall Datum.

failure of the monsoon in the previous year, but could not sink to the thirty feet level except after two consecutive failures of the monsoon.

"*Results of the Analysis of four Samples of Vehar Water drawn* 30*th July*, 1871.

A from the surface of the lake.
B from a depth of 15 feet from the surface of the water.
C from a depth of 30 feet ,, ,,
D from a depth of 45 feet ,, ,,

	A	B	C	D
Total solid matter ....Grains per Gallon	5·46	5·74	6·44	5·18
Loss on ignition.................. ,,	·42	·28	·42	·42
Chlorine........................... ,,	·89	·79	·79	1·09
Hardness before boiling......... ,,	6·65	7·00	6·30	6·65
Hardness after boiling	5·60	5·60	5·60	5·60
Ammonia in distillate from Carbonate of Soda...	·0046	·0042	·0047	·0045
Ditto in distillate from alkaline permanganate	·0210	·0245	·0231	·0248
Ditto nitrates and nitrites.........................	·0126	·0210	·0126	·0126
Total oxygen required by the water at about 140°F. in presence of acid..........................	·0210	·0350	·0350	·0490

"Sediment of much the same character in all four specimens —light brown in colour and flocculent; consists chiefly of vegetable debris and confervæ, a few parameria and altenophyrina also present. In no one of the four samples was the sediment abundant, but its quantity was sensibly greater in the samples drawn from the lower portions of the Lake.

"I think the above results show that the water of the Lake is of nearly uniform quality down to a depth of 45 feet below the surface. The only important departures from uniformity are—1st, that the amount of oxygen required by the water increases with the depth; and 2nd, that the amount of suspended matter (as noted chiefly by vegetable debris) also increases with the depth.

"This is more than what one would expect from the conditions to which water stored in a large open reservoir like the Vehar Lake is subject. The first departure from uniformity of composition will remedy itself, for as the surface water is drawn away, the water below will become exposed to the action of the oxygen of the air, and the dissolved organic matters will become more fully oxidized by its influence. No apprehension need therefore be entertained on this score. The second point of difference between the deep and the surface water may possibly necessitate the adoption of some method of mechanical straining, should it ever become necessary to supply Bombay with water from what are now the lower depths of the lake. If this were done, or if the water supplied were filtered by the consumer (say through sand or sand and charcoal), there need be no fear of inferior quality, at any rate down to a depth of 45 feet below the surface of the water as it stood on the 30th July, 1871.*

"As the health of Bombay so greatly depends on the purity of the Vehar water, it would be interesting to repeat experiments, similar to those of which the results are stated above, at some time during the hot weather, *i.e.*, before the lake has become disturbed by the influence of the monsoon."†

It is impossible to gainsay the beneficial results to the town which have followed the introduction of Vehar water.‡ The best proof, perhaps, of its superiority to all other sources of supply in the island, such as tanks and wells, lies in the fact that, although the strongest prejudices existed in the native mind against its use, these prejudices have now all disappeared, and the native who cannot obtain Vehar water considers he has a just complaint against the Municipality.

Much has been said and written of the manner in which

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* This would be down to the level of 57·5 feet below the surface of the lake when quite full. As this is only 18 inches above the mouth of the lowest inlet, it follows that, practically, all the water which can by present arrangements be drawn off would be fit for use.

† There is no doubt about the wisdom of this suggestion, for, as I have already pointed out in the note in page 25, a most marked change comes over the lake shortly after the monsoon sets in.

‡ No one perhaps is more competent to speak on this subject than Dr. Blaney, who has resided in Bombay for more than thirty years—who must remember the state of the town under its old and primitive system of water-supply—and who knows so well its present condition. In Appendix A will be found *in extenso* Dr. Blaney's views on this subject. He has been kind enough to write this paper specially for this Water Report, and I feel much indebted to him for his kindness in thus coming forward and giving the public the fruits of his long experience on the subject.

the works were carried out, but it is not my intention to enter on this subject, as no practical good could come of it now. It is sufficient for me to state that the cost of the Vehar Works, instead of being, as originally estimated, twenty-five lakhs of rupees, amounted with interest to the large sum of sixty-five and a-half lakhs of rupees.

Let it be remembered too that three-fifths (fifteen lakhs of rupees) of the original estimate was for a main of forty-one inches, and that the main laid down was thirty-two inches only in diameter. In spite of the reduction, therefore, which ought to have taken place in the largest item of the estimate, the works cost more than two and a-half times the original amount.

1856 to 1861.

The Vehar project was commenced by the Government in the latter end of 1856—the main dam was completed in May, and the other two dams in August, 1858; by October, 1859, the lake was filled up to about 9 feet from the top of the waste weir—the delivery of water in the town commenced in March, 1860; by September the lake had risen to a point 5 feet higher than that which it had reached the previous year, and in July, 1861, it was quite full, and the water running over the weir. Since then it has continued to fall every season after the monsoon, reaching its lowest level about June or July, when it has continued to rise again, reaching its highest level sometimes as early as August, sometimes as late as October, but generally in September.

In order now to explain how the Municipality became connected with the Water Works, and its position with regard to the Government, I must break the thread of my narrative and return to the year when the works at the Lake were nearly completed.

The Municipality become connected with the works.

As the project was undertaken by the Government for the town, the Government of course looked to the town to reimburse them not only for the cost of the works, but for their yearly maintenance. In July, 1858, a new Act, known as "The Bombay Municipal Act," was passed, and in it the following Section* regarding the Water Works is found :—

"The Commissioners shall pay to the Governor in Council out of the Municipal Fund an annual sum not less than one hundred and seventy-five thousand rupees on account of the expense which has been or may be incurred by Government in the construction of the works called the Vehar Water Works; and such annual payment shall continue to be made until the whole of the expense so incurred (except such portion thereof, if any, as shall be defrayed by Government out of the public revenue), with interest thereon at the rate of four per centum per annum, shall have been paid. The Commissioners shall also pay to the Governor in Council in each year such further sum as shall be equal to the cost of the maintenance of the said works during the preceding year."

The Vehar Works transferred to the Municipality.

Up to 1863, while the town paid the expenses of maintenance, the works remained under the control and management of the Government, but in that year it was determined to transfer them to the town. A new Act, called "The Vehar Water Works Act," was passed, and in this, under certain pecuniary and other conditions, the Government yielded all their rights to the Municipality. It is most important that the Justices should know exactly in what position they are with reference to the Government in this matter.† Without following the clauses in the order in which they are placed in the Act, the following summary will give a general idea of the scope of the Act and of the existing relations between the Government and the Municipality.

It is forbidden to build or carry on any trade, manufacture, or agriculture within the watershed of the lake. All the works,

* No. XXX. of the Act.

† So much attention has this subject attracted during the last two years, that I have thought it best to give "The Vehar Water Works Act" complete, *vide* Appendix B.

including all the movable and immovable property, and all the public tanks and wells in the town, are vested for a term of ninety-nine years in the Municipality, which has power to alter, repair, or improve the works, or to enter any land or property for these purposes. Subject to the approval of the Government, the Municipality can levy rates and supply water to the town on such terms as it chooses. On the other hand, the Municipality is bound to keep a proper system of accounts, and to furnish an annual statement of the same for publication in the *Government Gazette.* It is also bound to maintain the works in proper order, and, if it fails to do so, the Government have power not only to supersede it by appointing others to the charge of the works, but to execute the repairs themselves under their own control and at the cost of the Municipality. The surplus funds may, with the approval of the Government, be expended in improving the works, and, when these funds exceed in a single year the sum of fifty thousand rupees, the Municipality may, but again only with the consent of the Government, alter the water rates. If the Municipality declines to do so, the Government can fix such rates as they choose, and these become binding on the town.

The pecuniary obligations attached to the transfer of the property were these. The Municipality was to be considered as a debtor to the Government to the extent of a sum of money equivalent to twenty-five lakhs of rupees in addition to half the cost of the works above this sum. As, at the time of passing the Act, the works had cost with interest about sixty-five and a half lakhs of rupees, half the excess over the twenty-five was about twenty and a quarter lakhs, so that the total debt in 1863 was represented by forty-five and a quarter lakhs less the payments which had been made by the Municipality up to that time. As these amounted to about seven and three-quarter lakhs, the actual total debt in 1863 was thirty-seven and a half lakhs of rupees. The

Act, however, put it at 37,30,053 Rs. To liquidate this, the Municipality is bound to pay the Government every year the sum of one hundred and seventy-five thousand rupees, until the entire debt is expunged, when the works will, for the remainder of the lease, belong to the town. If on the 1st of July in any year there is a failure of payment, the Government, after giving two months' notice thereof, can seize the Water Works, and manage the property themselves.

The Vehar debt and the relations between the Government and the Municipality.

The following is a condensed Statement of the Vehar debt from the commencement, and made up to the 1st January 1872:—

	Rs.	a.	p.
Amount disbursed in England for stores and other charges	17,78,316	15	6
Do. do. Bombay	38,47,642	11	10
Simple Interest on do. at 4 per cent. from the different dates of payment	9,58,829	11	7
Total charges	65,84,789	6	11
Deduct Refund, sale proceeds of stores, &c.	40,902	7	5
Actual cost of works	65,43,886	15	6
Deduct amount of original Estimate	25,00,000	0	0
Total	40,43,886	15	6
Moiety of the above excess	20,21,943	7	9
Add amount of original Estimate	25,00,000	0	0
Total	45,21,943	7	9
Deduct payments made up to 30th June 1863	7,71,438	5	8
Total	37,50,505	2	1
Deduct amount struck out in adjusting the charges against the Municipality to accord with that specified in Act II. of 1865	20,452	2	1
Total Vehar Debt on 1st July 1863 ...	37,30,053	0	0
Add accumulation of interest up to 1st January 1865, with amounts disbursed by Government, less Instalments paid up to this date	1,35,727	2	4
Total	38,65,780	2	4
Deduct Instalments paid between 1st January, 1865, and 31st December 1871, less interest up to the latter date	1,29,292	2	4
Total Vehar Debt on 31st December 1871	Rs.37,36,488	0	0

To ascertain what the debt should have been with which the Municipality ought to have started, we must bear in mind that the actual cost of the works, without interest, was 56 lakhs of rupees. A moiety of the cost above 25 lakhs is 15½ lakhs. If to this we add 25 lakhs, the amount of the original estimate, the total debt at starting ought to have been about 40½ lakhs. The excess over this in the above Statement is caused by the addition of interest. Comparing the original debt with our present liabilities, it will be seen that we are not very far off from the position we originally occupied. I will now show when our liabilities will cease.

As the interest on the debt demanded by the Government is four per cent., it follows that out of the Rs.1,75,000, Rs.1,50,000 go yearly towards defraying this charge, and consequently Rs.25,000 only go towards the reduction of the principal. The Bench, therefore, are reducing the debt at this present moment by Rs.25,000 yearly, plus the interest on this sum, or altogether by Rs.26,000. As the principal and the interest decrease, so the rate of reduction of the debt increases, and, if the payments are continued as at present —viz., monthly—the debt will be expunged about the year 1920.

There is a general feeling among all classes that the Municipality has been hardly dealt with by the Government, and is made to pay more than it should be legitimately called upon to do. In fact, ever since the delivery of the water in the town the sick man has not only revived, but has begun to grumble at the doctor's bill. At first he expressed his feelings in mere mutterings, but of late he has denounced what he considers the imposition of the Government in very strong language.* His idea is not only that he has to discharge a heavy bill, but that the works, with the carrying out of which *he* had nothing to do, are in such an insecure state, as to

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* *Vide* the Proceedings of the Bench in 1869, 1870, and 1871.

render the further expenditure of money imperative on him. I, too, was at one time under the impression that the Government had not acted with fair consideration for the interests of the town, but I am bound to admit that a careful study of both sides of the question has convinced me there is no reasonable cause of complaint on the part of the Bench. In order to prove the case it is enough to ask the simple question, "What is it that the Municipality complain of?" Is it of being saddled with the Vehar debt; and, if so, are they willing to hand this over to the Government, *along with the revenue derived from the Water Works?* If they are, I must be candid, and say plainly that they are contemplating a very foolish thing, and I will prove why it is so.

The Vehar debt is about 37,50,000 rupees. The annual revenue derived from the works now is 3,80,000 rupees. Of this latter sum 50,000 rupees go towards maintenance and extensions, and there is consequently a balance of 3,30,000 rupees left to the Municipality. At present they pay the Government 1,75,000 and pocket the remaining 1,55,000 rupees. Now, if they quarrel with the Government, and the Government turn round and say, "Very well; we will relieve you of the Vehar debt and also of the revenue," what will be the state of things? Simply this, that the Government will obtain 3,30,000 rupees yearly to repay themselves for the 37,50,000 rupees. In other words, they will be in the position of a company obtaining nearly nine per cent. on their speculation. Surely it is more sensible for the Municipality to pay the Government 1,75,000 rupees (say five per cent.) and to secure the remaining 1,55,000 rupees (about four per cent.) for themselves.

My advice to the Bench, therefore, is to let well alone—to accept the debt, and to raise the revenue in every legitimate way, applying all surplus above the cost of maintenance towards new works, which, indeed, are urgently needed.

On one point only do I think the Bench may fairly ask for a remission of the terms from the Government. According to the Act, and even if the entire debt is discharged, the Vehar works revert to the Government after ninety-nine years. It is, perhaps, not likely that the Government would really claim them, but still the power to do so should not be left to them. The Bench should urge that if the debt is repaid, the works shall become their own absolute property.

The insecurity of the Vehar Dams, the dependence of the town for its supply of water on the durability and strength of the single line of pipes under No. 1 Dam, and the impossibility of repairing this pipe if it should give way (as it must ultimately in the course of nature, and may at any moment), have all contributed to render the public dissatisfied with the existing state of things, and have determined them to rectify it by obtaining a further supply of water from some other source.*

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* "A time must come when the 41-inch iron main running through it (No. 1 Dam) must be worn away. No arrangements were made in the construction of the dam to enable the engineer to put down another main when this one became useless. Should a leak ever occur in this main under No. 1 Dam, it will be a most serious matter for the town, and the very worst consequences may be expected.

"The pipe lies about seventy feet from the top of the dam, and there is a pressure of from 63 to 50 feet of water on it, dependent on the lake being full or otherwise. Suppose there is a burst in the main (and this supposition is no extraordinary one), water will issue from the pipe with a pressure of say 25lbs. on the square inch. What the effect of a stream passing with a velocity due to this pressure will be on the surrounding earth it is hardly necessary for me to explain. Material must be washed out from the dam by the water in its outward course, and after this has continued for a short time the stability of the work must be destroyed. To repair a leak of this nature in the manner which I have adopted to render Nos. 2 and 3 Dams secure (that is, by dropping a vertical puddle wall down into the natural soil through the exterior slope of the dam) will be not only attended with great risk, but impossible, unless the supply to the town is stopped for several consecutive weeks. This fact, therefore, must be looked in the face—viz., that a time must come, sooner or later, when from the pipe under the embankment being worn away (as all iron ultimately wears away), and from there being no means of substituting another pipe in its stead, the inhabitants of Bombay, unless they furnish themselves with some other source of supply, will have to pass through a water famine.

"The question is really a very serious one for the community. The arrangements for drawing water from the Vehar Lake are most imperfect. The

In July 1868, Mr. Russel Aitken, the Executive Engineer to the Municipality at that time, in compliance with instructions from Mr. Arthur Crawford, the Municipal Commissioner, sub-

Mr. Russel Aitken's Projects. 1868.

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masonry of the tower leaks so badly that I am told an attempt which was once made to examine the mouth of the outlet pipe at the bottom, nearly resulted in the death of the diver, who was almost forced into the pipe by the quantity of water falling on him from above. It will thus be seen that to close the mouths of the strainers does not render the tower dry. It follows, therefore, that if a pipe bursts under the embankment, it will be impossible to discover the point of fracture by sending a man down the tower. The only thing to be done in this case will be to block up the mouth of the outlet pipe so as to prevent any water entering it. Even this may be attended with difficulty, but if it is successful, the next thing will be to send a man into the pipe through the sluice valve at the outer foot of the embankment. If a real fracture of the pipe has taken place, it will not perhaps be difficult for the man to discover its position, but if the leak were due to an imperfect joint, no examination of the pipes from the inside could enable a man to discover its locality.

"Under these circumstances, I cannot but draw the attention of the Bench to the risk they are running in delaying to construct proper outlet works for the Vehar Lake—works which should have no connection with any of the dams, and be so arranged that any defective portion may be repaired without difficulty or danger."

"But in either case, whether the iron is fractured or whether the joints have separated, it will be impossible to repair the pipes from the inside. And let the pipes be repaired in any way whatsoever, the supply to the town must be shut off for weeks."—*Extract from my "Report on the Vehar Lake Dams."*

"I think the Bench should thank Captain Tulloch for the very moderate report he has written upon the Vehar Dams. There is nothing in it exaggerated, but on the contrary, I think he has missed one point, which is the point we must look at now. I think that during the dry season the puddle dam must be completed, but the most difficult thing will be the pipe. Now I will try to explain. I could do it better upon a black board, but I will endeavour to do it orally. The danger that there is in connection with this pipe is this: that there has been, for several years probably, a leakage through the dam at the supply pipe, and it is certain the leakage is not at the top, and it is equally certain it is at the bottom of the pipe. You cannot have water running even on a hard rock without the rock being gradually worn away. And although no perceptible amount of mechanical deposit has been found in the water, there is no doubt in my mind that a small quantity is coming through from under the pipe, and that there is a considerable cavity under it. Some time or other the pipe must break, and then there will be the whole pressure of the Vehar water scouring through the aperture in the earth." Mr. Ormiston concluded by recommending the Bench to spare no expense in carrying out the repairs on the plan Captain Tulloch had commenced, and to consider well the scheme which Captain Tulloch intended to bring forward for a separate outlet. It might be many years before new water works could be ready, and he thought no means should be neglected to render secure the present dams at a reasonable expense."—*Extract from Mr. Ormiston's Speech at the Meeting of the Justices on the 12th August* 1871.

mitted a "Report on the Extension of the Bombay Water Works." In this Report he proposed four different schemes for consideration.* Of the first he wrote :—

The Shewla Scheme.

"The hills on the mainland in the immediate vicinity of the northern part of the Island of Salsette do not present any facilities for the construction of reservoirs, as they either cannot give a sufficient supply of water, or they are not situated at a sufficient height to allow of the pipe having the necessary fall towards the city.

"Being unwilling to abandon the search, the survey parties moved up the streams until at last at Shewla, in the talooka of Moorban, or 56 miles from Bombay, a site for a reservoir was found which fulfilled all the required conditions.†

"If the cost of all works for the improvement of the sanitary condition of the city is to be defrayed from loans to be raised on Municipal revenue, it will be absolutely useless for me to say any more about a project which would be so expensive as the Shewla Scheme. Nevertheless, I consider it my duty to lay the entire project before you, as the natural

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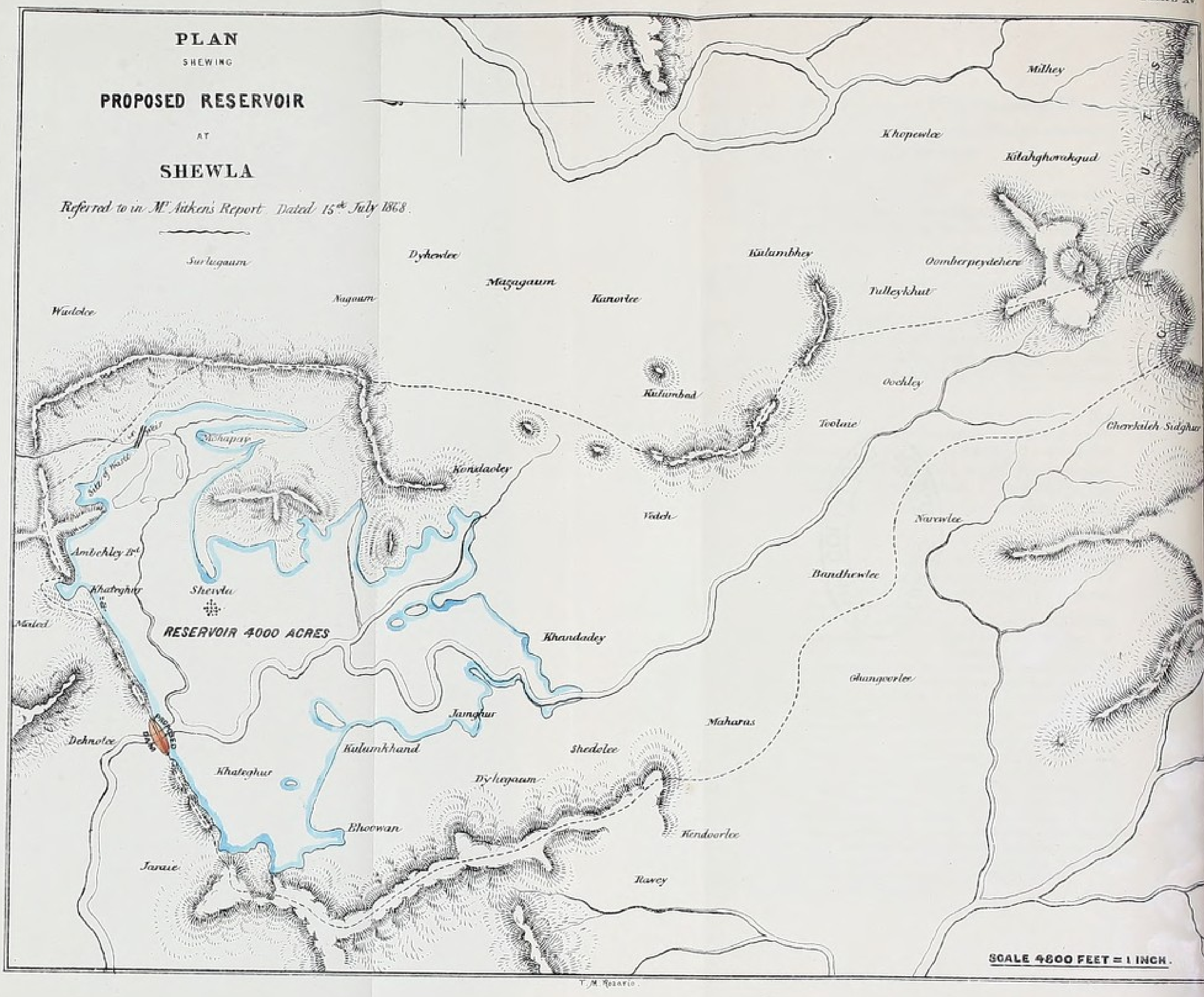
* In order to prevent confusion, I should mention that in his levels of the Vehar Lake, Mr. Aitken has an error of nearly 15 feet. The waste weir of the lake is not, as he has it in his plans, 197 feet above mean sea level, but 182·20 feet or 262·50 feet on Town Hall Datum.

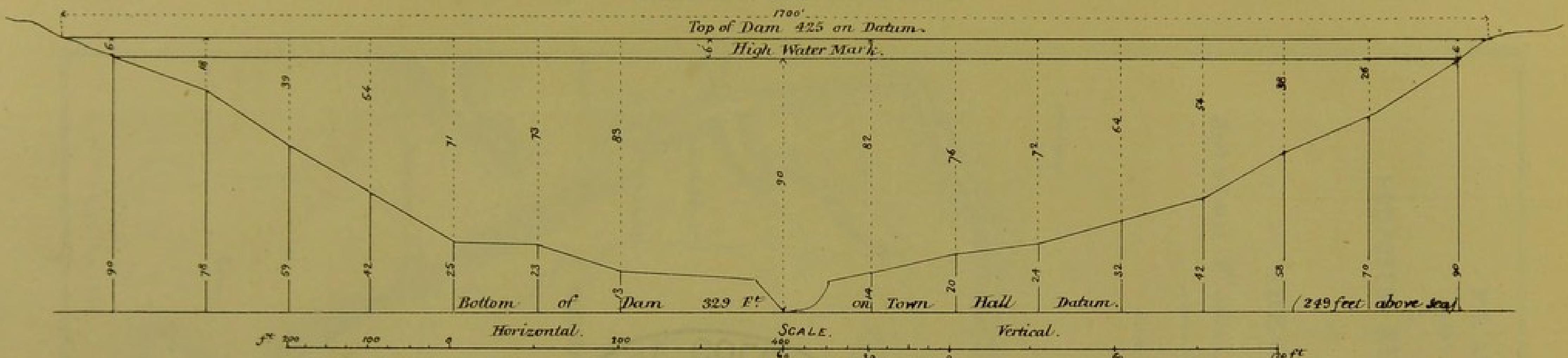
It is a great pity Mr. Aitken did not work to the same datum as the rest of the profession in Bombay, viz., the Town Hall Datum. He took as his datum a point fifty feet below mean sea level. But the exact level of mean sea is disputed, and it is most confusing to fix as a datum a point regarding which there is any difference of opinion. The person best capable of speaking on the subject is Mr. Ormiston, who has taken a series of tidal observations, and he makes mean sea level more than half a foot higher than the point fixed by Mr. Aitken. Mr. Ormiston's mean sea level is 80·30 on Town Hall Datum, whilst Mr. Aitken's is 79·70. My motives in condemning this change of datum, against which Mr. Ormiston has, with his usual judgment, protested, will not be misunderstood when I add that I myself am to blame in the matter for having in my Drainage Report and in the plans of the Toolsee project adopted Mr. Aitken's mean sea level datum. My excuse is that until Mr. Ormiston expressed to me his objection to the datum in the Toolsee project, I was not aware that there was any generally recognised datum. But having helped to add to the confusion, I unhesitatingly make my apology to the profession, and I have endeavoured to atone for my fault by reducing the drawings in this report to the now universally accepted Town Hall Datum.

† *Vide* Map facing title page and Plate XV.

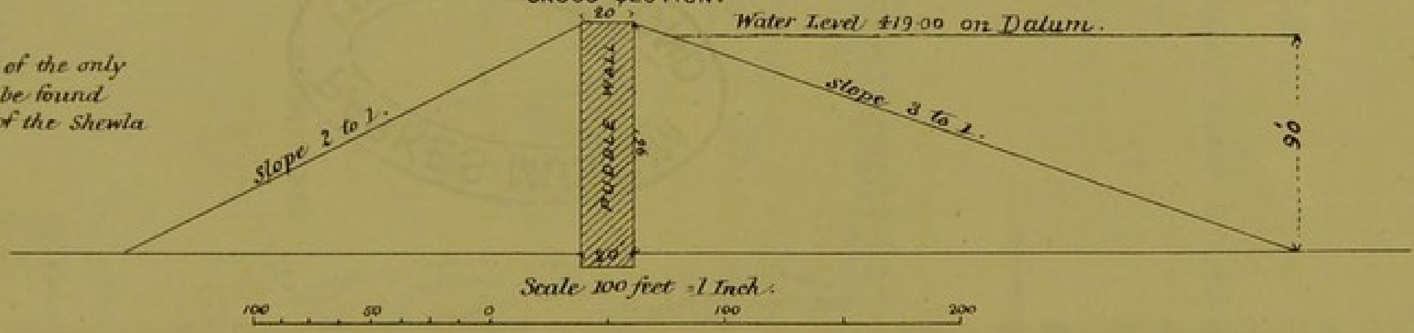
PLATE XV


PLAN
SHEWING
PROPOSED RESERVOIR
AT
SHEWLA
Referred to in Mr. Aitken's Report Dated 15th July 1868.
Surlegaum
Wadolee
Nagaum
Dyhewlee
Mazagaum
Kanorlee
Kulumbhey
Tulleykhut
Oomberpeydehere
Khopewlee
Kilahghorakgud
Milhey
Kulumbad
Oochley
Toolaie
Cherkaleh Sidghur
Kondaoley
Vateh
Narwlee
Bandhewlee
Ambehley Bt.
Khateghur
Shewla
Mailed
RESERVOIR 4000 ACRES
Khandadey
Ghangoorlee
Maharas
Jamghur
Kulumkhand
Shedolee
Dehnolee
PROPOSED DAM
Khateghur
Dykegaum
Kendoorlee
Bhoowan
Jaraie
Ravey
SCALE 4800 FEET = 1 INCH.
T. M. Rozario.

SHEWLA DAM, LONGITUDINAL SECTION.

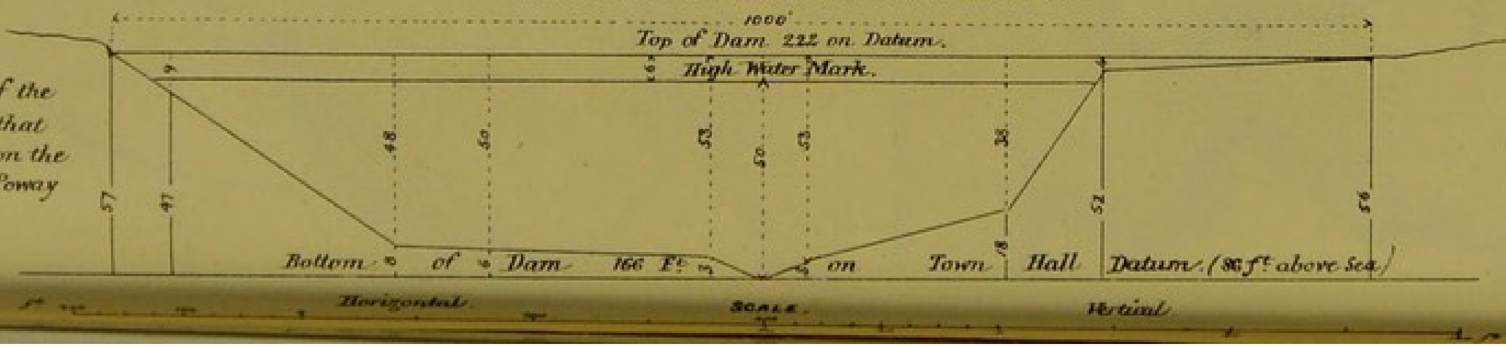


CROSS SECTION.



These are Copies of the only Plans that can be found on the Records of the Shewla Dam.

POWAY MAIN DAM, LONGITUDINAL SECTION.



This is a Copy of the the only Plan that can be found on the Records of the Poway Dams.

advantages of the Valley are so great, that even if the Municipality cannot make any use of the facilities which it presents for impounding water, perhaps Government may be able to construct a reservoir for irrigational purposes.

"The total area of the proposed lake with a dam* 96 feet high, or with a depth of water 90 feet above the bed of the stream, would be not less than 6¼ square miles, or 4,000 acres, whilst it would contain 33,000 million gallons.

"The quantity of earthwork, &c., which would be required to construct the embankment would be 687,000 cubic yards, or only 30 per cent. more than the total amount of earthwork, &c., in the three dams at Vehar."

From this reservoir Mr. Aitken proposed to bring the water into Bombay through a steel main 4½ feet in diameter and carried on masonry pillars.† The contemplated supply was 25,000,000 gallons daily.

To meet the objection, suggested by himself, that the character of the works was not of a permanent nature, Mr. Aitken said :—

"I have no doubt but that when the proposed 4-feet 6-inch main is worn out, Bombay will be ready and able to pay for a new main of twice its capacity."

The cost of the Shewla Scheme was as follows :—

	Rs.
Reservoir and works at Shewla, including 10 per cent. for contingencies	10,97,292
Steel main 56 miles long, including do. do....	1,24,78,611
Land	4,49,280
Total............Rs.	1,40,25,183

Or say 140¼ lakhs.

* *Vide* Plate XVI. for information regarding the dam.

† I cannot give a plan or section of the line along which the main was to run, as they were not given by Mr. Aitken himself. In fact, there was no survey made of the line.

The Second Project proposed by Mr. Aitken was :—

"The construction of an entirely new reservoir in the valley of the Tassoo River just below the Kennery Caves.* The total area of the proposed lake, which will hereafter be called the Kennery reservoir, and of the gathering ground, will be nearly 3,400 acres, or about equal to Vehar. I propose that the embankment shall be 136 feet high, which will impound water to a depth of 130 feet above the bed of the stream. This is a very great depth of water, and is 22 feet higher than any dam with which I am acquainted; yet as there is an abundance of excellent material in the immediate vicinity of the dam, and as we can supply ourselves with water for consolidating and working it by pumping from Vehar, I should have no hesitation in undertaking the work, nor should I entertain any doubt as to its perfect success.†

Kennery Scheme.

"The total amount of material required for the construction of this dam‡ amounts to no less than 1,110,000 cubic yards, nor would it be possible to do with a less size of dam than is now proposed, as otherwise, owing to the configuration of the ground, we should be unable to impound the requisite quantity of water.

"The area of the proposed Kennery reservoir is only 500 acres in extent, or less than one-half that of Vehar, and its storage capacity is only 7,400 million gallons, or one-third less than Vehar. The total annual supply available for the use of the city will, however, amount to 4,201 million gallons."

The Third Scheme which Mr. Aitken proposed was :—

"The construction of a dam in the River Tassoo§ just below the village of Toolsee, whereby the waters of the upper portion of that river will be diverted into the Vehar Lake, which would thus

The Toolsee Scheme.

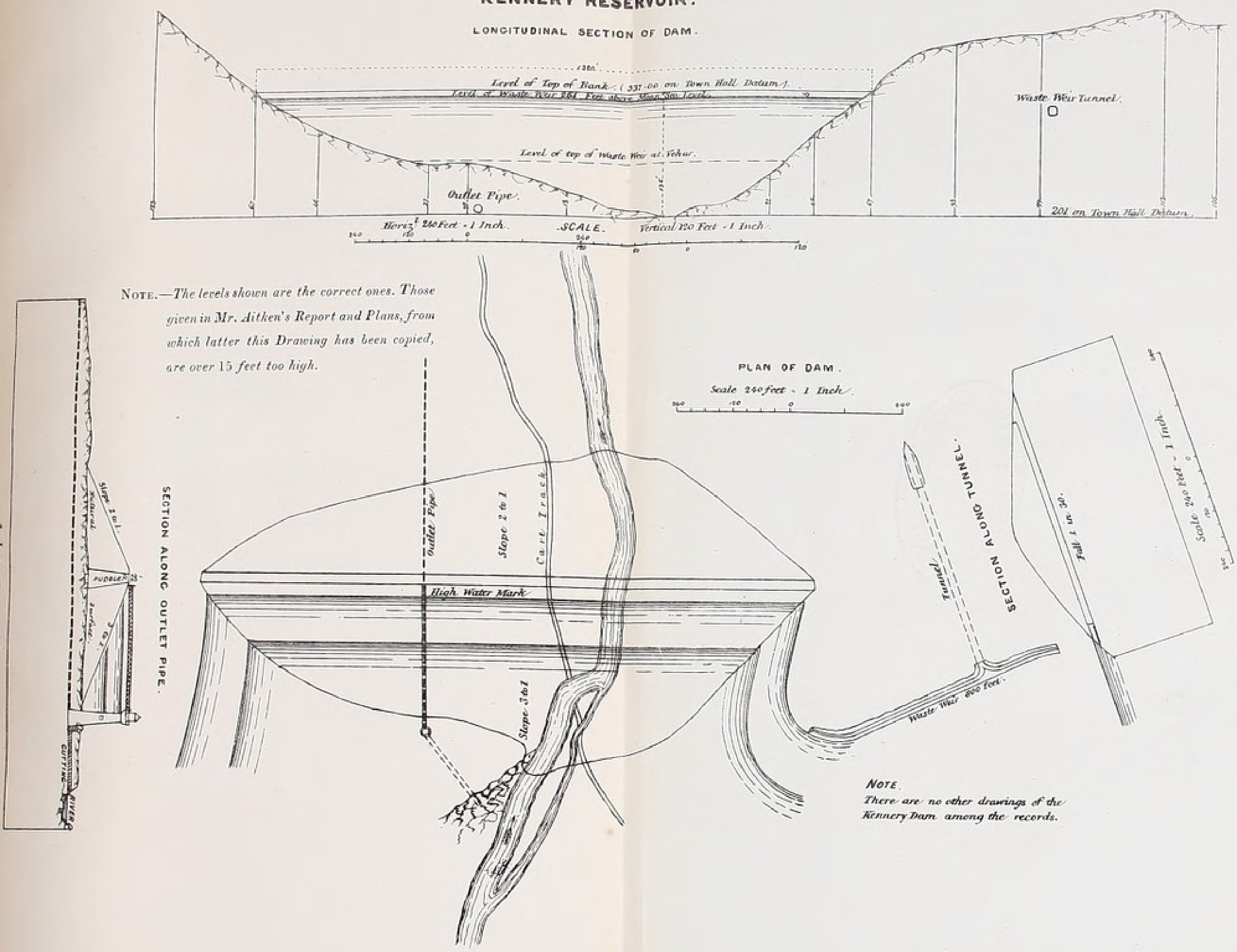
* For the position of this valley *vide* Map facing title page. The only plan of the Kennery Lake proposed by Mr. Aitken is one which it would be useless for me to give, as it was roughly drawn and is incorrect. There was no careful survey made of this valley by Mr. Aitken. For an accurate plan *vide* Plate XXVIII.

† In connection with this subject, *vide* Appendix D. Mr. Rankine, our highest authority in the theoretical branch of the profession, doubts whether an earthen dam can be relied on where the depth of water exceeds 100 or 120 feet. *Vide* also page 77 of this report.

‡ *Vide* Plate XVII.

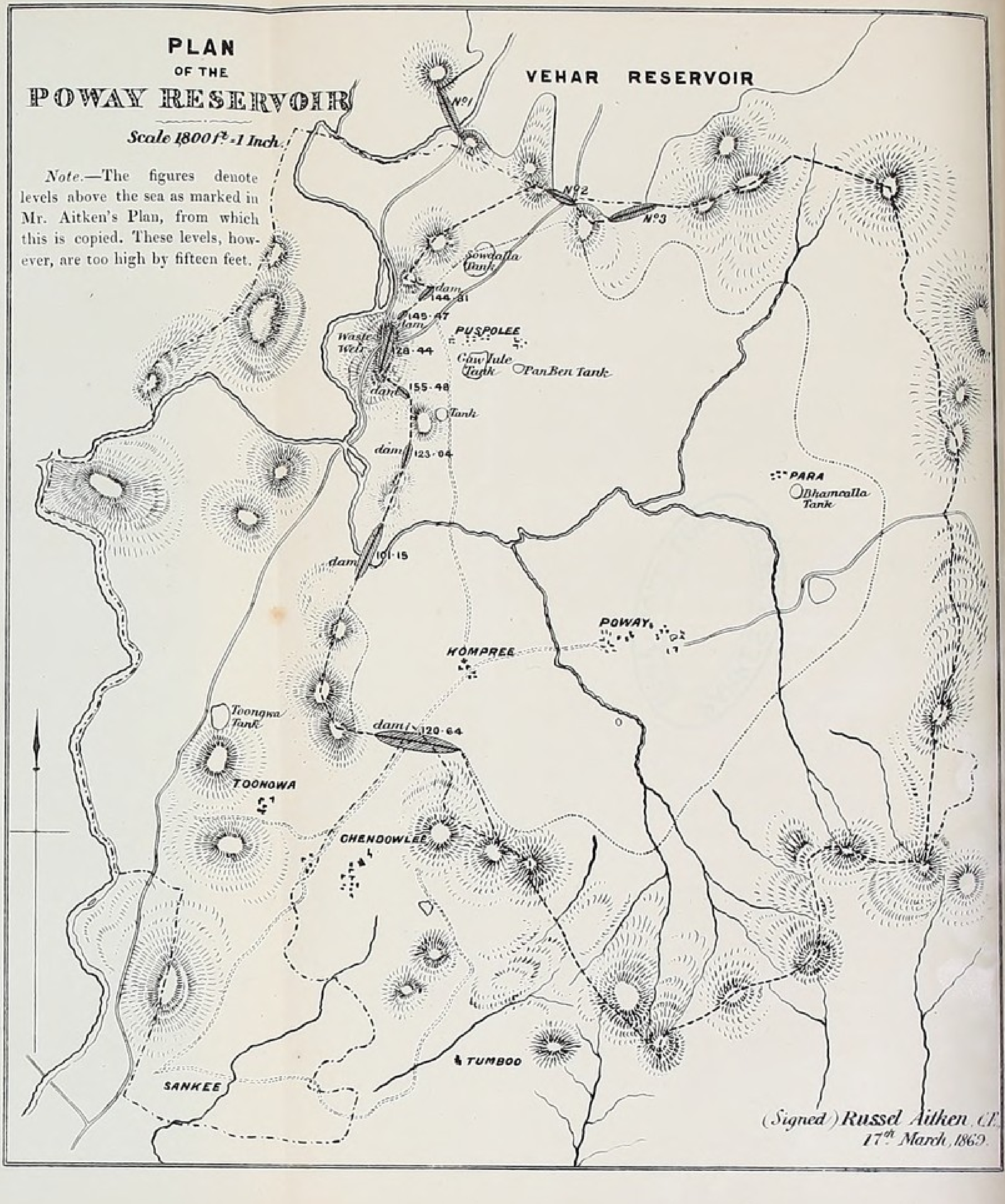
§ The survey of this valley had not been made when Mr. Aitken submitted his

KENNERY RESERVOIR.



NOTE.—*The levels shown are the correct ones. Those given in Mr. Aitken's Report and Plans, from which latter this Drawing has been copied, are over 15 feet too high.*

NOTE.
There are no other drawings of the Kennery Dam among the records.


PLAN
OF THE
POWAY RESERVOIR
Scale 1800 ft = 1 Inch.
Note.—The figures denote levels above the sea as marked in Mr. Aitken's Plan, from which this is copied. These levels, however, are too high by fifteen feet.
VEHAR RESERVOIR
No 1
No 2
No 3
Sowdalla Tank
dam
144·31
145·47
dam
Waste Weir
128·44
PUSPOLEE
Gaw Jule Tank
PanBen Tank
dam
155·48
Tank
dam
123·04
PARA
Bhamcalla Tank
dam
101·15
POWAY
HOMPREE
Toongwa Tank
dam
120·64
TOONOWA
CHENDOWLEE
TUMBOO
SANKEE
(Signed) Russel Aitken, C.E.
17th March, 1869.

have its gathering ground increased by 1,600 acres, so that the present supply from Vehar might be increased from 5 to $6\frac{1}{4}$ gallons.

"A new 28-inch main pipe will be required to convey to Bombay this extra quantity of water, and I estimate the cost of this work at $16\frac{1}{2}$ lakhs of rupees, or from $5\frac{1}{4}$ to $6\frac{1}{4}$ annas per gallon."

Of his Fourth Scheme Mr. Aitken wrote :—

The Poway Scheme.

"It embraces Scheme No. 3, but in addition to the supply to be obtained from the upper part of the Tassoo, I propose to construct a new reservoir at Poway.* A reservoir can be constructed in the Poway valley 980 acres in extent, and the total amount of earthwork in the dams will amount to but 380,000 cubic yards. The Poway basin presents very great facilities for the construction of a large reservoir, but unfortunately the gathering ground is very limited, being only about the same area as the Lake. This deficiency would, however, be supplied by running the surplus water from the Vehar Lake into the Poway reservoir.†

"If this scheme be carried out, 10 or 12 gallons per head may be secured at a cost of about $35\frac{1}{2}$ lakhs of rupees.

"The size of the main from Poway would require to be 36 inches in diameter to enable us to work it along with the supply from Vehar, and as we could depend on the Vehar Lake being filled every year, I would propose to lay another 32-inch main from Vehar, to join this proposed new main from Poway."

In forwarding Mr. Aitken's Report to the Government on the 12th October 1868, the Municipal Commissioner said : "I must reluctantly pronounce the construction of the Shewla Scheme pecuniarily impossible to Bombay at present," and Mr. Crawford recommended the carrying out of the Kennery

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Report. It was completed shortly before my arrival in Bombay in June 1870. A plan of both the Toolsee gathering ground and reservoir is given in Plate XIX.

* *Vide* Plate XVIII.

† I cannot give drawings of the dams of which there were to have been six. Excepting a longitudinal section of the main dam, copy of which may be seen in Plate XVI., there is no information on record regarding these works.

Scheme at the cost of 41½ lakhs of rupees. The financial view of the question taken by him was put thus :—

"The present income from the Vehar water rate is four lakhs of rupees. Of this one and three quarter lakhs goes towards payment of the Vehar works, and one lakh is needed for maintenance and minor extensions. This leaves one lakh and a quarter annually available for the construction of new works.

"I assume that Government would treat Bombay like Culcutta, and obtain the money required on its own guarantee at 4 per cent.

"The repayment of the loan should be spread over 50 years, and, besides interest, one fiftieth should each year be set aside as a sinking fund.

"To construct the Kennery works, the sum of 41,50,000 rupees is required.

Interest at 4 per cent......................	Rs.	1,66,000
One fiftieth for sinking fund	,,	83,000
Total amount required	Rs.	2,49,000

"I would provide this amount partly from the excess of the existing water revenue over expenditure, and partly by a light general water rate, which should be made leviable by law for 50 years, thus—

Excess available	1,25,000
One per cent. water rate	1,32,000
	Rs. 2,57,000."

The Government appoint a Commission on the Water-supply and Drainage. 1869.

In a resolution passed on the 12th January 1869, the Government appointed a Commission of the following gentlemen to take evidence and report on the Water-supply and the Drainage of Bombay: The Honourable A. R. Scoble, Chairman, Colonel W. Kendall, Lieutenant-Colonel J. S. Trevor, R.E., Dr. W. G. Hunter, M.R.C.P. With reference to the former subject the duty of the Commission was :—

"To consider Mr. Russel Aitken's schemes for increasing the water-supply, and to report on their relative general advantages, and to examine and discuss the details of that which they might consider most suitable, should they be of opinion that either of them was calculated to effect satisfactorily the object in view."

The Commission's conclusions.

The Commission sat for the first time on the 17th March 1869, and continued its sittings till the 7th of April following. At this stage in the history of the water-supply of Bombay, I became a party to the discussion. I gave evidence before this Commission, but I took an unfavourable view of all Mr. Aitken's projects. It is not my intention, however, in this report either to support my propositions or to criticise Mr. Aitken's schemes. I shall, therefore, merely state the conclusions at which the Committee arrived, and as far as possible in their own words. I beg to draw especial attention to these conclusions, as I think they are most worthy of consideration, and display a largeness of view on this important subject, which it behoves the town to weigh well. Regarding the Shewla Scheme, they wrote thus :—

"The Commission consider that it is too gigantic a work to be undertaken by the Municipality. Its cost would appear, if anything, to have been under-estimated by Mr. Aitken; for Mr. Ormiston puts it at two millions sterling, and Captain Tulloch at 180 lakhs. The proposal to carry the water for a distance of fifty-six miles in an exposed steel is also, in the opinion of the Commission, too novel an experiment to be tried on so large a scale in the first instance; and, without adopting Dr. Blaney's opinion, that the water would 'come into Bombay in the afternoon in a state for boiling an egg, warming a child's conjee, or giving a rheumatic patient a hot bath,' the Commission have no doubt that, should it be found necessary to bring water into Bombay from so great a distance, a masonry conduit would be in every respect preferable to a steel main."

Of the Kennery and Poway Schemes they said :—

"The Kennery and Poway schemes are both open to the work at 16½ lakhs, including the cost of a second main from Vehar to Bombay.

"The Commission recommend the adoption of this scheme, not only because, so long as the Vehar dams last, it will give an increase of 50 per cent. to the water-supply at a small cost, but also because it appears, from Captain Hancock's evidence, 'that the supply of water to the Vehar Lake is not much more than sufficient to meet the present drain upon it in average years,' and that, if a succession of years of low average rain-fall were to occur, there would be a considerable risk of the lake becoming exhausted if the consumption were not proportionately restricted."

The Commission then discussed the system of distribution, but this need not detain me. On the general subject of the water-supply of Bombay they expressed themselves thus :—

"The Commission venture to express their conviction that no scheme involving any considerable outlay should be adopted by the Municipality, or sanctioned by Government, unless it combines the least possible engineering risk in the method of its construction, with a capability of inexpensive extension from time to time to meet the growing wants of the population. By the last census the inhabitants of the Town and Island of Bombay numbered 816,562*; and it is reasonable to suppose that, in the course of the next 20 or 30 years, this number will be considerably augmented. In the construction of new and costly water works, the future as well as the present wants of the city should be borne in mind."

And they concluded their report in these important terms :—

"While it is the opinion of the Commission that by greater economy of distribution, and the addition of the Toolsee water, much will be done to alleviate the evils of the present scanty water-supply of Bombay, it is no less their conviction that no time should be lost in securing a full and permanently reliable supply of water to the town. Even

* The census taken last year (1871) shows the population to be as nearly as possible 650,000.

with the addition of Toolsee, the supply from Vehar will be sufficient only for an intermittent service, a *minimum* supply for domestic uses, and an unreliable supply in case of fires. The recommendations of the Commission, therefore, so far as they have gone, point only to temporary measures of relief. A continuous service, at full pressure, is what is required for Bombay, and Bombay should be satisfied with nothing less. This, the Commission consider, will be most securely obtained by a low level reservoir, from which the water should be brought by a covered masonry conduit to Bombay ;* and they recommend that surveys should be made without delay with a view to carrying out this proposal. With such a reservoir, not only could the supply of water to Bombay be made to keep ahead of any possible increase of the population, but all the water not required for Bombay might be made available for the service of towns on the road, for the supply of the Railways, and for irrigation. In this point of view, the work might fairly be regarded as an Imperial work, and not one of a merely local Municipal character."

The Government on the Water-Supply of Bombay. 1870.

With the Report of the Commission before them, the Government passed a Resolution on the 31st March 1870, and on the particular projects proposed by Mr. Aitken they expressed themselves thus :—

"Government concur with the Commission, in rejecting the Shewla scheme. It does not appear to have been ascertained beyond a doubt, that as good a storage basin cannot be found in closer proximity to Bombay, nor are the details of the scheme sufficiently well considered. The amount of the outlay involved also puts it beyond the power of the Municipality for the present at least.

"The Kennery and Poway schemes would not give results commensurate with the outlay they would involve, and the construction of either would only be a half-measure.

"A very substantial addition to the Vehar Lake, at an

* Further on the reader will observe that I have not failed to bear in mind the opinion of the Commission on this point. The Kamun scheme, which involves a low-lying reservoir and a masonry conduit, has been specially investigated to ascertain the advisability and expense of carrying out a project of this class.

expenditure which is within the means of the Municipality, might, however, be made by the execution of the Toolsee scheme, and Government concur with the Commission that this would be the best practical arrangement."

And on the general question of water-supply they went on immediately after to say :—

"It (the Toolsee scheme) could only, however, be regarded as an *interim* expedient, for it does not provide for the full quantity (fifteen gallons) of water per head for the number of people that now probably inhabit Bombay ; and would, therefore, year by year, as the population increases, become more and more inadequate : many years would, however, probably elapse before any practical inconvenience would be felt, and it is reasonable to suppose, in that interval, not only will some suitable scheme for a substantial increase be devised, but that means will be forthcoming for carrying it out.

"It is quite clear that, as a permanent arrangement, this city should not be left to depend on one source of supply, liable to suffer from insufficient rain-fall in successive years, or destruction from accident, to the impounding dams.

"The risk of either contingency may not be great, but it does, no doubt, exist, and, therefore, the Municipality should lose no time in having the further investigation suggested by the Commission made, in view to the selection of a suitable site for another reservoir, so that all may be ready for action as soon as suitable means can be made available ; in the meantime the dams of the Vehar Lake should be strengthened, as recommended, and the question of another main from Vehar should be seriously considered."

The Toolsee Project re-submitted by me to a Committee appointed by the Bench.

On the receipt of this Government Resolution, the Municipal Commissioner took action by having a careful survey made of the Toolsee valley. When I arrived in Bombay in June 1870, this survey was finished,* and I was directed

* I find now that the levels of all the dams which were referred by the Surveyor, Mr. Preston, to the supposed levels of the Vehar Lake, are wrong by nearly fifteen feet. The correct levels are given in the accompanying drawings, Plates XIX. and XX.

PLAN OF THE TOOLSEE VALLEY RESERVOIR.

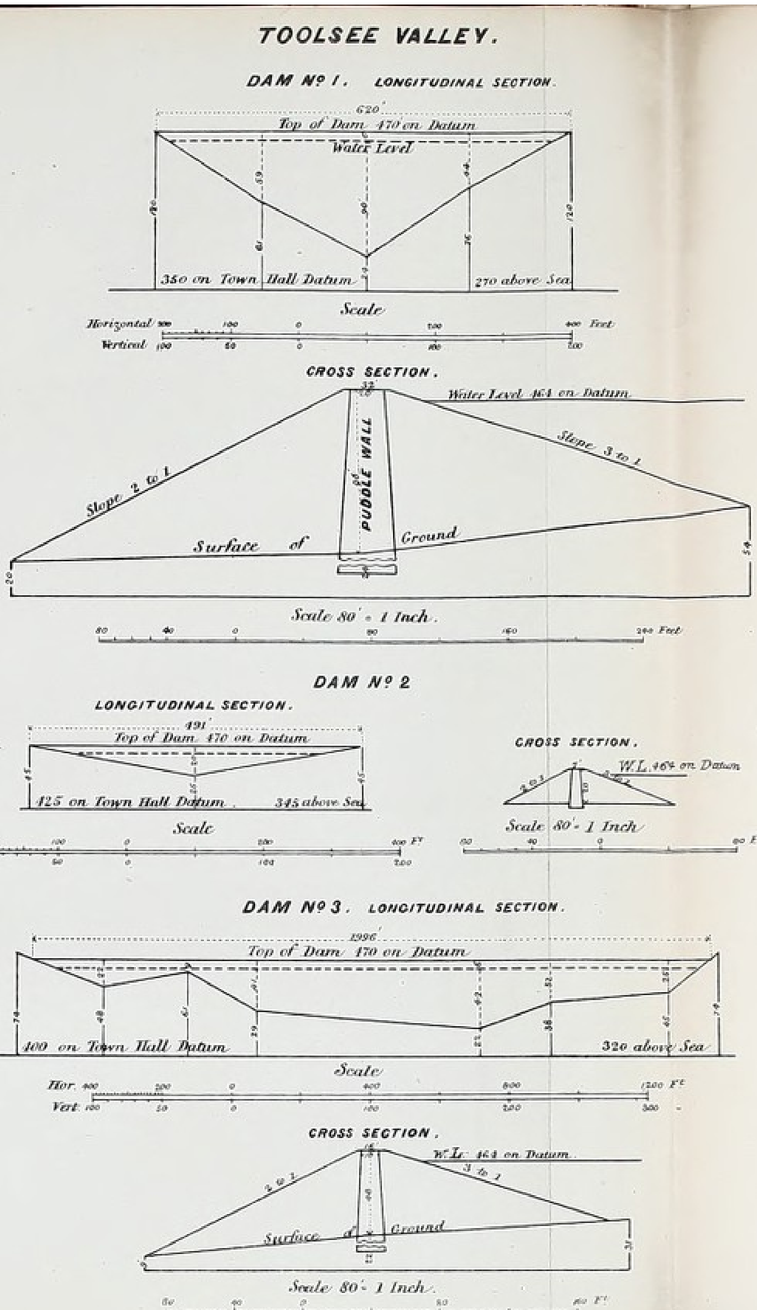
PLATE XIX.

SCALE 800 FEET TO AN INCH.

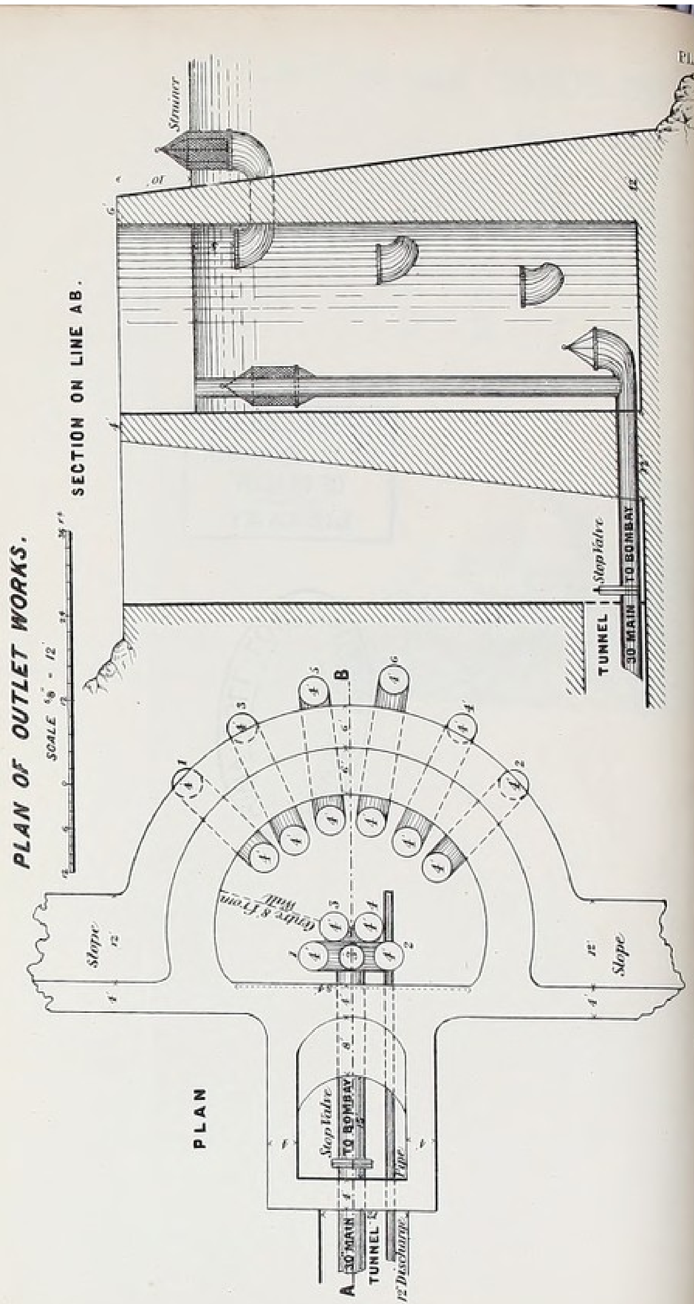
Area of Gathering Ground __ 1447 Acres.

Area of Lake at the	35 Feet Contour	50 Acres;	Capacity of Reservoir	69 Millⁿ Gallons.		
D°	D°	50	D°	125	D°	D° 410
D°	D°	60	D°	198	D°	D° 658
D°	D°	70	D°	262	D°	D° 1,346
D°	D°	80	D°	308	D°	D° 2,060
D°	D°	90	D°	345	D°	D° 292

(Sd.) H. Tulloch, Captn., R.E.,
Executive Engineer, Municipality.



TOOLSEE VALLEY.
DAM No 1. LONGITUDINAL SECTION.
620'
Top of Dam 470 on Datum
Water Level
350 on Town Hall Datum
270 above Sea
Scale
Horizontal
Vertical
Feet
CROSS SECTION.
Water Level 464 on Datum
Slope 2 to 1
Slope 3 to 1
PUDDLE WALL
Surface of Ground
Scale 80' = 1 Inch.
DAM No 2
LONGITUDINAL SECTION.
491'
Top of Dam 470 on Datum
125 on Town Hall Datum
345 above Sea
Scale
CROSS SECTION.
W.L. 464 on Datum
Scale 80' = 1 Inch
DAM No 3. LONGITUDINAL SECTION.
1996'
Top of Dam 470 on Datum
400 on Town Hall Datum
320 above Sea
Scale
CROSS SECTION.
W.L. 464 on Datum
2 to 1
3 to 1
Surface of Ground
Scale 80' = 1 Inch.



PLAN OF OUTLET WORKS.
SECTION ON LINE AB.
PLAN
Strainer
Stop Valve
TO BOMBAY
TUNNEL
30" MAIN
Slope
12" Discharge Pipe

to submit the Toolsee project as soon as possible. Accordingly in July the plans and estimates were ready, and the Bench of Justices then appointed a Committee composed of the following gentlemen to report on the scheme: Major General Tremenheere, Royal Engineers; Mr. Ormiston, C.E.; Mr. Le Mesurier, C.E.; and Doctor Lyon. According to the Committee's request, I drew up a brief memorandum on the subject, but, feeling that so short an investigation as one occupying me six weeks only did not justify my speaking with the least authority on so great a subject, I wrote :—

"I should preface my remarks by informing the Committee that I feel I am in no way capable of forming an opinion as to whether the Toolsee project, in any shape, is the best which the people of Bombay can adopt."

I went on then to say that the project was merely submitted for them to accept or reject on the facts put before them, and that I could neither condemn nor recommend it. I pointed out then that, as no rain-gauge had been kept in the Toolsee valley, it was impossible to say with any degree of certainty what quantity of rain fell there yearly. I showed, however, that such records as there were even on the question of the rainfall at Vehar were utterly unreliable; that, while it had always been supposed that the rainfall at Vehar was considerably in excess of that at Bombay, the records threw doubt even on this conclusion; that under these circumstances I preferred to assume that the rainfall was what Mr. Conybeare and Mr. Aitken had assumed it to be—viz., 102 inches or 8½ feet per annum. To this I added 12 inches, or about 12 per cent., to obtain the rainfall at Toolsee, which was thus calculated to be 9½ feet. I reasoned thus: the rainfall at Bombay is 75 inches, and the rainfall at Vehar (102 inches) is 36 per cent. in excess of it. But Toolsee lies as much (200 feet) above Vehar as Vehar lies above Bombay. Now it is an indisputable fact that in the Concan the higher the position the greater is the rainfall. Thus then if the rainfall at Vehar is 36 per cent. above that of Bombay, the rainfall at Toolsee should most certainly exceed that at Vehar. I assumed this excess to amount to only 12 per cent. on the Vehar rainfall,* and I therefore took the total rainfall at Toolsee to be 9½ feet.

The area of the Toolsee gathering ground, exclusive of that of the lake, which is 214 acres, is 1,233 acres.† Assuming the evaporation on the lake to amount to five feet per annum, I put the following facts before the Committee :—

		Gallons.
On the supposition of the rainfall at Toolsee being 12 per cent. in excess of that at Vehar and $\frac{7}{10}$ths of total rainfall being collected on the gathering ground.	Quantity collected from over surface of lake......	262,176,750
	Do. from gathering ground............	2,551,132,800
	Total Gallons...	2,813,309,550
On the supposition of the rainfall at Toolsee being 12 per cent. in excess of that at Vehar and $\frac{8}{10}$ths of total rainfall being collected on the gathering ground.	Quantity collected from over surface of lake	262,176,750
	Do. from gathering ground............	2,232,300,262
	Total Gallons...	2,494,477,012

The water was proposed to be brought to Bombay through an iron pipe under pressure. In the former case the pipe was to be 30 inches in diameter, and the main dam 96 feet high, while the cost of the works was estimated at 33 lakhs. In the latter case the pipe was to be 27 inches in diameter, and the dam 87 feet high, while the cost of the project was reckoned at 23¾ lakhs.

* The observations taken in 1870 showed the rainfall in the Toolsee valley to be almost exactly 20 per cent. in excess of that at Vehar, but I am not inclined to place much reliance on the observations of a single year. The monsoon of 1871 failed, but the rainfall in Toolsee, 53 inches, was 40 per cent. in excess of that at Vehar, 39 inches.

† The capacity of the lake is given on Plates XIX. and XXI., and on page 126. For information regarding the dams, *vide* Plate XX.

The Committee appointed by the Bench came to the conclusion that not more than four gallons per diem per head of the population could be obtained from the Toolsee valley, and they estimated the cost of the works to secure this supply at 25 lakhs. On the general question of water-supply they expressed themselves thus :—

"We are of opinion that Toolsee should not be undertaken unless it be shown conclusively that no better scheme is practicable. This has not been done yet ; and we therefore recommend that in the first place the Kennery scheme be carefully worked out as soon as possible. To do this it will be necessary to have an accurate contoured survey of the valley, and a survey and section of the line of main into Bombay. If while this is in progress, Captain Tulloch can find another site more favourable, he should report on it."

Acting on the spirit of the Committee's recommendations, I, at once began an examination of the surrounding country, and a series of surveys of such valleys as I thought most suitable to the purposes of the town ; but, just as the work was drawing to a close, and while I was engaged in preparing this Report, a sudden and severe illness, contracted while prosecuting my outdoor duties, compelled my immediate departure to England on the 14th October 1871. Shortly after this, and in consequence of the failure of the monsoon, the question of water-supply assumed great prominence, and in November, my successor in the office of Executive Engineer to the Municipality, Mr. Rienzi Walton, was called upon to submit another report on the capabilities of the Toolsee Valley. This report, with plans, was ready by the end of December. (*Vide* Plate XXI.)

Mr. Walton's Projects.

Mr. Walton was of opinion that about 1,340,000,000 gallons yearly, or 3,670,000 gallons daily, could be obtained for use. This would be equivalent to $4\frac{1}{4}$ gallons per head per diem during a twelvemonth for the supposed population at that time—viz., 850,000, but equal to rather more than $5\frac{1}{2}$ gallons per head per diem per annum for the recently ascertained population—viz., 650,000.

In his first project Mr. Walton did not propose to impound any water for use in the Toolsee Valley, but to throw the entire available supply into the Vehar Lake. A dam 35 feet high was to be built across the Toolsee stream, and the water was to be led from the small reservoir thus formed into the Vehar Lake by a tunnel under the dividing ridge between the two valleys. This tunnel was to be 10 feet wide. and 7 feet high, and to have a slope of 20 feet per mile. Mr. Walton was careful to remind the public that only in the event of the lake being sufficiently low to admit of its holding the extra quantity of water could the latter be made available. In any other case the water must necessarily, after flowing into the lake, run to waste over the weir.

In his second project Mr. Walton proposed to impound water to such a height (64 feet) as to utilize the ridge of hills between Vehar and Toolsee as a waste weir, so that the surplus water, after the new reservoir became full, might pass into the Vehar Lake. The capacity of the new reservoir was ascertained to be 581,000,000 gallons, or say $2\frac{1}{2}$ gallons per head per diem for one year for a population of 650,000. If the Vehar Lake happened to be full, the surplus water was to be temporarily dammed up on the ridge and passed over a weir near the Toolsee Dam.

No. 3 Project differed "from No. 2 only in having higher dams, and consequently increased storage." The dam was to be 74 feet high, and the capacity of the lake 1,451,000,000 gallons, equivalent to, say, six gallons per head per diem for 650,000 people for one year. In this case a dam 21 feet high was proposed on the ridge between Toolsee and Vehar. The arrangements for drawing off the surplus water were similar in their nature to those proposed in No. 2 Project.

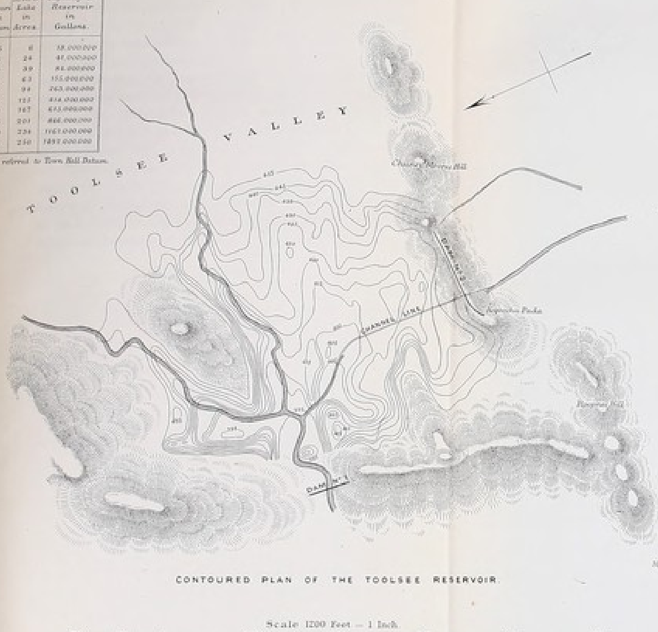
Mr. Walton estimated the cost of the different projects at

Contours on Datum.	Area of Lake in Acres.	Capacity of Reservoir in Gallons.
395	6	18,000,000
405	24	41,000,000
410	39	81,000,000
415	63	155,000,000
420	94	263,000,000
425	121	414,000,000
430	167	613,000,000
435	201	848,000,000
440	234	1163,000,000
445	250	1497,000,000

CAPACITIES OF THE RESERVOIR

Area of Gathering Ground 1447 Acres, Bed of River 395 on Town Hall Datum.

Levels referred to Town Hall Datum.

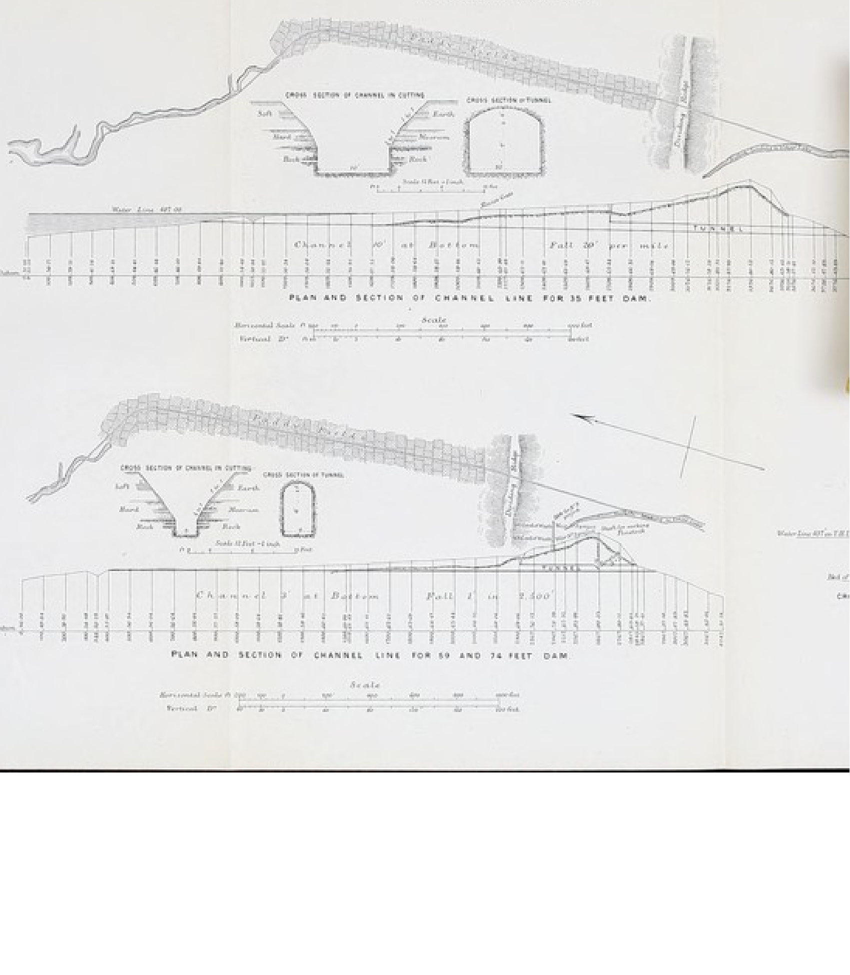


CONTOURED PLAN OF THE TOOLSEE RESERVOIR.

Scale 1200 Feet = 1 Inch.

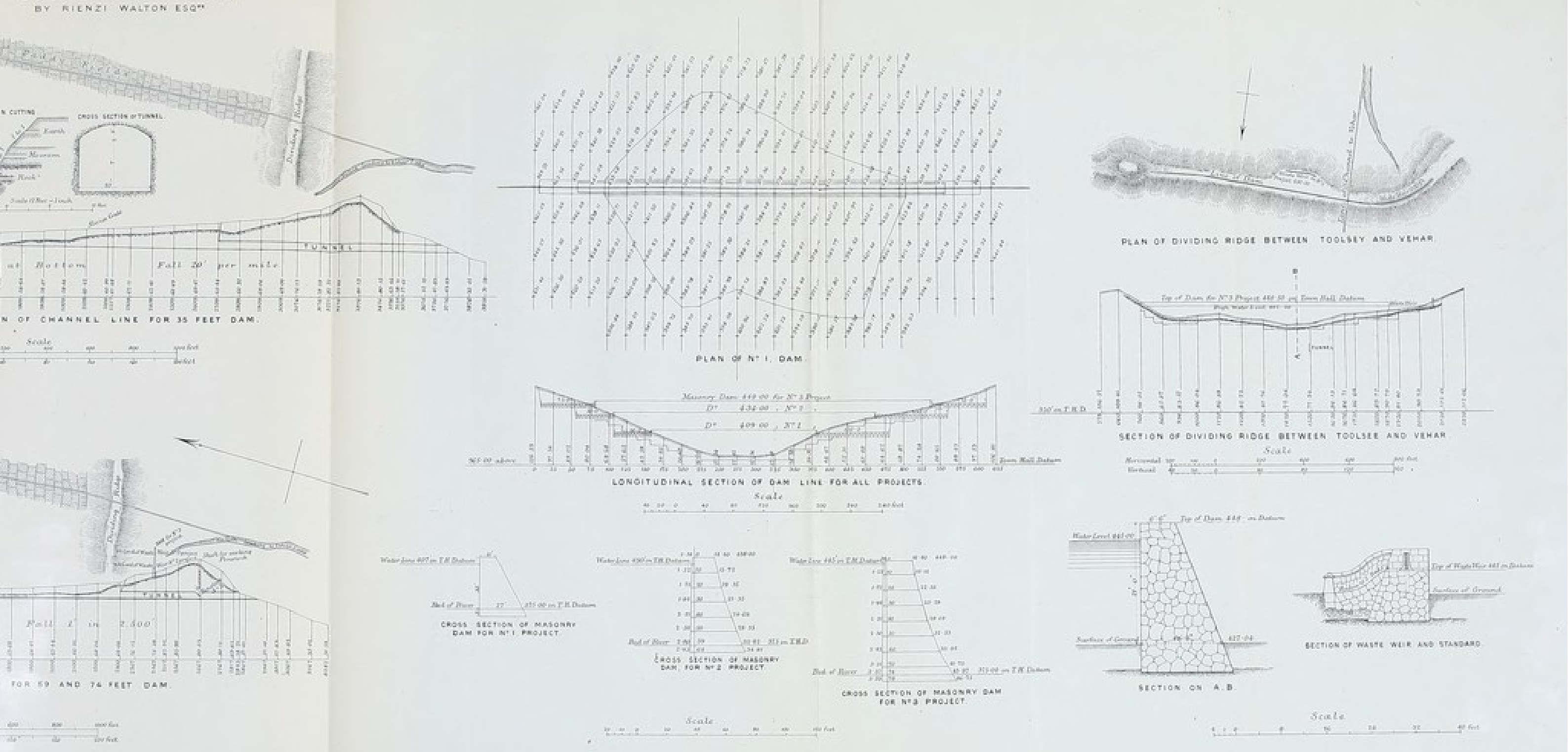
TOOLSEE PROJECT.

BY RIENZI WALTON ESQ^RE



TOOLSEE PROJECT.

BY RIENZI WALTON ESQre



Mall. Bros. Lith. London.

—No. 1, Rs.1,38,315—No. 2, Rs.1,75,221 —No. 3, Rs.3,59,153. He strongly recommended the last, and showed its great superiority to the other two. This project, with some slight modifications proposed by Mr. Ormiston, was approved by the Bench, and an application was made to Government for five lakhs of rupees—the sum which Mr. Ormiston estimated the works would cost. The Government offered the Bench four lakhs only. Some correspondence passed on the subject, but the ultimate result was that the season was too far advanced to admit of much work being done till after the monsoon.

The reader having now been made acquainted with the main events which have occurred in connection with the Water-supply of Bombay during the last quarter of a century, will be in a better position to form a judgment on this most important subject.

CHAPTER II.

DESCRIPTION OF THE COUNTRY ABOUT BOMBAY.

Salsette.

If we examine a map* of the surrounding country about Bombay, we find that the town stands on an island about eight miles long and two miles wide. This island is separated from the mainland by an arm of the sea, which, forming the harbour, and gradually narrowing into a creek, runs for about 25 miles in a northerly direction, and then, suddenly taking a turn to the west, issues into the Indian Ocean near the ancient town of Bassein. This tortuous creek forms a second island known to us as Salsette, and having an area of over 150 square miles. It presents, moreover, physical features which, for the purposes of water supply, have always attracted much attention, and therefore deserve the fullest consideration at my hands. The centre portion consists of several ranges of hills, some attaining an altitude of over fifteen hundred feet above the sea. Even the valleys between the ranges are at a great height and have a considerable command of elevation over Bombay. Of these valleys, however, three only are of any practical use for the purposes of so large a town. The rest are not sufficiently exten-

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* *Vide* "Index Map," facing title page.

sive in area to meet its wants. The southernmost valley, that known as Vehar, has already been utilized. There remain two others; the Kennery valley* which debouches to the north-west, and the Ewoor valley, which, carrying its waters northwards, throws them into the Tannah Creek. The area of these three valleys are, roughly speaking, about equal to each other. Each offers us six square miles of gathering ground, so that if we take the rainfall in the Vehar valley as the average rainfall over all, three times the supply which we now obtain from Vehar, or say 25,000,000 gallons per diem, will fairly represent the utmost capabilities of Salsette.

Geologically there is but one formation—trap. Such other strata as may be found on these hills are merely superficial deposits, below which, at a few feet of depth, the same characteristic rock, and generally of a hard unyielding nature, will invariably be met with.

Thus, then, at present we have found two valleys which require to be investigated—the Kennery valley, and the Ewoor valley. The facts of these will be given in full detail hereafter.†

The country about Panwell.

If we leave Salsette and return to Bombay, and then, crossing the harbour, pass on to the mainland, we shall find under our feet a low-lying country with numerous rivers all flowing westward, and with numerous ranges of hills of varying heights, some con-

* The Toolsee valley which, later on in this Report, I have, at the request of the late Municipal Commissioner, Mr. Hope, gone into thoroughly, forms merely the upper portion of the Kennery valley, and is, therefore, comprised in it.

† I should mention here that it is not my intention to consider the Poway valley, the facts in connection with which were given by Mr. Aitken, in his Report on the Water-supply. The scheme has been condemned because there is an unanimous opinion among all the intelligent and educated inhabitants that no project should be entertained for the construction of a reservoir, the safety of which is at all dependent on the safety of Vehar. Poway lies immediately below two of the Vehar dams, and, if anything happened to the latter, there would be very little left of the Poway reservoir. On the same ground the lower portion of the Marole (*i.e.*, the Vehar) valley has not been investigated by me; nor is it, indeed, at all suited to our purposes.

nected with each other, others standing by themselves. We shall also find the land steadily rising towards the east, and our progress in the distance threatened by the chain of mountains on which that lovely little sanitarium, Matheran, lies nestled.

Owleh Basin.

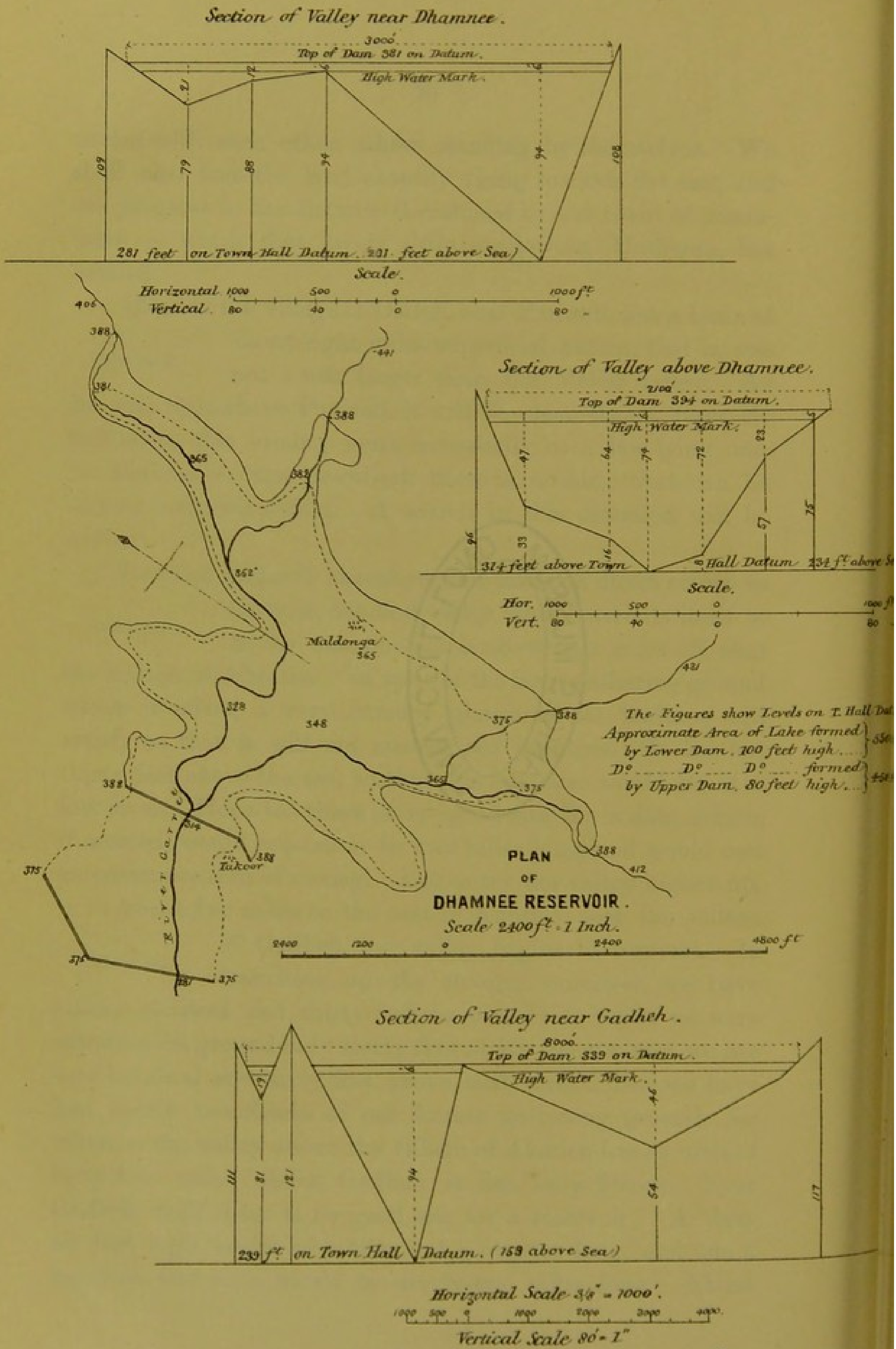
Close to the village of Owleh, near Panwell, lies a basin of about eight miles superficial extent, that is, one not much larger than the Vehar valley. As the tide rises above Panwell, it will be clear that a reservoir formed in this locality must necessarily be a low-lying one. In addition to this drawback there is nothing that can be termed a site for a dam. A search in this direction will be useless.

Akoorlee Basin.

Leaving Panwell, therefore, and taking a direct course to the east, the first valley which presents itself to us for examination is about four miles off, near the village of Akorlee. In spite of the large gathering ground which it offers, a very cursory glance at its features will satisfy us that it will not answer our purposes. It lies but thirty feet above the sea, so that this lake also would be at a low level. Here too there is no good site for a dam, which, if erected, would require to be two miles long, and would cost an enormous sum of money. Let us try the valley higher up.

Gadheh Basin.

About five miles to the east of Akorlee, near the village of Gadheh, the valley begins to contract. In travelling up the stream, moreover, we have risen a hundred and thirty feet, so that while before we were standing on ground only thirty feet above the sea, now we are one hundred and sixty feet above that level. But we have lost nearly two-thirds of our former gathering ground, for whereas the valley above the village of Akorlee has an area of forty-five miles, above Gadheh it has only fifteen. Near Gadheh itself there is no good site for a reservoir. A dam 80 feet high would be a mile and a quarter long, and one a hundred feet high would be nearly two miles long. About


Section of Valley near Dhamnee.
3000'
Top of Dam 381 on Datum.
High Water Mark.
281 feet on Town Hall Datum. (201 feet above Sea)
Scale.
Horizontal 1000 500 0 1000 ft.
Vertical 80 40 0 80
Section of Valley above Dhamnee.
2100'
Top of Dam 394 on Datum.
High Water Mark.
314 feet above Town Hall Datum 234 ft. above Se
Scale.
Hor. 1000 500 0 1000 ft
Vert. 80 40 0 80
The Figures show Levels on T. Hall Dat
Approximate Area of Lake formed by Lower Dam, 100 feet high
Do. Do. Do. formed by Upper Dam, 80 feet high
Maldonga
Takoor
River Gurree
PLAN
OF
DHAMNEE RESERVOIR.
Scale 2400 ft. = 1 Inch.
2400 1200 0 2400 4800 ft
Section of Valley near Gadheh.
8000'
Top of Dam 339 on Datum.
High Water Mark.
239 ft. on Town Hall Datum. (159 above Sea)
Horizontal Scale 3/8" = 1000'.
Vertical Scale 80' = 1"

Dhamnee Basin.

half a mile further up the river, near Dhamnee, a lake might be formed.* But now the gathering ground is still further reduced from fifteen to ten square miles. This objection may be got over in the minds of some on the consideration that the rainfall in this region is tremendous, and that these ten miles of collecting area would be really equivalent to forty or fifty miles anywhere else. On the other hand, others may urge that the heavy fall of three hundred inches yearly at Matheran is confined to the plateau itself, the area of which is trifling, and that the rainfall in the valleys is probably the same as that in other similar localities. Be this, however, as it may, there is unfortunately no storage capacity at Dhamnee for a large body of water. The streams run through gorges and have rapid falls—falls of from seventy-five to nearly a hundred feet per mile! Even a dam 170 feet high would not send the water back more than about two miles, and this only in the main streams. In fact, a dam higher than the highest† in the world and five times longer would not give us a lake of greater superficial extent perhaps than that of Vehar. Thus, although there may be abundance of water available for our purposes, and at a fair height above Bombay, still the physical features of the country do not admit of its being stored except at an enormous cost, nor, as will be shown presently, of its being brought into Bombay except at a greater one.

It is no use to follow this valley any higher. The gathering ground rapidly contracts, and all the objections already urged increase. Let us retrace our steps for some two or three miles, and then, proceeding in a south-westerly direction, let us stop at the village of Cheekleh. Before us stands the giant Prubhul pouring his waters down in numerous streams which meet at our

Prubhul Basin.

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* *Vide* Plate XXII.

† The Furens Dam, near St. Etienne in France. It is 164 feet high and about 330 feet long. *Vide* Chapter III. for fuller information regarding this work. *Vide* also Fig. 5, Plate XXVI.

very feet, but defying us to intercept them. No dam which we could construct here would be of any use, and higher up the valley we could not manage without two very expensive works. Let us pass through the gap in the range of hills to the south and continue our search eastward.

Matheran Basins.

We now come upon two promising valleys with a combined area of over twenty square miles and with a great water-supply. These two valleys, in fact, are the main recipients of the floods which fall upon Matheran, and they join their waters together close to the village of Chowk. Here then clearly would be abundance of water for our purposes if we could collect it. Unfortunately, however, the spur on the east is very low, lower even than the dam which would be required. We could not in fact intercept the two rivers after their junction at all. The only plan would be to deal with each river separately. But an attempt to do this even would be at great cost. The accompanying plan* gives a section of the western valley by itself, the more favourable one of the two, and it will be seen that a dam a hundred feet high would be not only nearly a mile long, but, which is really the point to look to regarding all dams, very high for the greater portion of the length. The valley, moreover, rises too rapidly (120 feet in two miles) to admit of the storage of much water, nor does it lie so high above Bombay as could be desired. We should not in fact have sufficient pressure for our purposes.

The eastern valley, with characteristics similar to those of the western one, offers us even still less hope of success.

Thus the hills about Matheran, in spite of the heavy rains which pour on them, and in spite too of their comparatively short distance from Bombay, do not offer those facilities for water-supply of which the engineer is in search. There are no flat wide opening valleys, narrowing suddenly into gorges.

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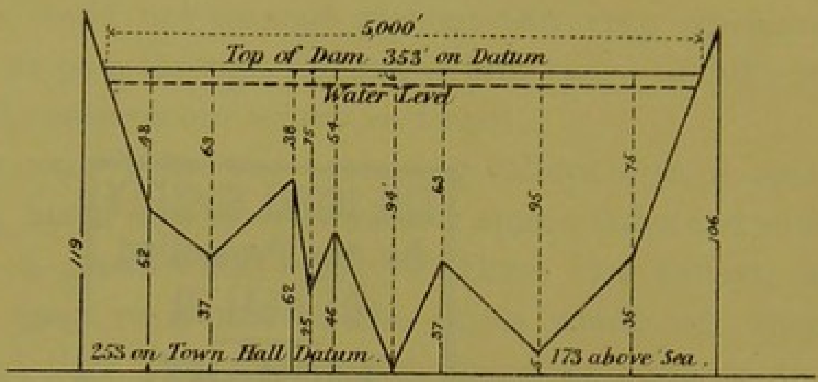
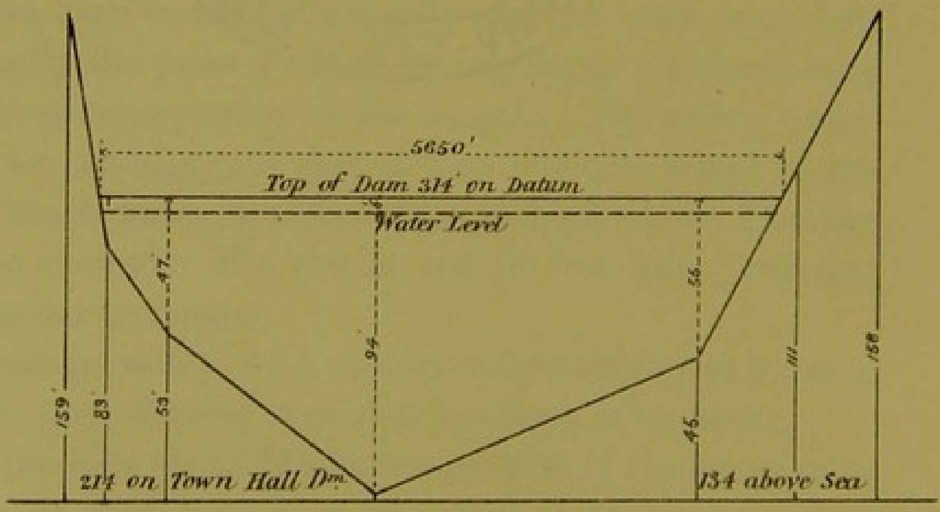
* *Vide* Plate XXIII.

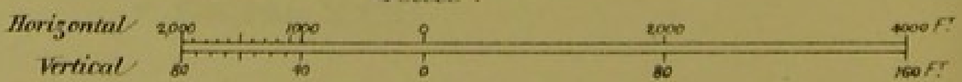
SECTION ACROSS THE WESTERN MATHERAN BASIN.



SECTION ACROSS VALLEY AT KHALAPOOR.



Scale.



On the contrary, either the ground from the bottom of the valleys rises on each side with too great a slope to admit of the storage of much water, or the streams have too rapid falls, or there are no very narrow gorges suitable for dams. Nature evidently had not the commonplace question of the water-supply of Bombay in her mind when she fashioned these grand old hills into their present picturesque forms.

Khalapoor Basin.

Let us leave Chowk and travel southwards, and this will bring us into a large valley fed with rain from the precipitous heights of the western ghauts. Near the village of Khalapoor, where the valley narrows to a width of about two miles, would seem to be the most natural site for the dam. A reference to the accompanying plan* will show how expensive the dam would be. But this is not all. Two more dams would be required to stop up other gaps in the hills, and worse than every other objection is the fact that the valley lies very low, fifty feet below even the Vehar basin. As the pressure from the Vehar Lake is only just sufficient for our purposes, it is manifest that the pressure from a basin so low and so far away as Khalapoor would not suffice.

Objections against bringing water from the east or south-east.

Before leaving this part of the country and in order to thoroughly convince the reader, in fact to leave no room for doubt in his mind, of the expense and inadvisability of drawing our water-supply from any of the valleys about Matheran or to the east or south-east of Bombay, I will now point out to him other and insuperable difficulties, which apply without exception to every reservoir that may be formed in this direction.

This part of the country, however promising it may look on account of its proximity to Bombay in a direct line, can only be considered close to us *practically* if the water is conveyed to the town by a direct route. Now let me point out what this would involve. It must involve a tunnel under

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* *Vide* Plate XXIII.

some part or other of the harbour.* I have not omitted to consider this matter carefully, and, if I had had any hope of overcoming the difficulties of constructing such a tunnel without the risk of its having to be abandoned ultimately, I should have added another to the present projects, and submitted one for the supply of the town from the east or south-east. But let me proceed to explain.

There are two routes we may take across the harbour. The first is from the mainland to Elephanta and on from Elephanta to Trombay ; and the second is from Elephanta to Butcher's Island and straight across to Mazagon. Along the former route there would be a tunnel more than 1½ miles or 7,920 feet long, and it would be under water fifty feet deep. As it would be practically impossible to have a shaft anywhere along the line, it follows that the headings would be 3,960 feet long—that is to say, that from each end we should have to pierce a tunnel of this length before the two met in the middle. Now suppose the rate at which we could advance to be one foot a day, which is probably under such circumstances the utmost daily average progress we could hope to make, it would take about eleven years to complete such a work. On the second line, which involves a tunnel three miles long from Butcher's Island to Mazagon, we should require just double the time, or twenty-two years, before we could bring the supply to the town. And suppose, having got our tunnel, anything were to go wrong with it—that a burst in the pipe laid along the inside were to take place. What a long interruption in the supply would occur! Or, in order to prevent this, suppose the tunnel were made wide enough for two or three lines of pipes, so that, on one failing, the stop valves on it could be closed and the other lines could be used. Then conceive how large a tunnel would be required for this purpose, and how great would be the cost. My own opinion is that if

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* *Vide* Map facing title page.

we went to a sufficient depth below the bottom of the harbour we might probably find solid rock of a sound nature, but *how deep* we should have to go to find it no one could possibly say. No borings could be perfectly satisfactory. It is this risk, this uncertainty as to the depth at which we could make sure of finding solid rock, that has induced me to look unfavourably on any project for the supply of water from the east or south-east of Bombay. To go exceedingly deep, say 200 feet below the bed of the harbour, would be only to increase our difficulty in another direction, for the pressure on the pipes would become so great as to involve the risk of their constantly bursting.*

If this region offered some extraordinary advantages, not to be obtained elsewhere, it would be different. The risk and danger of crossing under the harbour might then be entertained, but this is not the case. In the most essential point of all, the practicability of bringing the water by a high level conduit,† the country offers us no advantage. There is no range of hills running with a straight course in the direction of Bombay like the ranges in the Island of Salsette. The towns of Tannah and Panwell are in a direct line about the same distance from Bombay. Yet to convey water to Bombay from the reservoirs which might be formed near Tannah, say from the Toolsee or Ewoor valleys, would necessitate ten miles only of iron pipes, while to bring water from the nearest valleys in the neighbourhood of Panwell would involve us in a cost of from sixteen to twenty miles of pipes.

The route which a high level conduit from the direction

* Suppose a three and a half or a four foot main were used, (the head of pressure being about 450 feet), we should for India require the pipes to be about $1\frac{3}{4}$ or 2 inches thick. The cost of such a main would be tremendous.

† I must ask the reader to accept at present my bare statement for this. I could not stay to prove that a high level conduit is the best and cheapest way of bringing water to Bombay without breaking altogether the thread of my argument and wandering into a subject foreign to the purpose of this chapter. But the whole subject is discussed *seriatim* in Chapter IV., and if he cares to revert to it before proceeding further, I think he will find the arguments irresistible.

of Matheran would have to take is marked on the map facing the title page, and a reference to it will show that, if this mode of bringing the water to Bombay were adopted, the channel would be no shorter than those from other reservoirs possessing advantages which are not to be found in the valleys about Matheran.

When all these points are considered—the cost and risk of tunnelling under the harbour—the time required to complete such a work—the chance of the tunnel having to be abandoned through unforeseen difficulties arising in its construction—the delays that would take place in repairing the main when it burst—the heavy cost of the pipes—the great pressure of water to which the pipes would be constantly subjected—the indifferent sites for dams—the want of storage capacity in the basins—and lastly, the length of the channel if a high level conduit were adopted—the public will perhaps be disposed to agree with me, that, not until it has been proved that we cannot obtain water from elsewhere, should we be justified in attempting to bring it from beyond the harbour.*

I have now run cursorily over nearly all the country lying to the east of Bombay and to the west of the ghauts. I do not think it necessary to enter on the features of the valleys situated to the south of the Patalgunga river, because, however favourable a reservoir so far south may be found, still the cost of bringing the water to Bombay, in consequence chiefly of the obstruction which the harbour presents, must be so great, and the risk of failure is so probable, that the public would never entertain a project of this character.

The country about Callian.

Being close to the railway station of Kurjut, let us travel northwards and stop at Callian, the junction of the two trunk lines of the Great Indian Peninsula Railway. This will be an admirable stand-

* Should a Birkenhead spring up in the future about Hog Island, the basins near Matheran might then be turned to account for its supply.

point of view for a large tract of country. It will be seen that close to this town meet all the rivers from the western ghauts which take their rise in the great extent of country lying between the Tull Ghaut to the north and the Bhore Ghaut to the south—a distance apart of over sixty miles. It is well known that the rainfall along the western ghauts is among the heaviest in the world, and that during the monsoon the rivers which have their sources in them bring down enormous quantities of water—floods which no engineering works could possibly impound anywhere in the neighbourhood of Callian. No part indeed of the country about Bombay offers so few facilities for the storage of water as this district.

A glance at the map will show that on the south and on the west are wide plains, and that in the other directions, instead of the ranges of hills which we meet elsewhere, we have merely solitary hills standing apart from each other, as if they had passed a resolution among themselves to give the rivers as wide a berth as possible for their impetuous careers. There are three principal rivers. Let us begin by following the course of the southern one.

The Oolas and its southern tributaries.

It will be seen that the Poonah line of the G. I. P. Railway runs along the valley of the Oolas, and, therefore, that to dam up this river anywhere in its course would simply be tantamount to swamping the railway. This being out of the question, the only point is whether, as the main stream is not suited to them, some of its tributaries might not answer our purposes. The country through which the Posree, the Khansee, the Dhavree, the Chillar, and the Meercholee flow is open to the same objections as that about Matheran. The fact of its being further from Bombay gives still greater force to these objections. In addition to this, these tributaries soon after leaving the ghauts flow over ground unsuited to the construction of dams, and continue their courses apparently with a fixed determination not to be so foolish as to be caught passing through a gorge. Thus the large tract of country between the Matheran range and the Western Ghauts, well fed as it is with rain, is singularly innocent of any intention to gratify our propensities for storing water.

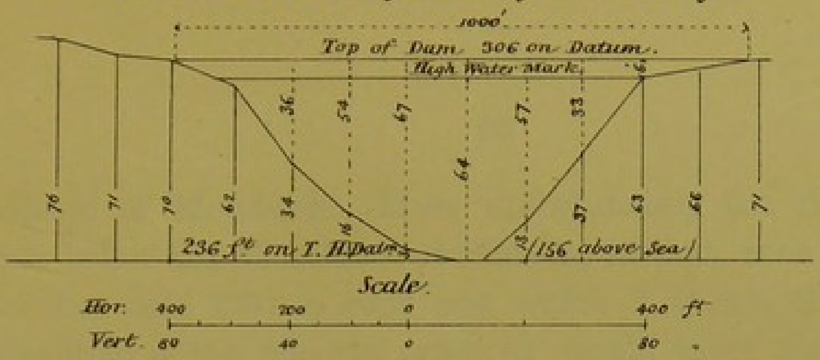
The Moorbaree and Mohoghur.

Leaving this ungrateful district, let us follow the career of the only other tributary of the Oolas. The Bhurvee is fed by two rivers, both of which rise in the Western Ghauts. Mr. Aitken, the late Executive Engineer to the Municipality, examined the valleys of these smaller tributaries, and I think he did wisely in preferring the northern one. It is in fact on this—viz., the Moorbaree, that the site for the Shewla reservoir proposed by him is to be found. So far as their positions with reference to Bombay are concerned, neither river possesses any advantage over the other; but the Moorbaree runs in a much higher bed. A reference to the map will show that while near Shewla the bed of the Moorbaree is 328 feet above datum (say 228 above Bombay) the bed of the Mohoghur at Tondlee, which is practically about the same distance from Bombay as Shewla, does not rise to more than 260 feet above datum (160 above Bombay). Thus there is a difference of 68 feet to the advantage of the Moorbaree. This command of elevation enables the engineer to give a better slope to his delivery channel, whether it be a pipe or a conduit, and thus to obtain either a greater discharge of water at the same cost or an equivalent discharge at a less cost. The valley of the Mohoghur having, however, been investigated, it is my duty to present the facts to the Bench, and the accompanying plan* shows the extent of the reservoir and the height and length of the dam near Tondlee.

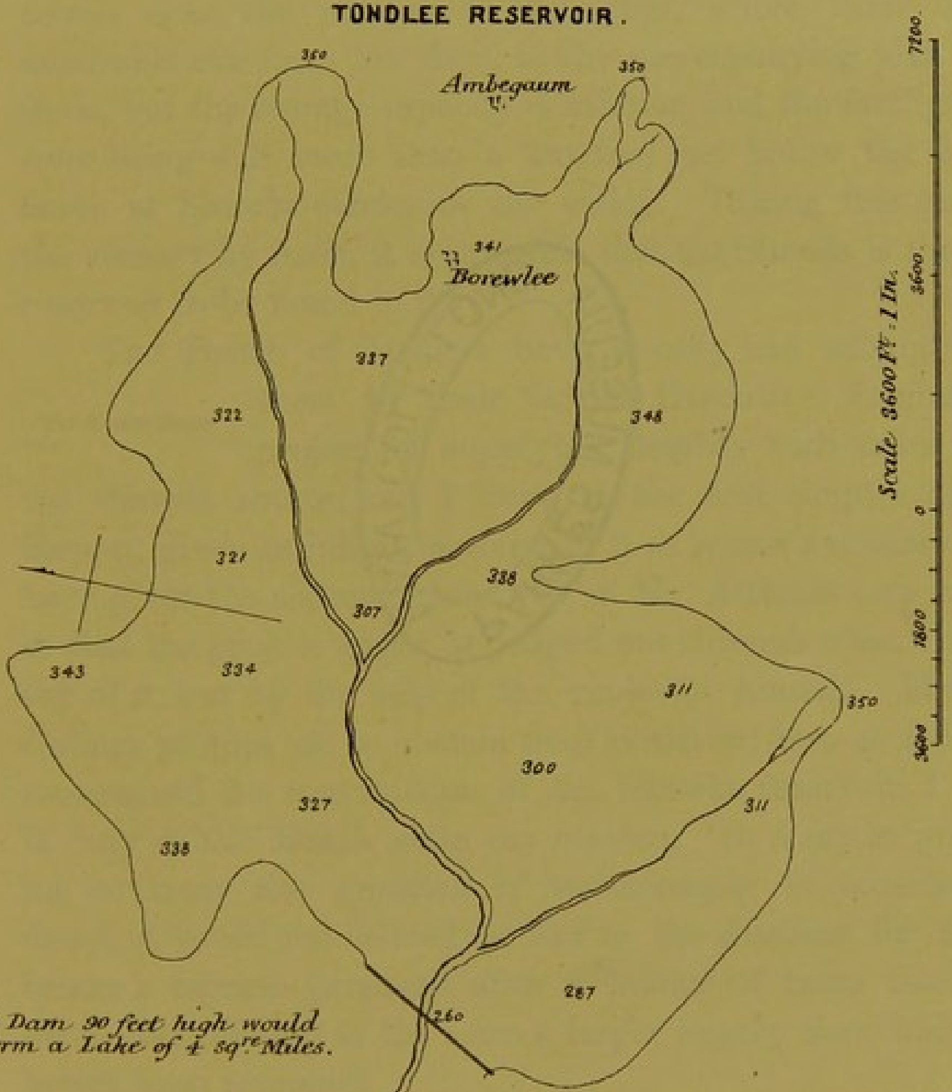
It may occur to many, on examining the map, that there are two gorges on the Mohoghur nearer to Bombay than Shewla, and requiring explanation. The first occurs near the

* *Vide* Plate XXIV.

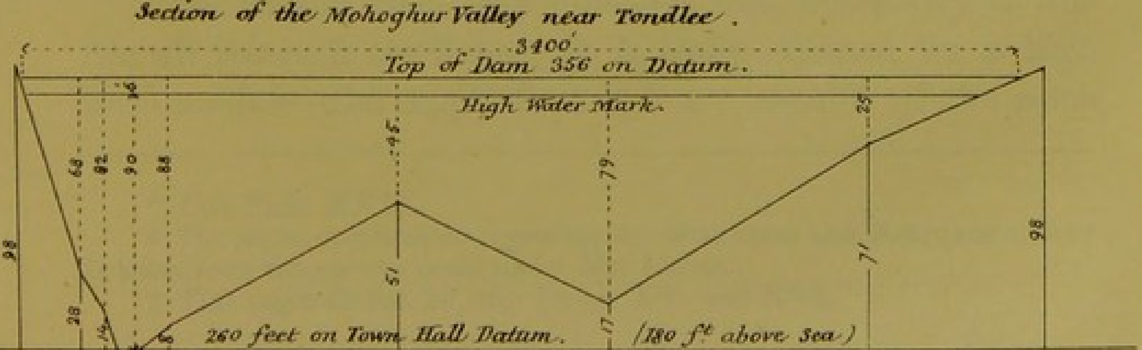
Section of the Mohoghur Valley near Mohoghur.



PLAN
OF
TONDLEE RESERVOIR.



Section of the Mohoghur Valley near Tondlee.



village of Mandweh. Here unfortunately the river is 150 feet below the Moorbaree at Shewla, so that, even if the site for the dam were a good one, which it is not, this superior elevation of the Shewla reservoir would more than counterbalance any slight advantage of distance. The other gorge occurs near the village of Mohoghur, where there is an admirable site for a low dam, as the accompanying plan will show, but the storage capacity is inferior, and the fact* of the river being still more than a hundred feet below the Moorbaree at Shewla condemns the valley. Taking this part of the country by itself, it is probable that the Shewla is the best reservoir to be found in it.†

The Shewla Reservoir.

The Bench of Justices have already had submitted to them by their former Executive Engineer a project for supplying Bombay with water from the Shewla source, and I have, in the first chapter of this Report, given as full an account of it as seems necessary.‡ I have given the account, moreover, in Mr. Aitken's own words, so that the project might be judged not through what I might say of it, but by the help of the projector himself. My own feelings prompt me to abstain from criticism; but, as I do not recommend the construction of the Shewla reservoir, I must in duty to the Bench state my reasons. In a report professing to treat the question of water-supply in considerable detail, it would not indeed be fair to the Justices for me to ignore a scheme prepared after a labour of more than two years, and offering to the town a larger supply than had ever before been proposed.

The reasons then why I do not look favourably on the Shewla reservoir are these. It is badly situated for a high level conduit—the supply from it is not capable of the same

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* *Vide* Plate XXIV.

† The above information regarding the Moorbaree and Mohoghur valleys is taken from the surveys made under Mr. Aitken.

‡ *Vide* pages 38 and 39, also Plates XV. and XVI.

amount of extension as another reservoir which will be proposed further on in this Report—the communications in that part of the country are in a wretched state—and heavy compensation would have to be given for the several square miles of most valuable land which would be submerged by the lake.

It would be out of place for me here to point out that the Shewla reservoir does not well admit of a high level conduit. Before doing so it is necessary I should prove that a conduit is preferable to a pipe. I engage, however, to show, hereafter, the great advantages which the former possesses over the latter with regard to both cost and durability. And, if I do so, it will then no doubt be admitted that, *cæteris paribus*, that is the best reservoir which offers us a high level duct for the greater portion of the distance to Bombay.

Regarding also the important point of the capability of extension, there is no comparison between the Shewla reservoir and the one submitted in this Report. It would not be possible to carry the Shewla dam above about ninety feet, for the water would escape in several directions. The limit, therefore, to the capacity of the lake is the quantity of water contained in the reservoir up to this level, but the capacity of the other reservoir is limited only by the consideration of how high a dam it is possible to build without running the risk of its crushing in by its own weight. The gathering ground, moreover, of the Shewla basin is little more than half that of the other.

The importance of good roads for the conveyance of materials for large works can hardly be magnified. There are no roads at all between the railways and Moorbar. The only communications are country tracks, and during the monsoon, or for four months in the year, the rivers are in flood, and the part of the country about Shewla is altogether cut off from Bombay. In the other case the reservoir would be but three miles, and the dam but five from the railway, and there is a metalled road running close along the greater portion of the proposed channel.

Nearly the entire area of the land which would have to be taken up for the Shewla Lake consists of the best paddy fields, yielding in this locality large returns to the villagers. To buy land of this class would cost three or four times as much as to buy ordinary jungle, of which practically the whole of the waterspread of the lake I propose would consist.

These points—the practicability of a high level duct, the capability of the extension of the supply, the necessity of good roads, and the cost of the land,—will be gone into more fully with reference to the Shewla Lake, when I explain in detail the characteristics of the reservoir I propose for a large scheme.

The Kalloo and its tributaries.

Before leaving this part of the country I think it as well to dispose of the river Kalloo, which lies to the north of Shewla. It will be seen that the area which drains into it is a very extensive one, and that the river has numerous tribubutaries all rising in the Western Ghauts. To dam the course of the main stream anywhere between its junction with the Bhatsa in the neighbourhood of Callian and the point near the village of Kinowlee where its largest tributaries meet in conflict, would be altogether out of the question. The works would have to be on a gigantic scale, and the destruction of property would be enormous. In fact the Kalloo itself is utterly unsuited to our purposes, nor indeed do its tributaries offer us any advantages. By reference to the Map it will be seen that the bed of the southernmost tributary near the village of Nandgaon, which is several miles further away than Shewla from Bombay, lies more than twenty feet below the bed of the Moorbaree, at the spot which Mr. Aitken selected for his reservoir. In addition to this, there are no extraordinarily good sites for dams on any of the tributaries to compensate for their greater distance from Bombay.

Knowing in fact that there is a site for a reservoir at Shewla with a sufficient command of elevation over Bombay, and knowing that to get the same command on any of the tributaries of the Kalloo must involve the cost of a greater length of channel with no saving in the cost of the dam, it should be clear that any investigation of the country lying beyond Shewla could lead to no practical result.

Having now examined all that tract which lies south of the latitude of Callian, let us return to this starting point. The valleys which remain to be gone over are those to the north of Salsette, besides that of the Bhatsa, and that of the Tansa. We will take them, too, in this order.

The Bhewndy Valley.

Leaving Callian, the first valley we come to is that in which the important town of Bhewndy stands, but it is utterly hopeless to make any use of it. There is no good site for a dam, as one, 60 feet high only,* would be nearly two miles long, and the compensation for the valuable property that would be destroyed, if the construction of a reservoir were attempted, would be ruinous. Let us pass on to the next.

The Lakewlee Valley.

The Lakewlee valley offers us a better prospect. It is thinly populated, it has an area of more than twenty miles, it is surrounded by high hills on which the rainfall must be considerable, the rocky well-worn beds of the streams support the inference of heavy floods, and, although no remarkably good site for a dam is to be found, still there are sites which might answer. Its proximity to Bombay is another advantage. What detracts, however, considerably from its position is that it lies low. The tide rises from the Tannah creek nearly up to the site of the dam, so that it would be impossible, without raising the water by artificial means either at Lakewlee, or at Bombay, or at some intermediate point, to supply the town. A

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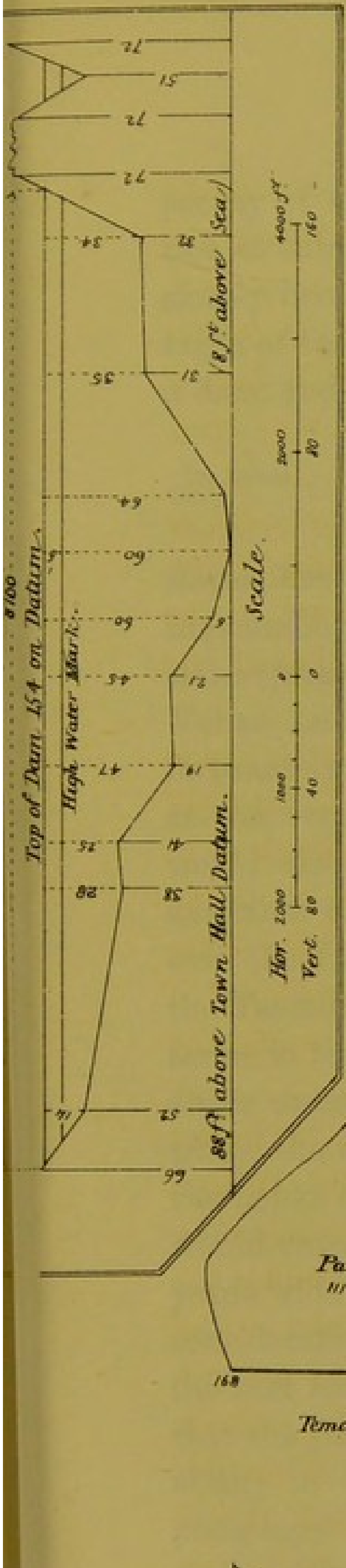
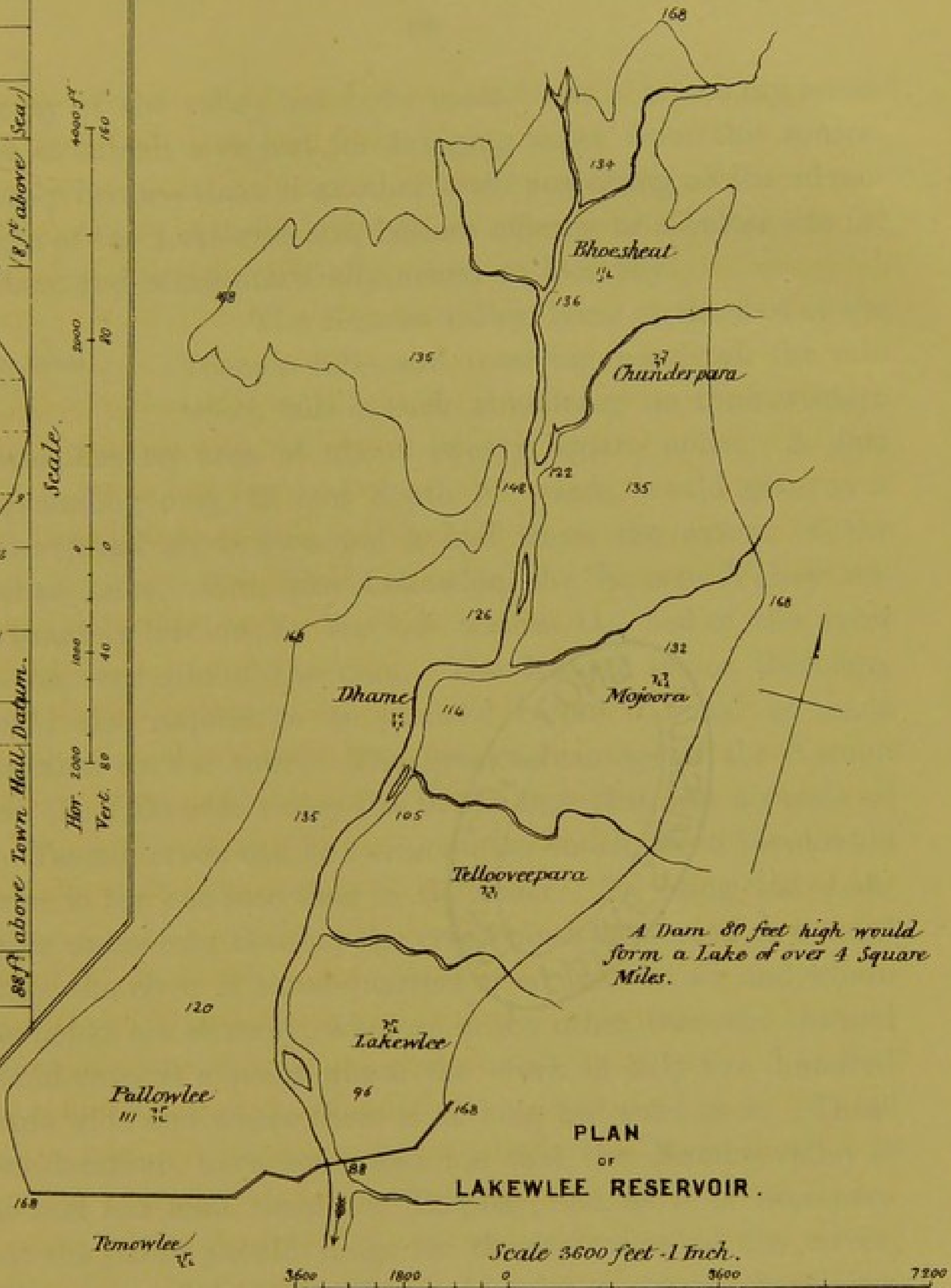
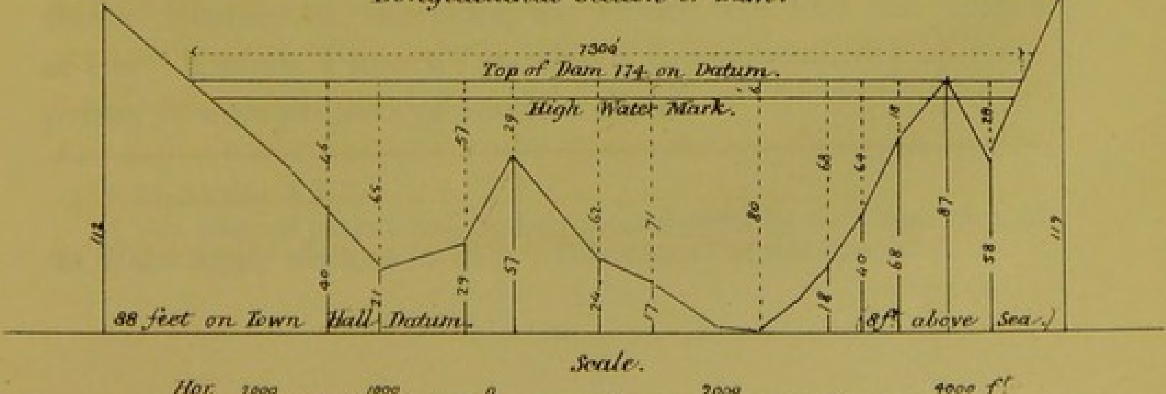
* *Vide* Plate XXV.





PLAN
OF
LAKEWLEE RESERVOIR.

Longitudinal Section of Dam.



survey of the valley has been made,* but it is not my intention to submit a project for bringing water from this source, simply because there is another basin possessing all the advantages of the Lakewlee one, besides offering us a better site for a dam, and being practically nearer to Bombay.

The Kamun Valley.

The Kamun valley, lying at the foot of the Toongar hills, and receiving nearly all the rain which falls in such abundance on their western slopes, has an area of about twenty square miles. A dam impounding only 80 feet depth of water, would give us a waterspread about two and a half times the extent of the Vehar Lake. But, like Lakewlee, the Kamun Valley unfortunately lies low, for the tide washes the bed of the river at the very site of the dam. The Kamun water, therefore, would also require to be pumped before it could be made available to the town. The great advantage of the Kamun over the Lakewlee valley lies in the fact that the obstacle of the Tannah creek can be overcome on much more favourable terms in the one case than in the other. To bring the Lakewlee water into Bombay the creek must be crossed at a point where the river is three-quarters of a mile broad and where the banks are swampy, whereas in the other case the channel would cross at a point where the creek is only five hundred yards wide and where there is nothing but solid rock. These considerations have convinced me that the Kamun valley is the best *low level* basin for Bombay, and, as it is necessary that the public should judge for themselves as to the advisability or inadvisability of carrying out a scheme involving pumping,† I have considered it my duty to put one before them. Further on, therefore, the reader will find full details of the "Kamun Project," and have the opportunity of comparing it with projects of another class.

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* *Vide* Plate XXV.

† This class of project was specially recommended by the Commission on the Water Supply which sat in 1869. *Vide* page 47 of this Report.

Beyond Kamun there remains yet another valley of the same kind, named Southolee, but it cannot compare with the former. It has a smaller gathering ground, not nearly so good a site for a dam, and it is farther from Bombay. I should be merely taxing the reader's patience, therefore, to dwell longer on it.

The Southolee Valley.

We have now passed over all the country lying to the direct north of Salsette. Let us again return to our old starting point, Callian, and follow the course of the Bhatsa.

Between its junction with the Kalloo and the village of Shapoor on the Jubbulpoor line of the G. I. P. Railway it would be impracticable to dam the Bhatsa, partly because the railway would be submerged, and partly because the works would be far too gigantic and expensive for the town to undertake. Not even though at Shapoor nor in its neighbourhood does the Bhatsa offer any peculiar advantages. By reference to the Map it will be seen that the bed of this river to the east of Shapoor, at the village of Sapgaon is 178 feet only above datum, or about 78 feet above Bombay. This is not nearly a sufficient command of elevation for a distant reservoir, and, as will be pointed out presently, not nearly so great an elevation as may be obtained in another basin in the same neighbourhood, but lying practically nearer to Bombay. In fact, to obtain a sufficiently high reservoir on the Bhatsa, we should have to travel many miles beyond Shapoor, and to no practical purpose. Let us, instead, examine the only other valley which now remains for consideration.

The River Bhatsa.

The Tansa is remarkable as being the only one among all the numerous large rivers discharging their waters into the sea north and south of Bombay, which does not rise in the Western Ghauts. It has its source in the high hills about Khurdee and Atgaon, which rise to an elevation of fifteen hundred and two thousand feet above the sea. It has several tributaries, but these are all too small for

The Tansa Valley.

our purposes. The only valley worth even a passing remark is the one in which the village of Kamballah stands, but it lies much too low for a distant basin, and there are gaps among the hills on the margin which would require to be closed. The lower portion, too, of the Tansa itself requires no consideration. It is the upper part which arrests our attention.

It would, indeed, have been strange if the bed of this river along its upper course had not been at a considerable elevation, but this point was soon set at rest. A line of levels carried from Bombay at once proved my inference to be correct. Not far from the village of Kandgaon the bed turned out to be 420 feet above datum, or 320 above Bombay, and even a few miles lower down, near the village of Bhowsa, the bed was 300 feet above datum, or 200 above Bombay. Here, therefore if a site for a dam and good storage capacity for a reservoir could be obtained, there was sufficient command of elevation for all practical purposes. A persevering search through dense forests rewarded our efforts. A remarkably favourable site for a dam was obtained, and a careful survey satisfied me that an enormous quantity of water could be impounded. The gathering grounds, moreover, proved to be far more extensive than, in fact nearly double, that which any other reservoir within the same distance from Bombay possessed. But of greater importance than any of these advantages was the additional one of the practicability of conveying the water to Bombay for the greater portion of the distance at a high level, in a conduit, and of thus effecting a large saving in the cost of iron pipes which, if adopted in any water supply project, must, do what we may, form the heaviest item of expense. From the Tansa reservoir it would be even an easy matter to throw water into the Vehar Lake, and thus, if found advisable in the future, though it need not be done at first, the Vehar Lake could be always kept full, so that a failure in the monsoon should be no matter of anxiety to the town.*

I have now, in as few words as possible, given a general

* The importance of this should be manifest to every thinking man.

Summary.

account of all the country about Bombay with reference to its capability of supplying the town with water, and the practical conclusions to which I have arrived are these :—

1st.—That the nearest valleys to Bombay demanding further investigation are those of Kennery, which includes Toolsee, and Ewoor, situated in Salsette; that these valleys, lying at a considerable elevation, offer us the advantage of high pressure, but possess the disadvantage of small gathering grounds and therefore of a limited supply of water.

2nd.—That the next nearest basin to Bombay, deserving consideration, is that of Kamun, lying to the north of Salsette. This has the advantage of an extensive gathering ground, but the disadvantage of lying low, which will necessitate the cost of pumping before the supply can be made available to the town.

3rd.—That to obtain abundance of water with high pressure it is imperative to go some distance from Bombay—that, on the one hand, the Shewla reservoir offers us a large, though limited, supply with ample pressure which the originator of the project, on account of the unsuitability of the line of country to a duct, proposed to render available by a steel pipe under pressure the whole distance to Bombay; that, on the other hand, the Tansa reservoir offers us with great command of elevation a practically unlimited supply, which can be brought to Bombay by means chiefly of a high level conduit.

Again I ask the reader to suspend his judgment. At present we are only able to say that these are the best schemes for consideration, but which is the best of them can only be decided after each has been explained in detail. The time for judgment will come when the cost and relative advantages and disadvantages of each project have been given, but before this can be done there are certain preliminary points which must be argued out rigorously, and to these I therefore proceed now to address myself.

CHAPTER III.

MASONRY *VERSUS* EARTHEN DAMS.

Earthen Dams.

In every project hitherto submitted for storing water for Bombay it has been proposed to make the dams of earth.* I will now discuss the question whether we should do well to adopt this material.

Most of our experience of earthen embankments is obtained in England, where it is almost the universal custom to use clay in preference to masonry. But hardly any one conversant with this branch of engineering would say that the works of this kind at home, taken as a class, are satisfactory. In consequence of the failure of some of them, the most frightful catastrophes have occurred. Those who have given much attention to this subject will probably be disposed to agree with me that the whole science of dam construction must before long undergo a great change. It is not generally known that many of the deep reservoirs in England are never filled to the height to which it was originally intended by the projectors that they should be filled. To prevent any risk being incurred, the greatest caution is exercised at this present moment in the management of these reservoirs. The penalty of failure is so awful that the surface of the water is kept twenty and thirty feet below the original proposed level. When we remember

* I do not include Mr. Walton's projects. I believe he came to the same conclusion as myself regarding the superiority of stone for dams in the Concan from the consideration of the facts brought forward in this chapter which were known to him.

that high earthen dams are quite a recent innovation, it is only natural that this branch of engineering should not be in a very advanced state.

The ordinary mode of construction adopted for works of this class may be explained in very few words. With a breadth of from twenty to thirty feet at the top, the dam slopes towards the water with an inclination of three feet in length to one of height, and in the opposite direction with an inclination of about two and a half feet to one. Along the middle of the dam and carried down (as it should be, though as it often is not) to a firm impermeable bed is a wall of clay, technically called *puddle.* This wall is usually about ten or twelve feet wide at the top and thickens as it descends at the rate of about two or three inches for every foot of vertical distance. On either side of the puddle is placed what is termed 'selected material,' that is, generally, the best that can be got at the spot. The rest of the dam is formed of almost any kind of suitable earth. In order to break the force of the waves and to prevent them from washing away the earth underneath, the slope towards the water is usually covered with a layer of stones, or *pitched,* as it is termed. The outer slope is turfed or pitched, according to the judgment of the engineer.

It is the puddle wall which should form the barrier to the escape of the water, and it is this part of the embankment to which the engineer trusts more than to any other for the safety of his works. The greatest care should be taken both in the selection of the clay and in the manner of putting it in the embankment. It should be thrown down in thin *concave* layers, as should also the rest of the dam, and should be with the rest well watered, and rammed, and beaten, and trodden down, so that the whole mass may be rendered as homogeneous as possible.

Until lately it was a common practice to lay the outlet or supply pipe through or under the embankment, and, in some cases, even without preparing a special foundation for it.* The great loss of life and destruction of property caused by the bursting of the Bradfield reservoir has, however, effectually put a stop to this system, and arrangements are now generally made by which the outlet works are altogether disconnected from the dams. We have in fact learnt by disaster what common sense should have taught us from the first. The dam, being naturally the weakest part of the reservoir, should be that which we could least afford to endanger by works liable in the course of nature to get out of order. The practice now obtains of carrying the outlet pipe through some one of the hills standing on the margin of the lake.

This being the English mode of dam construction, let me now revert to the Continental one.

Masonry dams.

In France and Spain, the two countries in which we find so many large reservoirs, the people put no faith in puddle and earth, except for dams of moderate height. They trust to masonry, and certainly they have no reason to complain of misplaced confidence. It is quite true that some of their dams have failed, but the causes of failure are so well known and so easily avoided, that, far from the material being distrusted by them in consequence, their faith in masonry has, on the contrary, largely increased, and is characteristically exemplified by their later works.

I doubt whether at this present moment there are three dams in England which could hold water to the depth of a hundred or even ninety feet without danger. There are dams, to my knowledge, constructed above this height, but they are not filled, as I have already pointed out.

This state of things contrasts most unfavourably with that in France and Spain. Some of the dams in the latter country have stood for hundreds of years, are in use to-day, and, although constructed at a period when science was but emerg-

* The outlet pipe from the Vehar Lake, unfortunately for the town, has also been placed under one of the dams.

ing into light, and when, therefore, no great knowledge of the theory of the subject could be expected, yet, from their having been built of masonry, still answer all the purposes of the original designers.

The Spanish dams are of huge proportions, and, having been built according to no generally accepted rules, there is very little similarity between even any two of them. It would, therefore, be impossible for me to give any description of them which should apply to all. A better idea will be formed of them from the accompanying drawing than by anything I could say.* Some of them have the most grotesque forms. One, Gros Bois,† has a greater slope on the water side than on the other. Another, that of the Val de Infierno‡ has such a hideous form that it naturally suggests the idea of its having been designed in that region. Rude though as these works seem to us by the light of modern science, it is a great point that they still exist and still fulfil their object. In other words, they have been successful in spite of the errors made in constructing them. It is not likely that these errors will be repeated.

The new principles of dam construction adopted by the French.

The construction of masonry dams has passed through a new stage within the last few years, and this in consequence of the success of a French work, which is unique in its character, as showing what science and art can really effect when brought to bear on a subject.§ We talk in England of dams a hundred feet high in terms of admiration, and we look at such works almost with feelings of awe, but the French have constructed a dam one hundred and sixty-four feet high, impound-

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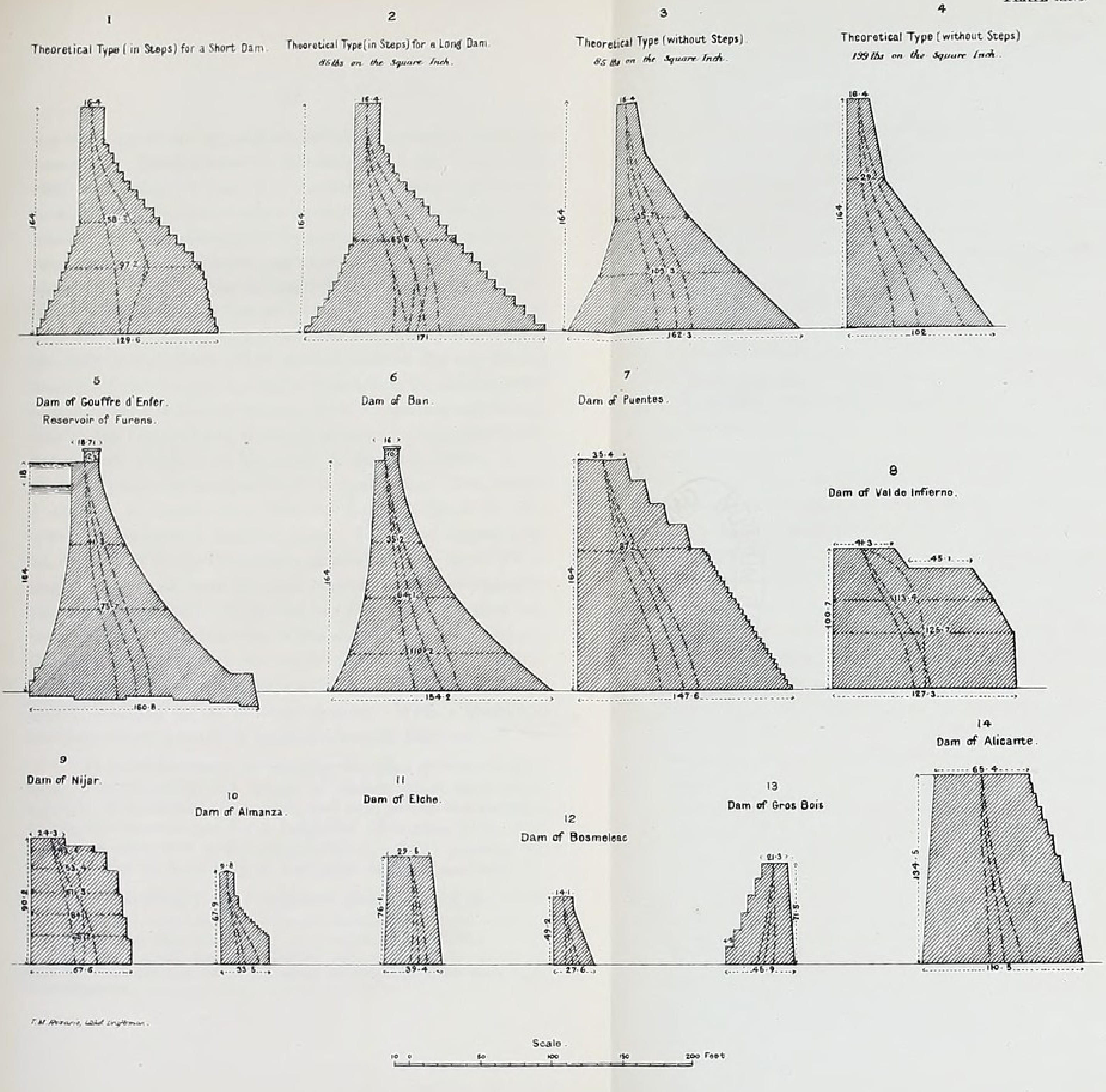
* *Vide* Plate XXVI. † *Vide* fig. 13. ‡ *Vide* fig. 8.

§ Colonel Fife, R.E., has rendered a great service to the profession by the publication of his translation from the "Annales des Ponts et Chaussées" of Messieurs Graeff and Delocre's papers on the subject of masonry dams. It is not too much to say that those who are unacquainted with these papers have much to learn, both of the theory and practice of dam construction. All the information in Plate XXVI. is taken from Colonel Fife's valuable pamphlet.


1
Theoretical Type (in Steps) for a Short Dam.
2
Theoretical Type (in Steps) for a Long Dam.
86 lbs on the Square Inch.
3
Theoretical Type (without Steps).
85 lbs on the Square Inch.
4
Theoretical Type (without Steps)
139 lbs on the Square Inch.
5
Dam of Gouffre d'Enfer.
Reservoir of Furens.
6
Dam of Ban.
7
Dam of Puentes.
8
Dam of Val de Infierno.
9
Dam of Nijar.
10
Dam of Almanza.
11
Dam of Elche.
12
Dam of Bosmelеac
13
Dam of Gros Bois
14
Dam of Alicante.
Scale.
200 Feet

ing water up to the top, and successfully resisting the enormous pressure.* The boldness of the design, and the constructive skill with which it has been carried out, are only to be matched by the consummate mathematical knowledge with which the whole principle of dam construction was previously investigated. The French engineers have reason to proud of their success. They have demolished empiricism, and established something like law at last. The old rule of thumb principle of making every dam at the base about three-quarters, in the middle about one-half, and at the top about a quarter of the height, has little foundation in mathematical science. Such a dam is far too thick at the top and far too thin at the bottom,† and there is an excess of material in the entire work which, in a high dam, so far from adding to its strength, positively detracts from its equilibrium. But, before I attempt to explain the views of the Frenchmen, I must give their opinion of earthen dams. It is not flattering to us, and it will no doubt provoke surprise among those whose acquaintance with dams does not extend beyond the examples existing in England. If we did not find the impression contradicted by the modest tone of Messieurs Graeff and Delocre throughout their papers, we might almost fancy the Frenchmen, from the matter-of-fact way in which they put it, were quietly laughing at us in their sleeves. With a simplicity that has almost a touch of humour about it, they say:—

"It is not necessary to consider the plan of constructing dams of earth, which are things of chance when they attain a height of 20 metres (65·6 feet), and it is out of the question to use this construction for a height of 50 metres (164 feet) which we have now under consideration. After passing the lesser height we have only to deal with dams of masonry."‡

And accordingly the Frenchmen utterly ignore the whole

* *Vide* fig. 5, Plate XXVI. † *Vide* Plate XLVI.

‡ I believe myself that if all English engineers could be asked, the majority would say that this is just about the height at which dams begin to be dangerous.

class of earthen dams above 65 feet high which are found in England. The case of high earthen dams they dispose of in the summary judgment given above, and it does not even occur to them that any one could have the temerity to dispute the point. They at once pass on to the subject of masonry, and I will now try and give a condensed view of their opinions and conclusions.*

A masonry dam is liable to be destroyed in three ways. It may be *overturned* by the thrust of the water. It may *slide* on its base or its joints. Or it may *crush in* vertically from its own enormous weight.

1st. There is no case on record of any dam having been *overturned*. In fact, to calculate the thickness of a dam which shall resist the pressure of the water to throw it over, is a very simple problem. Practically a dam which satisfies the other conditions of construction will be found to satisfy this one also. When those conditions are satisfied, a simple calculation will settle this point. We may, therefore, for the present discard the consideration of the liability of the dam to be overturned.†

2nd. There is no instance of any dam having been destroyed from its having slidden horizontally. This, therefore, is not an important point. After the third condition has been satisfied the solution of a very simple equation‡ will settle this question.

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* It is necessary I should say that the following exposition of the subject is, and intentionally so, not a scientific but a popular one. My object being to convey to the public such a view of the question as shall be understood by them, I have purposely, discarded, as far as possible, the use of technical language, and have altogether avoided the mathematics of the problem. Those who care for the latter, I must refer to Colonel Fife's pamphlet, in which, I venture to say, they will not complain of the absence of formulæ, nor of these being of too simple and elementary a nature.

† The Frenchmen hardly consider this subject directly, but I gather it from some of their incidental remarks, and from their method of mathematical analysis.

‡ "Calling H the height of any course below the summit, the force which tends to produce sliding on this course is equal to the horizontal component of

3rd. Every dam that has been destroyed hitherto has crushed in from its own weight. Nobody can fail to see at a glance the importance of this fact. To add more material than is necessary is not to strengthen but to weaken your work. The old Spanish idea of making dams of huge proportions on no mathematical principles at all has resulted, as already mentioned, in some lamentable failures. To look at the dam of Puentes * one would at first be inclined to think that such a Cyclopean structure would almost have answered to stem the tide between the Pillars of Hercules. But what is the fact? The giant succumbed not from the thrust of his adversary, but from his own weight. In fact he was too heavy

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the thrust of the water against the part of the interior face situated above that course, and it is given by the equation.

$$F = \frac{\delta H^2}{2}$$

The resistances which are opposed to the action of this force are the friction of the two courses which tend to slide upon each other and the force of cohesion of the masonry.

The friction is proportional to the weight of the upper part of the structure and the force of cohesion to the thickness of the wall.

Calling f the co-efficient of friction of the masonry, γ and the force of cohesion per superfical unit, s the surface of the part of the profile situated above the course under consideration, and b the thickness of the wall at that point, the resistance to sliding will be

$$R = s\,\delta' f + \gamma\, b$$

and it is necessary that we have

$$s\,\delta' f + \gamma\, b > \frac{\delta H^2}{2}$$

or

$$2\,\frac{(s\,\delta' f + \gamma\, b)}{\delta H^2} > 1$$

This inequality should be verified for all the horizontal sections of the profile by giving to f and γ the values proper to the materials that may be employed.

It is equally necessary to verify it for the base of the foundations; f and γ would represent then the coefficients which are applicable to the ground upon which the structure rests.

It will be convenient in practice, for more security, that not only should the ratio $2\left(\frac{s\,\delta' f + \gamma b}{\delta H^2}\right)$ be greater than unity, but that it should not descend below the value found for that ratio in the walls of existing reservoirs which have not suffered injury on trial."—*Vide* page 56 of Colonel Fife's Pamphlet on "*Dams of Masonry.*"

* *Vide* Plate XXVI., fig. 7.

for his work. The ground literally could not sustain him, and in 1802 he was *hors de combat.* Some of the Spanish works have cost fifty and even a hundred per cent. more than they need have, and are now subjected to causes of destruction which would not have existed if they had been constructed with half the quantity of material better disposed, and which far exceed in intensity all the forces of the water against which only the Spaniards strove to contend. In fact, in trying to avoid the dangers of Charybdis, the Spaniards have fallen on Scylla.

This then being the case—viz., that the most important point in the construction of high masonry dams is the consideration of the causes which tend to make them crush in—the French engineers have devoted great pains to the thorough investigation of the subject. The principle with which they start is this:—

Suppose a dam is to be built of stone and mortar. Manifestly no stone could be used unless it were of the best, or at all events of a kind fit for building purposes. Such a stone must necessarily be stronger than mortar. Mortar, therefore, being the weaker material of the two, it is essential at the outset to ascertain the resistance to compression of the particular mortar proposed to be used. Thus on the strength or the weakness of the mortar, which is the strength and the weakness of the dam, must the calculations for the form of the latter be based. Of course a large margin must be allowed as a factor for safety. In the case of the Furens Dam the Frenchmen assumed that the safe amount of compression to which their mortar might be subjected was 80 lbs. on the square inch. It was necessary, therefore, that the pressure on no horizontal layer of the dam should exceed this. It might be less, as of course it must be in every dam for some distance from the top, but it was not to be more. Assuming then a practical width for the top of the dam, and proceeding downwards, immediately we come to that layer where the pressure approaches 80 lbs. on the square inch, we must commence increasing the width of the layer so that, as we go lower, still no portion of the masonry shall be called upon to resist more than the allotted amount of compression.

But another point must be borne in mind. It is manifest that every dam must be exposed to two different sets of conditions. One set when the reservoir is empty and when, in consequence of there being nothing to relieve the weight of the masonry, the pressures on the inner face become most intense, and the other set when the reservoir is full and when, therefore, in consequence of the thrust of the water, the pressures on the outward face become most intense. The outer and inner faces, therefore, being those parts of the dam which under different conditions are subjected to the greatest pressures, care must be taken that the pressure of 80 lbs. on the square inch is not exceeded on the inner face when the reservoir is empty, nor on the outer face when it is full.

There is yet another point to be considered. In very narrow valleys where, by giving a curved form to the dam, part of the pressure of the water may be conveyed to the hills on the sides, the dam need not be of so strong a section as in a wide valley, where it cannot act as an arch and where therefore the whole thrust of the water must be borne by the masonry itself. The French Engineer, Monsieur Delocre, has calculated the theoretical forms of two dams to suit these different positions. These are given in figures 1, 2, 3, and 4, Plate XXVI. The Furens dam is of the former type, but, in order to make the work a pleasing object to the eye,* the faces of the dam have been gracefully curved, as shown in figure 5.†

* The French lay great stress on the æsthetic aspect of the dam, and some of the objections brought against their work under this head, though they would be ridiculed by the so-called "practical" Englishman, were most gravely considered by them.

† Fig. 6 is a section of the dam which, in consequence of the success of the Furens work, was proposed to be constructed across the Ban in a locality where the lime was exceptionally good. The boldness of this design does great credit to the French.

Having now obtained the form of the dam according to the third of the conditions we started with—viz., that the masonry shall not crush in by its own weight—a simple calculation will at once prove that the first and second conditions are also satisfied—viz., that the dam will neither be overturned nor slide on its joints. Moreover, certain practical points almost naturally suggest themselves, but even these were, I believe, never adopted till the Furens Dam was built.*

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* I have paid a visit to the Furens Lake, and have examined it closely on purpose to place the facts before the Justices for their information. Standing on the top, the dam does not look nearly so grand a work as it really is, but when seen from below, the proportions of the work at once impress the beholder with their magnitude. Although the inner face slopes a little towards the water, it is difficult to believe that it is not perpendicular, in so perfectly a straight line does the wall seem to descend. The gorge across which the dam has been built is a narrow one, not more than about 350 feet wide, and the stone used in construction was quarried from the hills on the side. Samples of this stone, which will be recognised as gneiss, as also of the mortar found lying about the dam, are forwarded for the inspection of the Justices, who will see that the building stones of Bombay, which abound in every hill and valley, do not suffer by comparison, nor is there any reason to suppose that the mortar is superior to that made from the lime procurable in Salsette. For building purposes I should prefer the hard traps of Bombay to the Furens stone, and although my experience of the Salsette lime is small, yet, from what I have heard of its strength, if allowed to harden away from the influence of water, I have no doubt that the Bombay mortar used in a dam would be as successful as we could wish.

The rock about the Furens dam is fissured wherever the quarried face of it can be seen, but like the hard strata about Bombay, I doubt whether the fissures extend deep into the rock. The faces exposed to the air have an appearance very similar to the exposed surfaces of the Bombay stone.

At the time of my visit the water was rather low in the lake, there being only about 90 feet depth in it; I had thus a good opportunity of examining the inner face of the dam. The masonry looked as sound as it well could, but as a work of art its appearance was not enhanced by the numerous iron rings which have, for the purposes of facilitating future repairs, been fixed in it.

The surface extent of the impounded water is ridiculously small when compared with the great height of the dam. In fact, the water looks more like a long winding canal than a lake. Of course, this is caused by the fall of the stream being so great, that even the dam of 164 feet high does not send the water back very far. The Vehar lake, as a waterspread, has a far more imposing effect. The tortuous course of the stream, which runs in and out constantly among the hills, quite destroys the grandeur of the Furens lake, however it may add to the beauty of the scenery. At the time of my visit there was not much water flowing into the lake, the stream being about four or five feet wide and only an inch or two deep.

Almost the entire outer surface of the dam below the then water-line was sweating—*i.e.*, covered with a thin film of water exuding through the pores of the

In order that the pressure may be equally distributed throughout the work, the dam should be one homogeneous mass built in every part of the same kind of material. No interior or exterior facing of ashlar which may have a tendency to separate from the rest of the work, and no partial use of cement or concrete, must be permitted. In order, moreover, to increase the resistance to sliding, horizontal courses must be rigorously avoided. The dam must simply be a mass of uncoursed rubble, without any hollows, every portion resembling the rest of the work as closely as possible.

Previous to my acquaintance with the mode of dam construction adopted by the French Engineers, I had for many years been of opinion that the ordinary form given to masonry dams was wrong in principle and occasioned great waste of material. I considered that, with the view to save material and in order to make the least quantity of it effectually resist

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stone. I did not observe anything worse than this, nothing that could be termed a leak.

The water is taken to the town of St. Etienne by a channel several miles long. I walked along the entire course of this channel, which has throughout been built in open cuttings made on the slopes of the hills. Even where the slopes are very precipitous, as they are in some parts, the channel has been built in this way. The stone excavated in making the cuttings, which are from 10 to 20 feet deep, furnished the material for construction. After the conduit was completed, the cuttings were closed again with the debris. As a matter of course, the channel follows the configurations of the hills, but the hills below the dam do not wind much, so that open cutting in the case of the St. Etienne Works was probably found preferable to tunnelling as in the case of Glasgow. The conduit runs at a considerable height, from 150 to 300 feet or more, above the bottom of the valley, and, where streams occur, the water is made to pass over the conduit. There is not a single aqueduct along the line. The slope of the channel is tolerably uniform throughout, except at a few points, where, in order to bring the water to a lower level, it has been dropped as much as 20 feet in 150. I could find no ventilating shafts. At very irregular intervals, of from 50 to 250 yards apart, there are manholes leading into the conduit, but these are all stopped up with simple slabs of stone shutting close down on the openings. This is an interesting point for those who may think it necessary to ventilate channels intended for the supply of pure water. If the water to St. Etienne had been rendered impure from the want of ventilation, we may, I think, assume that the French would have constructed them before this.

There is much more that I could add about the Furens Works, but I have given merely those facts which have a special bearing on the Bombay Water-supply.

the pressure of the water, the centre of gravity of the dam should be thrown inwards as much as possible, and that this could only be done by making the dam lean as it were against the water. Of course I was aware that this principle, even if correct, could only be adopted for dams of moderate height,* because when the height became considerable the vertical pressure of the masonry itself along the inner face would become so great that the material must yield and crush in. The perusal of the French papers did not satisfy me that my position was untenable. Considering that the question involved to the Bombay public the saving of lakhs of rupees, I applied for and obtained the sanction of Mr. Crawford, the Municipal Commissioner at the time, to refer it to Mr. Rankine. I thought that both the public and my brother engineers would receive with as implicit confidence as myself any views on the subject which Mr. Rankine, who stands at the head of the profession in its theoretical branch, chose to communicate. In appendices C, D, and E, will be found the correspondence between myself and Mr. Rankine, and Plates XLVI. and XLVII. are illustrative of the subject.†

Mr. Rankine on dam construction.

Mr. Rankine doubts whether any earthen dam is to be relied upon when the depth of water exceeds 100 or 120 feet. He insists upon rubble masonry without continuous courses as the best material, and upon there being no hollows left in the wall. He likewise

* Nor am I yet convinced that the system would not be the best for low dams.

† I wished to dispense with my own letter altogether, but only in fairness to Mr. Rankine, in order to show what the question put to him was, and how it was stated, have I felt bound to give my letter. The reader must therefore excuse its appearance in the report.

I beg to draw the attention of the profession to the value of Mr. Rankine's papers. They throw a flood of light on the subject, and, confirming as they do in a remarkable manner most of the deductions of the French Engineer, Monsieur Delocre, to whom the credit of the Furens Dam belongs, they ought to satisfy the Bombay public that we shall not go very far wrong by building our dams on the principles theoretically established by the highest authorities in France and England, and actually carried out in practice with the greatest success in the former country.

agrees with the Frenchmen that the intensities of the pressures shall not exceed certain limits on the outer and inner faces of the wall. He, moreover, urges that, wherever it can be done, the dam should be constructed in a curved form, so as to relieve the masonry of as much thrust as possible by carrying it to the hills on the sides. At the same time he considers, in the present state of science, that the calculations of stability, treating the dam as a horizontal arch, are so uncertain as to be of doubtful utility, and, although he would give the dam a curved form, yet he would not rely on it as an arch.

The main points on which Mr. Rankine differs from the Frenchmen are these : that the limit of pressure on the outer need not be so great as that on the inner face, and that my proposal to throw the weight of the wall more inwards tends to realize this principle, but he objects to its being carried so far as to make the wall overhang—that the intensity of pressure on the outer face should not be the same throughout, but gradually diminish at the lower part where the slope increases ; and, in order that there should be no appreciable tension at any point of the masonry, whether at the outer face when the reservoir is empty, or at the inner face when the reservoir is full, "the line of resistance should not deviate from the middle of the thickness of the wall to an extent materially exceeding one-sixth of the thickness—*i.e.*, that the lines of resistance, when the reservoir is empty and full respectively, should both lie within, or but a small distance beyond, the middle third of the thickness of the wall."

Seeing then that Mr. Rankine confirms the correctness of the new principles on which the Furens Dam has been built, and bearing in mind the great success of this work, let me point out what the practical result of these new theories is.

According to the old rule, the average thickness of the wall is about half the weight. Now it is little more than one-third the height. The saving in material amounts to more than twenty-five per cent.! This saving on any project which may now be carried out for Bombay will represent a large sum of money.*

Although I have purposely not referred to the point, still the reader will understand at once that dams of solid masonry, with their enormous weight, are only suited to sites where foundations of solid unyielding rock are found. The French Engineers insist on this as a *sine quâ non*, pointing out that merely an ordinarily good foundation, or one on which we might safely trust many other structures, will not suffice for masonry dams. If solid rock is not found, the idea of a heavy masonry dam must be abandoned *at once*. Mr. Rankine expresses the same views in other words.

This brings me to the point where the subject interests the Bombay public so closely.

In the elucidation and investigation of projects we engineers must necessarily be to a great extent theorists, but in the application of our science we must be practical men. Masonry dams may be very good things in their way, but are they better suited than earthen dams to the country where our reservoirs would be situated, because this is the whole gist of the matter?

Advantages of Masonry over Earthen Dams in the Concan.

It is the consideration of this very point which induces me to adopt the former. The Concan is a country far better suited to masonry than to earthen embankments. Good clay for puddle, the essential part of every earthen dam, is not to be found. The only clay available is that obtained in paddy fields, which after all is impregnated with a great deal of vegetable matter

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* I hope that Mr. Crawford's permission to me to consult Mr. Rankine will be really appreciated as it deserves to be. It is too often assumed by the public that the Executive Departments of the Municipality do everything with the view to spend money. I can assure the Bench emphatically that the direct contrary is nearer the fact; that every expedient that can be thought of is adopted to save expense. And the next chapter will, I hope, show still further what an enormous saving in the Water-supply of Bombay will be effected by another expedient which I have to propose.

liable to decay. Those remarkable beds of stiff clay found in so many parts of England do not exist here. The fact of the difficulty of procuring clay sufficiently good for bricks even is itself a significant fact indicating the general absence of this material.

On the other hand, stone, the very best stone which the most exacting engineer could wish for, lies in untold abundance almost everywhere under his very feet, and in nearly every hill. Still further, there are but few sites for dams in the country about Bombay, where a foundation of solid rock does not exist, either at the very surface or at a moderate depth below it, and where stone may not be procured on the site itself. In fact, the question as to whether there is a stone foundation and abundance of rock has generally been dismissed by me in a few moments by the plainest evidence which any engineer could require, but the question as to whether there would be sufficient puddle or even earth has demanded grave consideration. Let me explain, by way of illustration, the sites for the dams in those valleys which I have already in Chapter II. pointed out as demanding investigation.

The Kennery Dam would stand over a river, the bottom of which is solid trap rock, and would rest against two hills, which also are rock, and there is enough stone at the site to build a hundred Great Pyramids. Good earth could not be procured except at the distance of a mile, and, as for clay, we should have to search the country all round or else denude the paddy fields, within a radius of two miles from the work, of the material which renders land of this class so valuable and would to us be so expensive.

The Toolsee Dam higher up in this valley is equally well situated for a work of stone, and very badly situated for one of clay and earth.

The Ewoor Dam would stand on a site still more favourable for rock than even the Kennery Dam, and I need not, therefore, dwell at all on it.

The Kamun Dam is the only one of those proposed by me which *might be* built of earth ; but even here I should prefer stone as the best material. The dam would be considerably higher than the limit of safety for earthen embankments, according to the French Engineers, and would reach the limit fixed by Mr. Rankine, and rock is not found except at about twenty feet from the surface of the ground. There is abundance of stone in the adjacent hills, and there is also plenty of earth and clay in the valley for our purposes, but it is doubtful whether the clay is sufficiently retentive to keep out the water. Shafts were sunk through the earth and clay twenty feet deep, but it was found impossible to keep them dry by mere ordinary baling.

The bed of the river at the site of the Shewla Dam is rock, but the hills on the sides have not a solid appearance on the surface. They are, moreover, so low that they give one the impression of having been worn away in consequence of the softness of the material of which they are composed. There is abundance of paddy-field clay, but none of any other kind has been observed by me. The height of the dam, 96 feet, as proposed by Mr. Aitken, would, however, render it advisable not to run the risk of an earthen construction.

The Tansa river runs on a bed of solid rock, which is exposed to view almost everywhere along its course, but is very plainly visible at the site of the dam where the surface is as smooth as a floor. The very character of the gap through which the river passes tells us that the strata must be rock. On one side the bank rises so abruptly that it is difficult to climb it, and on the other side also there is every indication of solid rock. If the strata had been soft, the river, instead of running through a narrow channel, would probably have washed away a great part of the valley. The rock, in fact, has held the river in its hand, and defies it even now to wander at all from its present course. It is almost absurd of me to say that there is abundance of the best stone for building purposes, because, excepting a superficial deposit of moorum and boulders, there is literally nothing else. The whole country is stone. Material of the first quality might be quarried almost in any spot taken at hap-hazard near the dam. On the other hand, the only clay there is would have to be brought from paddy fields, two miles away from the spot.

Let me add to all this the advantage of masonry over earthen dams pointed out by Mr. Ormiston, and in which I cordially agree with him :--

"If masonry dams are properly constructed, they are more satisfactory than earthen dams: a leak in the one is only so much loss of water, in the other it may be destruction."*

This point is well put, and is worthy of the greatest consideration by the people of Bombay.

Summary.

Let me now sum up the case of masonry against earthen dams.

We are warned by those who have a great claim to be heard on the subject that dams of earth over 65 feet in height are "things of chance." Our greatest English authority limits us to 100 or to 120 feet only. There is no good clay in the country. There is abundance of the best rock. All our sites are better suited to masonry than to earth. None of our dams would be lower than the limit of safety laid down by the French. Two, Kamun and Tansa, would reach the limit suggested by Mr. Rankine. Two, Kennery and Ewoor, would exceed even this limit. Lastly, earthen dams with leaks are liable to destruction, sometimes to a very sudden one, causing immense loss of life and property, whereas masonry dams with leaks are always safe against sudden destruction, and never liable to be washed away bodily at all.

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* *Vide* his "Memorandum" on the Toolsee Scheme. On this important point I am glad indeed to be able to quote Mr. Ormiston, an engineer of such great experience, and in whose judgment the Bench, and rightly so, place much confidence.

Thus then it will be seen, I trust, that the case of earthen dams when inquired into breaks down lamentably.

On all the above considerations, and bearing in mind that the well-being of a population approaching three-quarters of a million in number is concerned, the public, with the examples of the Vehar Dams before them, will no doubt agree with me that the town should set its face against works involving danger or even insecurity, and should insist on that class of work being carried out which will relieve them of their present anxiety, and be as little a source of anxiety to them as possible, even in the future.

CHAPTER IV.

MASONRY CONDUITS *VERSUS* IRON PIPES.

As in every project for the Water-supply of Bombay, hitherto submitted, it has been proposed to construct the dams of the reservoirs of earth, and indeed been almost silently assumed that no other material for works of this class could be adopted, so likewise in every project has it been proposed to bring the water from the reservoir to Bombay in iron or steel* pipes, nor have any other means of effecting this object been suggested. Having already shown the inadvisability of

* I have taken some trouble to ascertain what would be the relative cost of steel mains as compared with cast-iron ones. At any particular time the cost will, of course, vary according to the state of the market at that time. But, generally, it may be assumed that a steel main, about one quarter the thickness of an iron one, will cost as much as the latter. Steel plates could be conveyed up country very much more easily than iron pipes, and there would be some saving in the item of transit by employing the former; but I cannot recommend their use. It must be remembered that steel corrodes under the action of water much more rapidly than cast-iron, and that for the same money there would be four times as much metal in pipes made of cast-iron as there would be in those of steel. Under these circumstances, of course, cast-iron would last much longer. First cost, moreover, in cases of this kind, should not be considered as the only point. The expenses of renewal and maintenance are important items, and, when these are calculated, the superiority of cast-iron declares itself forcibly. I should add that my statement regarding the more

constructing dams of earth in the Concan, where no good clay is to be obtained, I will now show the inadvisability of bringing the water in metal pipes, or rather, as these must of necessity be employed to some extent, I will show the advantage of restricting their use as much as possible.

Limits to the size of Iron Pipes.

In the first place the size of iron mains, and consequently the quantity of water deliverable by a single line of pipes, is limited. I believe the largest main yet put down has not exceeded four, or at the utmost four and a-half feet in diameter. The reason why we are confined to about this size is that, if we make them larger, the pipes become too heavy and unwieldy to be carried across country. But it is an advantage to have them as long as possible, because, the longer each pipe is, the fewer are the joints in the entire line, and the less is the cost of laying down. All the smaller sized pipes, therefore, are cast in twelve-feet lengths, and they are not found inconvenient either to carry or to fix. But when the size increases to three and four feet in diameter, and especially if the pipes are to be taken to a rough country and laid along a line where there are no roads, it becomes necessary to cast them shorter or in about nine-feet lengths. This reduces the individual weight of each and makes it more manageable, but the effect is that in the entire line four joints become necessary where three only

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rapid corrosion of steel is not based on my general acquaintance with the use of this metal, but that it is the positive opinion of one of the largest steel manufacturing firms in England, who were consulted on the subject. Although it would have been manifestly to the advantage of this firm to have recommended the use of steel, they could not conscientiously do so. One fact of this kind is more convincing than a volume of general arguments. If the use of steel were ever to be contemplated, it would be well to specify in the contract that all plates worn out or found defective within a certain period, say five or six years, must be made good at the contractor's expense. The insertion of a clause to this effect would produce tenders which would at once show what confidence was placed in the power of steel to resist the action of corrosion.

I should not omit to mention that, as far as can be ascertained, no steel mains have yet been laid down in England. If there were an advantage in the use of steel over cast-iron, we might surely expect to find it used where it is produced.

sufficed before. Every extra joint, moreover, is equivalent in weight and cost to one-foot length of the pipe. Although, therefore, each pipe is lighter and costs less, the whole line is heavier and costs more. Thus an advantage secured in one direction is partially counterbalanced by a disadvantage appearing in another. Besides, the joints being those points in the line where leaks are most likely to occur, and which have to be made with special care, every extra joint simply adds to the chances of the waste of water as well as to the expense. These considerations, therefore, prove to us that we cannot, in order to make our large pipes lighter, shorten them to any great extent.

This being the case, the importance of the point with which I started will now be appreciated. If we are limited in the size of our mains, we are practically limited in our supply of water. Some may reply that there is no engineering reason why two or a dozen mains should not be laid down; that, although it may be the case that we cannot have one main larger than a certain size, there is no reason why we should not have several of that size. This is true, but it must be remembered that the engineering objections to this are not the greatest ones. The cost of two or more mains would be so great that no project could be floated with such a heavy weight. Thus, then, the limit to any project for the supply of Bombay with water is the discharging capacity of a pipe about three and a-half, or four feet in diameter, these being about the largest sized pipes ever made. Further on I will show what this amounts to.

The corrosion of Iron Pipes.

Another and a very serious objection to the use of metal is that it wears away so rapidly.* No really effectual means have yet been discovered to prevent the destruction of iron by corrosion, &c.

* "I have seen cast-iron pipes laid down in Bombay which have been corroded away (from the outside) in about five or six years." *Vide* page 14, Mr. Aitken's *Report on the Extension of the Bombay Water Works.*

How long a line of pipes may last in India no one could say, but, nevertheless, it is perfectly clear that every line laid down must, like a line of railway, sooner or later be renewed. The repeated cost of these renewals must, after some time, become enormous. It is the opinion of many that even the Vehar main, which has not yet been laid down fifteen years, will before long require renewal. This is supported in a great measure by the state of those pipes which have occasionally, in consequence of leaks, been taken up. The amount of corrosion, both inside and outside, is quite beyond what most people would suppose.

I have already pointed out that Mr. Aitken anticipated the wearing away of the steel main proposed by him to be laid down from the Shewla reservoir to Bombay, and in answer to this objection he replied that when the time came to renew the main, Bombay would be able to afford the cost of one of double the capacity. But any one can see that this is not the point. The point is whether, if the town can save the cost of renewal, it would not be foolish to incur it.

Large stock required in India.

Another objection to iron pipes is that, not being manufactured of sufficiently good quality in India, and being obtainable cheaper from England, it becomes necessary to keep a large stock in hand for contingencies. Their cost being, under even the most favourable circumstances, as I shall presently show, very great, a large capital must remain idle.

Skilled workmen.

Then, again, to repair pipes, skilled European labour is required, and to keep up a staff of Europeans for the purpose adds greatly to the cost of maintenance.

Cost of Iron Pipes.

But above all these objections is the insuperable one of their first cost. Let me assume that a pipe of $3\frac{1}{2}$ feet diameter is to be laid down for Bombay. Such a pipe, in my opinion, should not be less than, say, $1\frac{1}{4}$

inch thick. Its weight would be about 15 cwt. 2 qrs. per yard, or 1,364 tons per mile, allowing a joint at every nine feet. The price of iron, including every expense, will be £16 a-ton,* and the total cost of a mile of 3½-foot main would be, say, £22,000.

I will now turn to the subject of masonry channels, and first as to their limits in size. It is quite clear that, so far as the engineering of the question is concerned, it is just as easy to build a conduit ten or twenty feet as it is to build one five feet wide or high. This being the case, and, supposing masonry channels can be used, there is evidently no practical limit to the quantity of water which a *single* conduit, so different from a single iron pipe, may be made to convey. Thus one conduit would often suffice where two or three pipes might be required.

No limits to the size of masonry conduits.

In the second place, unlike pipes, the materials and labour for conduits need not be brought from England. They exist in the country—an advantage which it is hardly possible to magnify. The material is of the cheapest kind, and so is the labour. No large stock of the former need be kept at hand, nor need any expensive establishment of the latter be maintained. The nature of the work is both so simple and so well understood by the common labourers of the country, that they alone are quite sufficient for all purposes.

Materials and labour for conduits to be procured in the country.

Then, again, masonry does not soon wear away. If pro-

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* This has been fixed by me in communication with one who is well conversant with the iron trade. I wish I could lower the rate and sacrifice some portion of the strength of my argument in this place, in order to reduce the estimates of the various projects I shall have further on to submit to the Bench. But 160 Rupees a-ton is what I have calculated all the pipes in my projects at, and in spite of every desire to keep the estimates as low as possible. The price of pig iron has risen about 100 per cent. in the last twelve months. It is almost certain, moeover, that, in consequence of the rise in the price of wages, and of the reduction in the number of working hours which has taken place in England and Scotland, the price of iron will never fall again to what it was a year or two ago.

The durability of conduits.

perly constructed, it is practically imperishable. Some of the Roman aqueducts are standing to this present day, and I believe there are masonry channels now in use in parts of Italy which were constructed in the days of the Cæsars.* Under these circumstances, it will be readily understood that the cost of renewal of conduits need not be an item in the expense of a project—at all events, not for the next twenty generations.

The comparative cost of conduits and iron pipes.

And now as to the cost of conduits. As iron pipes are limited in size, the best plan will be to compare, say, a three and a-half foot main with a conduit capable of discharging a certain quantity of water. Such a main, with a fall of five feet per mile, will discharge† 13,000,000 gallons daily. A conduit having a waterway four feet deep and five feet wide, and being arched above, would with the same fall discharge‡ nearly 40,000,000 gallons, or three times as much. The cost of such a conduit will vary according to the soil in which it is built. In the case of the projects which I shall recommend for Bombay, the conduits would be almost entirely tunnels through solid rock, and a tunnel six feet high in the middle by five feet wide (about as small a one as could conveniently be constructed) at the rate which has been tendered for the Toolsee work under Mr. Walton would cost £6,000 per mile. If the soil were of the very worst description, and building, besides tunnelling, had to be resorted to, the cost of the conduit would be, perhaps, twice as much, or £12,000 a-mile. Considering that the

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* I have personally examined the masonry in the largest of the aqueducts at Rome, and was surprised to find in what a wonderful state of preservation it was.

† According to the formula most generally in use—viz., Hawkesley's—$G = \sqrt{\frac{(15 D^5, H}{L}}$; where G is the discharge in gallons per hour, L the length of pipe in yards, H the head of water in feet, and D the diameter of pipe in inches.

‡ By the well-known formula, which is a modification of Eytelwein's, $v = 55 \sqrt{2 h f}$, where v is the velocity in feet per minute, h the hydraulic mean depth in feet, and f the fall in feet per mile.

hills through which the tunnelling would have to be carried consist almost entirely of solid trap, and generally of the hardest description, I feel certain that a very small portion of the tunnel will have to be built. But let me even suppose that one mile out of every three has to be built, then the average cost would be Rs. 80,000, or £8,000 a-mile. I will, however, take it at more than this, at as much as £9,000.*

Thus, it turns out that a pipe, three and a-half feet in diameter, will cost two and a-half times as much as a conduit which discharges three times as much water. In other words, the cost of a conduit will, comparing the quantity of water delivered, be about one-seventh that of a pipe.†

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* Vide note to page 122.

† Only to give the reader an idea of the enormous cost of pipes as compared with the other items which go to form the estimate for a water-supply project, I take the following facts from *Mr. Aitken's Report on the Extension of the Bombay Water Works. Vide Pages* 29 *to* 32.

POWAY PROJECT.

Cost of Reservoir	$12\frac{1}{4}$ lakhs of rupees,	or	£122,500
,, Land	6 ,,	,,	60,000
Cost of Iron Pipes	$17\frac{1}{4}$,,	,,	172,500
Total.........	$35\frac{1}{2}$,,	,,	£355,000

Thus the pipe was to cost nearly as much as the reservoir and land put together.

KENNERY PROJECT.

Cost of Reservoir	17 lakhs of rupees,	or	£170,000
,, Land	1 ,,	,,	10,000
,, Iron Pipe	$23\frac{1}{2}$,,	,,	235,000
Total.........	$41\frac{1}{2}$,,	,,	£415,000

In this case the pipe was to cost more than the reservoir and land together.

SHEWLA PROJECT.

Cost of Reservoir	11 lakhs of rupees,	or	£110,000
,, Land	$4\frac{1}{2}$,,	,,	45,000
,, Steel Main..............	$124\frac{3}{4}$,,	,,	1,247,500
Total......	$140\frac{1}{4}$,,	,,	£1,402,500

And in this case the cost of the pipe was to be more than eight times as much as the reservoir and land together!

These facts show the necessity which exists for every effort being made to reduce the cost of the means of bringing the water to the town from the reservoir.

All the estimates in this Report illustrate the same subject—viz., the great cost of iron pipes as compared with that of the other items.

In order to convince the reader that this is no exaggeration, we may make the comparison in another way, and the result will be about the same. I have already mentioned that a main 3½ feet in diameter will cost £22,000 per mile. Let us ascertain what the size of a conduit to cost this sum would be, and how much water it would give us. A six-foot square tunnel, with as flat an arch above as possible, would not cost much more than about £10,000 a mile under favourable circumstances—*i.e.*, if the soil through which it was driven were rock, and no masonry were required. If the soil were bad, and the conduit required to be lined with masonry, such a tunnel would not exceed £20,000 per mile. Say that the average cost of the conduit through good and bad soil were £15,000 a mile. Then, as it would deliver 80,000,000 gallons daily, or six times as much water as the pipe, costing £22,000 a mile, the relative cost of the conduit would be about one-ninth that of the pipe.

Examples of the use of Conduits.

And now let me direct attention to a point I have purposely reserved to the last, and which, I think, the reader will admit to be an unanswerable argument in favour of conduits as opposed to pipes.

If there were any advantage in pipes, this advantage would be ever so much greater in a country where pipes could be manufactured cheaply, and, *vice versâ*, the advantage would be less in a country where they were difficult and costly to obtain. Let us then inquire whether pipes have been used in preference to conduits in the land of iron. I suppose if any one were asked where pipes could be obtained cheapest, he would at once say Glasgow, where both iron and the coal to manufacture it with are found in such abundance. But what do we find to be the case? In the Loch Katrine Works, among the first water works in the world, out of a total length of 34 miles of pipes and conduits, from Loch Katrine to Glasgow, there are only 12 miles of pipes and 22 of conduits, and in a total length from Loch

Katrine to the service reservoir of $25\frac{3}{4}$ miles, there are only $3\frac{3}{4}$ miles of pipes and 22 of conduits. Mr. Bateman, admittedly one of the first hydraulic engineers of the day, rather than lay down pipes, preferred to tunnel through hills, and some of the shafts were nearly 500 feet deep! Can any one after this doubt the necessity of *our* dispensing with the use of iron as much as possible? If Mr. Bateman found it cheaper to bring water through conduits to Glasgow, where iron could at the time be obtained at £4 and £5 the ton, and where every mechanical appliance, cheap fuel, and the best workmen could be obtained, how much more imperative must it be for us to adopt conduits in Bombay, where pipes will cost £16 per ton, where the use of mechanical applicances entails a heavy cost, where the price of coal is 60s. per ton, and where skilled workmen are not only expensive, but difficult to obtain.

Let me give another example in which conduits have been used in place of pipes, and one out of England, and where the features of the country are very similar in their character to those of the Conçan. The water from the great Furens Dam* is drawn for the supply of St. Etienne through a masonry conduit which has been built in open cuttings on the sides of the hills. In this instance it has actually been found cheaper to build a long masonry channel than to lay down a direct iron pipe, and the channel—just as would be the case in the Bombay Water Works—has been built of stone quarried from the excavations made to receive it. Open cutting has been resorted to for the St. Etienne Works in place of tunnelling, because the hills are not tortuous; but where they are so, and where, therefore, the length of the conduit would be out of all proportion to the direct distance of the reservoir from the town, there is no doubt that, as in the Glasgow Works, tunnelling would be by far the better method of the two.

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* *Vide* note to page 82.

Strong as this argument is, it becomes still stronger when we remember that the art of tunnelling has wonderfully improved since the Glasgow Water Works were carried out. There is hardly any branch of engineering in which such great strides have been made. This is shown by the last tunnel built under the Thames, which was successfully completed in a few months without the least difficulty, while Brunel's Tunnel took years to construct.

Tunnelled Conduits.

Where much water is found, and where the soil is sandy and treacherous, there are some difficulties to overcome; but, in the case of the tunnels for the Bombay Water Works, the strata everywhere are known to be trap, and generally of a hard compact nature. The tunnels, moreover, run from 200 to 300 feet above the water level of the country. I only hope water may be found, for it will render the work far more easy of accomplishment. The hills are so uncommonly dry, there is but little water to be found on them for even drinking purposes.*

Hitherto I have only spoken of conduits in the common acceptation of the word—*i.e.*, as channels through which water flows as through a canal. I wish now to say a few words on conduits under pressure.

The island of Bombay and the surrounding country consist, as I have already mentioned, of hardly anything but trap. In most parts this rock is hard and compact, and, if it were free from fissures, there is no doubt it could be depended upon for the conveyance of water, even under very great pressure. Unfortunately, however, trap is a rock which varies perhaps more than any other in its nature, passing from the hardest basalt to the softest volcanic tufa. The abundance, however, of basalt, and the fact of its being constantly found in the

Rock Syphons.

* I and my surveyors have always had to carry our water for use from camp. We have occasionally found water on the hills, but in very small quantities—either in pools or dribbling down the face of a rock.

valleys, compelled me to consider whether it would not be worth while to obtain the opinion of a geologist as to the likelihood of success, if rock syphons were attempted where the strata promised to be sound. The valuable opinion of Mr. Blandford, who is known to be one of the ablest geologists in India, will be found in Appendix E.* I regret to say that it is not favourable to the idea of rock syphons. At the same time I am bound to add that it is far from being so unfavourable as to prevent a trial being made.

It must be remembered that according to the quantity of water brought to Bombay, from one and a-half to more than two lakhs of rupees would be saved *in every mile* of rock syphon used in place of an iron pipe. What I would propose to the Bench is, not that they should make an experiment on a grand scale involving great expense; to arrive at an opinion on the subject, a small outlay is all that is required, and the experiment should be made without delay, and in the island of Bombay itself.

It does not matter what project is decided upon or what the quantity of water to be brought to the town may be; the tunnel will answer equally well for any of the projects, and the smallest sized one that can conveniently be made will deliver five and six times more water than can be required. Let the experimental tunnel be only half a mile long, and let it be constructed along some portion of the line which the pipes will follow, if the tunnel does not answer. Let shafts be sunk at intervals of two or three hundred yards apart, and let the tunnel be driven *at the depth of fifty feet below the point at which solid rock is found,* not merely fifty feet below the surface of the ground.† Nearly everywhere in the island sound

* For the information of the Justices, I should mention that Mr. Blandford's report has not cost them anything. The Government of India in a most liberal spirit lent Mr. Blandford's services gratis.

† This experiment should not be made in the neighbourhood of Koorla, or across the causeway, because the strata are not favourable, and iron pipes would probably have to be used in these places.

rock will be found at less than 20 feet from the surface, so that the tunnel would not lie more than about seventy feet below. If, in sinking the shafts, the rock at this depth were soft, it would not be necessary to carry the experiment further. I would not stop the work in hard rock, even if there were fissures, as one of the very points to be decided is whether the fissures could not be effectually stopped up to prevent the escape of the water. My own impression is that such fissures as may be met with will not extend to the surface, but be merely confined to the distance of a few yards from the tunnel, and that no water, therefore, would escape through them.

After the tunnel was constructed, it could be filled with water, and the mouths of the shafts stopped up,* and hydraulic pressure applied. There would not be the slightest chance of the tunnel bursting. Such a casualty would be impossible. At the very worst the water might escape to the surface, and this would soon be ascertained, and an opinion could be arrived at on the experiment.

The argument brought against such a proposition will of course be that a rock syphon has never yet been constructed. My reply to this is that I know of no town situated as Bombay is where a rock syphon could have been attempted with a chance of success. It would be a pity for the Bombay people to condemn the idea simply for its novelty. I do not for one moment maintain that rock syphons can be constructed, but, considering the extraordinarily exceptional nature of the rock about Bombay, I am most emphatically of opinion that the Bench should sanction, say, 30,000 rupees, to ascertain whether it is possible for them to save a first expense of eight or ten lakhs of rupees, and an ultimate one of perhaps fifty.†

* Any Justice who may wish for information on the subject will find detailed plans in the Municipal Office for closing the mouths of the shafts and drawing water from the tunnel. I did not think I should be justified in encumbering this Report with plans of works of a confessedly experimental nature.

† Since writing the above, the price of iron has gone up still higher, and it appears to me more than ever necessary to make the experiment recommended above.

To sum up, then, the arguments of this chapter, I trust the reader will see there is no doubt that masonry conduits are many times cheaper than iron pipes; that they are far better suited to the circumstances of Bombay, where the materials and labour for their construction are both cheap and abundant, and where pipes are costly; that a single line of conduits will out-last a dozen or more lines of pipes; and that in adopting conduits we should not be carrying out works of an experimental nature, but should merely be following the example of one of the finest and most successful water works in the United Kingdom.

Summary.

And, with regard to rock syphons, which must not be confounded with conduits, I trust he will see that, whatever may be the opinions of different people on a work, the like of which has never yet been tried, still, considering the enormous saving which the success of such a work would ensure, we should be justified in going to some slight expense to prove by direct experiment the feasibility of the proposition.

CHAPTER V.

ON THE ADVANTAGES OF A SERVICE RESERVOIR, AND THE NECESSITY FOR LAYING PIPES ABOVE GROUND.

Hitherto it has been proposed in every project to deliver the water to Bombay under direct pressure from the storage reservoir. As I am of opinion that this would not only entail needless expense, but cause many more interruptions in the regular supply to the town than would take place if we had a service reservoir nearer at hand, it is necessary that I should prove the point.

Cost of the Service Reservoir System.

It does not of course follow that because channels are cheaper than pipes, therefore to bring the water nearer to Bombay by help of channels first and then to deliver it by pipes, will be cheaper than to employ pipes only. It may so happen that the additional cost of the service reservoir in the former case may render that system on the whole more expensive. I will, however, show that, so far as Bombay is concerned, there is no doubt of the advantage of the method of distributing the water from a service reservoir. Let me take by way of illustration any of the projects which have been proposed. The Kennery Project will serve for the argument as well as any other.

In order to bring the Kennery water direct from the lake, Mr. Aitken proposed a main 32 inches in diameter, and $1\frac{1}{8}$ inch thick.* It was moreover to be 22 miles long, and to cost $23\frac{1}{2}$ lakhs of rupees, or rather more than a lakh a mile. Now I find that by means almost altogether of a conduit, the Kennery water can be brought to within $9\frac{1}{2}$ miles of Bombay, and that from this point the pipe, instead of being 32 inches in diameter, need not be more than 27. The unprofessional reader will naturally suppose that if the pipe is reduced in size, it will not deliver the same quantity of water, but this is not so. The pipe of 27 inches diameter will in the second case deliver quite as much water as the pipe of 32 inches will in the first. The apparent paradox is easily explained. A pipe delivers water in proportion to the head of water compared with its own length. A pressure of 500 feet is no more effective at the distance of 50 miles than the pressure of 100 feet at the distance of 10 miles. The discharges of all pipes are calculated on this principle. The discharge in the case of a pipe from the Kennery Lake would be in proportion to the head at that long distance. Let us suppose the water to be taken from the lake at a point 170 feet above Bombay, which is about the level at which it would have to be drawn. Then the average fall available for the pipe would be $\frac{170}{22 \text{ miles}}$, or not quite 8 feet per mile.

Now if, on the other hand, we first brought the water to within $9\frac{1}{2}$ miles of Bombay before delivering it to the town under pressure, I find this could be done with very little loss of head. The distance between the Kennery and the service reservoir is $8\frac{1}{4}$ miles, and, excepting in one portion of the line (three-quarters of a mile long) where, there being a depression in the hills, it would be too expensive to construct a masonry work, and a pipe would have to be laid, we could use conduits throughout. If we did so, we should not have to give the

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* *Vide* page 30 of his *Report on the Extension of the Bombay Water Works.*

channel a greater slope than 12 inches a mile, because, even with a waterway 5 feet wide and 4 four deep, it would discharge more than twice the daily supply from Kennery. The total fall, therefore, in the $7\frac{1}{2}$ miles would be $7\frac{1}{2}$ feet.

The syphon across the depression in the hills need not have a greater slope than 5 feet per mile, as, if it were even 36 inches in diameter, it would carry the daily supply from Kennery; but in calculating the cost I will suppose a 42 inch* pipe is used, or one capable of discharging one and a-half times the daily supply. The total fall, then, in the syphon, three-quarters of a mile long, would be $3\frac{3}{4}$ feet, and the total fall in the conduit and syphon together would be just $11\frac{1}{4}$ feet,† so that if the water, as I propose, left the Kennery Lake 170 feet above Bombay, it would reach the service reservoir at $(170 - 11\frac{1}{4})$ $158\frac{3}{4}$ feet above Bombay. This pressure being available at the distance of only $9\frac{1}{2}$ miles, the average fall would be $(\frac{158\frac{3}{4}}{9\frac{1}{2}}$ or) about $16\frac{5}{8}$ feet per mile, more than double that in the case of one long continuous pipe from Kennery. This great fall enables us to reduce the size of the pipe, so that, whereas a pipe of 32 inches diameter is required in the one case, a pipe of 28 inches diameter suffices in the other. Nor is this all; the smaller the pipe the thinner the metal to resist the pressure may be, so that besides a smaller pipe we need not have one so thick.

The cost of the $32\frac{1}{2}$-inch main from Kennery was calculated at $23\frac{1}{2}$ lakhs of rupees. The cost of the channel syphon and pipe would be :—

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* In my Kennery Project the pipe I propose is 48 inches in diameter, but this is for special reasons, which do not concern my argument here.

† In my Kennery Project the actual fall is $14\frac{1}{4}$ feet, but this also is proposed for special reasons, which are too long for me to explain now, but which may be found in pages 118 to 120. For the purposes of my argument the above statement is correct, inasmuch as we are concerned here, not with the fall it would be best to give to the channel and syphon—for that may depend on several other considerations—but the fall we could give to them in order to keep the water as high as possible.

$7\frac{1}{2}$ miles of channel at Rs. 80,000 a mile	Rs. 6,00,000
Syphon $\frac{3}{4}$-mile long, 42 inches in diameter and 1 inch thick,* weighing 832 tons at 110 Rupees a ton	91,520
$9\frac{1}{2}$ miles of 28-inch pipe, 1 inch thick, weighing 720 tons per mile, at 110 Rupees a ton,† or 79,200 Rupees a mile	7,52,400
	14,43,920
Add 10 per cent for contingencies, say...........	1,44,080
Total........................	Rs. 15,88,000

So that the difference of cost between a long pipe from the lake and a conduit, syphon, and pipe, amounts in this one project to about eight lakhs of rupees. Now the cost of a service reservoir will not be more than three lakhs, so that the advantage of a system with a service reservoir, so far as mere expense is concerned, is manifest. The argument would be still stronger if I took a project with a reservoir beyond Salsette—such, for instance, as the Shewla or the Tansa Project.

The greater convenience of the Service Reservoir System.

The other great advantage which a service reservoir possesses is this: we reduce the number of interruptions to the regular supply. If we have a long pipe—as, let us suppose, for instance, the one from Kennery—an accident in any portion of the line of 22 miles must necessarily cause the entire supply to the town to be cut off while the damage done is being repaired. But in the case of a service reservoir, if an accident happens above the reservoir, the supply can still go on from the latter while

* It might be only three-quarters of an inch thick, as it would not have to resist a greater pressure than a head of water of 50 feet.

† About the same rate at which the $32\frac{1}{2}$-inch main was calculated.

the conduit is being restored, and, when the conduit is open again for use, the service reservoir can be refilled.

The great length, fifty-six miles, of the continuous pipe from the Shewla reservoir to Bombay, proposed by Mr. Aitken, constituted in the eyes of most of the profession one of the greatest objections to the scheme. The longer the pipe the greater must be the number of bursts which take place in it, and the greater must be the number of stoppages to the supply to the town. So that, if the pipe from Vehar to Bombay, fourteen miles long, bursts a dozen times yearly, and the water has to be shut off from the town for twelve days in the year, it would have to be shut off four times as often, or for forty-eight days in the year, in a pipe four times as long—viz, fifty-six miles ; and this, where the interests and welfare of nearly three-quarters of a million people are concerned, is an important consideration.

Even if a service reservoir entailed considerable extra cost over a continuous pipe—which it fortunately, in the case of Bombay, does not—I should still most strongly advocate its adoption, in consequence of the great advantage it affords in the regularity of the supply not being dependent on the security of a single long line of pipes.

Here again, in recommending the use of service reservoirs situated nearer to the town than the storage reservoirs, I am merely following the practice of the most eminent hydraulic engineers of the day. Both at Manchester and Glasgow, and also at numerous other towns, the water is stored for use at a long distance from the town, but is distributed to the population from service reservoirs kept constantly filled from the distant lakes. Indeed, the time will come, if it has not already, when the inconvenience of the stoppage of the water from Bombay for even a few hours will be considered so intolerable, that it will be necessary to have one or two distributing reservoirs in the town itself to contain a sufficient supply for one or two days. I do

Distributing Reservoirs in the town.

not recommend their construction just now, because I think the town had better spend all its present available means in storing water and in bringing more to the people. Distributing reservoirs can be built at any future time when the want of them is really felt.

In conclusion, I have only to add that it is surprising to me to find that the necessity of bringing the water as near as possible to Bombay before distributing it under pressure should never before this have been pointed out to the Bench, and that I should have to bring it to their notice. The mere fact of the system being exactly in accordance with the best European practice should have drawn attention to the subject long ago.

I have already referred, in several parts of this work, to the rapid destruction of iron by corrosion, and Mr. Aitken has stated in his *Report on the Extension of the Bombay Water Works*, that he has seen cast-iron pipes laid down in the island corroded in five or six years. There is no doubt whatever that the process of corrosion is much more rapid in Bombay than it is in England, and that this is, in great part, due to the large quantities of saline matter mixed with the soil. So important did Mr. Aitken think the subject, that he considered it necessary to advocate that his pipe should be placed on standards above ground. The great objection urged against this proposition, during the sitting of the Water-supply and Drainage Commission in 1869, was that the water would arrive in Bombay at a temperature sufficiently high to boil an egg. Now, on this one point I agree with Mr. Aitken, and I altogether dispute the validity of the objection. I am of opinion that the temperature of the water in a pipe exposed to the sun would not be materially affected; but the fact can be ascertained by the simplest of experiments, and at a most trifling expense, perhaps 50 Rupees.

I propose that one of the 30-inch pipes in the possession of the Bench be taken and, being supported on standards, be exposed to the full heat of the sun some day in October, when the sun is, perhaps, as powerful as at any time of the year. Let the two ends of the pipe be closed with flat iron plates, the pipe filled with water, and arrangements be made for drawing off the water from time to time by a small cock. Beginning at six o'clock in the morning, let small quantities of the water be drawn at every hour up to six in the evening, and each time let a thermometer be plunged into the water to ascertain its temperature. We shall then know, to a certainty, to what extent exactly the water will be heated in a pipe exposed all day long to the action of the sun.

Let it be borne in mind that the water delivered in Bombay through a main would never be so warm as that in the experimental pipe suggested by me. In this latter case, the pipe will be exposed to the sun's rays all day long, and the water will be heating all this time; but the water in a main would not take more than five or six hours to reach the town after it left the reservoir.

If the experiment shows that the temperature of the water is not sensibly increased, the pipes can be laid above ground without any protection from the sun, but, if the temperature rises, it will be necessary to consider if steps could not be taken to protect them in some way so that the direct rays of the sun should not fall on them. I am of opinion that there are many ways in which this could be done, but I will merely suggest one or two, not advocating any particularly, but merely putting them forward for consideration with the numerous other plans which are sure to be proposed in Bombay. Bundles of dried grass, one of the few things to be had very cheap in Bombay, might be laid four inches in diameter over the upper half of the pipe, and a sheet of thin galvanized iron, bent to a semicircular form, be laid over the grass. At intervals of three or four feet apart, hoop iron might be passed round the whole, binding them together, and a coat of tar might be put over the upper half of the pipe for its better preservation.

Or a sheet of galvanized iron might be fixed over the pipe without any hay between, but in this case it would be well to have a space of about eight inches between the sheet and the pipe, so as to let the air play freely between them.

Tarred felt might also be tried, but I do not recommend it, as I fear it would not last long. But it does not matter what method is adopted. Some good plan is sure to be discovered finally. What is really necessary at first is, that the Bench should be satisfied that pipes laid above ground will last longer than if buried in the earth, and in order to prove this point, I only ask them to examine the line of pipes between Vehar and Bombay. Soon after leaving the Main Dam, the pipe runs over the Gopur stream, and is exposed to the air for a length of about a hundred feet.* This portion of the line appears now to be in nearly as good a state of preservation as on the day when it was laid down. But let any other part of the line which has been buried beneath the soil be exposed, examined, and compared with this portion. The pipes will be found with their surfaces rough, eaten through, or scaling off with corrosion. Facts of this kind are worth a thousand opinions, and if it be the case, as it undoubtedly is, that pipes exposed to the air do not corrode to anything like the same extent as those which are buried, there surely can be no doubt, considering the enormous price of iron now, of the advisability of our taking every step in our power to make our mains last as long as possible.

The mere saving in the water-supply alone should ensure the consideration of the subject. When pipes are buried, they may go on leaking for years without the fact being discovered, whereas, when they are laid above ground, the slightest leak betrays itself at once, and can be stopped without delay.

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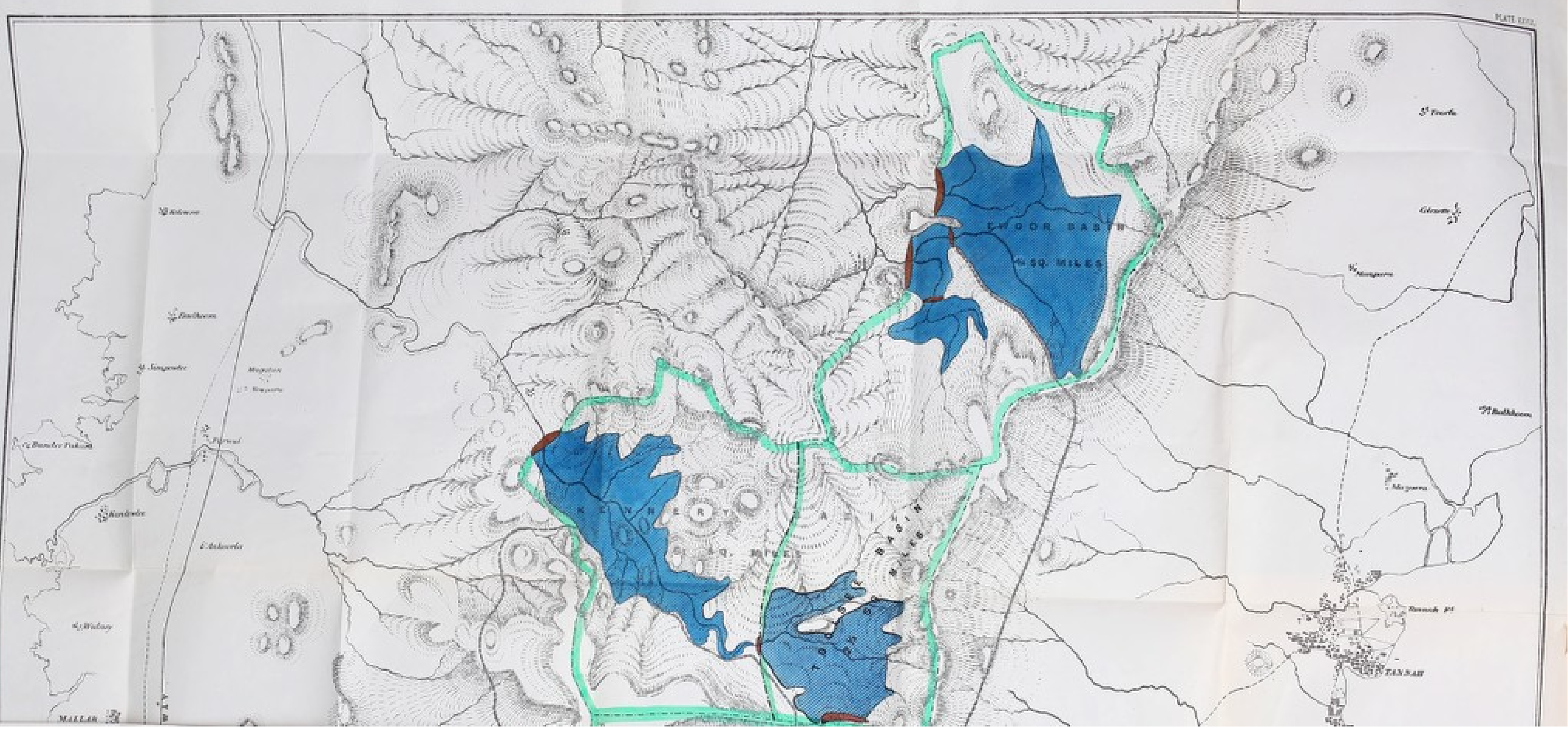
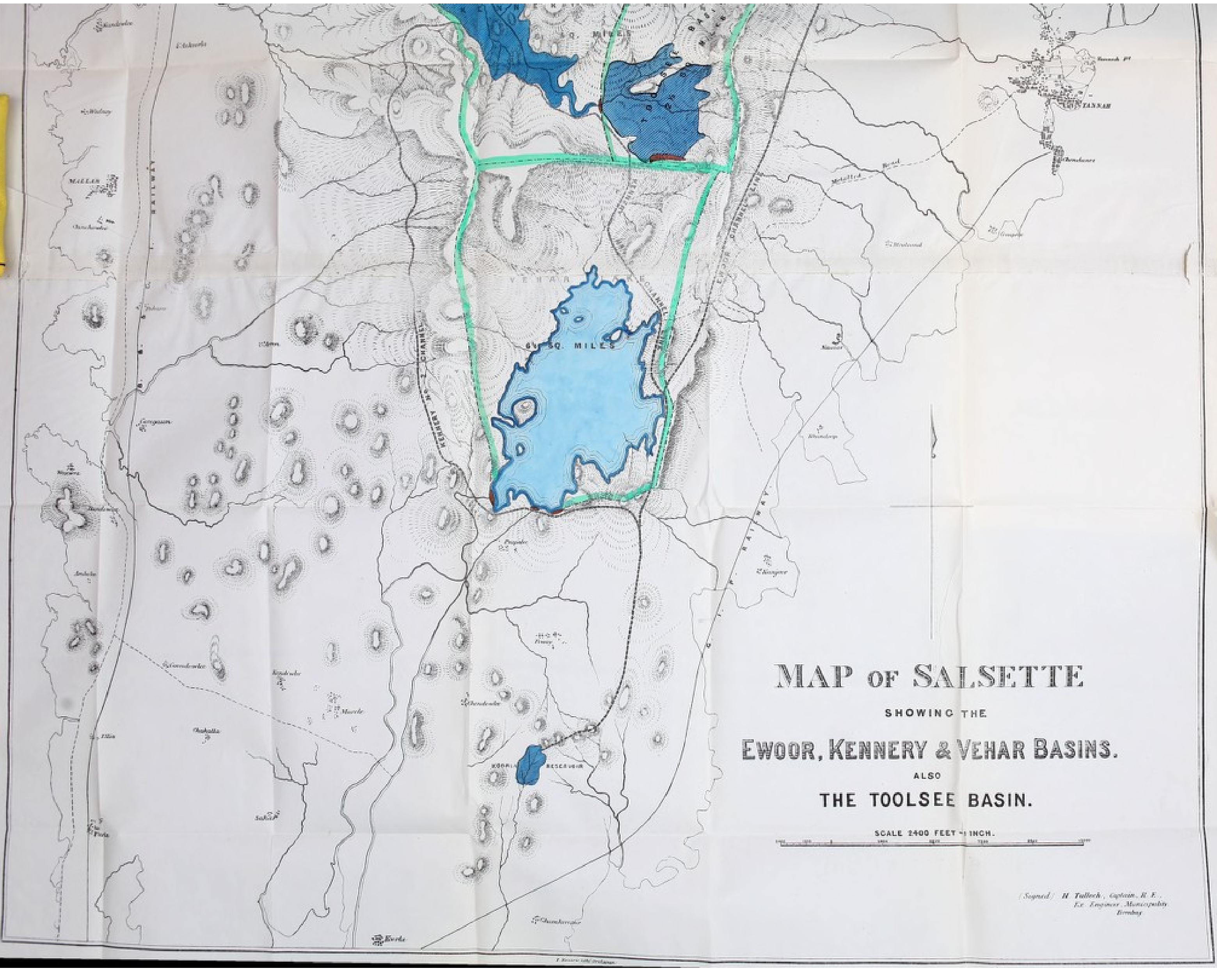
* I write from memory.

I trust I have now demonstrated that, before we go on blindly repeating what may prove to be the errors committed before, it is incumbent on us first to ascertain whether pipes above ground in Bombay do really last longer than those buried beneath the soil, and, if this is proved, whether the temperature of the water will be sensibly affected by exposing the pipes to the full heat of the sun, and, even if this be the case, to inquire whether steps cannot be taken to protect them from absorbing such an amount of heat as would raise the temperature of the water.



MILES
TANNAH


MAP OF SALSETTE
SHOWING THE
EWOOR, KENNERY & VEHAR BASINS.
ALSO
THE TOOLSEE BASIN.
SCALE 2400 FEET = 1 INCH.
(Signed) H. Tulloch, Captain, R. E.
Ex. Engineer, Municipality
Bombay
TANNAH
RAILWAY
SQ. MILES
RESERVOIR

CHAPTER VI.

THE KENNERY PROJECT.

The Valley, and the quantity of water to be obtained from it.

The Kennery Valley, as will be seen in the accompanying Map of Salsette (Plate XXVII.), lies directly north of the Vehar Lake. As it opens to the west, it is better situated to catch the monsoon rains than the Vehar Valley, which is sheltered in this direction by a high range of hills. The most convenient site for the dam—in fact, the only practical one—is a gorge between two hills sloping towards each other. The area of the watershed above this point is $5\frac{1}{2}$ square miles, and the bottom of the gorge is at the level of 203·00 feet on Town Hall Datum, or rather more than 100 feet above Bombay, taking the average level of Bombay at about 100 on datum. Before it can be decided how much water should be stored for use in Kennery, it is manifestly necessary to ascertain the quantity obtainable from the valley. Calculations of this nature are made up of two factors—1st, the quantity of water falling in the lake itself; and 2nd, the quantity not *falling on the gathering ground*, but flowing off from it. But both these quantities depend on the area of the lake, and this area, again, will depend on the level up to which it is determined to impound water, and the water stored for use will be the quantity contained between this level and that at which the water is drawn off. I will decide the latter point first.

I am of opinion that, whatever may be the capacity of the lake, it would be wise to draw the water at about 270·00 feet above datum, and I fix on this level for a very cogent reason. It would enable us to command the Vehar Lake. In other words, we should be able to throw the Kennery water into the latter whenever it were desirable to do so, which it obviously would be very often. For instance, the Vehar Lake might be comparatively low, while the Kennery Reservoir might be overflowing. To have the power, therefore, to save all the surplus supply might be of the greatest importance in the future. Now, the level of the Vehar Lake when full is 262·50 feet on datum, and if, as I propose, the water be drawn from Kennery at 270·00 feet on datum, we shall have a command of 7½ feet. The conduit from Kennery to Vehar would be about 2 miles long, and, if we gave it a slope of about 2½ feet per mile* (the reason for which will be explained hereafter), it would, on reaching the valley, be about 2½ feet above the lake—a command of elevation which I think it would be wise to retain. I should not personally offer any great objection to the water being drawn from Kennery at 265·00 on datum, which, if the slope of the conduit be reduced to one foot per mile, would allow of its reaching the Vehar Valley with its bottom about six inches above the lake, but I simply think it better not to run things too close. The higher the level at which we draw the water, the higher will be the level at which it reaches the service reservoir, and the greater will be the pressure in the main to Bombay.

I cannot refrain, at the same time, from pointing out that it would be a grave error, in constructing any new reservoirs, if such arrangements were not made as would enable us to run the surplus water into the Vehar Lake. In fact, all future water works for Bombay, while they may be made independent of Vehar, should at the same time be so constructed as to improve the present system by rendering it less liable to failure.

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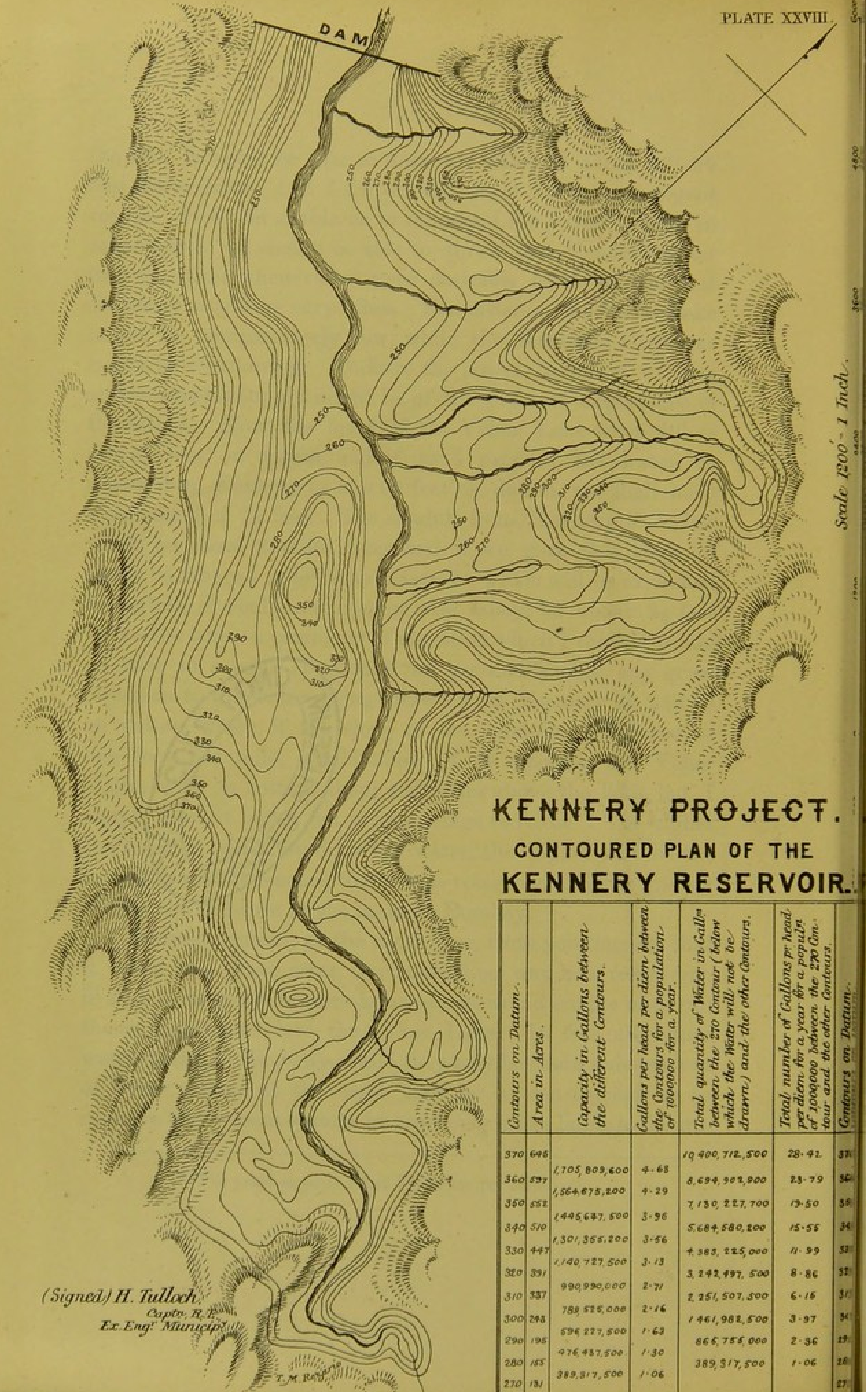
* The exact slope is 2 feet 7½ inches per mile.



KENNERY PROJECT.

CONTOURED PLAN OF THE KENNERY RESERVOIR.

Contours on Datum.	Area in Acres.	Capacity in Gallons between the different Contours.	Gallons per head per diem between the Contours for a population of 1000000 for a year.	Total quantity of Water in Gall^ns between the 270 Contour (below which the Water will not be drawn) and the other Contours.	Total number of Gallons p^r head per diem for a year for a popul^n of 1000000 between the 270 Contour and the other Contours.	Contours on Datum.
370	646			10,400,712,500	28·42	37
		1,705,809,600	4·68			
360	597			8,694,902,900	23·79	36
		1,564,675,200	4·29			
350	552			7,130,227,700	19·50	35
		1,445,647,500	3·96			
340	510			5,684,580,200	15·55	34
		1,301,355,200	3·56			
330	447			4,383,225,000	11·99	33
		1,140,727,500	3·13			
320	391			3,242,497,500	8·86	32
		990,990,000	2·71			
310	337			2,251,507,500	6·16	31
		788,525,000	2·16			
300	248			1,461,982,500	3·97	30
		596,227,500	1·63			
290	195			865,755,000	2·36	29
		476,437,500	1·30			
280	155			389,317,500	1·06	28
		389,317,500	1·06			
270	131					27

(Signed) H. Tulloch,
Capt^n R.E.
Ex. Eng^r Municip^l

If, then, we say that the water is to be drawn from the Kennery Lake at 270·00 on datum or thereabouts (for a few feet difference will not affect the calculations to follow), the quantities of water which can be stored for use may be seen from the table on Plate XXVIII. The largest lake which it would be possible to form would be one with an area of about 600 acres, involving a dam nearly 180 feet high, while the smallest lake which it would be advisable to form would be one of about 400 acres, with a dam 130 feet high. Such a lake, as will be seen presently, will not hold much more than a year's supply.

Assuming 600 acres and 400 acres to be the greatest and least superficial areas of the lake, 102 inches to be the rainfall, 54 inches or 4½ feet the proportion of rainfall flowing off the gathering ground, 2½ feet the evaporation, then the quantity of water obtainable from the Kennery Valley will be as follows:—

Quantity when lake is 600 acres in extent:—

	Gallons.
600 acres × 4,840 square yards × 9 square feet × 8½ feet rainfall × 6¼ gallons in every cubic foot............	1,388,475,000
2,920 acres × 4,840 square yards × 9 square feet × 4½ feet rainfall × 6¼ gallons in every cubic foot............	3,577,365,000
	4,965,840,000
Deduct for evaporation:—	
600 acres × 4,840 square yards × 9 square feet × 2½ feet evaporation × 6¼ gallons in every cubic foot............	408,375,000
	4,557,465,000
Deduct ⅓ for unaccountable waste	1,519,155,000
Total number of gallons yearly......	3,038,310,000*

* This is the method of calculation proposed by Mr. Ormiston, and I have adopted it throughout this report because it has been generally accepted. Of course objections may be made to it as no doubt he is aware, but any one who goes into the subject will find it difficult to suggest a better method. The truth is we have no reliable data regarding either the rainfall or evaporation, or the portion of the rainfall which flows off the ground.

Quantity when lake is 400 acres in extent :—

	Gallons.
$400 \times 4,840 \times 9 \times 8\frac{1}{2} \times 6\frac{1}{4} =$	925,650,000
$3,120 \times 4,840 \times 9 \times 4\frac{1}{2} \times 6\frac{1}{4} =$	3,822,390,000
	4,748,040,000
Deduct for evaporation :—	
$400 \times 4,840 \times 9 \times 2\frac{1}{2} \times 6\frac{1}{4} =$	272,250,000
	4,475,790,000
Deduct $\frac{1}{3}$rd for unaccountable waste =	1,491,930,000
Total number of gallons yearly.	2,983,860,000

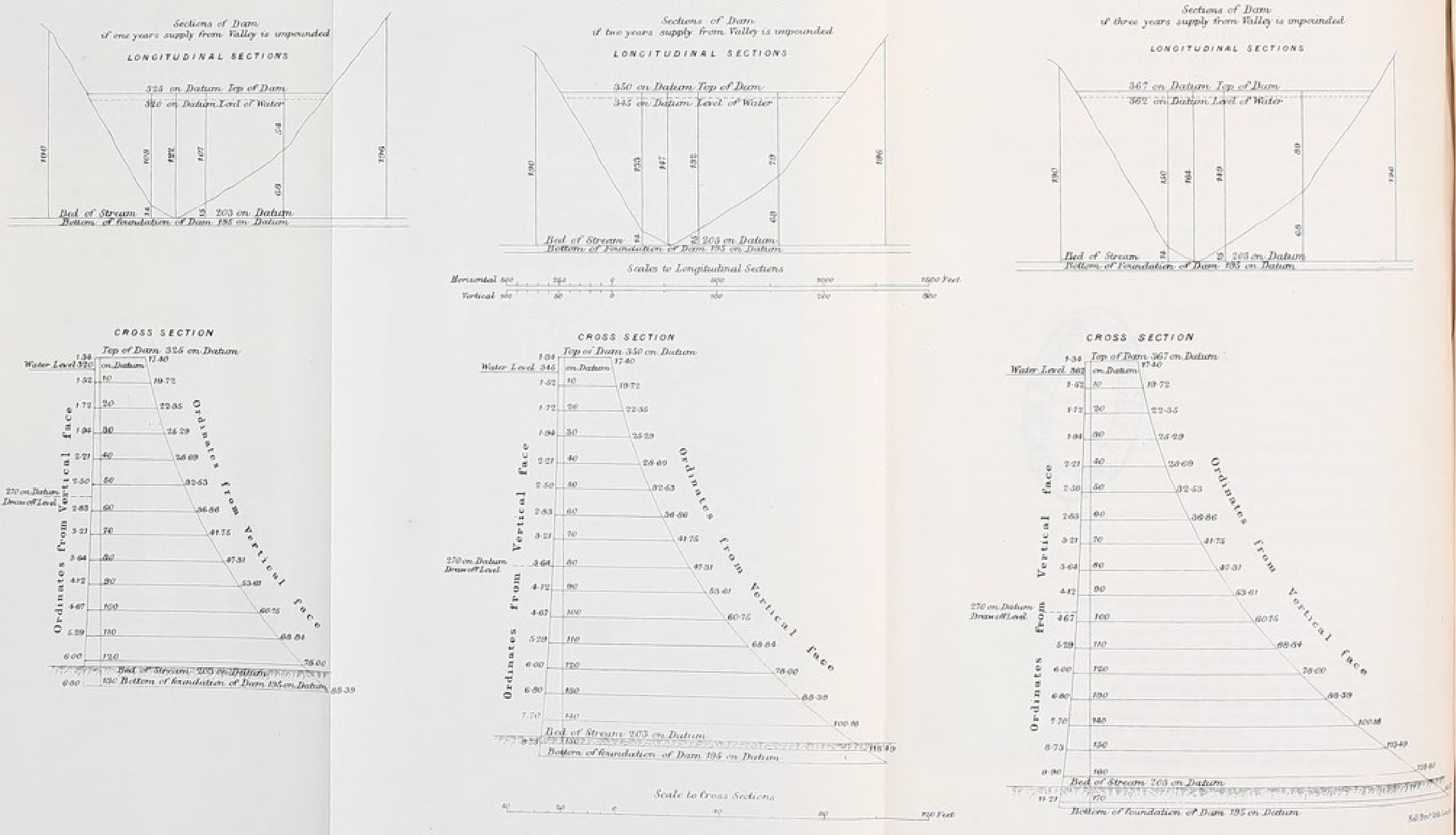
Thus it will be seen that, whether the lake has an area of 600 acres or of 400 acres, does not affect the calculation to any great extent; so that we may assume the total quantity of water obtainable from the Kennery Valley to be about 3,000 million gallons yearly, or say $8\frac{1}{4}$ million gallons daily, or nearly 13 gallons per head per diem for 650,000 people.

The total quantity obtained from Vehar, according to the same mode of calculation, gives us about 3,600 million gallons yearly (equivalent to nearly 10 million gallons daily), and this is just about as much as is contained in the lake between the average level to which the water rises and the average level to which it falls yearly.*

* In page 19 I have already mentioned that the average depth to which the surface falls is about $11\frac{1}{2}$ feet. Now suppose the Vehar Lake is full, the surface will be at 262·50 on datum, and the capacity of the lake (*vide* page 16) will be 10,800 million gallons. Suppose it falls $11\frac{1}{2}$ feet, the surface will then be at 251·00 on datum, and the capacity of the lake about 7,200 million gallons. The quantity that will have been expended in the year will therefore be the difference between 10,800 and 7,200 million gallons, or 3,600 million gallons, which, it will be seen, accords with the result obtained by calculation; the quantity lost by evaporation is probably equal to that which is delivered to the town in the four monsoon months while it is raining, when not only is the surface of the lake rising, but the supply to Bombay is going on at the same time. This supply, therefore, is not included in the 3,600 million gallons.

KENNERY PROJECT

KENNERY DAM



The question now is, how much water can we store in Kennery. By reference to the table on Plate XXVIII. it will be seen that to store 3,000 million gallons, or a one-year's supply obtainable from the valley, the surface of the lake, supposing no water to be drawn for use below 270·00 feet on datum, must be a little below 320·00 on datum. To store a two-years' supply, or 6,000 million gallons, the surface must be at about 345·00 on datum, and to store a three years' supply, as has been done in the Vehar Lake—or 9,000 million gallons—the surface must be at about 362·00 on datum. The bed of the river at the site of the dam is 203·00 on datum. To get a firm foundation we may not have to excavate more than four or five feet, but it will be safer to say eight feet. Then the bottom of the dam will be at 195·00 on datum, and as the masonry must be carried about five feet above the level of the water, the total height of the dam to impound the different quantities of water will be as follows :—

The Storage of the Water.

To impound 3,000 million gallons, or one year's supply (325·00—195·00)	130 feet.
To impound 6,000 million gallons, or two years' supply (350·00—195·00)	155 ,,
To impound 9,000 million gallons, or three years' supply (367·00—195·00)	172 ,,

All the necessary information regarding the dam may be found in Plate XXIX.

Having now shown how much water can be obtained from the Kennery Valley, and how it can be stored, the next point for consideration is how to bring it to Bombay.

The conduit between the Kennery and Koorla Reservoirs.

I propose to do so almost altogether by help of a conduit carried through the hills by means of tunnelling. I say almost altogether, because at one part in the line, where the hills are at too low a level for even an aqueduct, we shall be compelled to lay down a syphon. The conduit* would first pass into the Toolsee Valley, then into the Vehar Valley, then under the ridge running along the eastern margin of the lake, then on to the eastern ridge of the Poway Valley, where the syphon would have to be laid, and ultimately into a small service basin, called the Koorla Reservoir, this being the nearest point to Bombay where it is possible to have a high level reservoir at all, and which it is possible to reach from Kennery by conduit. The section of the proposed line of channel is given on Plate XXX., so that it will be seen the idea is easy of accomplishment. There will be only one aqueduct on the line—a small work which I need not further notice.

I have already proposed to draw the water at 270·00 on datum, and to give the first two miles of the conduit a slope of rather more than 2½ feet per mile. I would give the rest of the conduit, 5½ miles long, a slope of one foot per mile, and the syphon, which would be a pipe 48 inches in diameter and three-quarters of a mile long, a slope of 5 feet per mile. The total fall of the conduits and syphon combined would be 14½ feet. Thus, the conduit, leaving the Kennery Lake with its invert at 270·00 on datum, would reach the service reservoir near Koorla at 255·50 on datum, and as the water would be four feet deep in the channel, its actual level in the reservoir would be 259·50 on datum, just three feet below the Vehar Lake when full.

From the Kennery Lake to the service reservoir at Koorla, there are, as will be seen on Plate XXVII., two lines of channel to choose from. The one I prefer is that which runs into the Vehar Valley, and continues along the eastern ridge of the Salsette hills. The other line would run along the western slope of the western ridge, but it would be longer. Moreover, in order to reach Koorla, it would have to cross the Vehar and Poway Valleys, and this is an objection to it, inas-

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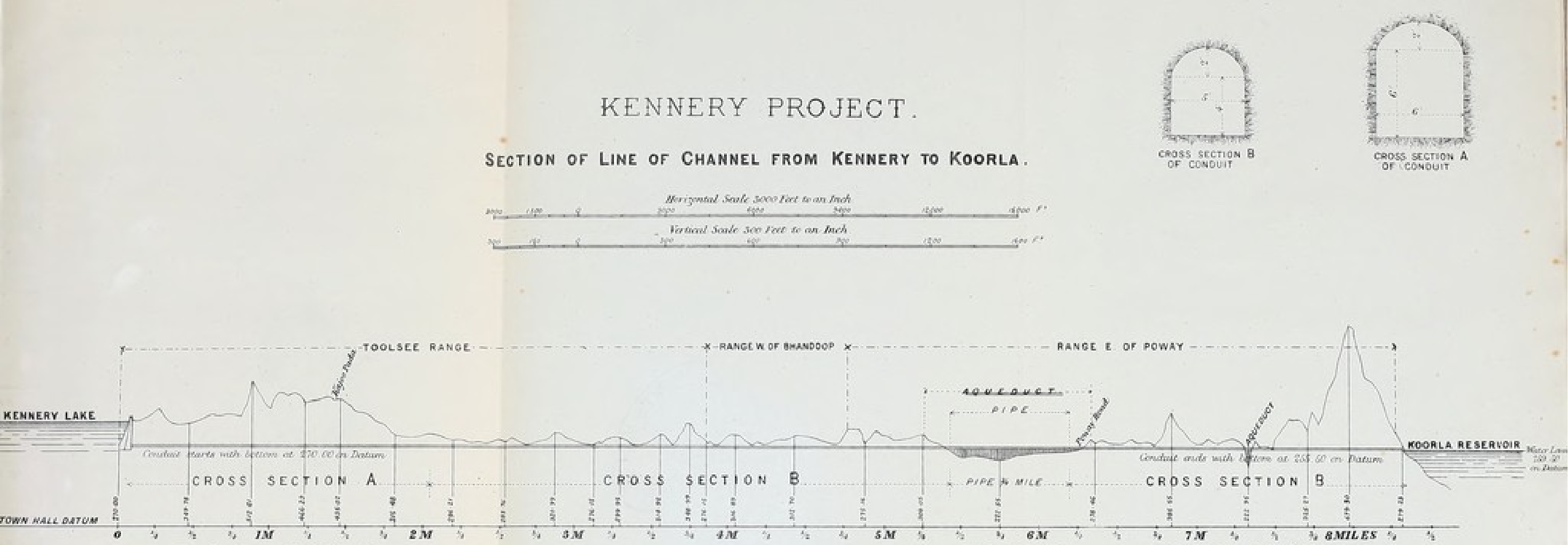
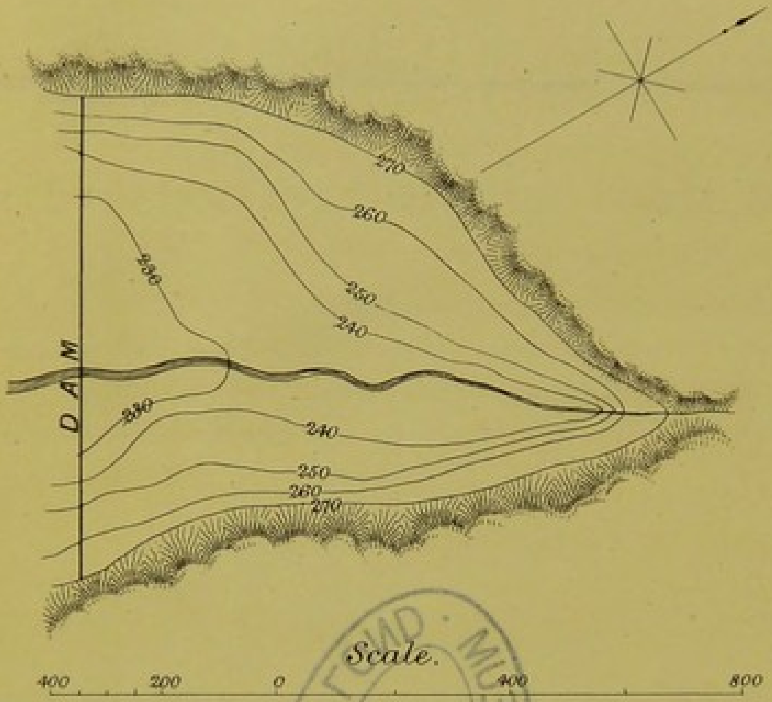
* *Vide* Kennery No. 1, Channel line, Plate XXVII.


KENNERY PROJECT.
SECTION OF LINE OF CHANNEL FROM KENNERY TO KOORLA.
Horizontal Scale 3000 Feet to an Inch
Vertical Scale 300 Feet to an Inch
CROSS SECTION B OF CONDUIT
CROSS SECTION A OF CONDUIT
TOOLSEE RANGE
RANGE W. OF BHANDOOP
RANGE E. OF POWAY
AQUEDUCT
PIPE
KENNERY LAKE
KOORLA RESERVOIR
Conduit starts with bottom at 270.00 on Datum
Conduit ends with bottom at 255.50 on Datum
CROSS SECTION A
CROSS SECTION B
PIPE ¾ MILE
CROSS SECTION B
TOWN HALL DATUM
0
1M
2M
3M
4M
5M
6M
7M
8MILES
FALL 2 FEET 7½ INCHES PER MILE
FALL 1 FT PER MILE
FALL 5 FT PER MILE
FALL 1 FOOT PER MILE
(Sigd) H. Tulloch, Captn, R.E.,
Ex. Engr Municipality

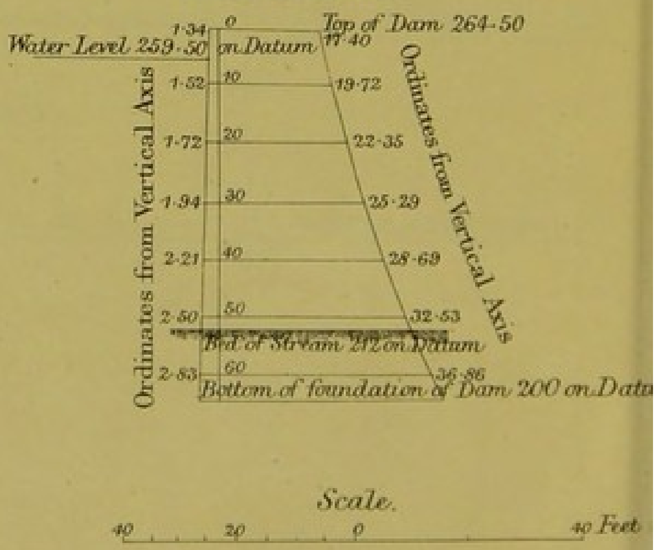
KENNERY, EWOOR AND TANSA PROJECTS.

CONTOURED PLAN OF UPPER KOORLA RESERVOIR.

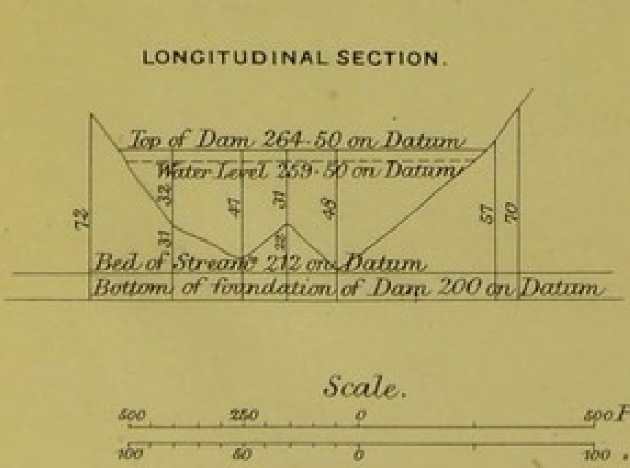


Contours on Datum	Area in Acres	Capacity in Gallons between the different Contours.	Total quantity of water in Gallons between the 240 (below which the water will not be drawn) and the other contours.
270	11·0	27,185,937	75,567,812
260	8·9	20,947,500	48,381,875
250	7·1	16,434,375	27,434,375
240	4·9	11,000,000	11,000,000
230	4·		
212		Bottom of Stream	
200		d° foundation	

CROSS SECTION.



LONGITUDINAL SECTION.



Kell Bros lith.

much as if the Vehar dams burst, the Kennery Channel would be carried away. By keeping to the east of the Vehar Lake, the line is much more secure—in fact, almost perfectly so.

The Koorla Reservoir.

Plate XXXI. gives all the necessary information regarding the Upper Koorla Lake. It will be a small work, and has been designed simply for a service reservoir—*i.e.*, one from which the water can be delivered to Bombay under pressure, and in which a certain quantity of water can be kept for use in the event of any accident to the channel between Kennery and Koorla. The section of the dam is that proposed by Mr. Rankine for high dams. So strong a work is not absolutely required, and, if the greatest economy is insisted on, the thickness may be reduced throughout, and a saving in the quantity of masonry, amounting to about 25 per cent., may be made.* But, considering the position of the reservoir, I am inclined not to depart from the section given to all the other dams. A very strong dam would be all the more desirable, because it is quite manifest that after some time a second service reservoir would be required, and it could not be built except below this one, and the water impounded in it would extend up to the proposed dam, which should therefore be made as safe as possible.

I would draw the water from the Koorla Reservoir at 230·00 on datum, so that between this and 259·50 (*vide* table on Plate XXXI.), we should have a stock of water equivalent to 48 million gallons, or to say nearly a week's supply from the Kennery Basin. Such a reservoir would not entail a dam higher than about 65 feet.

Size of the Conduit.

I would, moreover, make the conduit from Kennery for the first two miles 6 feet wide and 6 high, and with as flat an arch as possible. The remaining 5½ miles I would have of much smaller dimensions, with a waterway 5 feet wide and 4 deep. The former

* *Vide* paragraph 22 of Mr. Rankine's Paper. *Appendix* D.

portion of the conduit would discharge 57 million gallons daily, and the latter 17. The object of making the conduit so large for the first portion will be seen presently.

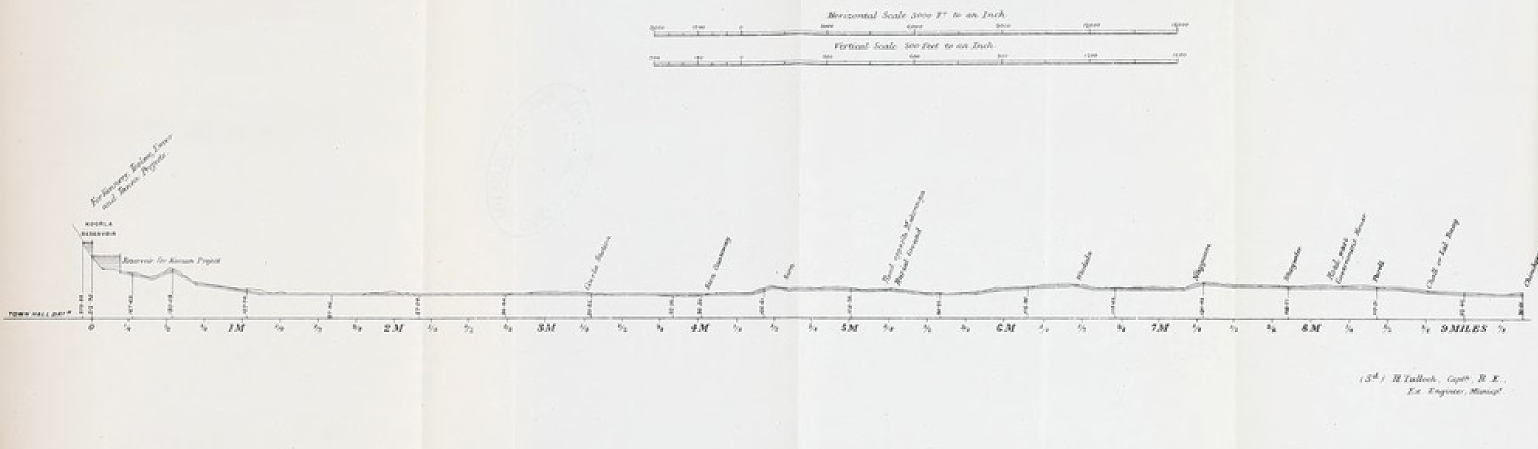
Pipes rom Koorla to Bombay.

The quantity of water obtainable daily from Kennery is, as previously calculated, about 8¼ million gallons. The pipe, therefore, from the Koorla Reservoir would have to convey this supply to Bombay. A pipe, 28 inches in diameter and 1 inch thick, would suffice for the purpose. For a section of the line from Koorla to Bombay, *vide* Plate XXXII. It is as favourable as could be desired; and as there would be no difficulties of a special kind in laying such a line, no information beyond that given in the Plate is needed at my hands. Arrangements would have to be made for drawing the water into the pipe not only from the Koorla Reservoir, but also direct from the Kennery Conduit, so as to secure the greatest head of water possible. As a general rule, the supply would be taken from the conduit, and only when the conduit was under repair would recourse be had to the lake.

I will now explain the object of making the conduit larger in the upper part of its course. Suppose the Kennery Lake were to be full during the monsoon, and the Vehar Lake were to be in want of a supply, and, instead of letting the Kennery water go to waste over the weir, we brought it to Vehar to fill the latter. The conduit would convey 57 million gallons daily; of this only 8¼ would be required to pass on to Koorla for the supply of Bombay; therefore, the remaining 48¾ gallons could be flowing into Vehar. It is not necessary to point out the advantage of this.

If the conduit required repair, the town could be supplied from the Koorla reservoir for nearly a week, and, when the repairs were completed, the channel and syphon would bring to Koorla 17 million gallons daily, of which 8¼ would travel on to Bombay through the pipe, while the remaining 8¾ gallons could be thrown into the Koorla Reservoir to refill it.

SECTION OF PIPE LINE FROM KOORLA RESERVOIR TO CHINCHPOOGLEE



(S^d) H. Tulloch, Capt^n. R.E.,
Ex. Engineer, Munic^l.

In five or six days, therefore, it would be full again and ready for another emergency. If it be considered that a week's supply at Koorla is not sufficient to retain in the service reservoir, another Reservoir, with a dam about 45 feet high, could be built below the first (*vide* Plate XLV.), and it would hold about 130 million gallons, or more than a fortnight's supply from Kennery.* Altogether, therefore, there would be a stock of water for emergencies equivalent to a three-week's supply, and during such a period extensive repairs could be completed to the channel. If the population of Bombay increased considerably beyond its present limits, it would be advisable to connect the Koorla Reservoirs with the Vehar Lake also, so that water might be passed from the latter into the former, and thus Bombay would be further insured against a deficient supply. The water drawn from, in fact lent by, the Vehar Lake for this purpose could be returned to the lake by the channel from Kennery. Thus the Vehar and Kennery Projects, although capable of acting independently, would be made at the same time to improve each other.

Quality of Water.

With regard to the question of purity of supply, it is but necessary for me to say that the hills from which the water would be collected are all of primitive formation, and that the only possible source of pollution even at present is the village of Toolsee, containing merely a few huts, which can be bought and removed for a trifle. I have no doubt that the Kennery water will prove as pure for all practical purposes as can possibly be desired.

Waste Weir and Outlet Works.

I will explain the arrangement I propose in order to get rid of the waste water from the Kennery Lake, after I have described the Toolsee Project, which is so closely connected with the Kennery Scheme. I will explain the outlet works, which are on the same system for all the reservoirs, when I come to the Tansa Project.

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* It could be made to hold a month's supply, if considered desirable, simply by making the dam high enough.

It will be instructive if in this place I compare the salient points of the Kennery Project with the Vehar Scheme. It is obvious at a glance that the Kennery Valley is by no means a favourable one for the storage of water. The Vehar Lake, with a dam 96 feet high, has an area of about 1,400 acres; while the Kennery Lake, with a dam even 170 feet high, would not have an area of more than about 600 acres. The Vehar Lake is a broad expanse of water. The Kennery Lake would be a long narrow basin, but while the Vehar Valley required three dams before water could be impounded in it, one dam only would suffice for the Kennery Valley. In quality the Kennery water would be equal to that of Vehar, as both lakes draw their supply from hills of the same formation.

Kennery compared with Vehar.

The cost of the Kennery Scheme with a dam to impound a one, a two, and a three years' supply, would be as follows:—

Estimates.

Estimate No. 1.

COST OF KENNERY SCHEME.

Dam 130 feet high, and impounding a one-year's supply, 3,000 million gallons, or $8\frac{1}{4}$ million gallons daily :—

2 miles of channel, 6 feet high by 6 wide, at Rs.150,000 per mile	Rs.3,00,000
$5\frac{1}{2}$ ditto, with a waterway 4 feet deep by 5 feet wide, at Rs.80,000 ditto*	4,40,000

* This rate, with contingences which are allowed for further on, is nearly £9,000 a mile. The Glasgow aqueduct, the cross section of which has a superficial area twice as great as that of this channel, cost about £18,000 a mile. At this rate, therefore, the latter ought not to cost more than £9,000 a mile. Since the construction of the Glasgow aqueduct, and particularly within the last three years, the art of tunnelling has improved immensely, and I think we may now assume that the Bombay Aqueduct would not exceed this sum. I am confident, from a close examination of the strata along the entire line, that a very small proportion of the channel would have to be built. The Glasgow aqueduct passed in many parts through water-bearing material, which of course must have given great trouble to work through, and must have affected the cost of the scheme materially. There is not the slightest chance of our having to tunnel through strata charged with water.

Brought over	Rs.7,40,000
$\frac{3}{4}$ of a mile of syphon pipe, 48 inches in diameter and 1 inch thick,* weighing 960 tons, at Rs.160 a ton	1,53,600
$9\frac{1}{2}$ miles of 28-inch pipe, from Koorla to Bombay, 1 inch thick,† delivering $8\frac{1}{4}$ million gallons daily, and weighing 720 tons per mile, or 6,840 tons, at Rs.160 a ton	10,94,400
Kennery waste weir‡	2,00,000
Koorla Reservoir§, with its outlet works and waste weir	3,00,000
Dam 130 feet high, containing 3,280,800 cubic feet of rubble masonry at Rs.25 per 100 cubic feet	8,20,000
Outlet Works at Kennery, tower being 75 feet high (these works will be exceptionally expensive)	3,00,000
Total	Rs.36,08,000
Add 10 per cent. for contingencies, say	3,60,000
Land	50,000
Total	Rs.40,18,000

Or, say, $40\frac{1}{4}$ lakhs of rupees for 13 gallons per head per diem for the present population.

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* This pipe has to resist a pressure of from 15 to 50 feet only, and it is exceptionally thin and therefore cheap for its size.

† The pressure in this pipe will be 160 feet.

‡ This will be an expensive work.

§ If a thinner section for the dam is insisted upon than that shown in Plate XXXI. (*vide* page 119), there will be a reduction in this item amounting to about Rs.40,000.

Estimate No. 2.

COST OF KENNERY SCHEME.

Dam 155 feet high and impounding a two-years' supply (6,000 million gallons) :—

Channel, pipes, waste weir, and Koorla Reservoir, as before—viz.	Rs.24,88,000
Dam 155 feet high, containing 5,726,800 cubic feet of rubble masonry, at Rs.25 per 100 cubic feet	14,31,700
Outlet Works, tower being 100 feet high	3,50,000
Total	Rs.42,69,700
Add 10 per cent. for contingencies, say	4,26,300
Land	75,000
Total	Rs.47,71,000

Or, say, 47¾ lakhs of rupees.

Estimate No. 3.

COST OF KENNERY SCHEME.

Dam 172 feet high and impounding a three-years' supply (8,000 million gallons) :—

Channel, pipes, waste weir, and Koorla Reservoir, as before—viz.	Rs.24,88,000
Dam 172 feet high, containing 7,663,000 cubic feet of masonry	19,15,750
Outlet Works, tower being 117 feet high	4,00,000
Total	Rs.48,03,750
Add 10 per cent. for contingencies, say	4,80,250
Land, say	1,00,000
Total	Rs.53,84,000

Or, say, 54 lakhs of rupees.

CHAPTER VII.

THE TOOLSEE PROJECT.

The Valley, and the supply obtainable.

The Toolsee Valley, as may be seen by reference to Plate XXVII., is merely the upper half of the Kennery Watershed, and is contiguous to Vehar, but lies at a considerable elevation (about 200 feet) above it. As in the case of Kennery, there is only one site for a dam—a gorge between two hills, where the stream runs over a bed of solid rock. The bed of this stream is at 375·00 on datum, and therefore 112½ feet above the surface of the Vehar Lake, even when the latter is full, and about 275 feet above Bombay. The area of the watershed above the site of the dam is 1,450 acres. In this case, as the entire lake would lie above the Vehar Reservoir, it is not necessary to consider the question of the level at which the water had better be drawn for use. If we drew the water from the very bottom of the lake, we should still be able, if we chose, to throw it into Vehar. The draw-off level should, therefore, be determined on another consideration—

What is the lowest level below which the quantity of water stored is too small to be worth drawing for use? The following is a table* showing the capacities of the Toolsee Lake:—

Contours on Datum.	Area of Lake.	Capacity in Gallons.
475	420	4,532,000,000
470	385	3,872,000,000
465	360	3,282,000,000
460	335	2,752,000,000
455	310	2,282,000,000
450	275	1,862,000,000
445	250	1,492,000,000
440	234	1,162,000,000
435	201	866,000,000
430	167	615,000,000
425	125	414,000,000
420	94	263,000,000
415	65	155,000,000
410	39	84,000,000
405	24	41,000,000
395	6	18,000,000
375	Bed of stream.	
370	Bottom of foundation of dam.	

In my report of 1870 on this valley, I proposed to draw the water at 409·00 feet on datum. Mr. Walton has proposed to draw it at 406·00 on datum. The quantity of water in the lake below these levels is not worth consideration, and it is not of any importance which of the two levels is decided upon.

As before, in order to calculate the quantity obtainable from the Toolsee Watershed, we must know the area of the lake, and, as in the case of Kennery, I will assume the largest and smallest areas. For reasons to be stated hereafter, I consider the largest lake it would be advisable to form in the Toolsee

* This is prepared partly from Mr. Walton's Report of 1871, and partly from my Report of 1870.

Valley should be one of about 400 acres; the smallest—that which Mr. Walton recommended—one of about 250 acres. Taking the rainfall and evaporation to be the same as in the case of Kennery, and the area of the watershed at 1,450 acres, the quantities of water from the two lakes will be—

Quantity in lake of 400 acres, superficial extent :—

	Gallons.
$400 \times 4840 \times 9 \times 8\frac{1}{2} \times 6\frac{1}{4} =$	925,650,000
$1{,}050 \times 4{,}840 \times 9 \times 4\frac{1}{2} \times 6\frac{1}{4} =$	1,286,381,250
	2,212,031,250
Deduct for evaporation :—	
$400 \times 4{,}840 \times 9 \times 2\frac{1}{2} \times 6\frac{1}{4} =$	272,250,000
	1,939,781,250
Deduct $\frac{1}{3}$rd for unaccountable waste	646,593,750
Total number of gallons yearly	1,293,187,500

Quantity in lake of 250 acres, superficial extent :—

	Gallons.
$250 \times 4{,}840 \times 9 \times 8\frac{1}{2} \times 6\frac{1}{4} =$	578,531,250
$1{,}200 \times 4{,}840 \times 9 \times 4\frac{1}{2} \times 6\frac{1}{4} =$	1,470,150,000
Deduct for evaporation :—	
	2,048,681,250
$250 \times 4{,}840 \times 9 \times 2\frac{1}{2} \times 6\frac{1}{4} =$	170,156,250
	1,878,525,000
Deduct $\frac{1}{3}$rd for unaccountable waste	626,175,000
Total number of gallons yearly ...	1,252,350,000

The mean of these two results, or 1,272 million gallons, is almost exactly what Mr. Ormiston calculated* the supply from Toolsee to be, and this is equivalent to, say, 3½ million gallons daily, or to nearly 5½ gallons per head per diem for a population of 650,000.

A reference to the table given before will show that to store this supply the surface of the lake must be at about 442·00 on datum, to store double this quantity (2,544 million gallons), or a two-years' supply, the surface must be at about 457·00 on datum, and to store a three-years' supply, or 3,816 million gallons, the surface must be at about 470·00 on datum.

The bed of the river at the site of the dam is rock, and stands on 375·00 on datum. Let us suppose that we have to cut away five feet of stone to obtain a perfectly satisfactory foundation ; the bottom of the dam will then be at 370·00 on datum, and, remembering, as in the case of the Kennery Lake, that the top of the dam must be carried five feet above the level of the water, the height of the dam to impound the different quantities of water will be :—

	Feet.
To impound 1,272 million gallons, or a one-year's supply (447·00 — 370·00)	77
To impound 2,544 million gallons, or a two-years' supply (462·00 — 370·00)	92
To impound 3,816 million gallons, or a three-years' supply (475·00 — 370·00)	105

The only source of pollution in the Toolsee Valley is the

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* *Vide* page 6 of his "*Memoranda as to the Toolsee Scheme.*" He calculated the quantity at 1,903 million gallons without deducting for unaccountable waste, which, on his assumption of ⅓rd, would reduce the supply to 1,269 million gallons.

Quality of the Water.

village, which of course would have to be removed. The water would then be as pure as that from Vehar.

Toolsee compared with Vehar.

As compared with Vehar, it will be seen that the Toolsee Valley does not offer us much of a supply, nor would the lake, with a dam as high as the main Vehar Dam, make a waterspread of more than about one-quarter the area of the present lake.

Pipe to Bombay.

To bring the Toolsee water to Bombay, the cheapest plan would be to lay down a pipe * which, as it need not be more than 21 inches in diameter and three-quarters of an inch thick, would cost less even than a masonry conduit. Another advantage which a pipe in this particular instance would give us would be that we should be able to supply all the high localities of Bombay under pressure, and without the help of pumps.

Of course, if the Kennery Project were carried out in conjunction with the Toolsee Scheme, it would be absurd to go to the expense of a special iron pipe from Toolsee to Bombay. In such a case the Toolsee water should decidedly be thrown into the channel from Kennery to Koorla, and this could be done at a trifling cost, inasmuch as the channel would pass close to the Toolsee Lake. The conduit and syphon, already proposed for the Kennery Scheme, would be capable of carrying more than this extra quantity of water.

Outlet Works.

The outlet works, if the two schemes were carried out together, would be of the character to be described when I come to the Tansa Project; but if the water were drawn by a pipe, they would be of the character proposed by me in 1870. *Vide* Plate XX.

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* No survey has been made specially to show the line of pipe, but it is hardly necessary for me to say that there will be no difficulty in laying down the line. It should run along the eastern margin of the Vehar Lake and along the eastern ridge of the Poway Valley, and so on to the village of Koorla, from which point it would run as shown in Plate XXXII.

But whether the Toolsee Scheme were carried out by itself or in conjunction with the Kennery Project, I would still arrange the works so as to be able to pass the surplus water at will into either the Vehar or the Kennery Valley, and thus to fill whichever of the lower lakes might happen at the time to be in want of a supply.

Waste Weir and Waste Water.

If the Kennery Lake were full, I would on no account—not even if the Vehar Lake were full also—pass any water from Toolsee into the Kennery Valley. The surplus water in such a case had far better be thrown into the Vehar Lake. My object in drawing attention to this point is to avoid the expense of a large waste weir in the Kennery Valley, which, indeed, is not at all suited to such a work. Now the Vehar Valley admits of the construction of waste weirs to great advantage. There are several spots round the margin of the lake admirably situated for works of this kind, and notably one behind the present Municipal bungalow. Here a large weir could be constructed, to pass off the surplus water from the Toolsee Valley, at a much less cost than one of half the size at Kennery, and the water would escape down a natural stream and cause no damage. At Kennery the water from the waste weir would escape down along the foot of the dam, and it would be well to reduce this quantity of water as much as possible, otherwise special works at considerable cost would have to be carried out to prevent the dam being injured. In fact, I would arrange so that the Kennery waste weir should be able to discharge the surplus water from the lower portion only of the valley, and never would I even allow the whole of this quantity to pass over it, as I would carry off as much as possible by the channel and throw it into the Vehar Lake.

Estimate No. 1.

COST OF TOOLSEE SCHEME.

Dam to impound a one-year's supply, 1,272 million gallons, or $3\frac{1}{2}$ million gallons daily :—

	Rs.
17 miles of 21-inch pipe, one inch thick, weighing 560 tons per mile, or, 9520 tons at 160 Rs. a ton	15,23,200
Waste Weir............	75,000
No. 1 Dam, 77 feet high, containing 4,59,700 cubic feet of rubble masonry at 25 Rs. per 100 cubic feet	1,14,925
No. 2 Dam (*vide* Plate XX.), will not be required	
No. 3 Dam, a small work	70,000
Outlet works, tower being 50 feet high	1,00,000
	18,83,125
Add 10 per cent. for contingencies, say	1,88,875
Land, say............	50,000
Total............Rs.	21,22,000

Or, say $21\frac{1}{4}$ lakhs of rupees for $5\frac{1}{2}$ gallons per head per diem for the present population.

Estimate No. 2.

Dam impounding two-years' supply, 2,544 million gallons.

	Rs.
Pipe as before	15,23,200
Waste Weir as before	75,000
No. 1 Dam, 92 feet high, containing 774,700 cubic feet of rubble masonry at 25 Rs. per 100 cubic feet	1,93,675
No. 2 Dam, an insignificant work	10,000
No. 3 Dam, containing 1,386,400 cubic feet	3,46,600
Outlet works, tower being 65 feet high	1,25,000
	22,73,475
Add 10 per cent. for contingencies, say	2,27,525
Land, say	50,000
Total ... Rs.	25,01,000

Or, say, 25 lakhs of rupees.

Estimate No. 3.

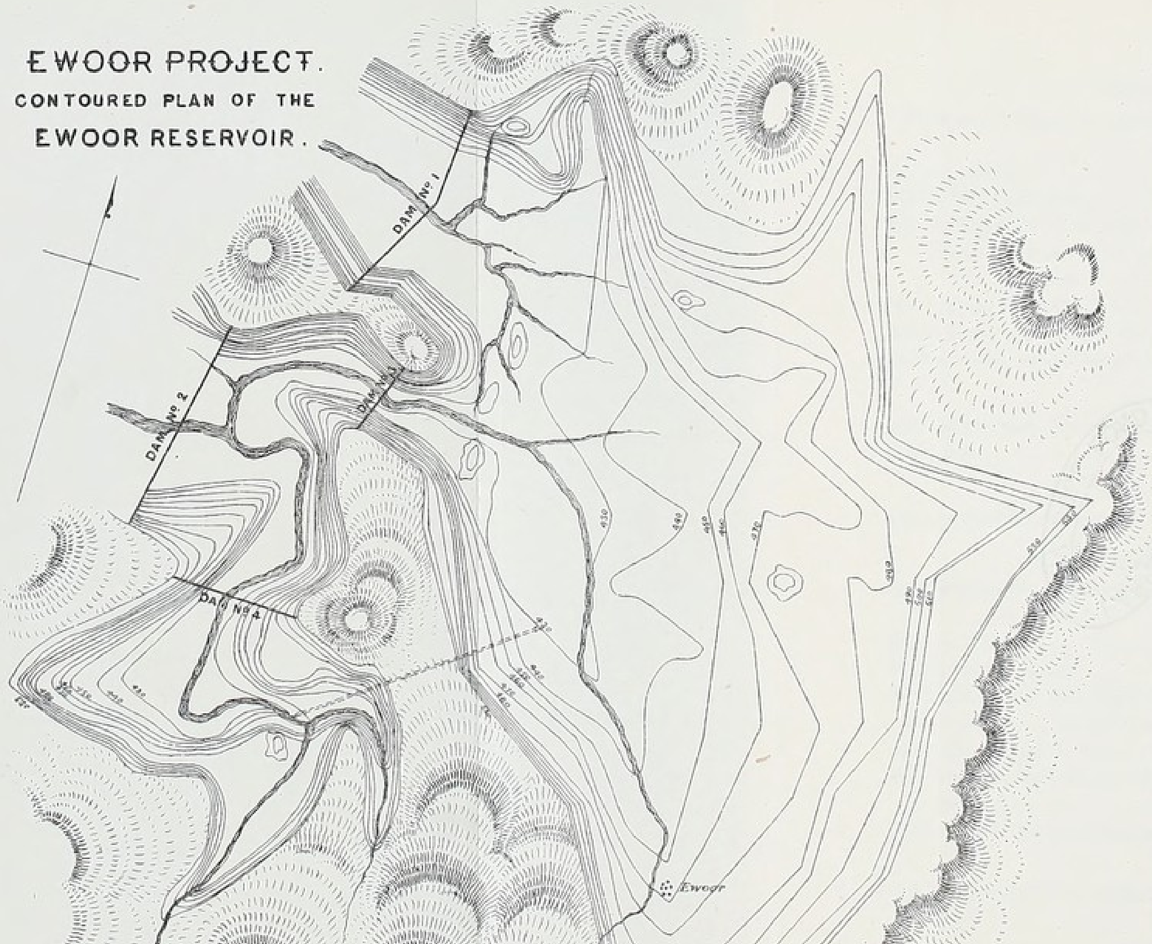
Dam impounding a three-years' supply, 3,816 million gallons:—

	Rs.
Pipe as before	15,23,200
Waste weir as before	75,000
No. 1 Dam, 105 feet high, containing 1,001,600 cubic feet of rubble masonry	2,50,040
No. 2 Dam, a small work	70,000
No. 3 Dam, containing 1,911,200 cubic feet of masonry	4,77,800
Outlet works, tower being nearly 80 feet high ...	1,55,000
	25,51,040
Add 10 per cent. for contingencies, say	2,51,960
Land, say	50,000
Total ... Rs.	28,03,000

Or, say, 28 lakhs of rupees.

EWOOR PROJECT.

CONTOURED PLAN OF THE EWOOR RESERVOIR.



Contours on Datum.	Area in Acres.	Capacity in Gallons between the different Contours.	Gallons per head per diem between the Contours for a population of 1000,000 for a year.	Total quantity of water in Galls between the 430 Contour (below which the water will not be drawn) and the other Contours.	Total number of Gallons per head per diem for a year for a population of 1000,000 between the 430 and the other Contours.	Contours on Datum.
		FOR DAMS 1 & 2.				
530	1019			16,826,356,800	46·102	[illegible]
		2,302,462,400	7·404			
520	967			14,123,894,400	38·698	[illegible]
		2,521,252,800	6·908			
510	886			11,602,641,600	31·790	[illegible]
		2,326,109,000	6·373			
500	822			9,276,537,600	25·417	[illegible]
		2,082,168,000	5·705			
490	733			7,194,369,600	19·712	[illegible]
		1,815,580,800	4·975			
480	633			5,378,788,880	14·737	[illegible]
		1,571,644,800	4·306			
470	527			3,807,144,000	10·431	[illegible]
		1,296,345,600	3·552			
460	426			2,510,798,400	6·877	[illegible]
		1,068,091,200	2·926			
450	359			1,442,707,200	3·953	[illegible]
		850,291,200	2·330			
440	265			592,416,000	1·623	[illegible]
		592,416,000	1·623			
430	170					[illegible]
		FOR DAMS 1, 3 & 4.				
530	918			19,932,386,000	42·911	[illegible]
		2,934,132,800	6·669			
520	870			17,498,255,200	34·291	[illegible]
		2,265,120,000	6·206			
510	792			10,233,115,200	28·038	[illegible]
		2,082,168,000	5·705			
500	736			8,150,947,200	22·331	[illegible]
		1,892,246,400	5·185			
490	653			6,258,700,800	17·147	[illegible]
		1,651,795,200	4·526			
480	553			4,606,905,600	12·621	[illegible]
		1,386,950,400	3·800			
470	459			3,219,955,200	8·822	[illegible]
		1,122,105,600	3·074			
460	364			2,097,849,600	5·747	[illegible]
		911,275,200	2·497			
450	305			1,186,574,400	3·252	[illegible]
		712,641,600	1·953			
440	217			473,932,800	1·299	[illegible]
		473,932,800	1·299			
430	130					[illegible]

(Sd) H. Tulloch, Captn, R.E.
Ex. Engr Municipality

CHAPTER VIII.

THE EWOOR PROJECT.

The valley, and the Quantity of Water to be obtained from it.

The next valley to consider is that of Ewoor, which (*vide* Plate XXVII.) lies to the north of Toolsee, being separated from it by a high range of hills. It is by no means so well suited to the storage of water as either Kennery or Toolsee, and consists of one small and two larger valleys, the latter being divided by a ridge (*vide* Plate XXXIII.). The upper part of the middle valley is very flat, but there is no site for a dam, and the gathering ground is exceedingly limited, being hardly a square mile in area. There are two practical ways in which a lake might be formed in Ewoor. The first is by damming the streams in each valley separately, the second is by damming the northern stream by itself and the two southern streams below their point of junction. In the first case, three dams would be required, and, in the second, only two. But to be of any use, the dams must be very high, as will be seen presently. Whether the project of two or that of three dams were adopted, the area of the watershed would not differ to affect our calculations, so that it may be taken at about $4\frac{1}{4}$

square miles, or 2,720 acres. It would not be advisable to draw the water at a lower level than 430·00 on datum, as the capacity of the lake below this point is very small. The area of the largest lake it would be possible to make would be about 900 acres, and the area of the smallest lake it would be advisable to have would be 450 acres. Taking the rainfall and evaporation to be the same as before, the quantities of water obtainable from the Ewoor Valley in the two cases would be :—

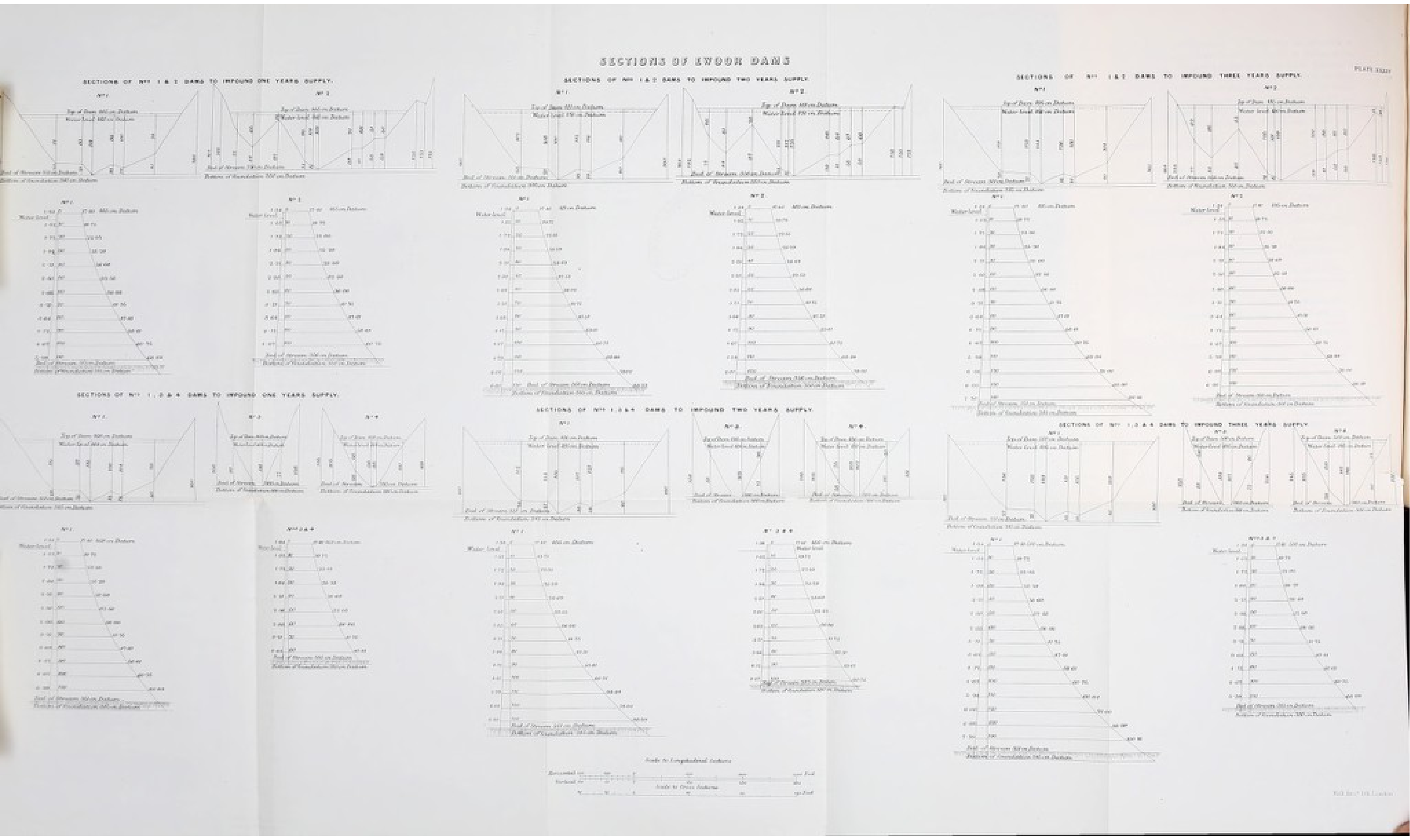
Quantity when area of lake is 900 acres :—

	Gallons.
$900 \times 4,840 \times 9 \times 8\frac{1}{2} \times 6\frac{1}{4} =$	2,082,712,500
$1,820 \times 4,840 \times 9 \times 4\frac{1}{2} \times 6\frac{1}{4} =$	2,229,727,500
	4,312,440,000
Deduct for evaporation :—	
$900 \times 4,840 \times 9 \times 2\frac{1}{2} \times 6\frac{1}{4} =$	612,562,500
	3,699,877,500
Deduct $\frac{1}{3}$rd for unaccountable waste	1,233,292,500
Total number of gallons yearly ...	2,466,585,000

Quantity when area of lake is 450 acres :—

$450 \times 4,840 \times 9 \times 8\frac{1}{2} \times 6\frac{1}{4} =$	1,041,356,250
$2,270 \times 4,840 \times 9 \times 4\frac{1}{2} \times 6\frac{1}{4} =$	2,781,033,750
	3,822,390,000
Deduct for evaporation :—	
$450 \times 4,840 \times 9 \times 2\frac{1}{2} \times 6\frac{1}{4} =$	306,281,250
	3,516,108,750
Deduct $\frac{1}{3}$rd for unaccountable waste	1,172,036,250
Total number of gallons yearly......	2,344,072,500

The difference is not great between the two results, so


SECTIONS OF EWOOD DAMS
SECTIONS OF NOS 1 & 2 DAMS TO IMPOUND ONE YEARS SUPPLY.
SECTIONS OF NOS 1 & 2 DAMS TO IMPOUND TWO YEARS SUPPLY.
SECTIONS OF NOS 1 & 2 DAMS TO IMPOUND THREE YEARS SUPPLY.
SECTIONS OF NOS 1, 3 & 4 DAMS TO IMPOUND ONE YEARS SUPPLY.
SECTIONS OF NOS 1, 3 & 4 DAMS TO IMPOUND TWO YEARS SUPPLY.
SECTIONS OF NOS 1, 3 & 4 DAMS TO IMPOUND THREE YEARS SUPPLY.

that we may assume 2,400 million gallons yearly, or say 6½ million gallons daily (equivalent to 10 gallons per head per diem for the present population of 650,000), to be the supply obtainable from the Ewoor Valley.

The Storage of the water.

By reference to the table on Plate XXXIII., it will be seen that, to store this quantity, the surface of the lake must be, in the case of the reservoir with two dams at about 460·00 on datum, and, in the case of the reservoir with three dams, at about 464·00 on datum. To store double this quantity (4,800 million gallons), or a two-years' supply, the surface of the lake in the two reservoirs must be at 476·00 and 481·00 on datum respectively; and, to store three times this quantity (7,200 million gallons), or a three-years' supply, the surface must be at 490·00 and 495·00 on datum.

If we suppose the bottom of the foundation of the dam to be six feet below the bed of the stream, which runs over rock, it will be at 345·00 on datum, and, if we suppose the masonry to be carried five feet above the surface of the water, the height of the main dam to impound the different quantities of water will be :—

	Reservoir with 2 Dams. Feet.		Reservoir with 3 Dams. Feet.
To impound 2,400 million gallons, or a one-year's supply (465 − 345) and (469 − 345)	120	......	124
To impound 4,800 million gallons, or a two-years' supply (481 − 345) and (486 − 345)	136	......	141
To impound 7,200 million gallons, or a three-years' supply (495 − 345) and (500 − 345)	150	......	155

These dams are not so high as those required to store a one, two, and three years' supply in the Kennery Valley, but the supply from Kennery is greater than that from Ewoor in the proportion of 3,000 to 2,400 million gallons yearly, or of 13 to 10 gallons per head per diem for the present population. To compare the heights for the absolute quantities of water stored, the dams in the two valleys, to store 3,000, 6,000, and 9,000 million gallons, would be about the same height—130 feet, say 150 feet, and say 170 feet. All the necessary information regarding the dams is given on Plate XXXIV.

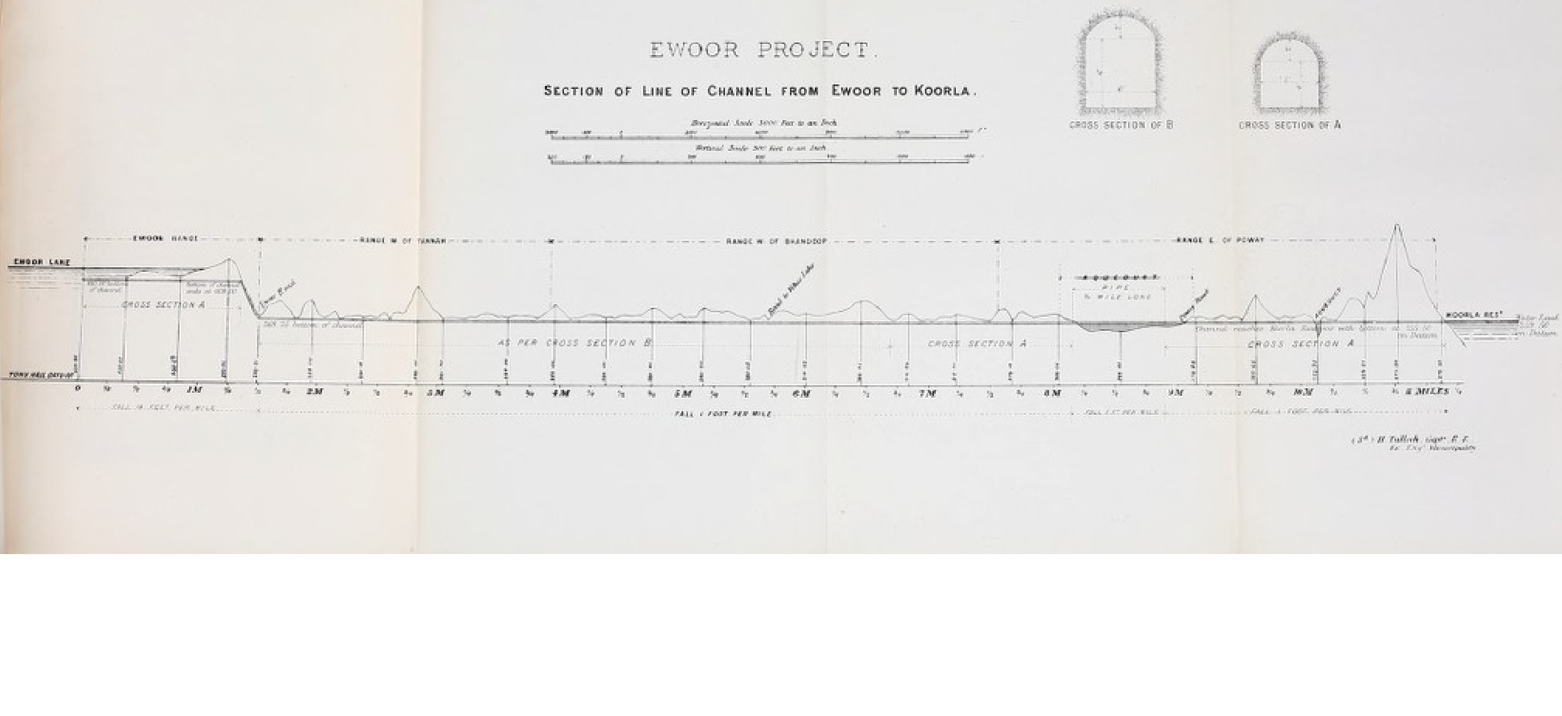
Quality of the Water.

There is a small village, named Ewoor, which would have to be removed in the event of this valley being utilized, and, if this were done, the water would be of the same character as that from the other sources in Salsette.

The Conduit between the Ewoor and Koorla Reservoirs.

I would draw the water from the Ewoor Lake by a channel, as the cheapest and best method. If a pipe were adopted, it would require to be 27 inches in diameter and, in order to resist the pressure of nearly 500 feet, $1\frac{1}{4}$ inch thick. Such a pipe would cost about $1\frac{1}{2}$ lakhs of rupees a mile, and would deliver but $6\frac{1}{2}$ million gallons daily ; while a channel with a waterway four feet deep by five wide would cost Rs.90,000 a mile, and would, with a slope of one foot per mile, carry 17 million gallons daily to Koorla.

Plate XXVII. will show the course which the channel would take, and Plate XXXV. is a section of the line. The Ewoor Lake lying as it does at a considerable elevation above Vehar, a great slope could be given to the channel. If, for instance, the water were to be drawn at 430·00 on datum, as previously proposed, there would be an available fall for the six miles of channel to Vehar of nearly 170 feet. Such a slope amounts to more than 28 feet per mile, and a channel of the above dimensions with this fall would discharge more than 90 million gallons daily, but the velocity of the stream would



(Sd.) H. Tulloch, Capt. R.E.

exceed 500 feet per minute, or say 8 feet a second—more than any conduit should, in my opinion, be subjected to.

It will be seen in Plate XXXV. that, instead of this great slope, one of only a foot a mile has been given to the channel, and I will explain the reason.

If the Ewoor Project were ever to be carried out, I think the same principles should be borne in mind as, I have endeavoured to explain, should guide us in the Kennery Scheme. In describing the latter, I pointed out how important it would be to construct the works so that they should be independent of Vehar, but still arranged in such a way as to add to the security of the existing supply. And I recommended that the channel from the Kennery Lake should, for the first two miles of its course, have not only a greater slope, but a greater section, in order that, if the Kennery Lake were full, a considerable quantity of the waste water might be passed into the Vehar Lake to get it full also.

Now, with regard to the Ewoor Lake, I have shown that an enormous fall is available for the channel, and that, if we chose, we could, without even enlarging the section, deliver a great quantity of water to Vehar. But I would not recommend this course. It must already be evident to every one that the time will shortly arrive, if it has not done so already, when, in order to add to the water-supply of Bombay, we shall be compelled to make a high level reservoir beyond Salsette.* Such a reservoir must have a high level channel along the range of hills lying to the west of Kolset, Tannah, and Bhandoop; and it would be a grave mistake not to construct it at such a level that it should command Vehar. Now, such

* I say a *high level*, because, as the reader will see further on, the best project, with a low level reservoir—viz., Kamun—cannot compare with projects of the high level reservoir class, either for convenience or cheapness. Under these circumstances, there is not a great probability of such a project being carried out.

a channel must follow as nearly as possible the course of the last 9½ miles of the Ewoor Conduit,* shown in Plate XXXV. This being the case, and supposing that the Ewoor Project were carried out, then I think it would be very wise to give the portion of the Ewoor Channel lying above the Vehar Lake, 5¼ miles long, a much larger section than the rest—a section 6 feet wide by 6 high. Such a channel would discharge 36 million gallons daily. The first 1½ miles of conduit from the Ewoor Lake should have a fall to deliver the same quantity at least into the lower channel. But I should prefer to give it even a greater slope than this—in fact, the greatest slope possible without incurring the risk of the velocity of the water injuring the channel. As we have an excessive slope at our command, it may be convenient, especially as to do so will entail no additional expense, to arrange for drawing as much water as we can from the Ewoor Lake. The greatest velocity which the stream might have is about five or six feet per second, and a channel having a waterway 5 feet wide and four deep, with the latter velocity, would deliver 64 million gallons daily, and would require a slope of 14 feet per mile. As the portion of channel with this slope would not be more than 1½ miles long, the total fall, when it reached the lower level conduit, would be 21 feet, and as the lower conduit, at the point of junction with the upper, would be at 268·25 on datum, and the upper conduit, starting from the lake at 430·00, would be at 409·00, the water would have to be dropped, say, 140 feet.

Thus, then, the arrangements which I would make regarding the channel are as follows. It would leave the Ewoor Lake at 430·000 on datum with a slope of 14 feet per mile, and a waterway five feet wide by four deep. After

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* The reader will see the force of all this when he comes to the Tansa Project, or if he chooses now to refer to Chapter X., he may convince himself on the subject.

running for $1\frac{1}{2}$ miles, it would suddenly drop about 140 feet and start again on its course at 268·25 on datum, with a slope altered to 1 foot per mile, and a waterway six feet wide by six deep. On reaching its point of junction with the Kennery Channel* (near the Vehar Lake) it would be at 262·50 at datum—*i.e.*, exactly the level of the lake when full. From this point it would follow the course of the Kennery Channel precisely, and so arrive at the Koorla Reservoir, with its invert at 255·50 on datum, and the level of the water in the Koorla reservoir would be as before—viz., 259·50 on datum, or three feet below the surface of the Vehar Lake.

If the Kennery and Ewoor Projects were carried out conjointly, one conduit from the point of junction of the two channels would suffice, inasmuch as that proposed for either (with a waterway five feet wide by four deep, and with a slope of a foot per mile) would be capable of discharging the supply from both.

Now let us see what the effect or working of the proposed arrangements would be.

Action of the Works.

If the Ewoor Lake were full, and it were considered advisable to throw the surplus water into Vehar, the channel would bring down 36 million gallons daily, and as $6\frac{1}{2}$ millions only would be required for the daily supply to Bombay, the remaining $29\frac{1}{2}$ million gallons could be thrown into the present lake. And when the time came to construct a high level reservoir beyond the island of Salsette, the portion of the Ewoor Channel along the eastern slope of the Tannah range of hills and up to Vehar, a length of five and a quarter miles, would be ready to hand and would answer for the project perfectly, and without further outlay. If, on the other hand, the channel from the Ewoor to the Vehar Lake were constructed of a smaller size, and, in order

* *Vide* Plate XXVII. The point of junction in this Plate should be higher by about half a mile.

to get the same discharge, an uniform slope of twelve feet per mile were given to it, and this could easily be done, then the channel would not work in with, or be of any use to, the future projects. It would be far above the level to which it would be possible to bring the water from any distant reservoir.*

The surplus water which might not be required for Vehar, could be passed over a waste weir down into the lower portion of the Ewoor Valley; but as this weir would be of the ordinary kind, it is unnecessary for me to dwell on it.

Outlet Works.

The outlet works at the Ewoor Lake would be similar in character to those proposed for the Tansa Reservoir, and described further on. Special arrangements of the same kind would also have to be made for dropping the water from the upper into the lower conduit, or this might be effected by letting the water down a series of steps. The hill at the site of the proposed works is exceedingly rocky, and therefore well suited to the purpose.†

Upper Koorla Reservoir.

The Upper Koorla Reservoir would answer just as well for the Ewoor as for the Kennery Project, and having already described it, nothing further need be said on the subject.

Service Pipe to Bombay.

From the Koorla Reservoir a pipe 26 inches in diameter would be required to Bombay, and this should be at least one inch thick. The line along which the pipes would run is shown in Plate XXXII.

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* This will be evident to the reader after the description of the Tansa Channel.

† Another mode of bringing the water down from the upper into the lower channel would be to erect a turbine or other form of water engine, and to apply the force of the water to some useful purpose. Six and a-half million gallons falling through 140 feet would be equivalent to more than 175-horse power.

Estimate No. 1.

COST OF EWOOR SCHEME.

Main Dam being 124 feet high, and impounding one-year's supply, 2,400 million gallons, or 6½ million gallons daily :—

	Rs.
5¼ miles of channel, with a waterway 4 feet deep by 5 feet wide, at 80,000 Rs. a mile	4,20,000
5¼ miles of ditto, 6 do. by 6 feet wide at 1,50,000 Rs. a mile	7,87,500
9½ miles of 26-inch pipe, from Koorla Reservoir to Bombay, 1 inch thick, weighing 650 tons per mile, or 6,175 tons at 160 Rs. a ton	9,88,000
¾-mile syphon pipe, 48 inches in diameter, and 1 inch thick, weighing 960 tons, at 160 Rs. a ton	1,53,600
Waste Weir	1,25,000
Koorla Reservoir, with its outlet works and waste weir	3,00,000
Works to take the water from the upper to the lower channel	1,40,000
	29,14,100
Main Dam 124 feet high, containing 6,260,600 cubic feet at 25 Rs. per 100 cubic feet of rubble masonry	15,65,150
No. 3 Dam	1,61,000
No. 4 Dam, ditto	2,21,000
Outlet works	2,00,000
	50,61,250
Add 10 per cent. for contingencies, say......	5,06,750
Land......	50,000
Total...... Rs.	56,18,000

Or, say, 56¼ lakhs of rupees for 10 gallons per head per diem for the present population.

Estimate No. 2.

COST OF EWOOR SCHEME.

Main Dam being 141 feet high, and impounding two years' supply, or 4,800 million gallons :—

	Rs.
Excepting Dams and outlet works, other works as before, viz.	29,14,100
Main Dam 141 feet high, containing 8,300,000 cubic feet at 25 Rs. per 100 cubic feet of rubble masonry	20,75,000
No. 3 Dam	2,51,000
No. 4 Dam	3,20,000
Outlet Works	2,00,000
Rs.	57,60,100
Add 10 per cent. for contingencies, say	5,76,900
Land, say	75,000
Total...... Rs.	64,12,000

Or, say, 64 lakhs of rupees.

Estimate No. 3.

COST OF EWOOR SCHEME.

Main Dam being 155 feet high, and impounding three years' supply, or 7,200 million gallons :—

	Rs.
Excepting Dams and outlet works, other works as before—viz.	29,14,100
Main Dam, 155 feet high, containing 10,743,000 cubic feet of rubble masonry at 25 Rs. per 100 cubic feet	26,85,750
No. 3 Dam	3,51,000
No. 4 Dam	4,09,000
Outlet works	2,50,000
	66,09,850
Add 10 per cent. for contingencies, say	6,60,150
Land	1,00,000
Total ......Rs.	73,70,000

Or, say, 73¾ lakhs of rupees.

If, in place of enlarging the channel for $5\frac{1}{4}$ miles, it were decided to have a conduit with a waterway five feet wide by four deep all the way to Vehar, and with a uniform slope of 12 feet per mile, the cost of each of the above projects would be reduced by about $4\frac{1}{3}$ lakhs of rupees.

If the project of two dams in place of three were adopted, the cost would be enhanced as follows :—

	Rs.
Project for one year's supply as before	56,18,000
Add for additional cost of dams	6,00,000
Total............................Rs.	62,18,000

Project for two years' supply as before	64,12,000
Add for additional cost of dams	7,59,000
Total............................Rs.	71,71,000

Project for three years' supply as before	73,70,000
Add for additional cost of dams	10,09,000
Total ....Rs.	83,79,000

In these three cases the quantities of water impounded would be slightly in excess of those obtained by the construction of three dams, but the practical difference is not worth consideration. The greater cost is caused by No. 2 Dam (*vide* Plate XXXIV.) being more expensive than Nos. 3 and 4 Dams taken together.

CHAPTER IX.

THE VEHAR LAKE EXTENSION PROJECT.

I have now shown the capabilities of the only two valleys* in Salsette which can be rendered useful for the supply of Bombay. The quantity of water to be obtained from Kennery is about 3,000 million gallons, and that from Ewoor is 2,400 millions yearly—the total from the two valleys being 5,400 million gallons yearly, or nearly 15 million gallons daily, or 23 gallons per head per diem for the present population.

I have also shown how high the dams in each valley must be to impound respectively a one, two, and three years' supply. I have, moreover, hitherto assumed that the water obtainable in each valley should be stored in that valley; but it is manifest that this need not be done in practice. I wish now to discuss the question, whether it is possible and preferable to store the water elsewhere.

As the Ewoor Lake lies considerably above both Kennery and Vehar, no water from these two latter valleys, nor indeed from Toolsee, could be thrown into it. Therefore to impound more water in Ewoor than can be supplied from its own gathering ground is not possible.

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* I am including Toolsee in Kennery.

Some of the water from Ewoor might be thrown into the Toolsee Lake, but this lake is a very small one, and it stands in such a position to Vehar as to render very high dams objectionable, so that it will not be able to hold more than a three-years' supply from its own gathering ground.

The Ewoor water could likewise be thrown into Kennery; but for this lake also, as the reader is aware, a dam of 155 feet high is required to impound a two-years' supply from its own gathering ground only. It is out of the question, therefore, to arrange for it to store a surplus supply from Ewoor.

There is only one alternative left to consider, and I am of opinion that, if it were feasible, it would be best to collect all the water from the Salsette Valleys into the Vehar Lake. This could not be done by raising the present dams. It would be the height of folly to attempt such a thing; but let us see if new dams could be substituted in place of those now existing. New dams might be built behind the present Nos. 2 and 3 Dams, but the lake would probably have to be emptied to make the work safe. It would, however, be impossible to build a new work behind No. 1 Dam. On the western side this dam rests on the slope of a hill which is only just wide enough to give it a hold. A dam immediately behind it would have nothing to rest against at all. Finding this to be the case, the idea occurred to me that it might be better to abandon No. 1 Dam altogether, and, in place of it, to build two dams lower down the valley—in fact, in the positions originally selected by Mr. Conybeare for what he termed his "Large Reservoir." By reference to Plate VIII. the positions of these dams, which were called No. 3 and No. 4 Dams, will be seen. Sections of the valleys at these points have been taken by me, but I regret to say the project has not turned out a promising one. It was, indeed, on account of the heavy nature of the work which these dams would have entailed that induced Mr. Conybeare to advocate the construction of the smaller lake and the building of what is now called No. 1 Dam, which in Mr. Conybeare's Plan (as in Plate VIII.) was called No. 5 Dam. He proposed that these dams should be only 80 feet high, and, moreover, added that "the high-water level might be increased to 84 feet, but not higher, without inconvenience."

Now, I calculate that if the Vehar Lake were made to hold a three-years' supply from the Kennery and Ewoor Valleys in addition to the three-years' supply from its own gathering ground, which is what it holds at present, the surface of the lake would have to be raised 25 feet above its present level. In addition to this, the surface of the ground does not give us a prospect of a solid foundation for any of the dams at a less depth than about 15 feet. It follows, therefore, that the two dams which would have to be built behind the present Nos. 2 and 3 Dams, which are about 50 feet high, would require to be 90 feet high, and the two dams to be substituted for the existing main dam, which, as it stands, is 90 feet high, would require to be 130 feet high. Nor is this all, for there is a ridge between these latter dams which is lower than the proposed level of the lake, so that a long dam would be required here to prevent the water escaping. There are also one or two other spots round the margin of the lake which would have to be embanked. Altogether, the cost of these works—about 72 lakhs of rupees—would be so out of proportion to the benefits to be derived from them, that we may look upon it as a hopeless task to attempt to store much more water in Vehar than it holds at present. The money that would be required for the new dams could be used to far better purpose otherwise.


TANSA PROJECT.
CONTOURED PLAN
OF THE
TANSA RESERVOIR.
SCALE. 2000 FEET = 1 INCH.
N.B. Between 430 and 480 Contours the Areas are only approximate.
HIGH GROUND
TANSA RIVER
Parelia Village
Chihara Village
Kharaguam Village
NOTE. The thick black line represents the Dam as at present proposed.
The whole length from A to B represents the top of the Dam when raised to its ultimate height.
DAM
(Signed) H. Tulloch. Captn. R.E.
Ex. Engr. Municipality.

CHAPTER X.

THE TANSA PROJECT.*

The valley, and the quantity of water to be obtained from it.

The position and extent of the Tansa Valley will be best gathered from the map facing the title page.† Its basin is considerably larger than that of any other valley in which a reservoir could be be formed. The Vehar Valley contains little more than six square miles—the Kamun not more than twenty; even Shewla contains but twenty-five; while the Tansa watershed has an area of 45 square miles. Its position for a gigantic scheme is most advantageous. In addition to the water falling on its own gathering ground, a supply could be obtained from the two great rivers, the Vathurna and the Bhatsa, between which the Tansa Valley lies. These two rivers, moreover, are flowing for several months after the monsoon ceases, so that, practically, there is no limit to the quantity of water to be obtained.

Besides its extensive area, the Tansa Valley, situated as it is, close to the western ghauts, has a rain-fall considerably greater than that of the Vehar, on which our calculations

* I have placed this before the Kamun Project, in order not to separate it from the other high level schemes.

† It would have been absurd to make a special survey of so large a tract of land.

have hitherto been based. In 1871 (when the monsoon failed), while 39 inches only fell at Vehar, 70 inches fell at Atgaum, the railway-station, 4 miles from the lake, and 75 inches fell at Khurdee, the railway-station at the head of the valley. If we remember, moreover, that on the ghauts, only a dozen miles to the west of Khurdee, the fall is 300 inches per annum (*i.e.*, two hundred per cent. in excess of the rain-fall at Vehar) and occasionally even more than this, we shall not be making any extraordinary assumption if we take the rain-fall in the Tansa Valley to be 33 per cent. only in excess of that at Vehar, or say 136 inches.* The quantity of water flowing off the Vehar gathering ground has been assumed to be 54 inches out of the total rainfall of 102 inches. At the same rate, the quantity of water flowing off the Tansa ground would be exactly 6 feet. If, then, the average area of the waterspread be taken at 6 square miles, the total quantity of water obtainable from the Tansa Valley will be as follows :—

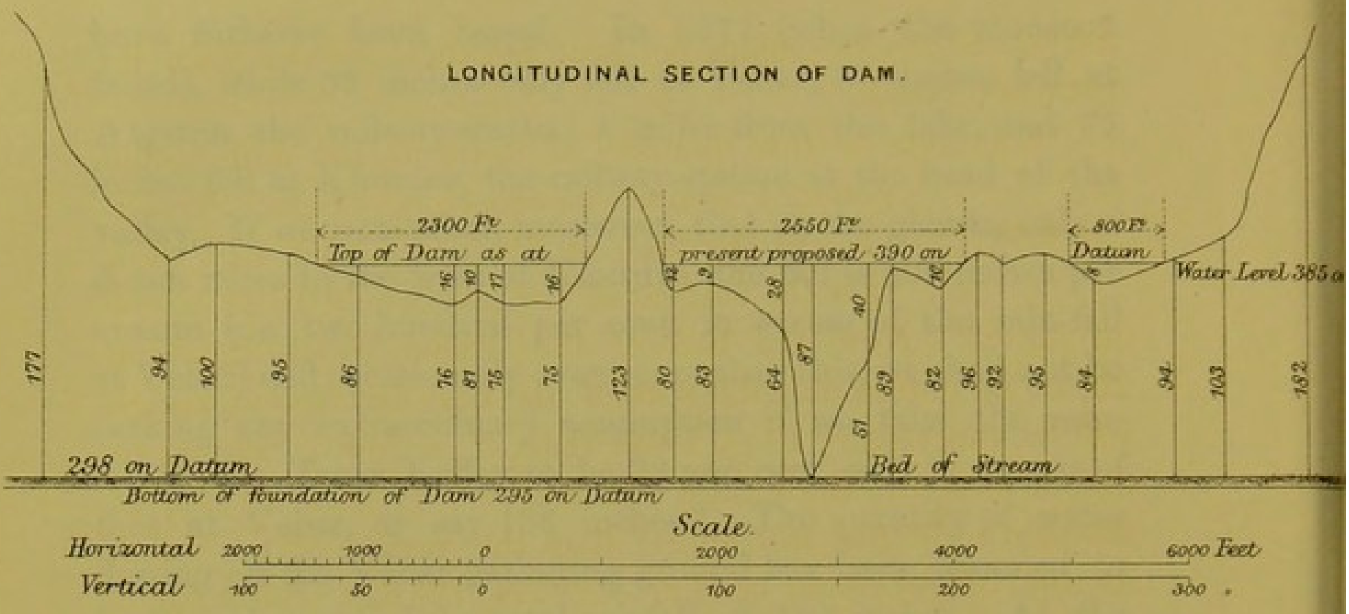
3,840 acres × 4,840 × 9 × $11\frac{1}{3}$ × $6\frac{1}{4}$ =	11,848,320,000
24,960 acres × 4,840 × 9 × 6 × $6\frac{1}{4}$ =	40,772,160,000
	52,620,480,000
Deduct for evaporation—	
3,840 acres × 4,840 × 9 × $2\frac{1}{2}$ × $6\frac{1}{4}$ =	2,613,600,000
	50,006,880,000
Deduct $\frac{1}{3}$rd for unaccountable waste	16,668,960,000
	33,337,920,000

which is equal to more than 90 million gallons daily—more than 140 gallons per head per diem for the present population,

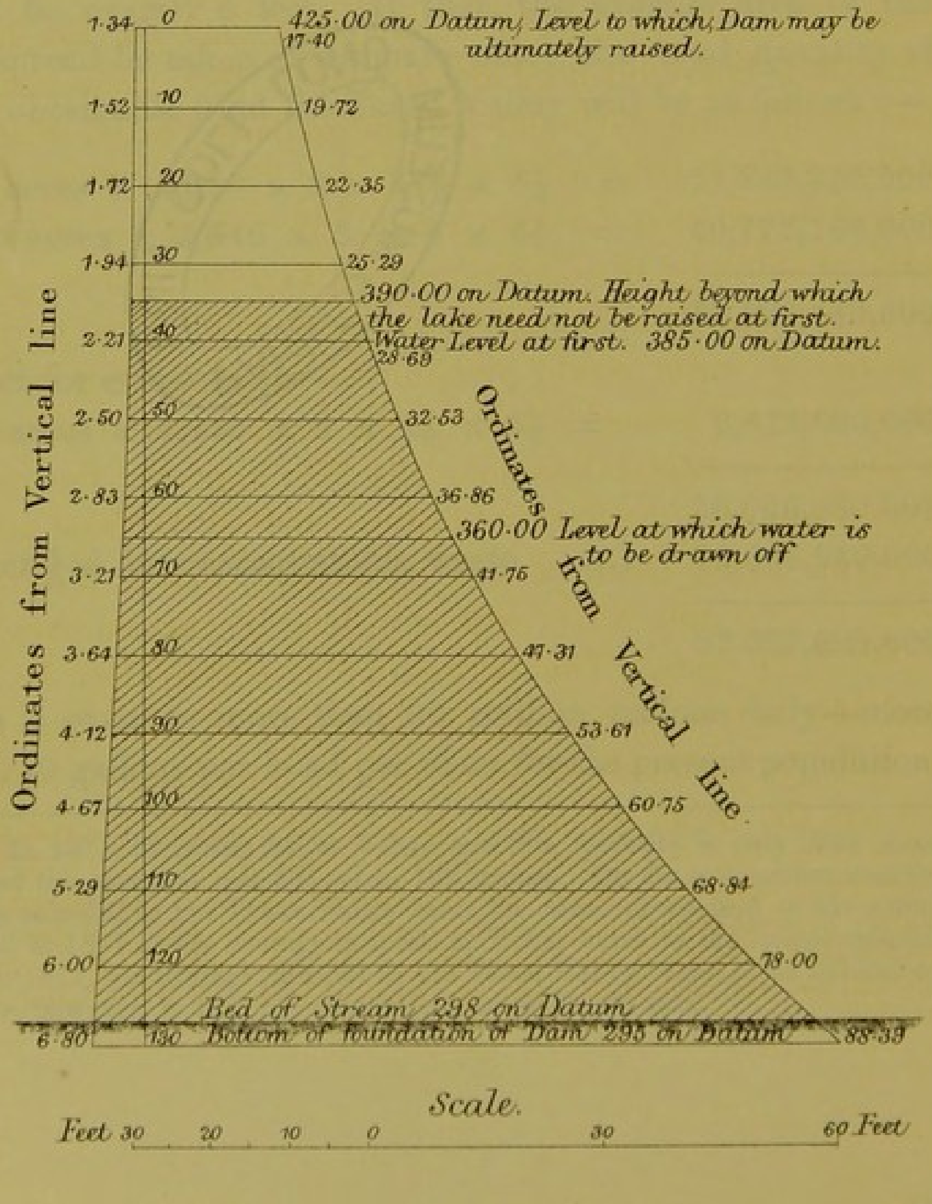
* In 1871, 39 inches fell at Vehar, and this quantity is only little more than $\frac{1}{3}$rd the assumed rain-fall—viz., 102 inches. On the supposition that the average rain-fall in the Tansa Valley bears the same proportion to the actual rain-fall in 1871 as the average rain-fall at Vehar bears to the actual rain-fall there in 1871, the average rain-fall in the Tansa Valley ought to be 183 inches. I prefer, however, to base my calculations on moderate data.

SECTIONS OF TANSA DAM.

LONGITUDINAL SECTION OF DAM.



CROSS SECTION.



Kell Bros. lith.

and more than 20 gallons per head per diem for two years for 2,000,000 people.

The storage of the water.

Enormous as this quantity of water is, the dam to impound it need not be exceedingly high. A reference to the table on Plate XXXVI. will show that the surface of the lake would be at 420·00 on datum. Now the bed of the stream, which stands at 298·00 on datum, is solid rock of the best description, and it will be unnecessary to go lower than, if so low as, 295·00 on datum to secure the firmest foundation. If then we suppose the dam to be five feet higher than the surface of the water, its total height would be (425 – 295 or) 130 feet. But it would be many years, perhaps generations, before such a large quantity of water would be required, and although I have shown what the ultimate height of the dam may be, the height when it is first built need not exceed 95 feet. Even such a dam would impound 9,000 million gallons yearly, or say 25 million gallons daily, or 20 gallons per head per diem for the present population for two years. It would be no use to think of storing a three-years' supply, as 9,000 million gallons are only a small fraction of the average rain-fall, so that this quantity of water would probably be received even in years when what are termed failures of the monsoon occur, but when, in fact, the monsoon does not really fail altogether, but merely gives a supply of perhaps a third or a half of its usual one.

The Dam.

The Tansa Dam, as will be seen by Plates XXXVII. and XLI., will be a long but not an expensive one. The portion of it which must be high (and this is the important point) would be very short, as the hills rise suddenly to an elevation on one side of seventy, and on the other of ninety feet.* With the exception of

* Those who have never had occasion to take out the quantities of masonry in dams of different sections would be surprised to find how much depends on the length of the high portion. A dam a mile long and 30 feet high will not cost more than a dam one-tenth of its length if the latter is 100 feet high.

the Toolsee Dam, the Tansa has the most favourable section of all the main dams yet proposed.* I would have the dam of one uniform section throughout, and that section to be the one designed by Mr. Rankine. The long low part would give us a surplus of stability,† and in the highest part we should have abundance of strength.

Waste Weir.

I would pass the surplus water over the low part of the southern end of the dam, which would, in fact, become the waste weir. The water would easily find its way back into the river lower down in the valley by another course. It could also be passed over the northern end of the dam if considered desirable. The waste weir for the Tansa Reservoir will, therefore, cost nothing.

Outlet Works.

Plate XXXVIII. illustrates the method proposed for drawing the water from the Tansa Lake. The designs are for a tower of about the greatest height to which one could practically be built, and for the largest quantity of water which could ever be required for a town. The principle may be applied to the Kennery, or Ewoor, or any other scheme involving a deep lake. The reader is aware that I do not propose to raise the Tansa Dam at first to above 390·00 feet on datum (the dam being 95 feet high), nor eventually to above 425·00 on datum (the dam being 130 feet high). The problem to solve is of a very special nature, and this will account for the novel features of the design. We have to draw a large quantity of water under a great head, and to deprive the water of its head *at once*, so that it shall flow off into a channel without pressure. To draw water under a great head by a pipe is easy enough, but the difficulty consists in starting it in a masonry conduit without any head at

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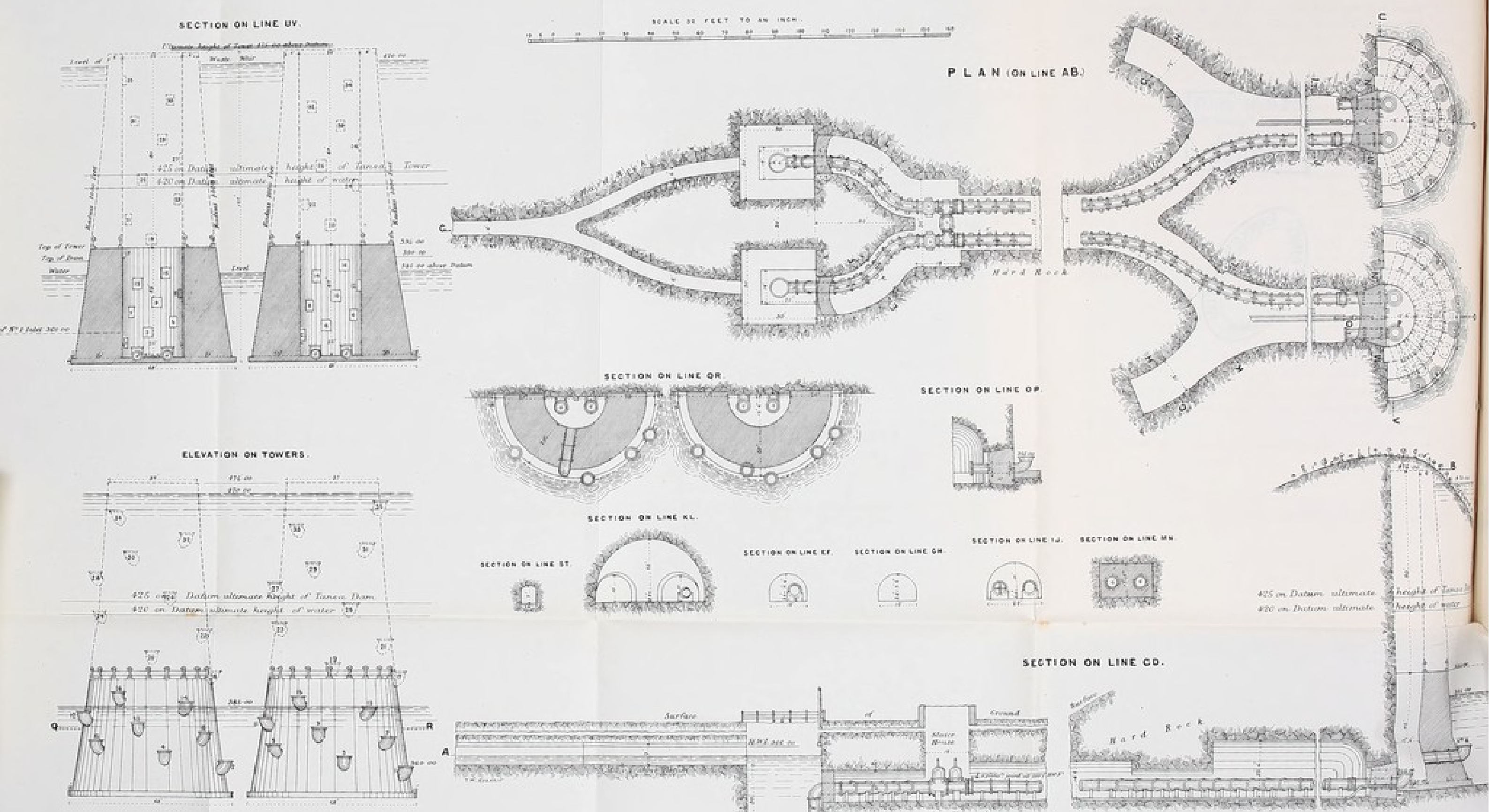
* *Vide* Plate XLI.

† *Vide* paragraph 22 of Appendix D. If, indeed, the whole of this chapter is studied, the force of my recommendation will be better appreciated.

TANSA PROJECT.

OUTLET WORKS.

These works are designed for a tower of about the greatest height which could occur in practice and for the largest quantity of water which could ever be required for a town. A modification of them will suit any of the Projects.



all.* In order to effect this, I propose to make use of the power which a smaller volume of water possesses to diffuse its pressure when discharged into a much larger volume. I propose to draw the water by large pipes, terminating with their mouths turned upwards in the bottom of a deep enclosed basin. The stream will issue with considerable force into this reservoir, but, meeting the resistance of a great body of water above it, the pressure will be diffused, and, as by regulating the sluices no more water will be permitted to enter the basin than it is desirable that the channel should convey away, the level of the water in the basin will be always kept at one level. If it is considered advisable afterwards, arrangements may be made for straining the water between the basin and the other channel.†

Instead of towers for drawing off water, standing in the middle of a lake, which it is so difficult to keep water-tight, and from which it is impossible, after the works have once been completed, to increase the supply,‡ I am satisfied the proposed method will be found more satisfactory. It is, in fact, the method submitted by me to the Bench in 1870, for drawing off water from the Toolsee Lake, but the design is modified to suit it to any amount of pressure and to the water flowing off in a channel instead of in a pipe.

A spot on the margin of the lake, where the rock is of

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* I am not aware of any instance where a large quantity of water is drawn under these peculiar conditions, nor do I know of any work on hydraulics which treats of this question.

In the Glasgow Water Works, when the water in Loch Katrine stands at even its raised level, the average pressure with which it issues into the channel is but 10 feet, and at low water the pressure is as little as 4 feet. But we have to deal with a pressure of from 25 to 80 or even 100 feet, dependent upon which project the Bench decide upon and up to what level it is determined to impound water in the particular reservoir which is approved.

† This is not shown in Plate XXXVIII., but any one can see how easily it could be accomplished by putting gauze strainers over the mouths of the channels.

‡ This is our great difficulty at Vehar. We cannot lay down a second pipe from the tower, and we are entirely dependent on the security of a single main running under the dam. If anything happens to this, a state of things frightful to contemplate would follow. *Vide* note to page 36.

a sound description, should be selected, and the tower should be built into the rock,* and be of a semi-circular form, so that the pressure may be thrown on the hill. The thicker the masonry of the tower the better, so that it may resist the creeping effect of the water. From the bottom of this tower a tunnel should be driven of such dimensions as will admit of the number of pipes that may ultimately be required being laid in it. Over the mouths of the pipes which draw the water from the lake into the tower, fine gauze strainers, similar to those in use at Vehar, may be used.

The advantages of the system are obvious. The supply could be increased at any future time by laying down another pipe—or any number of pipes—between the tower and the basin from which the channel starts. If a pipe in the tunnel were to burst, or repairs of any kind had to be carried out, all that would be necessary would be to close the mouths of the inlets in the lake, and to let the tower empty itself. Workmen could then descend to the bottom, or into the tunnel, and do what might be required.

In Plate XXXVIII. the towers are in duplicate. This, although not necessary, would be the most convenient arrangement. Of course, the sizes and the number of pipes must be modified to suit the particular case. That which I have dealt with is perhaps the most difficult that would ever occur in water works for the supply of a town. The pressure of the water is as much as 120 feet, which is not likely to be met in practice, and the pipes are 4 feet in diameter, and capable of delivering an enormous supply.

Conduit and pipes between Tansa and Koorla Reservoir.

From the Tansa Lake I would bring the water to the proposed Koorla Reservoir partly by channel and partly by iron pipes.† I say "partly," because the case is different to that of the

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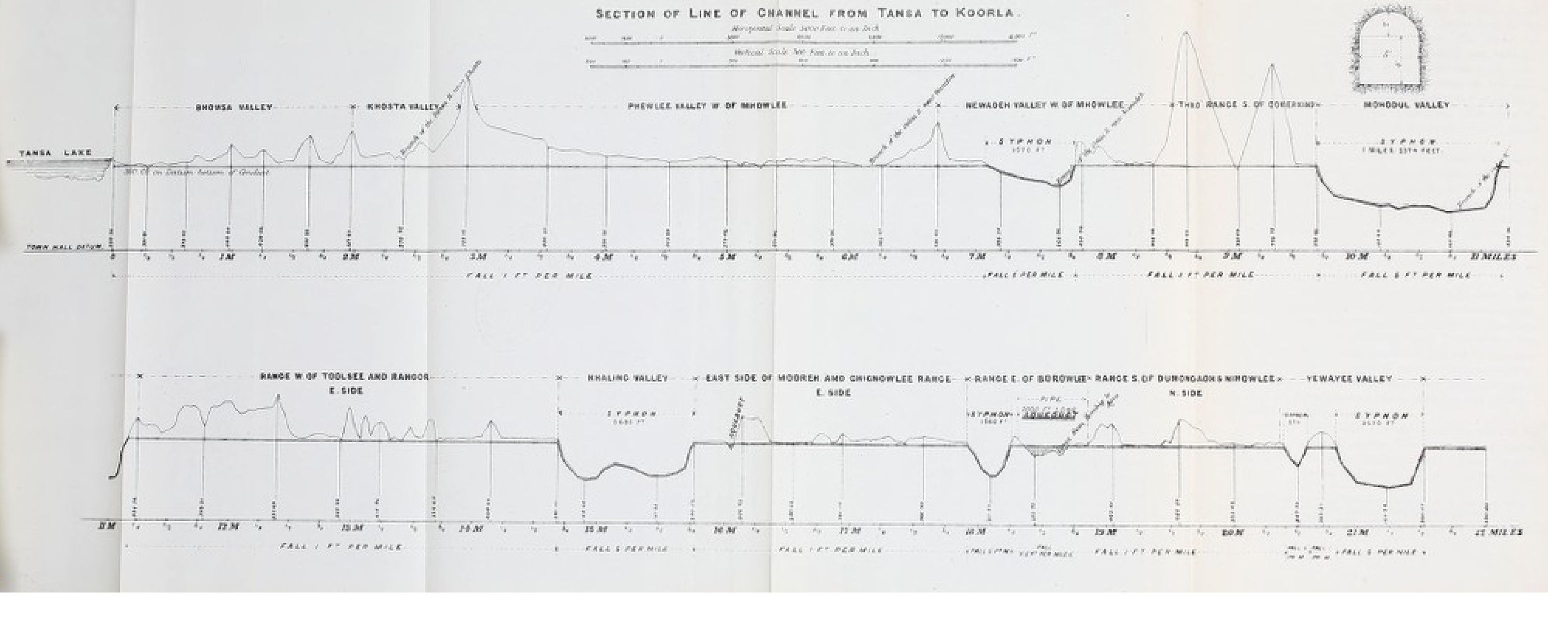
* This is not shown as clearly as could be wished in the Plate, but it is very necessary. The rock in the Tansa Valley is thoroughly sound.

† *Vide* Map facing title-page and Plates XXXIX. and XL.

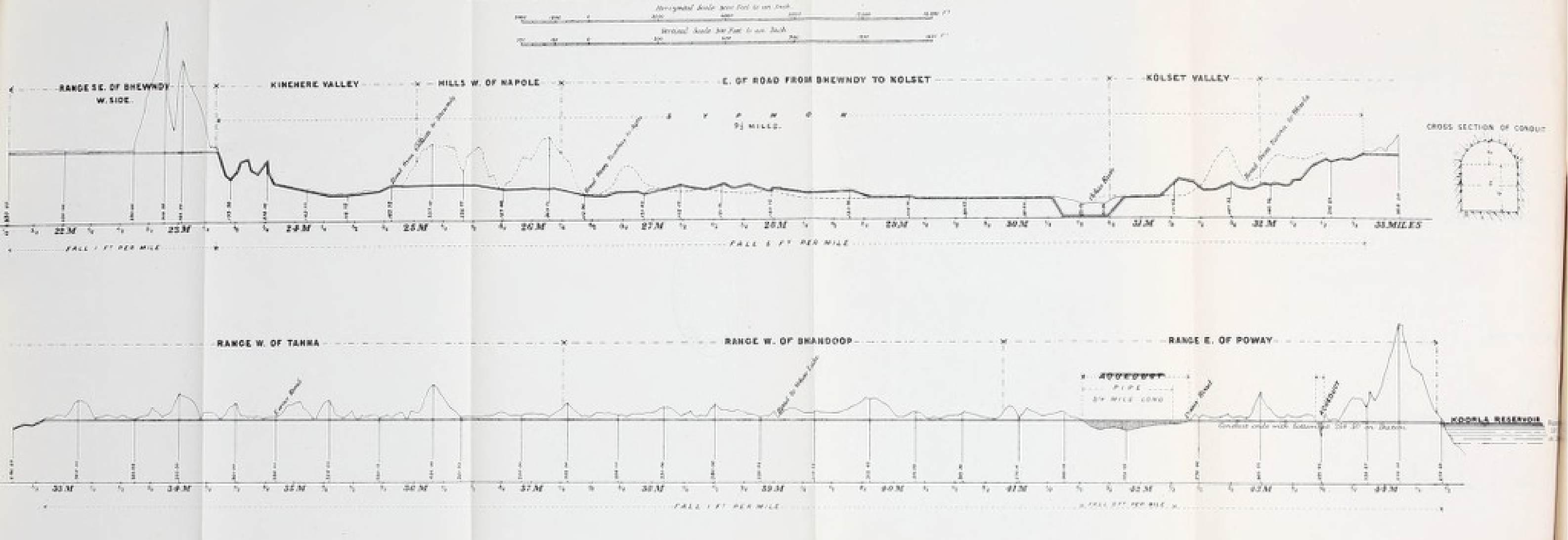
TANSA PROJECT.

SECTION OF LINE OF CHANNEL FROM TANSA TO KOORLA.



TANSA PROJECT.

SECTION OF LINE OF CHANNEL FROM TANSA TO KOORLA (CONTINUED).



Kennery, Toolsee, or Ewoor Schemes. In these the features of the country admitted of a channel or tunnel being carried to Koorla with hardly any break on the line, but in the case of the Tansa it must be remembered that the lake is more than 50 miles from Bombay, and there is no continuous range of hills extending from the reservoir to Salsette. There are several ranges most conveniently situated for our purpose, but there are gaps between them, and, to get the water from a channel on the top of one range into a channel on the top of the next, we should be compelled to cross the valley between. This could only be done by carrying the water under pressure in pipes laid across the valley, or by rock syphons which I will suppose may prove unsuccessful. An accurate survey of the entire line from the Tansa to the Koorla Reservoir has been made, and a section of it is given in Plates XXXIX. and XL., from which it may be gathered that, altogether, about $29\frac{1}{2}$ miles of channel and 15 miles of pipes would be required. I think one foot a mile a good slope for the former, and five feet a mile about the best relative one for the latter.* On these data, the total fall of the entire line will be ($29\frac{1}{2}$ feet + 15×5 feet =) $104\frac{1}{2}$ feet, so that at whatever level the water may start flowing from the Tansa Lake, it will reach the Koorla Reservoir $104\frac{1}{2}$ feet below that level.

The water might be drawn from the Tansa Lake at as low as 350·00 feet on datum, but I should prefer to draw it at 360·00. Supposing then that this latter level be decided upon, the water would reach the Koorla Reservoir at ($360 - 104\frac{1}{2}$ =) 255·50 on datum—the same level as that fixed for the water from either Kennery or Ewoor. But it is the bottom of the channel which would be at this level, and the surface of the water, supposing the channel were four feet

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* The reader will remember that this is the general slope I have adopted in the Kennery and Ewoor Projects. The slope Mr. Bateman has given to the Glasgow channel is 10 inches per mile, and to his syphons 5 feet per mile.

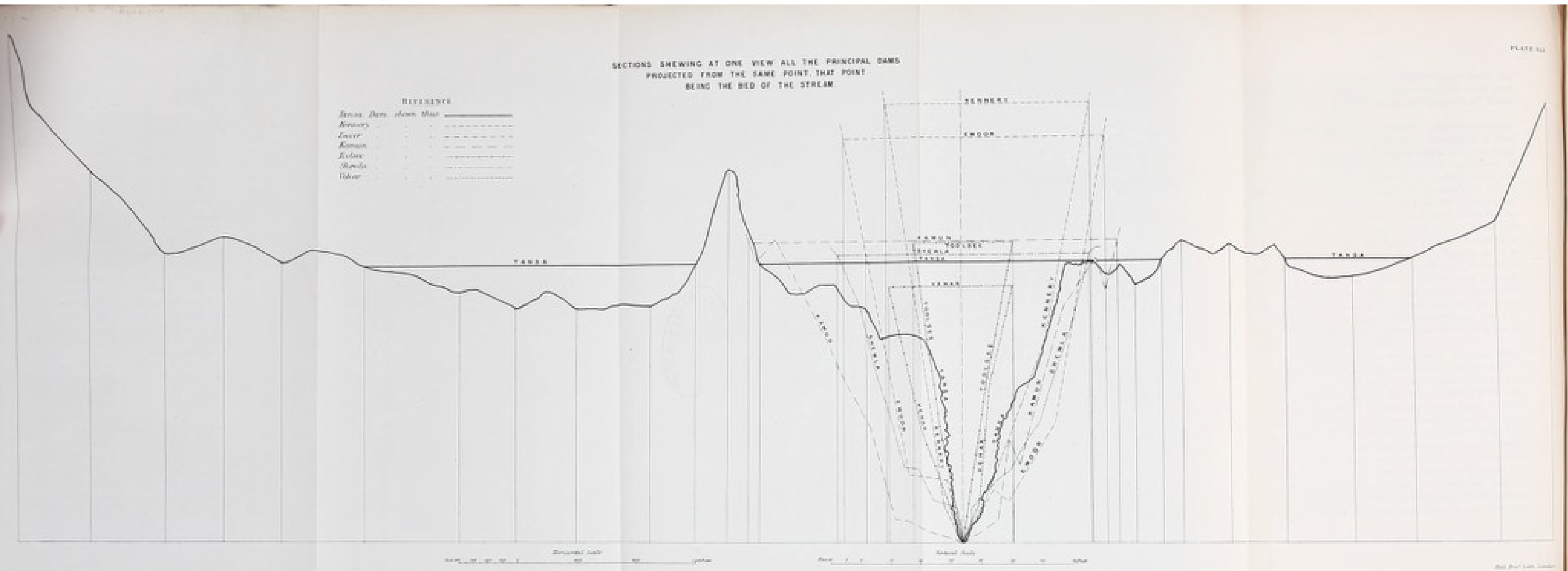
deep, would be at ($255\frac{1}{2} + 4 =$) 259·50 feet on datum, the highest level at which it is proposed that the water shall stand in the Koorla Reservoir for the Kennery and Ewoor Projects.

The Tansa water could be thrown into Vehar.

I will now show how the channel would run with reference to the Vehar Lake. The lake is $4\frac{1}{4}$ miles nearer than the Koorla Reservoir to the Tansa basin, and the portion of the line between it and Koorla would consist of $3\frac{1}{4}$ miles of conduit, with a rise from Koorla of $3\frac{1}{4}$ feet, and of three-quarters of a mile of syphon, with a rise of $3\frac{3}{4}$ feet. The total rise in the conduit and syphon together would be 7 feet, and, therefore, the channel would be 7 feet higher when it reached Vehar than it would be at Koorla. At Koorla, we see it would be at 255·50 on datum; therefore, at the Vehar Lake, it would be at ($259·50 + 7 =$) 262·50, which the reader will remember to be the exact level of the surface of the lake when it is full. Thus the arrangements would be such that the channel would have a perfect command of our present reservoir, and at any time water from the Tansa could be discharged into it to keep it full. This is a very important consideration to bear in mind in carrying out new works.

If the water were drawn from Tansa at 350·00 on datum, it would be best to reduce the slope of the channel from a foot to 10 inches a mile, and the fall of the syphons from 5 feet to $4\frac{3}{5}$ feet per mile, so as still to ensure its reaching Vehar with a command of the lake. Or, if the water were drawn at 360·00 on datum, and it were considered advisable to have the service reservoir even 10 feet higher than proposed by me, these slopes given to the conduit and syphons would bring the supply to Koorla at 369·50, and the water would, on its course, pass the Vehar Lake at 10 feet above the surface of the latter.

The entire line from the Tansa to Koorla has been accurately surveyed, and Plates XXXIX. and XL. are sections of the line reduced from the large plans in the Municipal


SECTIONS SHEWING AT ONE VIEW ALL THE PRINCIPAL DAMS
PROJECTED FROM THE SAME POINT, THAT POINT
BEING THE BED OF THE STREAM
REFERENCE
TANSA
KENNERY
EMOOR
KAMUN
TOOLSEE
SHEWLA
VEHAR
Horizontal Scale
Vertical Scale

Office. There is no doubt, therefore, of the correctness of the facts stated.* I particularly request that these Plates may be looked at closely.† The line has been arranged to avoid as much as possible long tunnels and deep shafts. As a rule, the tunnels will be from 200 to 300 yards long, or less if considered desirable, and the shafts would be about 20 or 30 feet deep, or less, also, if deemed more advantageous. I thought this about the least depth to ensure good sound rock. Excepting through five hills, it is quite clear the line is most favourable. These hills occur—the first at the 3rd milestone; the second and third between the 8th and 10th milestones; the fourth at the 12th milestone; and the fifth at the 23rd milestone. The first hill—viz., that at the 3rd milestone, is really the worst obstacle, but even here two shafts 150 feet deep would reduce the headings on each side to about 300 yards.‡ The hills between the 8th and 10th milestones might be tunnelled through with a shaft at each end and one in the middle. None of the shafts need be more than a few feet deep. The long

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* No plan of the line is given in this report. It has been omitted simply on grounds of economy. The number of Plates has already far exceeded what I ever contemplated. An accurate survey on a large scale may be consulted in the Municipal Office by those who desire detailed information. For the general reader, the index map, facing the title page, gives all the necessary facts.

Those who have never conducted a survey for a long line of this kind—*i.e.*, for a high level water channel, and in a hilly country covered with the densest jungle, where often an advance of fifty feet cannot be made without felling large trees and clearing a path through closely matted brushwood, can hardly realize what an amount of labour and exposure is involved to secure the best course. Two and three lines have to be surveyed and levelled before the best can be decided on, and this again has to be modified, re-surveyed, and re-levelled in consequence of facts brought to light subsequently. It is these things which render survey work for water supply so very expensive in Bombay.

† I had intended to give the position of every shaft, in order to show how favourable for tunnelling the line would be, but these Plates were done in Bombay while I was in England, and they could not, of course, be subjected to my final correction. The reader must be indulgent for omissions of this nature.

‡ The first hill through which Mr. Bateman so boldly tunnelled to take the Loch Katrine water to Glasgow had, besides several others, five shafts of an average depth of 150 *yards*.

tunnels in these cases would probably be preferable to sinking deep shafts. The hill at the 12th milestone looks the most formidable of all, but it is the least so. In fact, it is as favourable as any part of the line, because horizontal shafts* can be obtained of any required depth and at convenient distances apart. A shaft 100 feet deep in the middle of the hill at the 23rd milestone will remove all difficulty here.

Overflows would be constructed at numerous points along the line to discharge the water if at any time there were an obstruction in the conduits or syphons; and numerous ventilating manholes could be left, if considered desirable, at all points where shafts had been sunk.

Only three aqueducts would be required in the whole length (29½ miles) of channel, and this circumstance is, in my opinion, extraordinarily favourable. These works, moreover, would be of such an insignificant kind that I need not speak of them further.

The most formidable obstacle on the entire line would be the Tannah Creek, but this is incidental to every project with a reservoir out of Salsette, and, in fact, to every project for a large supply of water, which cannot, as the reader now knows, be obtained in Salsette. The cheapest way to overcome this obstacle would be to tunnel under the creek at a depth of from 50 to 100 feet below the bed. I have calculated the cost of several kinds of iron aqueducts over the water, but find they would all entail more expense than a simple tunnel with a cast-iron pipe laid in it.†

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* These cannot be shown in a section, but those who care to be satisfied on this point can refer to the plan of the line in the Municipal Office.

† If the Government were desirous to improve the high road to the Deccan by a bridge over the creek, and would meet the Bench half way by sanctioning a portion of the total outlay required for a bridge and aqueduct combined, no doubt this would be the cheapest and best mode of carrying the water across; but if the entire expense of such a work is to fall on the Bench, a tunnel will be cheaper. Perhaps the Government might consent to make over the tolls to the Bench, and to do away with the ferry. It might be worth while then to construct a bridge and aqueduct.

I will now point out what I delayed doing in a previous part of this report, when I mentioned that I should prove the disadvantageous position of the Shewla Reservoir. If I have made myself clear in Chapter IV., it must be evident now to the reader that, *cæteris paribus*, that must be the best reservoir which will admit of the water being brought to Bombay by a high level channel instead of in a pipe. In fact, the only hope of carrying out a large scheme will depend upon our being able to dispense as much as possible with pipes.*

The Tansa and Shewla Projects compared.

In the map facing the title page are shown the best lines along which the water should be brought from both the Tansa and Shewla Basins. Now the total length, by a careful survey, of the line from Tansa to Koorla is, as already mentioned, 44½ miles, of which 29½ miles would be channels and 15 miles would be pipes. The total length of the line from Shewla to Koorla is 47 miles, of which 21 only would be channels and 26 pipes. The line from Shewla, therefore, would be not only 2½ miles longer than that from Tansa, but there would be 11 miles more of pipes required for it than for the latter.

Nor is this all. From the same sized pipe in the two cases we should obtain more water from Tansa than from Shewla; or, in other words, a larger pipe, to convey the same quantity of water, would be required from the latter than from the former. The reason is obvious. We could not get so great a fall for the pipe. I have shown that the total fall of the line from Tansa to Koorla is 104½ feet, that the 29½ miles of channel on the Tansa line would have a slope of one foot per mile, and that the 15 miles of pipe would have a fall of 5 feet per mile. The Shewla Lake being about 20 feet higher

* I beg the reader at this point to refer to the note on page 97 (and especially that portion of it regarding the Shewla Scheme), where he will see the enormous cost in every project of the works for bringing water to Bombay as compared with the cost of storing it. The estimates in this report illustrate the same point, and although the cost of those works has been greatly reduced.

than the Tansa, the available fall, supposing the water were drawn from as high as 380·00 on datum, would be 124½ feet. If we gave the channel, of which there would be 21 miles, a fall of one foot per mile, we should have 103½ feet left for the 26 miles of pipe. Thus the fall per mile for the latter would be four feet instead of five, as in the case of the Tansa line. The fall being less, the discharge would be less, or, to obtain the same discharge, the size of the pipe and the thickness would have to be increased—*i.e.*, the cost enhanced.

If, in order to get the same slope for the pipe from Shewla as that from Tansa, it were decided to draw the water from a higher level, it would have to be drawn from 26½ feet higher, or from 306·50 on datum. But to do this would be to leave only 11½ feet depth of water in the lake, for I have already mentioned that the dam cannot be made higher than to impound water up to about 418·00.* The hills on the sides of the dam are not much above this level.

In addition to this, it will be seen from the map that the line from Shewla has to cross two large rivers, the Kalloo and the Bhatsa, just below their junction, and, to effect this, special and costly arrangements would be required.

A reference to the map, moreover, will show that the pipes on the Tansa line would be situated not far from a metalled road which, being indeed the high road to the Deccan, is open at all seasons of the year. Thus the facilities of carriage would be great and the cost comparatively small. Again, the site of the Tansa Dam itself is but five miles from a station (Atgaum) on the Great Indian Peninsula Railway, and the road from the station to the dam, running as it does on high ground, could be always open,† so that a perfect communication could be maintained even in the monsoon, and

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* This is the height of the water level proposed also by Mr. Aitken.

† Even a tram could be laid, if considered desirable, without any risk of its having to be closed in rainy weather.

materials could easily be carried wherever they might be required.

On the other hand, the Shewla Reservoir is 15 miles from the nearest station, and there is no metalled road in its direction. The track, such as it is, runs, every now and then, over swamps which, as the engineer officers of the Municipality have found to their cost, are impassable during rainy weather. It is really the case that for four months in the year no cart traffic takes place between the large town of Moorbar and the railways.*

I have referred in a previous part of this report to the valuable nature of the ground which would be swamped by the Shewla Lake. Now this point becomes, when carefully inquired into, one of great importance. It must be remembered that as many as 4,000 acres would have to be taken up if a reservoir were formed either at Shewla or in the Tansa Valley. For the Kennery, Toolsee, Ewoor, and Tansa Schemes, the land required would consist merely of jungle; but for the Shewla Lake the entire waterspread is almost all under cultivation for rice,† and, unless the owners were liberally dealt with, they would not part with their properties. Whatever may be the value of jungle, it must be clear to the most ordinary understanding that land, which has been brought into a high state of cultivation by the labour of years, must be four or five times as valuable; so that if 50 Rs. an acre be sufficient to pay for jungle, 200 Rs. an acre will not be too high a price to pay for an acre of the best paddy. At these rates the cost of the land for the Shewla Lake would be

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* Such hard labour is it considered for bullocks to work in this district in wet weather that, in order to prevent their cattle being seized for the purpose, many of the villagers, immediately the monsoon sets in, take off the wheels from their carts and bury them. The Municipal officers were always made welcome to the carts, but invariably found them without wheels.

† I am told that the rice produced in the Shewla Basin and all about Moorbar is of a superior quality and fetches a higher price in the market than most other kinds, and that the land-owners in Moorbar and the surrounding villages are very tenacious of their fields.

six lakhs of rupees in excess of that which we should have to pay for the land in the Tansa Valley. Moreover, nearly all the latter belongs to the Government, who, I have no doubt, would, with the prospect of the beneficial effects to be produced in the surrounding country by a large water scheme, grant it for a merely nominal sum, especially as it yields them nothing at the present moment; whereas the land at Shewla belongs to well-to-do people, who are fully alive to the value of their properties, and who would most certainly demand the utmost compensation for their loss, or proceed to law to obtain it.

Thus then the advantages of the Tansa over the Shewla Project for a gigantic project, may be summed up thus: The gathering ground of the Tansa, and, therefore, the supply to be obtained from it, is nearly double that to be obtained from Shewla. The capacity of the reservoir is greater. The line by which the water would be conveyed to Bombay is 2½ miles shorter. Only 15 miles of pipe would be required to reach the Koorla Reservoir in place of 26 miles in the case of Shewla. The slope which could be given to the Tansa pipe is greater than that which could be given to the Shewla pipe, without sacrificing other advantages; or, if the same slope were to be given to the Shewla pipe, the capacity of the reservoir would have to be so reduced as to make it but a small one. The communications between Tansa and Bombay are nearly completed already by railway, and the pipes could be carried close to their destination along a first-class metalled road; whereas the communications between Shewla and Bombay are most incomplete at the best, and closed during the monsoon, and the pipes would have to be carried to their positions along country tracks, and over low swampy ground. And, lastly, the land required for the Shewla Lake would cost many lakhs of rupees in excess of what would have to be paid for the land in the Tansa Valley.

When all these points are considered, it will be found on calculation that the difference in the first cost of the two lines would be from 15 to 20 lakhs of rupees, dependent on the quantity of water it might be decided to convey to Bombay, and the difference in the after-cost, as the works required extension and more water had to be brought to Bombay, would be enormously more.

I trust it will now be seen that the facts brought to light by the surveys and investigations undertaken by me have justified the rejection of the Shewla reservoir for a large scheme of water-supply. I will now pass on and complete my explanation of the Tansa project.

The Koorla Reservoir and the pipe to Bombay.

I need not describe the service reservoir at Koorla, which would be the same as for the Kennery or Ewoor Projects,* and the details of which are given in Plate XXXI. The pipes from Koorla to Bombay would run along the course shown in Plate XXXII. for the Kennery line. The size of the pipe would of course depend upon the quantity of water it was determined to deliver in Bombay. In order the better to effect a comparison between the several Kamun projects and the Tansa Project, I have estimated for pipes to convey various quantities of water to Bombay.

Quality of the water.

I have already mentioned that the land which would be covered by the Tansa Lake is nearly all jungle, and similar in character to that which would have to be taken up for any of the Salsette projects. The entire watershed, moreover, consists of rocks of primitive formation, and the water, therefore, would be of the same quality as that supplied at present to Bombay. The villages, which would be swamped by the water, consist in every case of merely a few straggling huts occupied by men of the poorest class, and it would cost little to compensate

* The reader will have observed that the Kennery, Ewoor, and Tansa Projects are all on the same system. The channel for each reaches the service reservoir at the same level; the service reservoir suits each scheme equally well, and the pipe to Bombay would run along the same line for each.

these men for their dwellings, which consist merely of mud walls thatched over with the grass growing close to them.

Estimate.

The following are estimates of the scheme for 13, 20, and 26 gallons per head per diem for the present population :—

Estimate No. 1.

COST OF TANSA SCHEME.

Dam to impound at first 9,000 million gallons, and supply to be 8¼ million gallons daily :—

	Rs.
Dam 95 feet high, but constructed so as to admit of its being raised from time to time so as ultimately to be 130 feet high, containing 4,496,000 cubic feet of rubble masonry at 25 Rs. per 100 cubic feet	11,24,000
29½ miles of channel, with a waterway 5 feet wide by 4 deep, at 80,000 Rs. a mile	23,60,000
15 miles of syphon pipe, between Tansa and Koorla, 36 inches in diameter and 1⅛ inch thick, delivering 8¼ million gallons daily and weighing 1,020 tons per mile, or 15,300 tons at 160 Rs. a ton	24,48,000
9½ miles of pipe from Koorla to Bombay, 28 inches in diameter and 1 inch thick, delivering 8¼ million gallons daily, and weighing 720 tons per mile, or 6,840 tons at 160 Rs. per ton...	10,94,400
No waste weir required (*vide* page 150)	
Outlet works	1,50,000
Tunnel under Tannah Creek, about ½ a mile long.	3,00,000
Koorla Reservoir, and works there..................	3,00,000
Rs.	77,76,400
Add 10 per cent. for contingencies, say	7,77,600
Carried forward.................. Rs.	85,54,000

Brought forward......................Rs.	85,54,000
Land, 2,420 acres of jungle for reservoir,* 32 acres for syphons and pipes, 4 acres for shafts, say, altogether, 2,460 acres at 50 Rs. each	1,33,000
Total..........................Rs.	86,87,000

Or, say, 87 lakhs for 13 gallons per head per diem for the present population.

Estimate No. 2.

COST OF TANSA SCHEME.

Dam to impound as before 9,000 million gallons. Supply to be 13 million gallons daily :—

Dam as before..Rs.	11,24,000
$29\frac{1}{2}$ miles of channel, as before	23,60,000
15 miles of syyhon pipe, between Tansa and Koorla, 42 inches in diameter and $1\frac{1}{4}$ inch thick, delivering 13 million gallons daily, and weighing 1,364 tons per mile, or 20,460 tons at 160 Rs. per ton	32,73,600
$9\frac{1}{2}$ miles of pipe, from Koorla to Bombay, 33 inches in diameter, and $1\frac{1}{8}$ inch thick, delivering 13 million gallons daily, and weighing 924 tons per mile, or 8,778 tons at 160 Rs. per ton	14,04,480
No waste weir is required.	
Outlet works, as before	1,50,000
Tunnel under Creek, as before........................	3,00,000
Koorla Reservoir, and works there, as before ...	3,00,000
	89,12,080
Add 10 per cent for contingencies, say	8,91,920
	98,04,000
Land as before	1,33,000
Total..........................Rs.	99,37,000

Or, say, $99\frac{1}{2}$ lakhs for 20 gallons per head per diem for the present population.

* This will be sufficient at first.

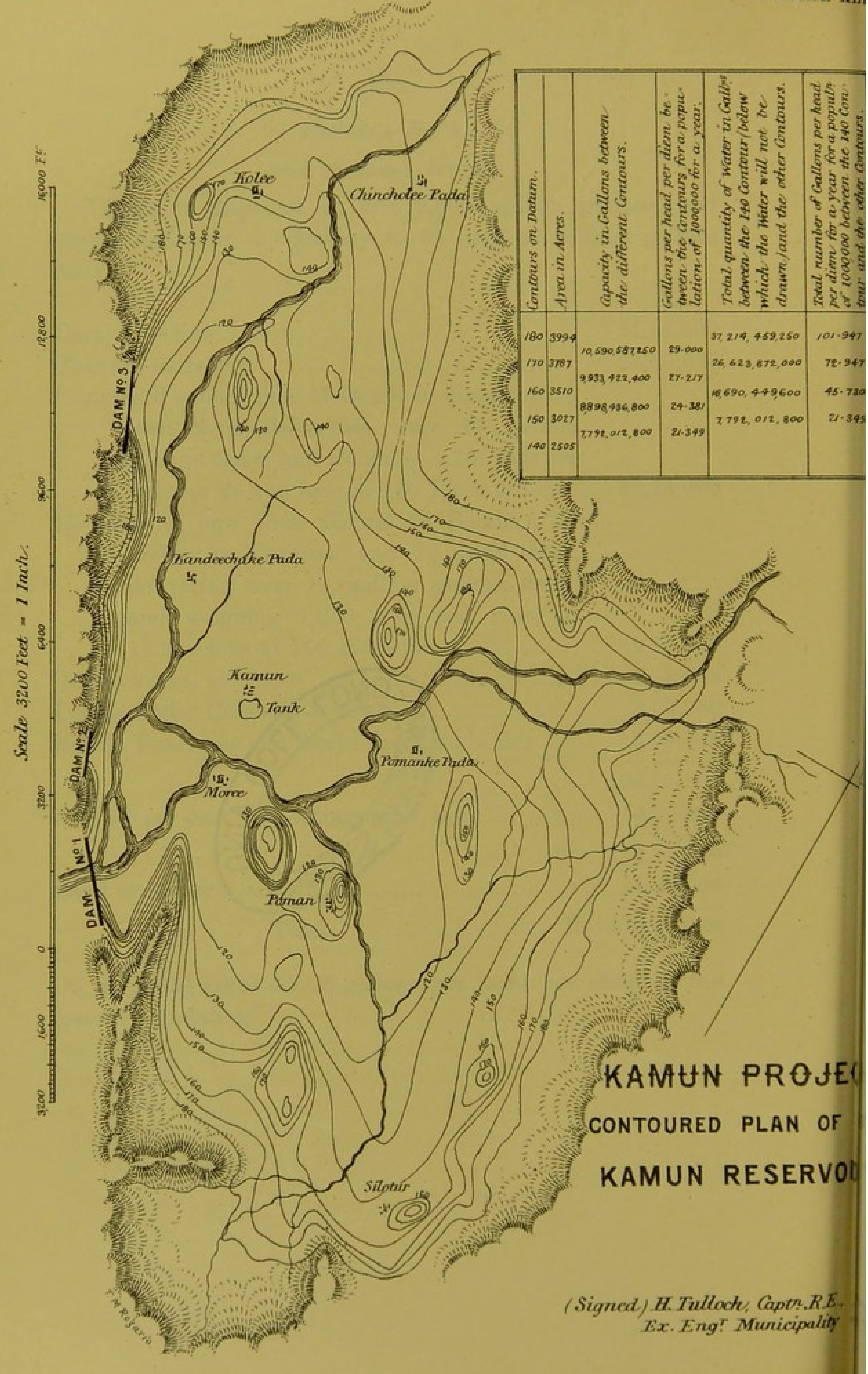
Estimate No. 3.

COST OF TANSA SCHEME.

Dam to impound at first 9,000 million gallons, and supply delivered to Bombay to be over 17 million gallons daily :—

	Rs.
Dam, as before	11,24,000
Channel, as before	23,60,000
15 miles of syphon pipe 48 inches in diameter, 1½ inch thick, delivering over 17 million gallons daily, and weighing 1,760 tons per mile, or 26,400 tons at 160 Rs. a ton......	42,24,000
9½ miles of pipe from Koorla to Bombay, 39 inches in diameter and 1¼ inch thick, delivering over 17 million gallons daily, and weighing 1,260 tons per mile, or 11,970 tons at 160 Rs. a ton	19,15,200
Outlet works, as before	1,50,000
Tunnel under Creek, as before.........................	3,00,000
Koorla Reservoir and works there, as before	3,00,000
	103,73,200
Add 10 per cent for contingencies, say..............	10,37,800
	114,11,000
Land as before	1,33,000
Total ....Rs.	115,44,000

Or, say, 115½ lakhs for 26 gallons per head per diem for the present population.



Contours on Datum.	Area in Acres.	Capacity in Gallons between the different Contours.	Gallons per head per diem between the Contours for a population of 1000000 for a year.	Total quantity of Water in Gallons between the 140 Contour (below which the Water will not be drawn) and the other Contours.	Total number of Gallons per head per diem for a year for a population of 1000000 between the 140 Contour and the other Contours.
180	3994			37,214,469,250	101·947
		10,590,587,250	29·000		
170	3787			26,623,872,000	72·947
		9,933,422,400	27·217		
160	3510			16,690,449,600	45·730
		8,898,936,800	24·381		
150	3027			7,792,012,800	21·349
		7,792,012,800	21·349		
140	2505				

KAMUN PROJEC[T]

CONTOURED PLAN OF

KAMUN RESERVO[IR]

(Signed) H. Tulloch, Captn. R.E.
Ex. Engr. Municipality

CHAPTER XI.

THE KAMUN PROJECT.

The valley, and the quantity of water to be obtained from it.

The general position and extent of the Kamun Valley will be seen on the Index Map facing the title page. It is admirably situated for the storage of water. The lower part of the basin is exceedingly flat, as may be gathered from the fact (*vide* table on Plate XLII.) that a dam impounding only 60 feet depth of water would form a lake of about four square miles, or nearly double the area of Vehar, and one impounding 100 feet depth of water, would have an area of more than six square miles, or nearly three times that of Vehar. The best, in fact the only, site for the main dam is at a spot* immediately below the junction of the two principal streams. These are fed by the rains which fall on the Toongar Hills, and, to judge by their size, they must bring down a very large quantity of water.

As already mentioned, the tide ascends to the very site of the dam, where the bed of the stream is at 80·00 feet on datum. If a reservoir were formed in this valley, it would be necessary to stop up also two gaps in the ridge of hills on the south-west margin of the lake. The length and depth of the required dams may be gathered from Plate XLIII. The area of the watershed above the site of the main dam may be taken at 20 square miles, or 12,800 acres. I have fixed upon

* *Vide* Plate XLII.

140·00 on datum as the level below which the water should not be drawn. A large quantity would be contained in the reservoir even below this level, but my object is to draw the water from as high a point as possible, in order to save the cost of pumping, which, it must be clear to every one, would be necessary before the Kamun water could be supplied to the town. It is true that by drawing the water at a lower level there would be the partially compensating advantage of lower dams, but I have calculated, and find it would be cheaper to construct dams to enable us to draw at 140·00 on datum than to construct lower ones, which would enable us to draw at, say, 120·00 on datum, but would at the same time compel us to pump the water the extra 20 feet. It would be even cheaper to draw the water at a higher level than 140·00 on datum, but then the dams would become higher than I think they should be for the kind of foundation we can find for them.

On the same data* as we applied to the other valleys, and taking the average area of the lake at 5 square miles, the quantity of water obtainable from the Kamun Valley would be :—

3,200 acres × 4,840 × 9 × $8\frac{1}{2}$ × $6\frac{1}{4}$ =	7,405,200,000
9,600 acres × 4,840 × 9 × $4\frac{1}{2}$ × $6\frac{1}{4}$ =	11,761,200,000
	19,166,400,000
Deduct for evaporation—	
3,200 × 4,840 × 9 × $2\frac{1}{2}$ × $6\frac{1}{4}$ =	2,178,000,000
	16,988,400,000
Deduct $\frac{1}{3}$rd for unaccountable waste =	5,662,800,000
	11,325,600,000

—*i.e.*, more than 31 million gallons daily, or, say, 48 gallons per head per diem for the present population.

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* I believe the rain-fall in the Kamun Valley to be considerably greater than that at Vehar. In 1871, 51 inches of rain fell at Kamun, while 39 only fell at Vehar. But it will be better perhaps not to be guided by the results of a single year.

KAMUN PROJECT

SECTIONS OF KAMUN DAMS.

Kell Bros lith London

It will thus be seen that so far as quantity is concerned the supply to be obtained from this low level basin of Kamun is abundant. The facilities for storing the water are also favourable. By reference to the table on Plate XLII. it will be seen that to hold a one-year's supply the surface of the lake must be at about 155·00 on datum—to hold a two-years' supply (say 22,000 million gallons), it must be at 166 on datum, and to hold a three-years' supply (33 million gallons), at 175·00 on datum.

The storage of the water.

The bed of the stream at the site of the main dam is 80·00 on datum, and it would be necessary to go twenty feet below this for a solid foundation, in which case the bottom of the dam would be at 60·00 on datum. If the dams were carried in each instance five feet above the level of the water, the height of the main dam to impound a one, two, and three years' supply, would be as follows :—

	Ft.
To impound 11,000 million gallons, or a one-year's supply (160 – 60)	100
To impound 22,000 million gallons, or a two-years' supply (171 – 60)	111
To impound 33,000 million gallons, or a three-years' supply (180 – 60).................................	120

Of course it is manifest that, with so large a quantity as 48 gallons per head per diem for the present population, it would be absurd at first to store more than a year's supply. Even this would be in excess of what we have in the Vehar Lake when full. In the estimates, therefore, of the Kamun Project, I shall assume that the dams are not to impound at first more than this quantity of water, but they must be constructed so that they may be raised at any subsequent period to impound a full three-years' supply.

The cheapest mode of bringing the water to Bombay

The works required if the water is pumped at Ewoor.

would, beyond all doubt, be by a conduit, and it must be evident to the reader that, considering the low level of the reservoir, it would be impossible to supply the town without pumping up the water by artificial means. Now, it is an important question in this scheme where the water should be pumped. It might be pumped at the lake itself, or at some point between Kamun and Koorla, or at Koorla, where we could have a service reservoir for contingencies, or in Bombay. If it were pumped at any point between Kamun and Koorla, I think the best place would be near the Ewoor Lake, and I would raise the supply, not by steam, but by the water in the latter reservoir. Although this will be considered by many a most novel proposition, still, when the estimates are submitted, the scheme will not be found to compare unfavourably with the others; and at the time of my investigation, when I was not aware how very expensive the Ewoor dams would turn out to be, this seemed the most promising of all the projects. However, the reader shall judge of it for himself.*

I have already proposed to draw the water from the Kamun Reservoir at 140 on datum, and I would adopt the same size of conduit in each of the Kamun projects, as I have in all the other schemes—viz., one with a waterway five feet wide and four deep. And I would give it the same slope as before—viz., one foot per mile.

There would be 9½ miles of conduit at this slope, between Kamun and Ewoor, and half a mile of pipes with a fall of 2½ feet under the Tannah Creek.† The conduit, therefore, starting at 140, would reach Ewoor at 128 on datum. Here the

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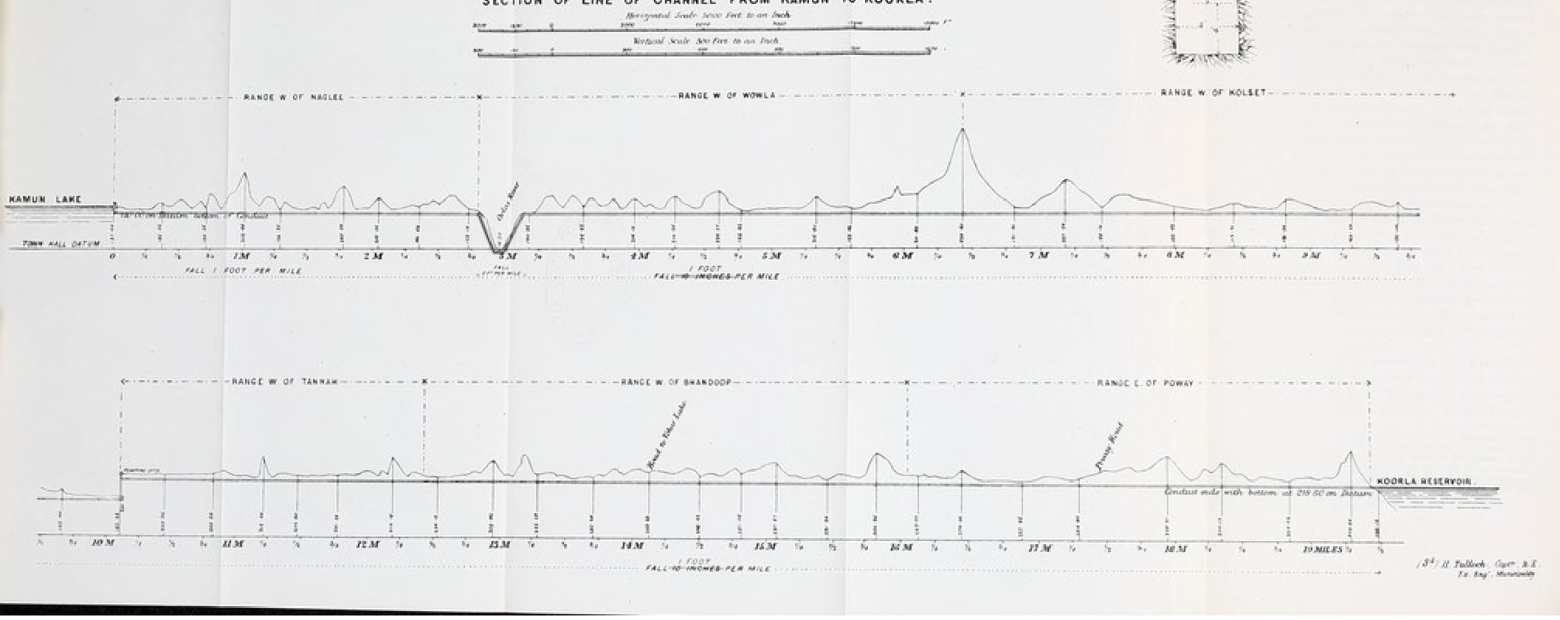
* When I had to leave Bombay so suddenly, both the Ewoor and Kamun Projects were under investigation, and, not having all the facts connected with them before me, I could not then decide finally which of the Kamun Projects would be the cheapest. Had I stayed, I should probably have completed a survey for a low level conduit from Kamun to Bombay; but the estimate submitted further on will show the Bench what the cost of a scheme, if the water is taken to Bombay and pumped up there, will be.

† *Vide* Oolas River. Plate XLIV.

KAMUN PROJECT.

Section of Line of Channel from Kamun to Koorla.



water would be pumped 100 feet, as I will presently explain at greater length, and then proceed in a conduit with the same slope as before till it reached the Lower Koorla Reservoir,* a distance from Ewoor of 9½ miles, at 218½ on datum.

The only obstacle of consequence on any line of conduit from Kamun to Bombay is the Tannah Creek, and I think this could best be overcome by a tunnel. Vertical shafts should be sunk† on each side to a depth of not less than 50 feet below the bed of the stream, which at the site is solid rock, and tunnels should then be driven from each end to meet in the middle. The width of the stream is but little more than a quarter of a mile, and I know of nothing to render the work unsuccessful. A tunnel would be cheaper than an aqueduct over the stream, as the current in this part of the creek is very strong, and the erection of piers would be more than ordinarily expensive.‡

Now, as to the works at Ewoor, I have already shown that the Ewoor Valley is very badly situated for the storage of water, but there is one point in connection with the scheme which, if the Kamun Project were contemplated, might render it advisable to carry out the two together. This point is that, although the water to be obtained from Ewoor would be small in quantity, yet it would be at so great an elevation as to be a most useful mechanical power for raising the Kamun water to a higher level. The yearly supply—2,400 million gallons—would lie at an average height for use of, say, 470 on datum.§ Now the Kamun water could, as I have shown, be brought to

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* *Vide* Plate XLV.

† In Plate XLIV. they are shown inclined, but this is an accidental error, and the tunnel is not put at a sufficient depth below the bed of the river.

‡ If an aqueduct were adopted, the suspension principle seems at first sight the best to apply, in order to obviate the necessity of piers, but there are grave objections to this, as any one will find who goes into the subject.

§ I am supposing that at least a two-years' supply is stored in Ewoor; and, if this were done, the water used every ordinary year—*i.e.*, when there was no failure of the monsoon—would lie (*vide* pages 134 and 135) between 481 and 464 on datum, or at an average level of 472½. I prefer, however, to say 470, as in the text.

Ewoor at 128 on datum. We should therefore have a power equal to 2,400 million gallons falling through (470 − 128), 342 feet. Theoretically, this should raise three times the quantity more than 100 feet high, but there is always a considerable loss of power even in the best engines. Suppose turbines, which are the most approved form of water engine, were used, and a loss of power of 25 per cent. took place, and suppose that, instead of dropping the water down 342 feet, which would necessitate its being wasted, we dropped it 242 feet, and let the water, after doing its useful work, flow off with the Kamun water in the same channel as the latter, we should then be able to raise ($\frac{3}{4} \times \frac{2,400 \times 242}{100} =$) 4,356 million gallons, which, with the Ewoor water (2,400 million gallons), would give us a total supply of, say, 6,756 million gallons yearly, which is about $18\frac{1}{2}$ million gallons daily,* or, say, $28\frac{1}{2}$ gallons per head per diem for the present population.

If more water than this quantity were required, there would be no help for it but to pump it by steam. The Toolsee water would be too small in quantity to use in the same way, and more than one pumping station would be objectionable.

Of course, if such a scheme as the above were ever contemplated, it would be better to impound a full three-years' supply from the very beginning in the Ewoor Lake,† as there would then be very little risk of the supply falling short through the failure of the monsoon. Without water in the Ewoor Lake to pump up the Kamun water, there would be no supply to Bombay.

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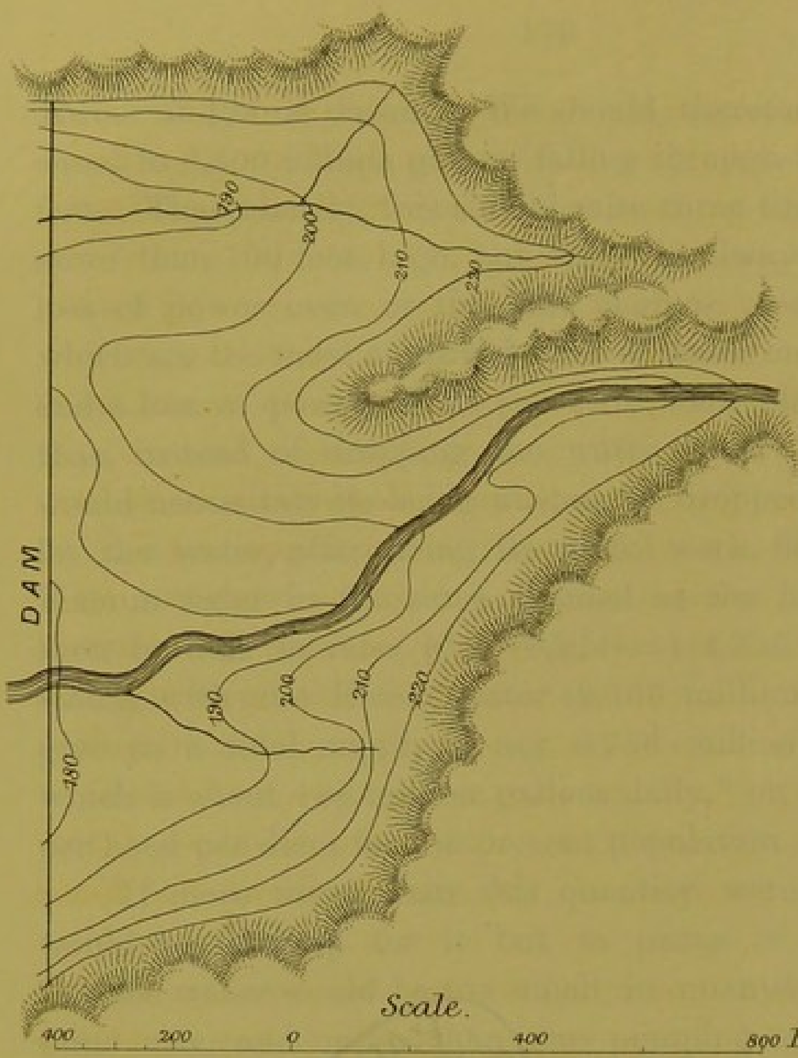
* The channel I propose—viz., one with a waterway five feet wide and four deep, would, with the slope to be given to it—viz., twelve inches per mile —carry away only $17\frac{1}{3}$ million gallons, so that there would be about a million gallons left. Instead of making the conduit a little larger or giving it a greater slope to carry away the full $18\frac{1}{2}$ million gallons, I would retain the one million for the use of the towns of Tannah and Bhandoop.

† In this case, as the water would lie about 18 feet higher, we should be able to pump up about one million gallons more, so that the total supply would be about $19\frac{1}{2}$ million gallons daily.

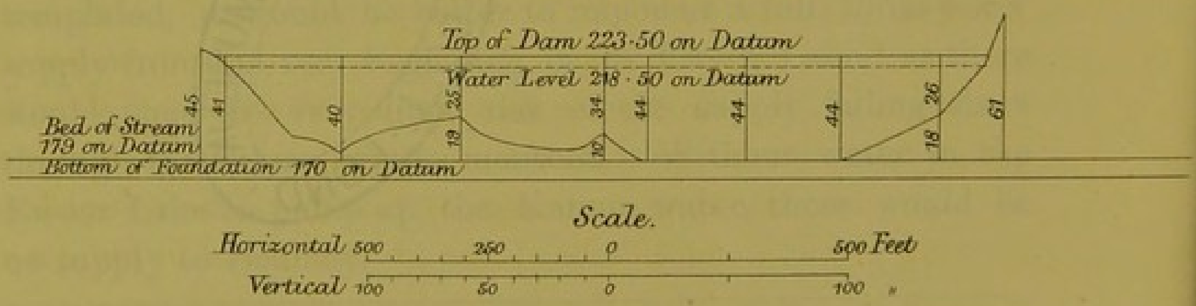
KAMUN PROJECT.

CONTOURED PLAN OF THE LOWER KOORLA RESERVOIR.

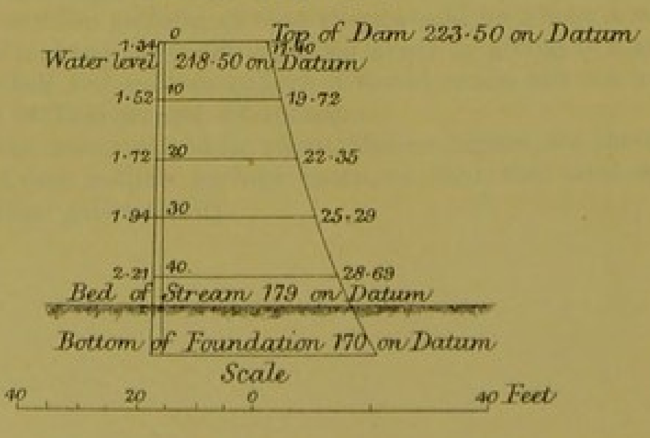


Contours on Datum	Area in Acres	Capacity in Gallons between the different contours	Total quantity of water in Gallons between the 180 (below which the water will not be drawn) and the other contours.
220	16.3	60,557,000	129,398,369
210	18.09	39,902,310	68,841,367
200	11.21	21,903,120	28,939,057
190	4.87	7,035,937	7,035,937
180	0.29		

LONGITUDINAL SECTION OF DAM.



CROSS SECTION.



Kell Bros. lith.

The outlet works at the Kamun Reservoir would be on the principle of those proposed for the Tansa Project,* and the waste weir would be a work of easy construction. The water might be passed into the lower part of the valley, or at several points over the ridge on the south-west margin of the lake, or into the Payah Valley,† close to the spot from which the conduit would start for Bombay.

Kamun Outlet Works.

The details of the Lower Koorla Reservoir will be best understood by reference to Plate XLV. It is intended simply for service purposes, from which the water would be sent to Bombay under pressure. It would be capable of holding nearly 130 million gallons, or, say, about a fortnight's supply at 10 million gallons daily. The dam, although a long one, would not be more than about fifty feet high. The water would be drawn for use on the principle of the system shown in Plate XXXVIII.

Lower Koorla Reservoir.

From Koorla a pipe would be laid to Bombay, and its size would of course depend on the quantity of water required by the town. It would follow the same course as the other pipes from Koorla, a section of which is shown in Plate XXXII.

Suppose, however, that instead of using the Ewoor water to raise the Kamun supply, we employed steam; I do not think there would be any advantage in fixing the pumps at Koorla. The choice lies between Kamun and Bombay. The great expense in pumping schemes is that of the coal consumed, which would have to be taken to Koorla by railway; whereas it could be delivered at Kamun by boats, there being water communication all the way between this town and the Bombay harbour. Besides this, there is no compensating advantage in the position of Koorla,

Pumping at Koorla rejected.

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* *Vide* Plate XXXVIII. † *Vide* Map facing title page.

whereas there are advantages attached to both Kamun and Bombay.

The works required if the water is pumped in Bombay.

If the water were brought to Bombay to be pumped, I do not think, considering the levels of the ground even along the best line which the conduit could take across the low lands* between Koorla and the island, and in the island, that it would be advantageous to carry it in at a higher level than about 90 on datum. It might be carried in at 100 on datum, but only at great expense, as I will show. The draw-off point in the Kamun Lake could not well be higher than 140 on datum, and there being 19 miles of conduit with a slope of 1 foot per mile, and half a mile of pipe at a slope of 5 feet per mile, the water could not therefore reach Koorla above about 118½ on datum. From Koorla there would still remain 9½ miles of distance to Bombay, and of this length it appears to me that it would be best to have about 4 miles of pipes and 5½ of conduit. If we had a conduit all the way from Koorla to Bombay, along the 4 miles where I have proposed to lay pipes, we should require a masonry aqueduct standing from 20 to 25 feet above the surface of the ground, and such a work would be more expensive than a pipe. If, then, we say, a pipe is preferable, the slope to be given to it should be as before—5 feet per mile, or 20 feet for the 4 miles, and for the 5½ miles of conduit we should require a slope of 5½ feet. So that the total fall of the conduit and pipe from Koorla to Bombay would be 25½ feet, and if we deduct this from the level, 118½ on datum, at which the water would arrive at Koorla, we find that it would reach Bombay at 93 on datum.†

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* *Vide* Plate XXXII., where it will be seen that along the 2nd, 3rd, and 4th miles the lands are not above 87 on datum, or just about the level of high water, and for part of the 5th and 6th miles also the ground is very low.

† No special survey has been made for this low level line of conduit and pipe from Kamun to Bombay, because it would have been mere waste of money to do so, while we had so much information already to enable us to decide on the merits of the scheme. In fact, no survey is required except for

I prefer, however, to say 90, because the ground lies better for a conduit at this level than for one a little higher.

Having now got our water into Bombay, the question is, how high it should be pumped. On this point I fear there will be some diversity of opinion. I have hitherto assumed that the average level at which Bombay stands for water-supply purposes—*i.e.*, the average level at which the water is drawn for use—is at about 100 on datum.* I think the water should be pumped somewhat more than 100 feet, or say 125 feet. Some may think the former height sufficient, and I should not oppose the proposition, but I suggest the latter as probably the one that will be preferred.†

The cost, then, of the Kamun Scheme, if the water were raised in Bombay, would be chiefly made up by the following items—the cost of the reservoir and land at Kamun—of 24½ miles of conduit—of 4½ miles of pipe—of engines, pumps, and engine and boiler-houses in the town—of a service reservoir for use in cases of emergency—and of the

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the portion between Ewoor and Koorla. The first portion of the line—*i.e.*, from Kamun to Ewoor—has been surveyed, and is precisely the same as that given in Plate XLIV., and the last portion—*i.e.*, from Koorla to Bombay—is given in Plate XXXII. It is only the intermediate portion for which a survey could be required. But any one will see that if we can have a high level conduit between Ewoor and Koorla—and I have shown we can in my description of the Ewoor and Tansa Projects, and by Plates XXXV. and XL.—we can of course have a low level one.

* This must not be confounded with the mean between the greatest height and the lowest level at which the water is drawn in Bombay. Of course some water is drawn at even 180 on datum, but this amounts to a very small quantity. Nine-tenths of the supply is drawn on the ground-floors of the houses and into wells, and these draw-off points are at very low levels—85, 90, and 95 on datum.

† When I first brought forward the idea of a low level reservoir with pumping in Bombay (which was in 1869, while the Commission on the Water-supply and Drainage was sitting), several engineers in the town seemed to think that 100 feet pressure in the mains, while we now had from Vehar a theoretical pressure of 160 feet, and an actual one of 140, as proved by experiment, would not be wise. I have, therefore, thought it best to suggest a pressure somewhat greater than this.

fuel consumed in raising the water. This last item must be capitalised.

The works required if water is pumped at Kamun.

Now let us consider what would be the effect if the water were pumped up at Kamun. The great advantage would be that it would never have to be raised so high as in Bombay. In the latter case the water would, as the reader has been informed, leave the lake at 140, and arrive in the town at 90 on datum. But the water in the lake itself would be higher than at 140, for, with even a one-year's supply, the surface of the Kamun Lake would stand at 155, with a two-years' supply at 166, and with a three-years' at 175. It would be most advantageous to store at once a three-years' supply, because the additional cost of the dams is not great. Suppose we did impound a three-years' supply at Kamun, then the water which would be used every year would lie between, say, 175 and 170. As a rule, therefore, we should not have to pump any water from below this point. We have proposed that, if the water were raised in Bombay, it should be about 125 feet, or up to 215 on datum. Now, if the water were pumped at Kamun, it is quite clear that it should be distributed to Bombay by a service reservoir at Koorla. The question, therefore, is, in order to effect a comparison between the two schemes, at what level the water should be brought to Koorla. Let me assume that the water is thrown either into the Upper or the Lower Koorla Reservoir. The great advantage of the former would be, of course, that we should command Vehar, and be able to fill that lake at any time we wished to do so. The advantage of the latter would be that we should not have to pump the water so high; but it must be remembered, on the other hand, that we should not have so great a pressure in the town by nearly 40 feet.

Supposing, then, we brought the Kamun water to the Upper Koorla Reservoir, and at the same level as the Kennery, Ewoor, and Tansa, waters would flow into it, or at 255·50 on datum.* The distance between Kamun and Koorla being $19\frac{1}{2}$ miles, $18\frac{1}{4}$ of this would consist of conduit with a slope of 1 foot per mile—there would be $\frac{1}{2}$ a mile of syphon under the creek and $\frac{3}{4}$ of a mile of syphon along the depression in the hills, or $1\frac{1}{4}$ mile of pipe with a slope of 5 feet per mile, or altogether of $6\frac{1}{4}$ feet. So that the water, in order to reach the Upper Koorla Reservoir at $255\frac{1}{2}$ on datum, would have to start from Kamun at ($255\frac{1}{2} + 18\frac{1}{4} + 6\frac{1}{4}$, or at) 280 on datum, and would have to be pumped up to this level from 170 on datum. The lift, therefore, would be 110 feet.

If the water were thrown into the Lower Koorla Reservoir, it would have to start from Kamun at 240 on datum,† and, having to be pumped to this level from 170 on datum, the lift would be 70 feet only.‡

The relative cost of the different schemes will be seen presently, when the estimates are given, but I will first notice such other points as call for remark.

The land required.

The land which would have to be taken up for the Kamun Reservoir would be more expensive than that for any other lake proposed in this report. The valley being exceedingly flat, it is well adapted for cultivation, and much grain and straw are produced and taken elsewhere. Large quantities, also, of firewood are sent in to Bombay. In fact, there is a considerable trade carried on by means of

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* There has been no special survey made for this high level line from Kamun to Koorla, but I need hardly say it is perfectly feasible. In fact, there is no survey required except for the portion between Kamun and Ewoor. The line from Ewoor to Koorla would be the same as that for the Ewoor and Tansa Schemes, sections of which are given on Plates XXXV. and XL. As there are high hills all the way between Kamun and Ewoor, of course a high level conduit could be made between these points.

† *Vide* page 168.

‡ No special survey has been made for this low level line. There is none required, except for the portion between Ewoor and Koorla. The line between Kamun and Ewoor would be the same as that shown in Plate XLIV. As we can have a high level conduit between Ewoor and Koorla, of course we can have a low level one.

barges between Kamun, which is a village of some local importance, and the neighbouring towns. Besides Kamun itself, five other villages would be swamped in the event of a reservoir being formed, and the amount of compensation for all the houses and land, and for the loss of trade, would be considerable. Unless the villages were removed, and the occupation of the watershed altogether prevented, objections would be made to the character of the water, but, if these measures were adopted, the water would be perhaps not quite so pure as the present supply from Vehar, but still pure enough for all practical purposes.

The quality of the water.

Estimate No. 1.

COST OF KAMUN SCHEME FOR A SUPPLY OF 8¼ MILLION GALLONS DAILY.

Supply to be pumped by turbines worked by the Ewoor water. Dams at Kamun to impound a one-year's supply from the valley, but equal to 16 gallons per head per diem for three years for the present population :—

19 miles of conduit, with a waterway 5 feet wide and 4 deep, between Kamun and Koorla, at Rs.80,000 a mile................................	Rs.15,20,000
½ a mile of syphon pipe under Tannah Creek, 36 inches in diameter and 1⅛ inch thick, delivering 8¼ million gallons daily, and weighing 510 tons at Rs.160 a ton...........	81,600
Tunnel under Creek....................................	1,50,000
9½ miles of pipe, from Koorla to Bombay, delivering 8¼ million gallons daily, 30 inches in diameter and 1 inch thick, weighing 790 tons per mile, or 7,505 tons at Rs.160 a ton.	12,00,800
Carried forward ....Total	Rs.29,52,400

Brought forward	Rs.29,52,400
Lower Koorla Reservoir,* with its outlet works and waste weir	5,00,000
No. 1 Dam, Kamun Reservoir (100 feet high, but capable of being raised to the height of 120 feet), containing 5,719,000 cubic feet of rubble masonry at Rs.25 per 100 cubic feet.	14,29,750
No. 2 Dam, containing 485,200 cubic feet of masonry †	1,21,300
No. 3 Dam, containing 1,154,200 cubic feet of masonry..	2,88,540
Kamun Waste Weir	1,50,000
Kamun Outlet Works..................................	90,000
Ewoor Dams and Outlet Works (a two-years' supply from the Ewoor Valley being impounded in the lake), *vide* page 142	28,46,000
Ewoor Waste Weir	1,25,000
$1\frac{1}{2}$ miles of conduit from Ewoor Lake to Turbine Pumping-station at Rs.80,000 a mile.........	1,20,000
Turbines to raise $8\frac{1}{4}$ million gallons daily 100 feet high, and all pumping arrangements and buildings..	3,50,000
	Rs.89,72,990
Add 10 per cent. for contingencies, say......	8,97,010
	Rs.98,70,000
Land for Kamun Reservoir, channels and pipes, and compensation for houses and loss of trade	5,00,000
Land for Ewoor Reservoir	75,000
Total Rs.104,45,000	

* If a thinner section for the dam be insisted upon than that shown in Plate XLV., there will be a reduction in this item of about Rs.75,000.

† If thinner sections than those shown in Plate XLIII. be insisted upo for Nos. 2 and 3 Dams, the reduction in the two items would amount to about Rs.1,00,000.

Or, say, 104½ lakhs for 13 gallons per head per diem for the present population.

If the Ewoor Dams were made high enough to impound a three-years' supply, the cost for the same quantity of water delivered would be about 9 lakhs more, or 113½ lakhs.

Estimate No. 2.

COST OF KAMUN SCHEME FOR A SUPPLY OF 13 MILLION GALLONS DAILY.

Supply to be pumped by turbines as before. Dams at Kamun to impound as before a one-year's supply from the valley:—

19 miles of conduit, as before	Rs.15,20,000
½ a mile of syphon pipe under Tannah Creek, 42 inches in diameter and 1¼ inch thick, delivering 13 million gallons daily, and weighing 682 tons at Rs.160 a ton	1,09,120
Tunnel under Creek as before	1,50,000
9½ miles of pipe from Koorla to Bombay, 36 inches in diameter, and 1⅛ inch thick, delivering 13 million gallons daily, and weighing 1,020 tons per mile, or 9,690 tons at Rs.160 a ton	15,50,400
Lower Koorla Reservoir, with its outlet works and waste weir, as before	5,00,000
No. 1 Dam, Kamun Reservoir, as before	14,29,750
No. 2 Dam, Kamun Reservoir, as before	1,21,300
No. 3 Dam, Kamun Reservoir, as before	2,88,540
Kamun Waste Weir, as before	1,50,000
Kamun Outlet Works Weir, as before	90,000
Ewoor Dams and Outlet Works, as before	28,46,000
Ewoor Waste Weir, as before	1,25,000
Carried forward .... Total	Rs.88,80,110

Brought forward	Rs.88,80,110
1½ miles of conduit, as before	1,20,000
Turbines and Pumping arrangements and Buildings to raise 13 million gallons 100 feet high daily	5,00,000
	95,00,110
Add 10 per cent. for contingencies, say	9,50,890
	104,51,000
Land, as before—viz.	5,75,000
Total	Rs.110,26,000

Or, say, 110¼ lakhs for 20 gallons per head per diem for the present population.

As before, it must be borne in mind that the Ewoor Dams have been estimated to impound a two-years' supply only, and for a three-years' supply about 9 lakhs must be added to this estimate.

Estimate No. 3.

COST OF KAMUN SCHEME FOR A SUPPLY OF OVER 17 MILLION GALLONS DAILY.

Supply to be pumped by turbines as before. Dams to impound a one-year's supply from the valley as before:—

19 miles of conduit, as before	Rs.15,20,000
½ a mile of syphon pipe under Tannah Creek, 48 inches in diameter, 1½ inch thick, delivering over 17 million gallons daily, and weighing 880 tons, at Rs.160 a ton	1,40,800
Tunnel under Creek, as before	1,50,000
9½ miles of pipe from Koorla to Bombay, 42 inches in diameter, and 1¼ inch thick, delivering over 17 million gallons daily, and weighing 1,360 tons per mile, or 12,958 tons at Rs.160 a ton	20,73,280
Carried forward ....Total	Rs.38,84,080

Brought forward	Rs.38,84,080
Lower Koorla Reservoir, with its Outlet Works and Waste Weir, as before	5,00,000
No. 1 Dam, Kamun Reservoir, as before	14,29,750
No. 2 Dam, Kamun Reservoir, as before	1,21,300
No. 3 Dam, Kamun Reservoir, as before	2,88,540
Kamun Waste Weir, as before	1,50,000
Kamun Outlet Works, as before......................	90,000
Ewoor Dams and Outlet Works, as before	28,46,000
Ewoor Waste Weir, as before	1,25,000
1½ miles of conduit, as before	1,20,000
Turbines to raise over 17 million gallons daily 100 feet high, and all pumping arrangements and buildings	6,50,000
	102,04,670
Add 10 per cent. for contingencies—say	10,20,330
	112,25,000
Land, as before...	5,75,000
Total	Rs.118,00,000

Or 118 lakhs for 26 gallons per head per diem for the present population.

And if a three-years' supply were stored in Ewoor for pumping purposes, the cost would be about 127 lakhs.

Estimate No. 4.

COST OF KAMUN SCHEME FOR A SUPPLY OF 8¼ MILLION GALLONS DAILY.

Supply to be pumped by steam in Bombay. Dams at Kamun to impound, as before, a one-year's supply from the valley :—

24½ miles of conduit, with a waterway 5 feet wide and 4 deep, between Kamun and Bombay, at Rs.80,000 a mile	Rs.19,60,000

Brought forward	Rs.19,60,000
½ a mile of syphon pipe under Tannah Creek, 36 inches in diameter and 1⅛ inch thick, delivering 8¼ million gallons daily, and weighing 510 tons, at Rs.160 a ton.........................	81,600
Tunnel under Creek..................................	1,50,000
4 miles of pipe, for the low ground about Koorla and in the island, 36 inches in diameter and 1⅛ inch thick, delivering 8¼ million gallons daily, and weighing 1,020 tons per mile, or 4,080 tons at Rs.160 a ton	6,52,800
No. 1 Dam, Kamun Reservoir, as before	14,29,750
No. 2 Dam, Kamun Reservoir, as before	1,21,300
No. 3 Dam, Kamun Reservoir, as before	2,88,540
Kamun Waste Weir, as before	1,50,000
Kamun Outlet Works, as before.....................	90,000
Engines of 300 nominal horse-power,* to raise 8¼ million gallons daily 125 feet high, at Rs.1,800 per H.P., including erection and everything...	5,40,000
Engine-houses, boiler-houses, coal-sheds, stand-pipes, and all arrangements in Bombay......	3,00,000
Service Reservoirs† in Bombay	5,00,000
	62,63,990
Add 10 per cent. for contingencies..................	6,26,010
	68,90,000
Land at Kamun, and for conduits and pipes	5,00,000
Cost of fuel for raising 8¼ million gallons daily 125 feet high, on the supposition that the average duty ‡ of the engines is 40,000,000	

* The actual horse-power by calculation is only about 220, but we must have some reserve of power for contingencies.

† If these were dispensed with, the engine-power should be increased by about 100 horse-power, but service reservoirs would be preferable for so large a town.

‡ The average duty for a whole year of the engines at the Sewage

pounds raised a foot high with a bushel 94 pounds of coal, or, say, 4,000 tons of coal yearly at Rs.30 a ton,* amounting to Rs.1,20,000 yearly, and supposing this sum capitalised at 6 per cent..........................	20,00,000
Total	Rs.93,90,000

Or, say, 94 lakhs of rupees for 13 gallons per head per diem for the present population.

If coals were at 35 Rs. a ton, the cost for the same quantity of water, raised 125 feet high, would be 97 lakhs.

If the water were raised 100 feet high only, and coals were at Rs.30 a ton, the cost of the project for 8¼ million gallons daily would be about 88 lakhs altogether.

If the watei were raised 100 feet high, and coals were at 35 Rs. a ton, the cost for the same quantity would be about 91 lakhs.

Estimate No. 5.

COST OF KAMUN SCHEME, FOR A SUPPLY OF 13 MILLION GALLONS DAILY.

Supply to be pumped by steam in Bombay. Dams at Kamun, as before, to impound a one-year's supply from the valley :—

24½ miles of conduit, as before.....................	Rs.19,60,000
½ a mile of syphon pipe under Creek, 42 inches in diameter, and 1¼ inches thick, delivering 13 million gallons daily, and weighing 682 tons, at 160 Rs. a ton	1,09,120
Carried forward ....Total	Rs.20,69,120

pumping-station at Crossness has been 75,000,000 foot pounds, but I assume that the coal in Bombay will not produce more than the above useful effect. I think this is fair, but I am aware that many are of opinion that coal loses fully half its power in India. The average dnty of Cornish engines is only 60,000,000 foot lbs. and the half of this would be but 30,000,000 foot lbs.

* The price of coal varies from year to year, and is exceptionally high at this moment; but I think Rs.30 a ton fairly represents the average cost.

Brought forward ....Rs.	20,69,120
Tunnel under Creek as before........................	1,50,000
4 miles of pipe, for the low ground about Koorla and in the island, 42 inches in diameter, and 1¼ inches thick, delivering 13 million gallons daily, and weighing 1,364 tons per mile, or 5,456 tons at 160 Rs. a ton	8,72,960
No. 1 Dam, Kamun Reservoir, as before	14,29,750
No. 2 Dam, Kamun Reservoir, as before	1,21,300
No. 3 Dam, Kamun Reservoir, as before	2,88,540
Kamun Waste Weir, as before	1,50,000
Kamun Outlet Works, as before......................	90,000
Engines of, say, 450 nominal horse-power* to raise 13 million gallons daily, 125 feet high, at 1,800 Rs. per horse-power, including erection and everything	8,10,000
Engine-houses, boiler houses, coal-sheds, stand-pipes, and all arrangements in Bombay......	3,50,000
Service Reservoirs in Bombay	5,00,000
Total ....Rs.	68,31,670
Add 10 per cent for contingencies	6,83,330
	75,15,000
Land at Kamun, and for conduits and pipes......	5,00,000
Cost of fuel for raising 13 million gallons daily 125 feet high: say, 6,200 tons at 30 Rs. a ton, or 1,86,000 Rs. yearly, representing, at 6 per cent., a capital of	31,00,000
Total ....Rs.	111,15,000

Or, say, 111¼ lakhs of rupees for 20 gallons per head per diem for the present population.

If coals were at Rs.35 a ton, the cost for the same quantity of water raised 125 feet high would be 116¼ lakhs.

* The actual horse-power by calculation comes to about 340, but, as before, we must allow for contingencies.

If the water were raised 100 feet high only, and coals were at 30 Rs. per ton, the cost of the project for 13 million gallons would be about 102 lakhs of rupees.

If the water were raised 100 feet high, and coals were at Rs.35 a ton, the cost for the same supply would be about 107 lakhs.

Estimate No. 6.

COST OF KAMUN SCHEME FOR A SUPPLY OF 17 MILLION GALLONS DAILY.

Supply to be pumped by steam in Bombay. Dams at Kamun, as before, to impound a one-year's supply :—

24½ miles of conduit, as before	Rs.19,60,000
½ a mile of syphon pipe under Creek, 48 inches in diameter and 1½ inches thick, delivering over 17 million gallons daily, and weighing 880 tons, at Rs.160 a ton	1,40,800
Tunnel under Creek, as before	1,50,000
4 miles of pipe for the low ground about Koorla and in the island, 48 inches in diameter and 1½ inches thick, delivering over 17 million gallons daily, and weighing 1,760 tons per mile, or 7,040 tons at Rs.160 a ton	11,26,400
No. 1 Dam, Kamun Reservoir, as before	14,29,750
No. 2 Dam, Kamun Reservoir, as before	1,21,300
No. 3 Dam, Kamun Reservoir, as before	2,88,540
Kamun Waste Weir, as before	1,50,000
Kamun Outlet Works, as before	90,000
Engines of, say, 600 nominal horse-power,* to raise 17 million gallons daily, 125 feet high, at Rs.1,800 per horse-power, including everything	10,80,000
Carried forward ....Total	Rs.65,36,790

* The actual horse-power by calculation comes to about 450.

Brought forward ....Rs.	65,36,790
Engine-houses, boiler-houses, coal-sheds, stand-pipes, &c., and all arrangements in Bombay.	4,00,000
Service Reservoirs in Bombay	5,00,000
Total ....Rs.	74,36,790
Add 10 per cent. for contingencies, say............	7,43,210
	81,80,000
Land at Kamun for conduit and pipes, as before	5,00,000
Cost of fuel for raising 17 million gallons daily 125 feet high, say, 8,000 tons, at Rs.30 a ton, or Rs.2,40,000 yearly, representing, at 6 per cent., a capital of	40,00,000
Total ....Rs.	126,80,000

Or, say, 127 lakhs for 26 gallons per head per diem for the present population.

If coals were at Rs.35 a ton, the cost for the same supply, raised 125 feet high, would be about 133½ lakhs.

If the water were raised 100 feet high only, and coals were at Rs.30 per ton, the cost of the project for 17 million gallons would be about 116½ lakhs.

If the water were raised 100 feet high, and coals were at Rs.35 a ton, the cost for the same supply would be about 122 lakhs.

Estimate No. 7.

COST OF KAMUN SCHEME FOR A SUPPLY OF 8¼ MILLION GALLONS DAILY.

Supply to be pumped by steam at Kamun and to flow into the Lower Koorla Reservoir. Dams to impound a three-years' supply from the valley :—

19 miles of conduit, as per Estimate No. 1 ......Rs.	15,20,000

Brought forward	Rs.15,20,000
½ mile of syphon pipe under Creek, ditto	81,600
Tunnel under Creek, ditto	1,50,000
9½ miles of pipe from Koorla, ditto..................	12,00,800
Lower Koorla Reservoir, ditto	5,00,000
No. 1 Dam, Kamun Reservoir (120 feet high), containing 6,500,000 cubic feet of masonry, at 25 Rs. per 100 cubic feet	16,25,000
No. 2 Dam, containing 750,500 cubic feet.........	1,87,625
No. 3 Dam, containing 1,986,400 cubic feet	4,96,600
Kamun Waste Weir....................................	1,50,000
Kamun Outlet Works	1,50,000
Engines of 200 nominal horse-power,* to raise 8¼ million gallons daily 70 feet high, at 1,800 Rs. per horse-power	3,60,000
Engine-houses, boiler-houses, and all arrangements at Kamun	2,00,000
	66,21,625
Add 10 per cent for contingencies, say	6,62,375
	72,84,000
Land at Kamun, and for conduits and pipes ...	5,00,000
Cost of fuel for raising 8¼ million gallons daily 70 feet high, say 2,160 tons at 30 Rs. a ton, or 64,800 Rs. yearly, representing, at 6 per cent., a capital of	10,80,000
Total............................	Rs.88,64,000

Or, say, 88¾ lakhs of rupees for 13 gallons per head per diem for the present population.

If coal be taken at 35 Rs. per ton, the cost for the same quantity of water would be about 90 lakhs.

* The actual power required by calculation is a little over 120.

Estimate No. 8.

COST OF KAMUN SCHEME FOR A SUPPLY OF 13 MILLION GALLONS DAILY.

Supply to be pumped at Kamun, and to flow into the Lower Koorla Reservoir. Dams to impound a three-years' supply from the valley :—

19 miles of conduit, as per Estimate No. 2	Rs. 15,20,000
½ mile of syphon-pipe under Creek, ditto	1,09,120
Tunnel under Creek, ditto	1,50,000
9½ miles of pipe from Koorla, ditto	15,50,400
Lower Koorla Reservoir, as before	5,00,000
No. 1 Dam, Kamun Reservoir (120 feet high), as before	16,25,000
No. 2 Dam, Kamun Reservoir (120 feet high), as before	1,87,625
No. 3 Dam, Kamun Reservoir (120 feet high), as before	4,96,600
Kamun Waste Weir	1,50,000
Kamun Outlet Works	1,50,000
Engines of, say, 260 nominal horse-power* to raise 13 million gallons 70 feet high, at 1,800 Rs. per horse-power	4,68,000
Engine-houses, boiler-houses, and all arrangements at Kamun	2,00,000
	71,06,745
Add 10 per cent. for contingencies, say	7,10,255
	78,17,000
Land at Kamun, and for conduits and pipes	5,00,000
Carried forward .... Total	Rs. 83,17,000

* The actual horse-power is, by calculation, about 190.

Brought forward	Rs.83,17,000
Cost of fuel for raising 13 million gallons daily 70 feet high, say 3,400 tons, at 30 Rs. per ton, or 1,02,000 Rs. yearly, representing, at 6 per cent., a capital of	17,00,000
Total	Rs. 100,17,000

Or, say, 100¼ lakhs of rupees for 20 gallons per head per diem for the present population.

If coal be taken at 35 Rs. per ton, the cost for the same quantity of water would be about 102 lakhs.

Estimate No. 9.

COST OF KAMUN SCHEME FOR A SUPPLY OF 17 MILLION GALLONS DAILY.

Supply to be pumped by steam at Kamun and to flow into the Lower Koorla Reservoir. Dams to impound a three-years' supply from the valley :—

19 miles of conduit, as per Estimate No. 3	Rs.15,20,000
½ mile syphon pipe under Creek, as per Estimate No. 3	1,40,800
Tunnel under Creek, as per Estimate No. 3	1,50,000
9½ miles of pipe from Koorla, as per Estimate No. 3	20,73,280
Lower Koorla Reservoir, as before	5,00,000
No. 1 Dam, Kamun Reservoir (120 feet high), as before	16,25,000
No. 2 Dam, Kamun Reservoir, as before	1,87,625
No. 3 Dam, Kamun Reservoir, as before	4,96,600
Kamun Waste Weir	1,50,000
Kamun Outlet Works	1,50,000
Carried forward ....Total	Rs.69,93,305

Brought forward	Rs.69,93,305
Engines of 350 nominal horse-power,* to raise 17 million gallons daily 70 feet high, at 1,800 Rs. per horse-power	6,30,000
Engine-houses, boiler-houses, and all arrangements at Kamun	2,00,000
	78,23,305
Add 10 per cent. for contingencies, say...........	7,82,695
	86,06,000
Land at Kamun, and for conduits and pipes	5,00,000
Cost of fuel for raising 17 million gallons daily 70 feet high, say 4,500 tons at 30 Rs. a ton, or 1,35,000 Rs. yearly, representing, at 6 per cent., a capital of	22,50,000
Total	Rs.113,56,000

Or, say, 113½ lakhs for 26 gallons per head per diem for the present population.

If coal be taken at 35 Rs. per ton, the cost for the same quantity of water would be about 117¼ lakhs.

Estimate No. 10.

COST OF KAMUN SCHEME FOR A SUPPLY OF 8¼ MILLION GALLONS DAILY.

Supply to be pumped by steam at Kamun, and to flow into the Upper Koorla Reservoir. Dams to impound a three-years' supply from the valley :—

18¼ miles of conduit, at Rs.80,000 a mile.........	Rs. 14,60,000
1¼ mile of syphon pipe (under Creek and along depression in the hills), 36 inches in diameter and 1⅛ inch thick, delivering 8¼ million gallons daily, and weighing 1,020 tons per mile, or 1,275 tons at Rs.160 a ton	2,04,000
Carried forward ....Total	Rs. 16,64,000

* The actual horse-power required by calculation is about 250.

Brought forward	Rs.16,64,000
Tunnel under Creek, as before	1,50,000
9½ miles of pipe, from Koorla to Bombay, 28 inches in diameter and 1 inch thick, delivering 8¼ million gallons daily, and weighing 720 tons per mile, or 6,840 tons at Rs.160 a ton	10,94,400
Upper Koorla Reservoir, as before	3,00,000
No. 1 Dam, Kamun Reservoir (120 feet high), as before	16,25,000
No. 2 Dam, Kamun Reservoir (120 feet high), as before	1,87,625
No. 3 Dam, Kamun Reservoir (120 feet high), as before	4,96,600
Kamun Waste Weir, as before	1,50,000
Kamun Outlet Works, as before	1,50,000
Engines of, say, 260 horse-power,* nominal, to raise 8¼ million gallons 110 feet high, at Rs.1,800 per horse-power	4,68,000
Engine-houses, boiler-houses, and all arrangements at Kamun	2,00,000
	64,85,625
Add 10 per cent for contingencies, say	6,48,375
Land at Kamun, and for conduits and pipes	5,00,000
Cost of fuel for raising 8¼ million gallons daily 110 feet high, say 3,400 tons at Rs.30 a ton or, Rs.1,02,000 yearly, representing, at 6 per cent., a capital of	17,00,000
Total	Rs.93,34,000

Or, say, 93½ lakhs of rupees for 13 gallons per head per diem for the present population.

If coal be taken at Rs.35 per ton, the cost for the same quantity of water daily would be about 96½ lakhs.

* The actual horse-power by calculation is a little over 190.

Estimate No. 11.

COST OF KAMUN SCHEME FOR A SUPPLY OF 13 MILLION GALLONS DAILY.

Supply to be pumped by steam at Kamun, and to flow into the Upper Koorla Reservoir. Dams to impound a three-years' supply from the valley :—

$18\frac{1}{4}$ miles of conduit, as per previous Estimate...	Rs.14,60,000
$1\frac{1}{4}$ miles of syphon pipe (under Creek and along depression in hills), 42 inches in diameter and $1\frac{1}{4}$ inch thick, delivering 13 million gallons daily, and weighing 1,364 tons per mile, or 1,705 tons at Rs.160 a-ton	2,72,800
Tunnel under Creek, as before	1,50,000
$9\frac{1}{2}$ miles of pipe from Koorla to Bombay, 33 inches in diameter and $1\frac{1}{8}$ inch thick, delivering 13 million gallons daily, and weighing 924 tons per mile, or 8,778 tons at Rs.160 a ton	14,04,480
Upper Koorla Reservoir, as before	3,00,000
No. 1 Dam, Kamun Reservoir, as before............	16,25,000
No. 2 Dam, Kamun Reservoir, as before............	1,87,625
No. 3 Dam, Kamun Reservoir, as before............	4,96,600
Kamun Waste Weir, as before	1,50,000
Kamun Outlet Works, as before	1,50,000
Engines of, say, 400 nominal horse-power* to raise 13 million gallons, 110 feet high, at Rs.1,800 per horse-power	7,20,000
Engine-houses, boiler-houses, and all arrangements at Kamun	2,00,000
	71,16,505
Add 10 per cent for contingencies, say	7,11,495
Carried forward ....Total	Rs.78,28,000

* The calculated power is 300.

Brought forward	Rs.78,28,000
Land at Kamun, and for conduits and pipes	5,00,000
Cost of fuel for raising 13 million gallons daily 110 feet high, say 5,400 tons, at Rs.30 a ton, or Rs.1,62,000 yearly, representing, at 6 per cent., a capital of...............................	27,00,000
Total........................	Rs.110,28,000

Or, say, 110¼ lakhs for 20 gallons per head per diem for the present population.

If coal be taken at Rs.35 per ton, the cost for the same quantity of water would be nearly 115 lakhs.

Estimate No. 12.

COST OF KAMUN SCHEME FOR A SUPPLY OF 17 MILLION GALLONS DAILY.

Supply to be pumped by steam at Kamun, and to flow into the Upper Koorla Reservoir. Dams to impound a three-years' supply from the valley :—

18¼ miles of conduit, as per previous Estimate...	Rs.14,60,000
1¼ mile of syphon pipe (under Creek and along depression in hills), 48 inches in diameter and 1½ inch thick, delivering 17 million gallons daily, and weighing 1,760 tons per mile, or 2,200 tons, at Rs.160 a ton.....................	3,52,000
Tunnel under Creek, as before	1,50,000
9½ miles of pipe, from Koorla to Bombay, 39 inches in diameter and 1¼ inch thick, delivering over 17 million gallons daily, and weighing 1,260 tons per mile, or 11,970 tons at Rs.160 a ton....................................	19,15,200
Upper Koorla Reservoir, as before..................	3,00,000
No. 1 Dam, Kamun Reservoir, as before	16,25,000

No. 2 Dam, Kamun Reservoir, as before	1,87,625
No. 3 Dam, Kamun Reservoir, as before	4,96,600
Kamun Waste Weir, as before	1,50,000
Kamun Outlet Works, as before.....................	1,50,000
Engines of, say, 500 nominal horse-power,* to raise 17 million gallons 110 feet high, at Rs.1,800 per horse-power........................	9,00,000
Engine-houses, boiler-houses, and all arrangements at Kamun	2,00,000
	78,86,425
Add 10 per cent. for contingencies, say......	7,88,575
Land at Kamun, and for conduits and pipes	5,00,000
Cost of fuel for raising 17 million gallons daily 110 feet high, say 7,100 tons at Rs.30 a ton, or Rs.2,13,000 yearly, representing a capital of	36,50,000
Total	Rs.128,25,000

Or, 128¼ lakhs for 26 gallons per head per diem for the present population.

If coal be taken at Rs.35 per ton, the cost for the same quantity of water would be about 134 lakhs.

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* The horse-power required by calculation is over 390.

CHAPTER XII.

SUMMARY AND RECOMMENDATIONS.

I have now given such an account of what has already been written and done with regard to the water-supply of Bombay as will enable the reader to understand the position in which the question at present stands. I have given such a description of the surrounding country as should enable him to form an opinion on the facilities for storing water which the different valleys afford, and on the means which would probably have to be resorted to in order to bring it to Bombay. I have, I trust, demonstrated the superiority of masonry over earthen dams, of conduits over iron pipes, and shown the desirability of making an experiment on the feasibility of rock syphons, and of keeping our pipes above ground. And lastly I have shown, with as much exactness as the question admits of, the capabilities for supply of those particular valleys which, after careful investigation, seem the most promising for our purposes, and I have furnished estimates of the probable cost which will have to be incurred to make the supply from any one of these valleys available for the town.

It is now necessary to summarize the results arrived at, in order that the reader may the more easily make a comparison between the different projects submitted to his judgment.

The quantity of water obtainable from the Kennery Valley is about 13 gallons per head per diem, for the present population. To store a one-year's supply will require a dam 130 feet high—a two-years' supply, one of 155 feet—and a three-years' supply, one of 172 feet. And the cost of the project will be, in the first case, $40\frac{1}{4}$—in the second, $47\frac{3}{4}$—and in the third, about 54 lakhs.

Toolsee offers us no more than $5\frac{1}{2}$ gallons per head per diem, for the present population, with dams 77 feet, 92, and 105 feet high, for a one, two, and three years' supply respectively, and the cost in the first case would be $21\frac{1}{4}$, in the second 25, and in the third 28 lakhs.

Ewoor could supply 10 gallons per head per diem, with dams 124, 141, and 155 feet high. The cost of this supply would be $56\frac{1}{4}$ lakhs with the first dam, 64 lakhs with the second, and $73\frac{3}{4}$ lakhs with the third.

From Tansa could be obtained 140 gallons per head per diem, for the present population, but to store this quantity at first would be absurd. A dam 95 feet high would impound nearly as much water as we now have in the Vehar Lake, and the cost of supplying 13, 20, and 26 gallons per head daily would be 87, $99\frac{1}{2}$, and $115\frac{1}{2}$ lakhs respectively.

The quantity of water which might be got from the low level reservoir, Kamun, is 48 gallons per head daily, but in this case, also, it would be absurd at first to deliver such a supply to the town. The Kamun water could be made available by various means. If pumped by the water in the Ewoor Lake, the cost of 13, 20, and 26 gallons per head daily would be $104\frac{1}{2}$, $110\frac{1}{4}$, and 118 lakhs respectively. But if the Kamun supply were pumped in Bombay 125 feet high, with coals at 30 Rs. per ton, the cost for the different quantities above would be 94, $111\frac{1}{4}$, and 127 lakhs respectively; but with coals at 35 Rs. a ton, the cost would be 97, 116¼, and 133½ lakhs. If pumped 100 feet high, with coals at 30 Rs. a ton, the cost would be 88, 102, and 116½ lakhs ; but with coal at 35 Rs. a ton, the cost would be 91, 107, and 122 lakhs.

Again, if the water were pumped at Kamun, with coal at 30 Rs. a ton, and delivered to Bombay from the Lower Koorla Reservoir, the cost would be 88¾, 100¼, and 113½ lakhs; but with coals at 35 Rs., the cost would be 90, 102, and 117¼ lakhs for 13, 20, and 26 gallons per head daily.

Lastly, if the water were pumped at Kamun and delivered to Bombay from the Upper Koorla Reservoir, the cost, with coal at 30 Rs. per ton, would be 93½, 110¼ and 128¼ lakhs, but with coal at 35 Rs. a ton, 96½, 115, and 134 lakhs.

The accompanying table shows, at one view, the cost of all the different projects.

I think it must be manifest to every one who gives but a few minutes' consideration to the subject, that it would be a mistake for the Bench to carry out a scheme with a dam to be raised no higher than sufficient to impound a one-year's supply from any of the smaller valleys. The failure of a single monsoon would, in such a case, cause the supply to the town to be suspended. A two-years' supply seems to me to be the very least which should be impounded. In such a case two successive failures of the monsoon must occur before the water could be consumed, and I think there are objections to a scheme with a reservoir of even such capacity. In considering the different projects, this point should have its weight. We will take the projects in the order exhibited in the table.

The Toolsee Valley not being capable of giving us more than 3½ million gallons yearly, we cannot look to it as a permanent source for increasing the supply of the town. If any one of the Toolsee Projects is carried out, it will hardly give sufficient relief to the town even at present, and we shall be compelled to adopt some other scheme in addition. We may,

TABLE SHOWING AT ONE VIEW THE COST, IN LAKHS OF RUPEES, OF SUPPLYING BOMBAY WITH VARIOUS QUANTITIES OF WATER FROM THE DIFFERENT VALLEYS.

Name of Valley...		TOOLSEE.			EWOOR.			KENNERY.			TANSA.	KAMUN.									
		Valley capable of supplying 1,272,000,000 gallons yearly, or 3½ millions daily, or 5½ gallons per head per diem for the present population.			Valley capable of supplying 2,400,000,000 gallons yearly, or 6½ millions daily, or 10 gallons per head per diem for the present population.			Valley capable of supplying 3,000,000,000 gallons yearly, or 8¼ millions daily, or 13 gallons per head per diem for the present population.			Valley capable of supplying 33,000,000,000 gallons yearly, or 90 millions daily; or 140 gallons per head per diem for the present population.	Valley capable of supplying 11,000,000,000 gallons yearly, or 31 million gallons daily, or 48 gallons per head per diem for the present population.									
												Dam for the present to be 100 ft. high, impounding 17,000,000,000 gallons.						Dam to be built at once, 120 ft. high, impounding as above 11,000,000,000 gallons.			
Number of Gallons per head per diem for the present population.	Number of million gallons daily.	Dam 77 ft. high, impounding one year's supply.	Dam 92 ft. high, impounding two years' supply.	Dam 105 ft. high, impounding three years' supply.	Main Dam 124 ft. high, impounding one year's supply.	Main Dam 141 ft. high, impounding two years' supply.	Main Dam 155 ft. high, impounding three years' supply.	Dam 130 ft. high, impounding one year's supply.	Dam 155 ft. high, impounding two years' supply.	Dam 172 ft. high, impounding three years' supply.	Dam for the present 95 ft. high, impounding 9,000,000,000 gallons, being a fraction only of the yearly rainfall.	Supply pumped by water in Ewoor Lake. Ewoor Dams to impound.		Supply pumped in Bombay.				Supply pumped into Lower Koorla Reservoir.		Supply pumped into Upper Koorla Reservoir.	
														100 ft. high.		125 ft. high.					
												Two years' supply.	Three years' supply.	Coals 30 Rs. a ton.	Coals 35 Rs. a ton.	Coals 30 Rs. a ton.	Coals 35 Rs. a ton.	Coals 30 Rs. a ton.	Coals 35 Rs. a ton.	Coals 30 Rs. a ton.	Coals 35 Rs. a ton.
5½	3½	Lakhs. 21¼	Lakhs. 25	Lakhs. 28																	
10	6½				Lakhs. 56¼	Lakhs. 64	Lakhs. 73¾														
13	8¼							Lakhs. 40¼	Lakhs. 47¾	Lakhs. 54	Lakhs. 87	Lakhs. 104½	Lakhs. 113½	Lakhs. 88	Lakhs. 91	Lakhs. 94	Lakhs. 97	Lakhs. 88¾	Lakhs. 90	Lakhs. 93½	Lakhs. 96½
20	13										Lakhs. 99½	Lakhs. 110¼	Lakhs. 119¼	Lakhs. 102	Lakhs. 107	Lakhs. 111¼	Lakhs. 116¼	Lakhs. 100¼	Lakhs. 102	Lakhs. 110¼	Lakhs. 115
26	17										Lakhs. 115½	Lakhs. 118	Lakhs. 127	Lakhs. 116½	Lakhs. 122	Lakhs. 127	Lakhs. 133½	Lakhs. 113½	Lakhs. 117¼	Lakhs. 128¼	Lakhs. 134

therefore, assume that, however desirable the Toolsee Scheme may be in itself, it cannot be considered as a solution of the water-supply question.

Let us analyze the Ewoor Project. To impound only one year's supply being absurd, it would cost us, with a dam impounding a two-years' supply, 64 lakhs to obtain 6½ million gallons daily from this valley. There are four objections to the adoption of this scheme. It is incapable of extension. Its cost, in proportion to the quantity of water supplied, would be very great. The main dam would require to be built at once 141 feet high. And, in the event of two failures of the monsoon, no water would be obtained from it. On these considerations, and remembering that by the expenditure of a few more lakhs we might secure far greater advantages than Ewoor offers, I am of opinion that the Bench would not be acting wisely to sanction any one of the Ewoor Projects.

The supply from Kennery would be cheaper than that from any other valley, excepting Toolsee. On the other hand, the fact must be looked at in the face, that the dam cannot be less than 155 feet high. It must also be remembered that the supply from Kennery is not capable of extension, and it is quite clear, therefore, that, if the Kennery Scheme be carried out, it must be supplemented by some other project after 10 or 15 years. It cannot be compared with either the Kamun or Tansa Schemes, because these afford us a supply which can be increased from time to time as the demands of the town become greater, whereas the supply from Kennery is only sufficient for the immediate requirements of the population.

The Tansa Project is the cheapest one admitting of extension.

The Kamun presents many aspects, but the idea of pumping the supply with turbines worked by help of the Ewoor water must be abandoned. The estimates show that the Ewoor Dams would be far too expensive for a project of this nature to be entertained. Nor do I think that it would be wise to erect the pumping engines at Kamun. It might be a little more expensive to pump up the water in Bombay, but then the great advantage of having the engines under the immediate care of the Bench and its officers would compensate for this. All kinds of irregularities might go on at Kamun without detection, but it would be the fault of the Justices themselves if irregularities were practised in the town. Under these circumstances I cannot recommend that form of the Kamun Scheme in which the water would be raised far away from Bombay.

For a large supply the issue is now confined to the merits of two projects—the Tansa, with its high level service reservoir at Koorla, and the Kamun, with its pumping works in Bombay. Both offer us much more water than we can possibly require at present. The Tansa would practically give us a somewhat greater pressure than we have in the Vehar mains. The pressure, if the water were pumped in Bombay, could be as great as the Bench chose to make it, but, to be the same as that obtained by the Tansa Project, the water would have to be raised from 125 to 150 feet high. Let us assume that the height of 125 feet would be sufficient, and that the same quantity of water were supplied from each valley. I am of opinion that for a large supply the Bench would do wisely to arrange for one of not less than 13 million gallons daily. The cost of this quantity from Tansa would be about 100 lakhs, from Kamun about 112 lakhs. If the water were pumped 100 feet high instead of 125 feet, the Kamun Project would cost about two lakhs only more than the Tansa. During this year coals have risen considerably in price, and the general idea seems to be that the rise will be a permanent one, and is due, not so much to excessive demand as to the rise in the price of labour, and to the reduction in the number of working hours which has taken place all over England. At all events, the price of coal is an uncertain element in the estimate of the Kamun Project, and while I think Rs.30 a ton will probably be a fair average to allow for some years to come, I am aware that many will contend this is too small an allowance. If coal continues to rise in price, of course the cost of raising the Kamun water in Bombay will be above what it has been put at. We will, however, assume that 13 million gallons daily from Kamun will cost about 10 lakhs more than the same quantity from Tansa.*

Another very uncertain element of the Kamun Project is the duty which may be expected from a bushel of coal. On this question also there is sure to be much diversity of opinion. The Crossness sewage pumping engines in London have done throughout the year an average duty of 75,000,000 foot lbs., and the average duty of Cornish engines is 60,000,000 foot lbs. I have assumed for the Bombay engines an average duty per bushel of 40,000,000 foot lbs., but I am aware that many are of opinion that coal in India does not produce a useful effect of more than half the amount it does in England. According to these engineers, therefore, I should not be entitled to take more than, say, 35,000,000 foot lbs. as the average duty to be expected from the use of coal in Bombay. If this be the case, the cost of coal will be increased by more than 12 per cent., and this will add several lakhs to the total of the estimate.

The height of the Kamun Dam at first would be 100 feet, and ultimately 120 feet; that of the Tansa Dam at first would be 95 feet, and ultimately 130 feet. It is not absolutely imperative that the Kamun and Tansa Dams should be of these heights, but I think the advantages which would be secured by building them as proposed are so great that it would not be advisable to have lower ones. In the case of Kamun, if the dam were made lower, the water would have to be drawn off from a lower point,—it would reach Bombay

* Since writing the above, I find coals have risen considerably in price, and it is currently reported that in the ensuing winter they will be as high as 42s. per ton in London.

at a lower level, and the lift, therefore, for the pumps would be a greater one. The uncertainty of the cost of coal, and the general principle upon which engineers proceed—viz., that first cost* is not nearly so important an item to effect a saving in as a constant yearly charge—induces me to recommend that the dam should be built ten or twenty feet higher—rather than that the water should be pumped this extra height. The difference then between the dams would be this: the Tansa Dam would be at first five feet lower, but ultimately ten feet higher than the main Kamun Dam. This would be somewhat to the advantage of Kamun if the sites were equally favourable, but it is in this respect that the Kamun Project is so inferior. The reader is aware that the bed of the stream at Kamun is at 80 feet on datum, or just at about mean sea level. The water at high tide, therefore, would be washing over the face of the dam wall. This I consider a very trifling objection, inasmuch as it would be easy to protect the wall from injury; but what is really a point worth great consideration is the depth to which we should have to carry the foundations. Several pits were dug along the line of the dam, and to the depth of from 15 to 20 feet. In every case the soil proved to be a mixture of clay and sand, through which the water came pouring in in such large quantities that it could not be kept down by baling. Moreover, in some of the pits, although we dug as low as 20 feet below the surface, we did not come on rock. These facts prove that, in building the dam, it would be absolutely necessary to keep the water out down to a depth of 20 feet below mean sea level, and probably to a greater depth than this; nor could we positively reckon on obtaining a perfectly sound foundation for a dam even at these low depths. In my estimates I have made no special allowance either for pumping or for building in the foundations, but have supposed that these charges would be covered by

* A first cost is known, but a yearly charge like that for coal is liable to increase from year to year, and to attain enormous proportions in the future.

the item of contingences at 10 per cent. Now in the case of the Tansa Dam nothing could be more favourable than the bed of the stream. It is as smooth as a pavement, and the rock lies bare so that its texture can be seen to perfection. If further evidence of the soundness of the rock be required, it is only necessary to trace the river for a mile either above or below the site of the dam. Everywhere it runs over the same kind of rock, hard and smooth—similar in its qualities to the best trap used for building purposes in Bombay.

Not only is the foundation for the dam better at Tansa than at Kamun, but the section across the valley is so much more favourable. The high portion of the Tansa Dam would be very short as compared with the high portion of the Kamun Dam. I pointed out previously how important, in judging of dams, this point was, and, if the reader will refer to Plate XLI., which gives a section of all the important dams, he will there find that, excepting the site for the Toolsee Dam, that for the Tansa is the most favourable of all. The hills rise at once from the banks of the river to 90 feet on one side and 70 on the other, and the high portion of the dam, consequently, is confined to the narrow gorge through which the river has cut a way for itself. Now the Kamun River flows, not through a narrow gap between hills, but across a plain about 250 yards wide, and the ground, instead of rising at once from the banks of the stream, does not rise except from the extremities of the plain.*

Considering, therefore, the depth to which we should have to excavate at Kamun to reach solid rock, the uncertain nature of the strata at the bottom, the difficulty and expense of keeping the foundations clear of water during construction, and the great length of the high portion of the dam, I am of opinion that a dam 150 feet high on such a site as we have got in the Tansa Valley, could be built with greater safety,

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* Vide Plates XLI. and XLIII.

and would afterwards be more secure than one 120 feet high at Kamun. But when we remember that the actual difference in height between the two dams cannot exceed 10 feet, and may not even be so much, because the excavations at Kamun may have to be carried to a greater depth than we have supposed, the advantages of the Tansa Dam are evident.

The quality of the water from the two valleys would not differ much ; perhaps that from the Tansa might be a little purer, as there is more rock in that district.

The means employed to bring the water to Bombay would be the same. Conduits and iron pipes would have to be employed. The Tannah Creek would have to be crossed in both cases, but the stream is twice as wide at Kolset as at the crossing point for the Kamun Channel. In the former case, however, the depth of the water is 25 feet, and in the latter as much as 100.

Considering, then, that with coals at Rs.30 a ton, and with the pumping engines doing an average duty of 40,000,000 foot lbs. for every bushel of fuel expended, the Kamun Scheme would still cost 12 lakhs of rupees more than the Tansa—considering that coals are steadily rising in price, and are higher at this moment than they have ever before been, and that, if they continue to rise, the allowance of Rs.30 a ton will not be sufficient to cover their cost—considering that the duty of the engines may also turn out to be less than that assumed in framing the estimates—considering the difficulties that must be encountered in building the Kamun Dam, and the uncertain nature of the strata on which the work must stand, and, considering, on the other hand, the remarkably favourable, indeed unexceptionable, foundation which is to be obtained for the Tansa Dam—considering how great is the length of the high portion of the Kamun Dam, and how short that of the Tansa one—considering, too, that by the help of the Tansa Project we can improve the existing water works, by keeping the Vehar

Lake always full, and that this advantage cannot be secured by the Kamun Scheme if the water is pumped in Bombay, —I cannot hesitate to recommend the Tansa Scheme as the one most worthy adoption by the Bombay people for a large supply of water.*

With regard to the Toolsee Project, if matters have not already proceeded too far to allow of the form of the dam being altered, I entreat that the height of this work be fixed at 105 feet. By making the dam 80 feet high only, as I understand is proposed, the Bench are foregoing their power to store water for future contingencies. No more water can be stored in Vehar, except at an enormous expense; none in Ewoor, except also at a great outlay. The only two valleys where, speaking financially, it is practicable to keep a supply for contingencies, are Kennery and Toolsee. And in Kennery this can only be done by the help of a very high dam, against which objections are sure to be raised. In fact, the Toolsee is the only valley in Salsette where we may keep a good stock of water, without incurring much expense, and with a dam of ordinary height. To the argument which may be

* In recommending the high level Tansa Project as one better worthy the consideration of the Bench than the low level Kamun one, it cannot be urged that I do so because it is more essentially my own proposition. Whatever little credit may attach to the suggestion of a low level project for Bombay, I think I may lay claim to it as having been the first to bring it to the notice of the former Commissioner, Mr. Crawford. In giving my evidence before the Water-supply and Drainage Commission, in 1869, I was severely cross-examined on this subject, and, although I felt perfectly certain at the time that a project with a low level reservoir was possible, I was aware that I had failed to convince many people of the practicability of bringing water to Bombay in a low level conduit. The members of the Commission, however, were evidently satisfied on the subject, as their recommendations were to the effect that a scheme of this kind was the best for the town. Little did I think, while giving my evidence, that not only was a low level conduit feasible, but that it was actually possible to have a high level one for the greater portion of the distance to Bombay. Had I mentioned at that time that such an idea had occurred to me, I feel certain I should have been laughed at. It is the fact of the practicability of a high level conduit, made manifest by my recent surveys, which has, in addition to the other reasons stated above, induced me to give the preference to the Tansa over the Kamun Scheme.

brought forward, that the dam on the dividing ridge between the Toolsee and Vehar Lakes may make the latter insecure, my reply is—in the first place, this dam would be no more than about 55 feet high ; in the second, its strength, if built according to Mr. Rankine's section, would be about 50 per cent. more than necessary ;* in the third, a masonry dam, and especially of such enormous strength, could not by any possibility be carried away bodily ; and in the fourth place, if the dam could not be carried away bodily, no harm could come to the Vehar Lake from its construction.

The projects, then, which in my opinion deserve the special attention of the Bench, are the combined Kennery and Toolsee Projects, for a supply of 13 gallons per head per diem for the present population, and the Tansa Project for a supply of 20.

In the former case, whatever may be the heights to which it may be decided to raise the Kennery and Toolsee Dams now, the sections for these dams should be such as to admit of the former being raised ultimately to the height of 155 feet, and the latter to the height of 105 feet. The reason why I recommend these heights is that the Toolsee Dam will then be able to impound a three-years' supply from that valley, and the Kennery a three-years' supply from its own valley, and in the two lakes together, it will hereafter be possible to store a three-years' supply from the whole watershed of these valleys taken together. However little water we may choose at present to store for our own purposes, we shall be doing our utmost on behalf of future generations by giving them the opportunity, should they think fit, to store, hereafter, a full three-years' supply. In fact, while looking to ourselves, we shall not be selfishly sacrificing the interests of those who come after us.

If, then, the Kennery and Toolsee Projects be decided

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* *Vide* paragraph 22, Appendix D.

upon, the water should be taken by one channel to the Upper Koorla Reservoir, and delivered to Bombay from that point. Beyond this remark there is no explanation called for on my part, as the description already given of these projects in Chaps. VI. and VII. is sufficiently explicit for all purposes. The financial aspect of the question only remains to be gone into.

To carry out the Kennery and Toolsee Projects, even if the Bench decide to raise the dams at once to the heights recommended by me, would cost almost exactly sixty lakhs of rupees. Public loans in England are now made repayable in 50 years, and I should think there would be no difficulty in getting the Imperial Government to grant money on the same terms to the town of Bombay. If this be the case, then the sum required by the Bench yearly to pay off 60 lakhs in 50 years, together with the interest thereon, so that at the end of that period they should have discharged all liabilities against them, would be Rs. 3,80,687½.* I have already shown † that the surplus in hand at the end of each year out of the receipts from the present water works, after paying what is due to the Government and for the maintenance of the works, amounts to Rs. 1,55,000. In order to carry out the Kennery and Toolsee Projects, the Bench would therefore require to raise a revenue of (Rs. 3,80,687½ − Rs. 1,55,000 =) Rs. 2,25,687½, and a further sum of about Rs. 35,000 would be required for the maintenance and extension of the works.‡ The total sum to be raised yearly would thus amount to, say, Rs. 2,60,000.

The present works yield Rs. 3,80,000 yearly, and they supply six gallons for every five which the Kennery and

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* This may be taken as correct, having been calculated from the table prepared by the Actuary of the National Debt Office, which is in use by Her Majesty's Government.

† Page 35.

‡ The present establishment, with a very small addition to it, would suffice for the superintendence of all the new water works, and this farther sum would go almost altogether towards the extension of works of distribution in the town.

Toolsee Works would give hereafter.* Considering that not even half the town of Bombay is properly supplied with water, there can hardly be any doubt of our being able to utilize all that we should obtain by the proposed projects. They should therefore yield Rs. 3,16,666. But we do not require more than Rs. 2,60,000. It will thus be seen that there is every prospect of success in the financial part of the undertaking. We should have a balance of about half a lakh of rupees yearly on the safe side.

If the Bench object to the Kennery Project on the ground that the dam must be so very high, then I am of opinion that it would be best to carry out the Tansa Scheme for 13 million gallons daily. The reason why I recommend this supply in preference to one of 8¼ million gallons is, that the difference of cost in the two cases is 12½ lakhs only. To supply the latter quantity would cost 87 lakhs, while to supply the former would cost 99½ lakhs; and the sum of money which the Bench would have to raise yearly, in order to pay off the former debt in 50 years, would be about 4¼ lakhs of rupees, while that required to expunge the latter would be about 5¼ lakhs.† Now, it seems to me that it would be easier to raise a revenue of 5¼ lakhs yearly with a supply of 13 million gallons daily, than it would be to raise one of 4¼ lakhs with 8¼ million gallons. If we obtained as much proportionately for the 13 million gallons daily as we now obtain from Vehar for, say, 10 million gallons, we should realize about 5 lakhs of rupees per annum,—very nearly as much as we should require. An inappreciable increase in the charge for water would cover the small deficit of 25,000 Rs., and enable the Bench to balance expenditure with income.

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* In Chapter VI. I have shown that the Vehar Valley yields 3,600,000,000 gallons yearly, while from the Kennery Valley (including Toolsee) we may expect to obtain 3,000,000,000 gallons only.

† These sums include about Rs. 35,000 yearly for maintenance and extensions, but I have, as before, assumed that Rs. 1,55,000 will be obtained from the Vehar Works.

If, however, the project of $8\frac{1}{4}$ million gallons daily from Tansa were carried out, the revenue we should obtain would be about Rs. 3,15,000,—or about Rs. 1,10,000 less than we should require. This project, therefore, does not give us the prospect of financial success which the other does.

Being well acquainted, as I am, with the Bombay Water Works, and having bestowed particular attention on the subject, I am most emphatically of opinion that there is great room for improvement in the distribution of the water throughout the town, and that the scale of charges should be revised. I have no hesitation in adding that, if the subject were taken in hand by a Committee and new regulations enforced, the Bench would realize nearly a lakh of rupees more than they do at present from even the Vehar supply, and that there would be really no financial difficulty in carrying out the Tansa Project for a supply of 13 million gallons daily. The revenue under an improved system would not only be sufficient to defray all charges on the debt, but would give a balance in hand for the still further extension of the water works when the time arrived for increasing the supply.

My recommendations, therefore, to the Bench are:—

Either to carry out the Kennery and Toolsee Projects for a supply of $8\frac{1}{4}$ million gallons daily, or to carry out the Tansa Project for a supply of 13 million gallons.

If the former be decided upon, the Toolsee main dam to be built at once—or, at all events, so as to admit of its being raised hereafter—to the height of 105 feet, so that the water may stand at 470 feet on datum, and a three-years' supply from the valley be impounded. And the Kennery Dam to be built at once—or so as to admit of its being raised afterwards—to the height of 155 feet, so that the water may stand at 345 on datum, and a three-years' supply from the lower portion of the valley may be impounded.

That, whatever is done now, "the future as well as the present wants of the city should be borne in mind." *

That future works should be, if possible, extensions of present ones, and not independent of them.

That, in carrying out any high-level project whatsoever, it would be a grave mistake not to command the Vehar Lake so as to be able to keep it full whenever considered desirable.

That, whatever reservoir be adopted, if the height for the dams proposed by me be not approved, the dams be, at all events, built so as to be capable of being raised in the future to those heights. Thus the prospective supply would not be marred by any steps taken to relieve our own immediate wants.

That the water from every high-level reservoir which may be constructed be brought by conduit as near to Bombay as possible—*i. e.*, to the Upper Koorla reservoir, before being delivered under pressure.

That conduits be adopted in preference to pipes wherever they are practicable, whether in open cutting or in tunnelling.

That all future dams be of masonry, and constructed according to the principles laid down by Mr. Rankine.

That an experiment be made regarding the practicability of rock syphons.

That an experiment be made to ascertain to what extent the temperature of the water in a main exposed to the sun would be affected, and, if the temperature be not affected so as to render the water practically warmer than it would be in a main under ground, that all pipes laid down hereafter for the supply of Bombay be placed on standards above ground.

* These are the words of the Commission on the Water-supply and Drainage of which Mr. Scoble was President.

APPENDICES.

APPENDIX A.

MEMORANDUM ON THE WATER-SUPPLY OF BOMBAY.

BY DOCTOR BLANEY.

Being asked by Captain Tulloch to say what I "consider have been the effects of the introduction of Vehar water into Bombay," my apology for submitting the following observations on a subject about which there is scarcely any difference of opinion amongst the intelligent part of the community, and none, as I believe, amongst the members of the Bench of Justices, is to consider the request of the Municipal Engineer as an appeal to undertake a public duty which cannot be disregarded. I am reminded by Captain Tulloch that my remarks should be brief.

In discussing the subject of a water-supply it will be convenient to divide what I wish to say under the heads of *past, present,* and *future.*

The Past.—Under my own experience from 1836 *to* 1860.

Mortuary returns for the city were not established until the year 1848. In going back, therefore, to what may be called a pre-historic period, I am sure I will be pardoned for reviewing the sanitary state of Bombay with reference to the water-supply, from my early recollections and observations.

At a period in the history of sanitation, when people more advanced in science, arts, and civilization than the people of India tested the quality of their potable water by its clearness and freedom from odour, it is not to be wondered at that the people of Bombay relied upon similar tests, and were well satisfied if their drinking water was not charged with palpable impurity to the eye, and not absolutely nauseous to the palate. But much of the drinking water of the city was incapable of sustaining even these doubtful tests of purity, especially during the hot months of April and May, when the water-level was low.

The supply was obtained from wells, averaging a depth of about thirty feet, also from large tanks, in which men and animals bathed, and clothes were washed. To have a well of water within the house itself was considered a special privilege and a luxury to be enjoyed by the rich alone; and many houses in the Fort were supplied in this way, receiving a water-supply by percolation from the ditch that surrounded the ramparts. No system of conservancy prevailed, and night-soil was infrequently and irregularly removed. There was no proper drainage. An immense population was closely huddled together, so that in several localities there was not so much as ten square feet per head. Many parts of this city were built on moorum and sandstone, while some were reclaimed from the sea, and the houses were built upon loose sand on a rocky trap base. On east and west, low basaltic hills half enclosed the city in a valley, and turned the natural drainage towards the houses.

The conditions of an impure water-supply were thus as abundantly fulfilled by the insanitary surroundings as it was possible to make them. If excreta were not actually present in the water, the facilities afforded to the drainage of organic impurities into the wells left little doubt in the mind that liquid sewage formed no insignificant constituent of much of the drinking-water. An analysis, made by Dr. Lyon, for the Drainage and Water-supply Commission, in July 1869, long after conservancy was established, gave the following results :—

The quality of the water of some of the wells of Bombay is also shown by the following analyses, made by Dr. Lyon, in July 1869 :—

		Total solid matter dried at about 280° F.	Chlorine.	Lime.	Magnesia.	Total earthy salts calculated as carbonate of lime.	Sulphuric acid.	Total oxygen required by the water at 140° F. in presence of acid.	Ammonia.		
									Of Nitrates and Nitrites.	In distillate from Carbonate of Soda.	In distillate from Permanganate of Potash.
1. Well, Jail-road, north side, No. 120	Grs. per gal.	33·60	6·56	7·15	1·80	17·26	·53	·0350	·5250	·0021	·0105
2. Do. do. south side, No. 30	,,	43·26	9·24	7·29	1·38	16·46	1.59	·0350	·5250	·0175	·0050
3. Do. Don Tar; 2nd Street, Mosque	,,	38·99	8·85	5·58	2·40	16·50	1·88	·0918	·5200	·0073	·0196
4. Tank opposite Church, N. S. de Salvacio, Mahim ..	,,	18·62	3·18	1·12	1·06	4·65	1·57	·0791	..	..	..
5. Well in Alliance Mill Compound	,,	56·42	15·53	14·19	2·94	33·95	4·33	·0350	·0840	·0211	·0104
6. Do. Gaumdavie - road, House No. 7	,,	54·84	10·44	9·66	5·21	30·27	7·13	·0280	·0146	·0014	·0007
7. Do. do. No. 2 B	,,	56·61	10·93	10·06	5·43	31·54	6·89	·0420	·0790	·0042	·0010
8. Do. Tara Naqueen's Oart, Breach Candy	,,	85·12	16·70	8·89	10·88	43·07	8·74	·0230	·3500	·0055	·0105
9. Do. Collywaddy, Funnuswaddy	,,	101·43	25·99	19·83	6·22	50·96	6·53	·0210	1·4000	·0080	·0096
10. Do. Gowalla Tank	,,	15·68	2·76	3·93	·47	8·19	·34	.0245	·0735	0105	·0070
11. Do. No. 1 Nacodas Oart, Chowpattee-road, Girgaum	,,	97·44	21·77	7·98	14·33	50·11	8·26	·0525	·0420	·0022	·0140
12. Do. No. 2 do. do.	,,	64·82	13·82	6·74	11·78	41·49	4·51	·0840	·0300	·0010	·0140
13. Do. Juggernaut Jewanjee Mistree's Oart, Funnuswaddy	,,	90·48	17·02	13·17	6·36	39·42	5·48	·0210	·0240	·0084	·0077

In striking contrast to the above the following shows the usual quality of the present water-supply :—

		Total solid matter.	Loss on ignition.	Chlorine.	Lime.	Magnesia.	Total earthy Salts as Carbonate of Lime.	Sulphuric Acid.	Total oxygen required by the water at 140° F. in presence of acid.	Ammonia. Of Nitrates and Nitrites.	Ammonia. In distillate from Carbonate of Soda.	Ammonia. In distillate from Permanganate of Potash.
Vehar Water from supply pipe	October 1, 1868..	5·88	·49	·99	1·30	·82	4·37	..	·0205	..	..	.
	April 1, 1869	6·72	·91	·87	1·72	·73	4·90	..	·0262	Trace	·0042	·0092
	June 1, 1869	7·00	·84	·77	1·64	·86	5·07	Trace	·0227	·1260	·0170	·0134
	July 1, 1869	5 60	·84	1·04	1·56	·62	4·35	do.	·0367	·0042	0077	·0127
										Nitric Acid (Approximate.)		
Dipping well, No. 7 Camateepoora Bazaar-street, September 1868........		9·17	·98	1·04	1·02	·51	3 09	do.	·0234	·21		
Do. 2nd Combharwada - street, do		5·95	·77	1·22	·79	·46	2·56	do.	·0428	·19		
Do, No. 10 Dongree Bazaar-street, do		7·51	1·89	1·17	1·18	·36	3·55	do.	·0234	·15		

It is proper to mention that the water submitted to analysis by Dr. Lyon was drawn from wells and tanks that had recently been filled after copious rain-fall. In the dry and hot months, to which allusion has already been made, as a matter of fact, the people were unable to draw water from many of the wells in seasons in which the rain-fall had been less than seventy inches, but were compelled to descend into the tanks and wells and Fort ditch to scoop up a semi-liquid mud which was transferred to the pitcher after being passed through a piece of dirty cloth. Thousands of persons were thus necessitated to drink a liquid which could only be regarded as sewage. Who will wonder, then, that at such seasons the cholera and fever mortality was fearful ? The terrors of the hot months were frequently not alleviated by the setting in of the rains. The first rain scarcely improved the condition of public health. Putrid matters on the surface were liquefied and carried into the tanks and wells, and fatal fevers were abundant. Epidemic diseases as frequently took their rise in Bombay as they were imported, and to the shipping in the harbour the shore influences were remarkably fatal. The rate of mortality was high throughout the year, giving that character to the city which distinguished it as *tropical* in a very deadly sense. Why the mortality was not greater than we know it to have been under such a state of the water-supply, may be accounted for partly by the excellent site on which the city is built, exposed to the influence of the sea breeze, and surrounded by water, and partly by the customs of the mass of the people to use the foreshore for natural purposes. If the use of house-closets had thus been general, while removal of excreta was scarcely undertaken and could not have been performed by the small number of halalcores in the city, the increase of the mortality would probably have mounted up to alarming proportions.

To the most unobservant individual it was apparent thirty years ago that the first great sanitary want of Bombay was an improved water-supply.

The Present.—From the introduction of the Vehar water-supply in 1860.

The supply of "pipe-water" through European agency was at first regarded with some suspicion, but much of the indifference to the general use of this water undoubtedly arose from ignorance of the impurity of the well water as compared with the supply from the Vehar reservoir; hence a period of ten years has been found necessary to teach somewhat less than one-half of the householders of the city to receive Vehar water into their houses by connections with the main. It should be mentioned, however, that the public sources of supply from wells, stand-pipes, and drinking fountains are numerous, though still deficient. For many of the latter we are indebted to the liberality of Cowasjee Jehangheer, Esq., C.S.I.

The height of water in the Vehar reservoir at the termination of each rainy season, and again at the close of the dry season, has frequently caused anxiety, not so much for the quantity as the purity of the supply. It is not my purpose to consider the irregular way in which the reservoir has been supplied in each successive season. What most nearly concerns the object of this paper is the lowest safe level at which water may be supplied to the city. In May 1865 the water level in the reservoir reached a minimum of 44 feet at the tower gauge. The supply was then discoloured, thick with vegetable matter, and offensive to taste and smell. I cannot learn whether an analysis was made at that time, but it is a significant fact that the deaths registered in that month were 3,792, or about 100 per cent. above the average. The deaths in May from 1865 to 1870 inclusive have been:

Years.	Total Deaths.	Water level at close of season.		Water level at commencement of previous season.	
		Ft.	In.	Ft.	In.
1865	3,792	44	0	55	9
1866	1,735	46	1	57	4
1867	1,448	46	2	59	0
1868	1,452	47	6	57	0
1869	1,737	....		....	
1870	1,241	....		....	

Imperfect as are the data before me for correctly estimating the lowest safe level of the Vehar water-supply, practically it may be considered that the water loses in purity with the fall in the reservoir. I am aware that an analysis was recently in contemplation, and has probably been carried out, with the view of testing the water at different levels. The results of this experiment might possibly be vitiated by taking the water when the reservoir was high, and when vegetable growth was more active or less rank than it is during the months of April and May. A more reliable plan seems to be to make fortnightly analyses throughout the year, and especially in a year when the reservoir has not been well filled. I will not, however, speculate on this subject, but will leave the gentleman who has been entrusted with the water analysis to give the Bench of Justices the result of his observations.

The importance of being able to say *beforehand* at what level the Vehar reservoir water is likely to derange public health cannot be over-rated. If this question were set at rest it would then be known what further measures, if any, were required for purifying the water. My contention is, that such measures are necessary, and should not be neglected, for if they should be proved to be necessary at any time, they cannot be carried out in a day or a month. There is a choice of three plans :—

1. To remove as effectually as possible the existing rank vegetation, as recommended by Dr. Leith's Committee. The theory of this process is, that a new and active growth will spring up, during the rapid spread of which organized oxygen will be freely liberated with the power of oxidising or fixing any existing impure or noxious matter.

2. To provide extensive sand bed filters for use in the dry months.

3. To supply the reservoir with some weed of more than usually rapid growth which will act in the same way as ordinary new vegetation, and to add to this the water beetle.

These various plans would not at all be similarly efficacious, and they involve a vastly different financial expenditure. It was with the object of meeting the necessities of our water-supply that I suggested to the Commissioner the introduction of the *Anacharis Alsinastrum* or "Magical weed" into the Vehar reservoir. On a reference home Mr. Crawford obtained the views of Professor Frankland on the subject; * and as these views are at first sight somewhat unfavourable to the experiment, while filter-beds are recommended, I shall content myself with this reference for the present, as this paper is not the place for

* *Vide* note to page 25.

fully discussing the question, merely observing that, after well considering Professor Frankland's observations, I am more than ever persuaded that the weed should be introduced into the Vehar reservoir in the absence of any better plan for purifying the water in seasons of deficient rain-fall, and that it will be my duty to contest the matter very earnestly with the Commissioner, who, I have no doubt, will render me all the assistance in his power to secure the important object in view. I think we should be in a position to be able to say authoritatively for ourselves that the weed is good or bad, useful or useless, for the intended purpose.

Setting aside the short and unfrequent periods during which our water-supply has not been so good or efficient as it might be, the steady and remarkable improvement that has taken place in the public health of the water-drinking people of Bombay since the introduction of Vehar water in 1860 is too intimately associated with a very decidedly improved water-supply to leave any room for doubt that the greatest sanitary blessing which has been vouchsafed to Bombay was secured when the Vehar Water Works were completed and the mains were laid. And the experience of all great water-supplies will confirm this testimony as to the great advantages which the public health of communities derives from improved water, especially where the supply was previously notoriously impure. No conservancy expenditure, however great, and no conservancy supervision, however good, could yield results half so satisfactory as those which have been secured to the people of this city at an annual cost for good water of about 8 annas, or one shilling per head of general population, or rupees four lakhs.

The Future.—When the unsatisfactory state of the Vehar dams is remembered, and to this are added the facts that (*a*) the highest and most distant parts of the city are unsupplied; (*b*) that the permanent population is increasing; (*c*) that the seasonal rain-fall cannot be depended upon; (*d*) that fires cannot be speedily extinguished; (*e*) that additional house connections cannot be made on account of the insufficiency of pressure in the mains; (*f*) that additional water is required for a drainage system; (*g*) that water pressure for purposes of power is not available; and (*h*) last, though not least, that a full supply of water, being one of the greatest essentials of public health, is not always within the reach of all; then I contend there can be no room for a difference of opinion, and there should be no hesitation in placing the city beyond the reach of these objections—beyond the reach of a destroying calamity, to the full extent of the city's means.

It might perhaps be expected that I should here discuss at length the question of our future water-supply. To this proceeding there appear to be some objections, such as the quantity of water that is necessary, the source from which it should be obtained, the length and character of the channel, conduit, or main, the views of the Water-supply Commission, and the borrowing capacity and powers of the Municipality—all questions which must be discussed by the Bench of Justices, and will be best discussed at a public meeting in which I look forward to be able to take part. I will not therefore attempt to anticipate the decision which will be arrived at by those to whom Government has entrusted the vital interests of the public of this great city.

THOMAS BLANEY.

Byculla, 19*th September* 1871.

APPENDIX B.

BOMBAY.

ACT No. XIII. of 1863.

An Act to provide for the Management of the Vehar Water Works.

[*Received the assent of the Governor of Bombay on the* 16*th day of May* 1863, *and of the Governor-General of India on the* 2*nd day of October* 1863, *and published by the Governor of Bombay on the* 3*rd day of November* 1863.]

Preamble.

Whereas by Section XXX. of Act XXV. of 1858 it is enacted that the Municipal Commissioners for the Town of Bombay shall pay to the Governor in Council certain annual sums in discharge of the original cost, with interest, of the works called the Vehar Water Works, and of the cost of maintaining the same, and whereas it is desirable, in consideration of the large outlay incurred in the construction of the said Works, and in purchasing up the rights of the tenants or occupants of the site of the said Lake or Works, that one moiety of the same in excess of twenty-five lakhs of rupees should be defrayed by the Governor in Council, and whereas it is expedient that the management of the said Vehar Water Works be transferred to the said Commissioners, and that the said Commissioners be invested with powers for making such management effectual, and for raising certain funds for the purposes aforesaid, in addition to the funds which by law they may now raise, and that in the exercise of such powers, and the disposal of such funds, they be subject to certain rules and limitations; it is hereby enacted—

Short Title.

I. This Act shall be called "The Vehar Water Works Act."

The Vehar Lake and Works to be vested in the Municipal Commissioners of Bombay.

II. From and after the 1st day of July, 1863, the Vehar Lake in the Island of Salsette and all the land adjacent thereto up to the level of the embankment on the southern side thereof, and included within the limits delineated in a plan deposited in the office of Secretary to Government of Bombay, and authenticated by the signatures of the Governor and Members of Council, and marked A, and all the land and other immovable property which is necessary for the purpose of conveying the water of the said lake by pipes into the town of Bombay, and there distributing the same, and which, being the property of Government, has ordinarily been applied to, or employed for, the purposes aforesaid, shall be vested for a term of 99 years in the Municipal Commissioners of the town and island of Bombay, in trust for the purposes of this Act, and subject to the conditions hereinafter provided; and it shall be lawful for the Governor in Council at the end of the period of 99 years aforesaid and thenceforward from time to time to order that the said property shall vest in the said Commissioners on the conditions and for the purposes aforesaid for such further period not exceeding 99 years from the day of any such order, as shall seem expedient: Provided that on the expiration of the said first term of 99 years, or of any further period for which the Governor in Council may have ordered that the said property shall vest in the said Commissioners under this Act shall forthwith cease and determine, and the said property shall revert to and become vested in the Governor in Council as the same were vested in the said Governor in Council before this Act was passed.

Access to land and conduits, &c.

III. It shall be lawful, whenever the same may be necessary, in order to repair, renew, extend, improve, or examine the Lake, conducting pipes, or any other portion of the Water Works aforesaid for the Commissioners and their servants at all reasonable times to enter upon and pass through any land or other property adjacent to the same or in the neighbourhood thereof, in whomsoever such property may be vested, and to convey into and through the said land or other property such materials, tools, and instruments as may be necessary for the purposes aforesaid: and any person obstructing such entrance or passage, or conveyance, shall, on conviction before any magistrate, be liable to a fine not exceeding rupees fifty, commutable, if not paid, to one month's simple imprisonment, provided that all damage done to land or other property by the said Commissioners or their servants in the exercise of the powers by this Act conferred, shall be made good by the Commissioners to the owners of the same.

Movable property vested in Municipal Commissioners.

IV. All materials, tools, instruments, and other movable property purchased or otherwise acquired, prior to the said 1st day of July 1863, by or for the Governor in Council for the purposes of the Water Works aforesaid, and on that day vested in the Governor in Council or in any person in trust for him, shall then forthwith become vested in the Commissioners aforesaid in trust for the purposes of this Act.

Management and maintenance by the Municipal Commissioners.

V. From and after the day aforesaid the said Water Works and the business thereof shall be exclusively managed and conducted by the said Commissioners, who shall be bound to keep the said Water Works and the property pertaining thereto in good repair and effective for the proper purposes of the same, and the said Commissioners shall make such extensions, improvements, and alterations in the said Water Works and property as may be necessary, and for such purposes may expend such sums as may be necessary out of the Municipal Fund, subject, however, to such prohibitions and limitations as the Governor in Council, upon the representation of the Bench of Justices, may in any case think fit to prescribe.

Part repayment to Government by Commissioners of cost of Water Works.

VI. Whereas by the provisions of Sections XXX. and XXXI. of Act XXV. of 1858 certain sums are now and may become payable by the Municipal Commissioners of the Town and Island of Bombay to the Governor in Council, and will continue to be payable until the whole of the expense incurred in the construction of the Vehar Lake and Water Works, with interest at four per centum per annum, shall have been repaid; except such portion thereof as shall be defrayed by Government out of the public revenue, and that the said Commissioners shall also pay to the Governor in Council such further sum in each year as shall be equal to the cost of the maintenance of the said Works during the preceding year, and whereas a sum in excess of 25 lakhs of rupees has been expended in the construction of the said Vehar Lake and Water Works, and in purchasing up the interests of the tenants or occupants of the site of the said Lake and Works, and it has been agreed that one-half of all sums so expended in excess of 25 lakhs of rupees shall be defrayed out of the public revenue, it is hereby enacted that the said Municipal Commissioners shall pay annually on or before the 1st July to the Governor in Council a sum not less than the total amounts payable under the provisions of the Sections of the Act aforesaid, which sums shall be appropriated to the liquidation of the amount payable with interest by the Municipal Commissioners until the whole amount be defrayed, and the said amount shall be the total of the said 25 lakhs of rupees and of a moiety of the excess above 25 lakhs of rupees expended on the construction of the said Vehar Lake and Water Works, the amount of which moiety shall be determined on a scrutiny of the accounts by the Deputy Auditor and Accountant-General of Bombay, whose decision shall be subject to the approval and confirmation of the Governor in Council of Bombay, and when so confirmed shall be final, and from and after the day upon which this Act shall come into operation, the liability of the said Commissioners to pay to the Governor in Council in each year the amount of the cost of the maintenance of the said Vehar Lake and Water Works, shall cease and determine, but if the said Commissioners shall in any year fail to pay on or before the 1st July to the Governor in Council such sums as are in this Section prescribed, it shall be lawful for the Governor in Council to give two months' notice to the said Commissioners, requiring payment of all arrears accrued due on account of the sums so payable, and on failure of the Commissioners to make such payment, the said Vehar Water Works and all the movable and immovable property appertaining thereto and vested in the said Commissioners, shall cease so to vest, and shall forthwith become vested in the Governor in Council in trust for the purposes for which it was previously vested in the said Commissioners: Provided that all sums received by the Governor in Council on account of water supplied from the said Works, shall, after deduction of all sums expended in the management and maintenance of the same, be credited to the said Commissioners as having been paid on their account and received by the Governor in Council, in liquidation of the amount payable by the said Commissioners and in this Section.

Water-rates may be levied by the Municipal Commissioners.

VII. From and after the day upon which this Act shall come into operation, it shall be lawful for the Municipal Commissioners, with the consent of the Bench of Justices and the approval of the Governor in Council, to impose such annual or other periodical rates for the supply of water from the said Vehar Water Works, and such periods for the payment of the same, upon houses, wharves and other structures, and upon all works and places whatsoever so supplied with water, and thereafter with such consent and approval so to alter the said rates and periods as may be necessary or expedient, and such rates shall be recoverable by the said Municipal Commissioners in like manner as rates payable under the provisions of Act XXV. of 1858.

Municipal Commissioners may supply water by measurement and by Contract.

VIII. It shall be lawful for the said Commissioners, with the consent of the Bench of Justices and subject to such rules as the Governor in Council may, from time to time, prescribe, to supply water to any person from the said Water Works, in such quantities and on such terms and conditions as shall seem fit, and to contract for the supply of such water for any purpose whatever to any person without measurement at a reasonable fixed rate, and all moneys due to the said Commissioners on account of any water so supplied shall be recoverable in like manner as the rates in the last preceding Section mentioned.

Public wells and tanks to be preserved.

IX. All public wells, tanks, reservoirs and the like vested, or which may hereafter be vested in the Municipal Commissioners, and from which the public may or shall ordinarily have drawn water without payment, shall be continued and maintained by the said Commissioners, so long as the Bench of Justices or the Governor in Council shall require, and the public shall have free access thereto and may draw water therefrom without hindrance or payment of any fee whatever.

Punishment for fraudulent disposal of water.

X. Every person liable to the payment of any rate or price to the Municipal Commissioners for any water supplied to him from the said Vehar Water Works upon certain conditions as to the use of the same, who shall fraudulently dispose of such water to persons or for purposes in violation of the said conditions, shall be liable, on conviction before any magistrate of police, to a fine not exceeding Rs.500 and in default of payment of such fine shall be punished with simple imprisonment for a period not exceeding two months.

Inspection of Works by Government Officers.

XI. The Municipal Commissioners shall at all reasonable times permit all persons appointed by the Governor in Council on that behalf, to enter upon, and inspect, and take account of all the property by this Act vested, or which, in virtue of the same, may become vested in the said Commissioners; and the persons so appointed as aforesaid shall be entitled to enter upon and pass through any property adjacent to, or in the neighbourhood of, the said Vehar Lake and Water Works, or any part thereof, subject to the same conditions as the Municipal Commissioners, and if from the report of any person appointed as aforesaid it shall appear that the said Lake or Water Works, or any portion of the same, are not in a sound and effective condition, it shall be lawful for the Governor in Council by notice, under the signature of a secretary to Government, to call upon the said Commissioners to repair, improve, and make effective the said Works or Lake or portion thereof within such a period as may seem reasonable, and the said Commissioners shall be bound within such period to comply with such requisition, failing which the Governor in Council may immediately on the expiration of such period order the said Lake or Works or portion thereof to be repaired, improved, and made effective, in such manner and by such means as shall seem fit, and the Municipal Commissioners shall, in any such case, be bound forthwith to pay to the Governor in Council the cost of the work so performed, in addition to any other sums by them payable.

Municipal Commissioners to keep accounts.

XII. The Municipal Commissioners shall keep accounts of all receipts and disbursements on behalf, or by reason, of the said Vehar Water Works, apart and distinct from any other accounts, and shall annually present to Government, and cause to be published in the *Government Gazette*, a statement of such accounts, and the said accounts shall at all reasonable times be open to examination and audit by any person appointed on that behalf by Government, and if upon the report of the person so appointed it shall appear that the accounts are falsely, erroneously, or negligently kept, it shall be lawful for the Governor in Council to order the same to be corrected, and to be kept in future with due diligence according to such plan as Government may prescribe, as truly representing the affairs of the said Water Works, and the Municipal Commissioners shall be bound to conform to such order.

Disposal of surplus funds.

XIII. If from any such annual report of the Commissioners, or any report of an examiner appointed by the Governor in Council as aforesaid, it shall appear that after paying to Government the sums due under this Act, and after providing for the repairs and maintenance of the Lake and Water Works and the payment of necessary salaries, any surplus remains in the hands of the said Commissioners or their agents, of moneys received on account of the said Works, it shall be lawful for the said Commissioners, with the consent of the Bench of Justices, to expend the same in such extensions and improvements of the said Works and of the apparatus connected therewith, as the Governor in Council may approve, and if such improvements or extensions shall appear to be necessary, it shall be lawful for the Governor in Council, with the concurrence of the Bench of Justices, to require that the same may be made; and if it shall appear that the surplus, after providing for such payments to Government and for such expenses of repairs and maintenance as aforesaid, has in any year exceeded the sum of fifty thousand rupees, the said Commissioners may forthwith prepare a new scale of rates and prices, so calculated as to reduce the annual receipts on account of the said Water Works, either by the whole amount by which the same exceed the necessary disbursements on account thereof, or by such sum as shall remain after providing for the extensions and improvements which may properly be made out of the said surplus or profits, and shall submit the same for the approval of the Governor in Council, and in failure thereof the Governor in Council, with the concurrence of the Bench of Justices, may order such new scale to be made, or may prescribe a new scale calculated as aforesaid, which new scale the said Commissioners shall forthwith adopt, and shall thereafter recover such demands only for supplies of water as are in accordance therewith.

If Commissioners fail to perform their duties under this Act, they may be temporarily superseded.

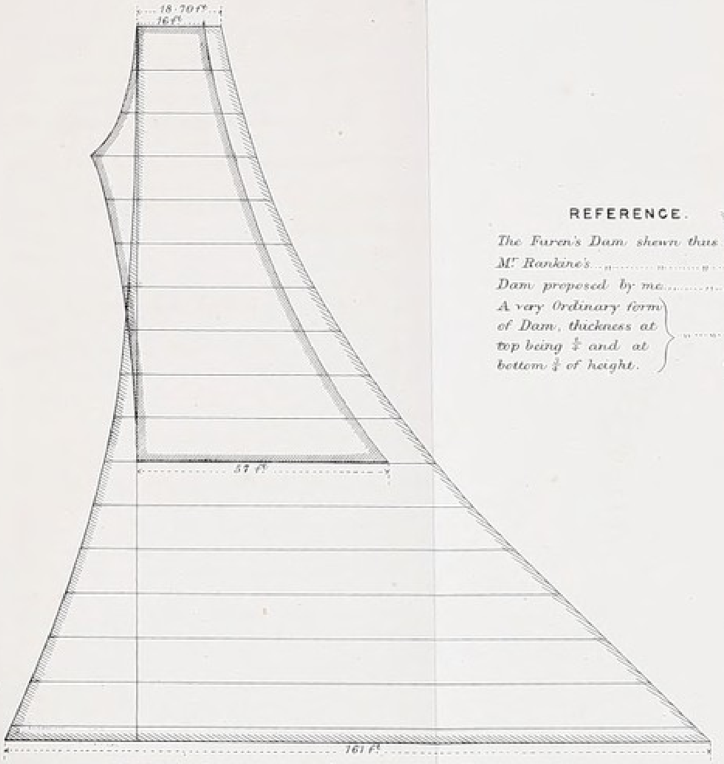
XIV. If the Municipal Commissioners shall refuse or fail duly and diligently to maintain and manage the Vehar Lake and Water Works, or to keep accounts of the same, or to perform any duty which, under this Act, they are bound to perform, it shall be lawful for the Governor in Council, after such notice as shall seem fit, to appoint any person or persons for the performance of all or any of such duties, until the next ensuing election of Municipal Commissioners, and to assign to such persons such salary as shall seem reasonable, to be paid out of the Municipal Fund, and the person so appointed shall have and exercise in the performance of the duties assigned to them by the Governor in Council the like powers and privileges as the Municipal Commissioners, and the Municipal Commissioners shall, from the date of such appointment, cease to perform the duties assigned to the persons so appointed, and shall transfer to the said persons all documents, accounts and property necessary for the proper performance of such duties, provided that from and after the next ensuing election of Municipal Commissioners the duties and powers of the person so provisionally appointed by the Governor in Council as aforesaid shall cease, and shall forthwith devolve on and vest in the Municipal Commissioners, and that such person shall be bound to transfer to the Municipal Commissioners all documents, accounts, and property held by them or under their control, on account of the said Vehar Water Works.

Building, &c., within the limits of the watershed prohibited.

XV. From and after the day upon which this Act comes into operation, it shall not be lawful for any person to erect any building, shed, or other structure, for the purposes of dwelling or manufacture, trade or agriculture, within the limits of the watershed of the Vehar Lake, as defined in a plan marked B, and deposited in the office of the Secretary to Government of Bombay, and authenticated by the signatures of the Governor and Members of Council, or to extend or alter any such structure heretofore existing within the said limits, or to apply the same to purposes different from those to which it has heretofore been usually applied; and it shall not be lawful within the said limits for any person to carry on any operation of manufacture, trade, or agriculture, in any manner whereby any injury may arise to the said Lake, or the waters of the same may be fouled or rendered less wholesome; and any person so offending shall, at the prosecution of the said Municipal Commissioners, be subject, on conviction before any magistrate, to imprisonment of either description for any period not exceeding one month, or to a fine of rupees one hundred, or to both; and it shall further be lawful for the magistrate of the district, in case of any such conviction as aforesaid, to order the immediate removal of such building or structure, and the discontinuance of such operation or use of the land as aforesaid; and in case of disobedience to remove such structure and to prevent such operation or use, and for any opposition to such removal or other disobedience of such order as aforesaid, the offender shall be liable, in each instance, to the penalty in this Section above provided.

SECTIONS OF DIFFERENT FORMS OF DAMS.

Fig: 1.



SECTION OF FURENS DAM AND THAT PROPOSED BY ME.

REFERENCE.

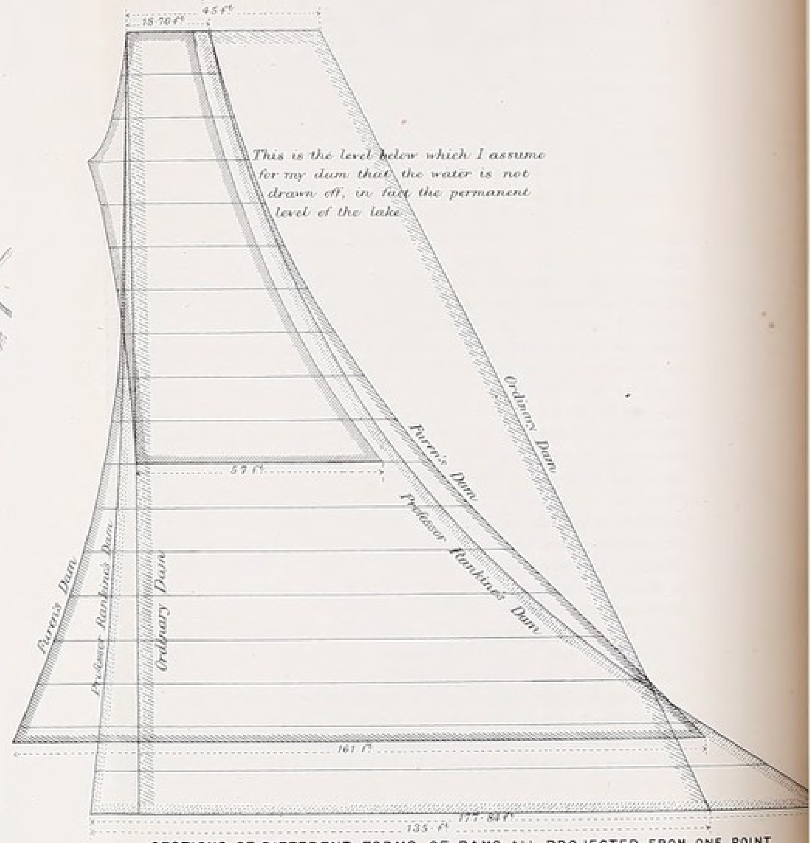
The Furen's Dam shewn thus

Mr. Rankine's „ „

Dam proposed by me

A very Ordinary form of Dam, thickness at top being ⅒ and at bottom ⅘ of height.

Fig: 2.



SECTIONS OF DIFFERENT FORMS OF DAMS ALL PROJECTED FROM ONE POINT.
(THAT POINT BEING THE TOP OF THE INNER FACE.)

Scale.

Feet 30 20 10 0 30 60

Kell Bros. Lith.

APPENDIX C.

MUNICIPALITY, CITY OF BOMBAY,

Executive Engineer's Office, Water Works Department, 10th December 1870.

FROM THE EXECUTIVE ENGINEER, MUNICIPALITY,

TO PROFESSOR W. J. M. RANKINE,
University, Glasgow.

SIR,—For some years I have had a conviction that the mode of constructing high embankments for the purpose of impounding water usually adopted by the profession is faulty. I consider the fact of the puddle wall in the middle of the dam being virtually all the resistance that the dam can bring to bear against the water, renders all our dams far too weak. My mind has been led on to the subject of masonry dams and the best mode of constructing them. A few months ago I accidentally came across the work which you will receive along with this letter.* I do not know whether you have ever read the papers contained in it, but I have no doubt that they will prove very interesting to you. You will there see that while England possesses hardly a single dam which is considered perfectly safe with a pressure of 100 feet, the French have constructed one, and with the greatest success, 165 feet high. Not a drop of water escapes from this masonry work. The principles on which the Furens dam is constructed are fully explained in the book. I was very much struck with the work, but I am still not disposed to abandon an idea which I have all along had regarding the construction of dams.

In the building of the Furens dam three points were considered. The dam might slide, the dam might be overturned, and it might yield by the compression of its own weight. No case of a dam having ever slidden is on record. The tendency to failure in this respect, especially if the wall is of uncoursed rubble, is so small that it was discarded in the calculations. Again, no dam has ever been overturned. Every dam, in fact, has been strong enough to resist the mere pressure of the water. To make a wall, therefore, to stand against a certain head of

* Colonel Fife's pamphlet on "Dams of Masonry."

water, disregarding other considerations, is a simple enough problem. Lastly, every dam has given way by its own compressing force, and the French Engineers, as I understand them, say that, having provided a certain thickness of wall to resist the mere pressure of the water, the best and cheapest distribution of the material would be that in which the weight was evenly and equally distributed throughout. Beyond all doubt, in my humble opinion, they have constructed a work which, considered either in its scientific or æsthetic aspect, has put into the shade all works of a similar nature ever before constructed. But, in spite of this, I think a still more effective disposal of the material with a less quantity may be made, and one which to the eye will present as pleasing and as imposing an aspect.

My idea is this, that up to that height of the dam below which the water is not intended to sink, the embankment should lean as it were against the water. Of course I see the objection which French Engineers would make, that in this case we add very much to the weight to be borne by the inner portion of the wall, causing it to slip downwards; but still we surely cannot reach anything like the point of compression by adopting this method for dams of the ordinary heights. They would not be likely to slip. There can be no doubt that we should be able to make a great saving in material, for the power of a dam (constructed as I propose) to resist the presure of the water to overturn it would be considerably increased. As the problem to be rigorously calculated requires the higher methods of mathematical analysis, I have applied and obtained the permission of the Municipal Commissioner of this town to submit it to you. What I should like is a rigorous mathematical solution, and after this the practical effect of the proposition. I may be quite wrong, but Mr. Crawford is of opinion that the highest authority should be consulted on so important a subject, which involves the saving of thousands of pounds.

I send you a plan showing the Furens dam, and approximately the section which I would propose to give.*

We should feel obliged if you would have a section of the best form of dam drawn out, according to your calculations, both for short and for long dams. The French Engineers propose, as I understand them, the same *form* for dams of all heights, so that, taking the Furens dam at 165 feet high, the best form for a dam 100 feet high would be simply to take the Furens section for the upper hundred feet. Perhaps one uniform section may not be possible according to your calculations, in which case a sketch showing dimensions of all dams, from say 50 to 165 feet (by tens of feet), would be very convenient.

I should inform you that the materials for which the dams should

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* *Vide* Plate XLVI.

be calculated are rubble masonry, made with a fairly hydraulic (natural) lime and hard trap rock, the resistance of which rock to crushing and the weight of which might be taken the same as for granite.

We should also desire your opinion as to whether coursed or rubble masonry would be the best on all accounts. Of course you will see my object is to reduce the mass of masonry as much as I can, and I endeavour to do so by throwing the centre of gravity of the dam as far forward (towards the water side I mean) as possible, and thus immensely strengthening the dam's resistance to the power of the water to overturn it. My object, moreover, in giving the upper portion of the dam a reverse slope is to throw its weight back as much as possible, and thus to relieve the front of the wall from as much compressing force as I can. This portion of the dam is not *always* subjected to the pressure of water, but may or may not be according as the reservoir is full up to its intended height or empty.

The section which I have drawn, as an illustration of my idea, I need hardly say, has not been calculated out. It is of no particular dimensions, and merely a rough illustration of what is intended.

Any remarks which you might like to make on the French Engineer's papers would be very acceptable.

I have the honour to be, Sir,

Your most obedient Servant,

H. TULLOCH, Captain R.E.,

Executive Engineer, Bombay Municipality.

APPENDIX D.

REPORT ON THE DESIGN AND CONSTRUCTION OF MASONRY DAMS.*

Subject of Report.

1. I have carefully considered the letter of Captain Tulloch, R.E., Executive Engineer of the Municipality of Bombay, dated the 10th December, 1870, on the subject of Masonry Dams or Reservoir Walls of great height, and also the papers on the same subject by M. Graeff and by M. Delocre, which appeared in the "Annales des Ponts et Chaussées." These last I have studied, both in the original and in the very faithful translation by Colonel J. G. Fife. I have also made mathematical investigations as to the proper figure and dimensions of such dams, which are given in an Appendix to this Report.

Material.

2. As regards the material best suited for a Reservoir Wall or Embankment, I consider that it must be determined by the nature of the foundation. That foundation should be sound rock, if practicable, and should a rock foundation be unattainable, firm impervious earth. It may be doubted whether any earthen foundation is thoroughly to be relied on where the depth of water exceeds 100 or 120 feet. It is not advisable to build a masonry dam on an earthen foundation; for the base of the dam must be spread to a width sufficient to distribute the pressure, so that it shall not be more intense than the earthen foundation can bear; and this involves the use of a quantity of material which would lead to immoderate expense if the material used were masonry.

Mode of building.

3. In the case of a rock foundation the proper material is unquestionably rubble masonry, laid in hydraulic mortar; and the opinion of M. Graeff, that continuous courses in building that masonry are to be avoided, is fully corroborated by experience; for the bed-joints of such courses tend to become channels for the leakage of the water.

4. The very fact, however, of the irregular structure of that masonry, renders necessary unusual care and vigilance in superintend-

* Plate XLVII. is a copy of Mr. Rankine's Proposed Dam. Plate XLVI. gives some useful information regarding dams.

ing its erection, in order to insure that every stone shall be thoroughly and firmly bedded, and that there shall be no empty hollows in the interior of the wall, nor spaces filled with mortar alone where stones ought to be placed. The practice of "grouting," or filling hollows by pouring in liquid mortar, should be strictly prohibited.

Principles determining profile.

5. With respect to the profile of the wall, its figure is in the main to be determined by principles nearly the same with those laid down by the French Engineers already referred to, and put in practice in the dams of the rivers Furens and Ban; that is to say, the intensity of the vertical pressure at the inner face of the wall, should at no point exceed a certain limit, when the reservoir is empty; and the intensity of the vertical pressure at the outer face of the wall should at no point exceed a certain limit, when the reservoir is full.

Limits of Vertical Pressure.

6. In the theoretical investigations of M. Delocre and the practical examples given by M. Graeff, the same limit is assigned to the intensity of the vertical pressure at both faces of the wall. But it appears to me that there are the following reasons for adopting a lower limit at the outer than at the inner face. The direction in which the pressure is exerted amongst the particles close to either face of the masonry is necessarily that of a tangent to that face; and, unless the face is vertical, the vertical pressure found by means of the ordinary formulæ is not the whole pressure, but only its vertical component; and the whole pressure exceeds the vertical pressure in a ratio which becomes the greater, the greater the "batter," or deviation of the face from the vertical. The outer face of the wall has a much greater batter than the inner face; therefore, in order that the masonry of the outer face may not be more severely strained when the reservoir is full than that of the inner face when the reservoir is empty, a lower limit must be taken for the intensity of the vertical pressure at the outer face than at the inner face.

Weight of wall to be thrown inwards.

7. The proposal of the Executive Engineer, to throw the weight of the wall further inwards than in the French designs, tends to realize the principle just stated; and so far I fully approve of it, and have carried it out in the profile which accompanies this report.

8. I do not, however, concur with the Executive Engineer in the proposal to throw the weight of the wall so far inwards as to make it overhang, for the following reason: The additional stability against the horizontal thrust of the water, gained by giving the wall an overhanging batter inwards, is not that due to the whole weight of the overhanging masonry, but only to the excess of that weight above the weight of water which it displaces; in other words, about half the effect of the weight of the overhanging mass of masonry in giving stability

is lost through its buoyancy; and hence the additional stability gained by making the wall overhang inwards is not proportionate to the additional load thrown upon the lower parts of the inner face; and more stability would be gained by placing a given mass of masonry so as to form an uniform addition to the thickness of the wall than by making it overhang inwards.

Limits of Vertical Pressure, how fixed.

9. In choosing limits for the intensity of the vertical pressure at the inner and outer faces of the wall represented by the accompanying profile, I have not attempted to deduce the ratio which those quantities ought to bear to each other from the theory of the distribution of stress in a solid body; for the data on which any such theoretical determination would have to be based are too uncertain. The limits which I have chosen are as follows, and they are given in the first place, in feet of a vertical column of masonry whose weight would be equivalent to the pressure; and are then reduced to various other measures :—

Limits of Vertical Pressure at	Inner face.		Outer face.
Feet of Masonry	160	...	125
Feet of Water	320	...	250
Lbs. on the square foot (nearly) .	20,000	...	15,625
Mètres of Masonry (nearly) .	49	...	38
Mètres of Water (nearly) . .	98	...	76
Kilog. on the sq. centimetre (nearly)	9·8	...	7·6

In choosing these two limits, I have been guided by the consideration of the following facts. As regards the inner face, where the deviation of the direction of the stress from the vertical is unimportant, it is certain, from practical experience, that rubble masonry, laid in strong hydraulic mortar and good rock foundations, will safely bear a vertical pressure equivalent to the weight of a column of masonry 160 feet high, if not higher. As regards the outer face, the practical data given by M. Graeff show that masonry of the same quality, in the sloping outer face of a dam, will safely bear a pressure whose vertical component, as found by the ordinary rules, is equivalent to the weight of a column 125 feet high.

Diminution of Vertical Pressure towards foot of slope.

10. The same reasons which show that the intensity of the vertical components of the pressure ought to be less for a battering than for a vertical face, show also that this intensity ought gradually to diminish at the lower part of the outer face, where the batter gradually increases. In the present state of our knowledge we should not be warranted in framing any definite theory as to the law which this diminution ought to follow; and, therefore, in preparing the accompanying design, I have thought it best to be guided in this, as in the

previous case, by practical examples, and to consider it sufficient to make the law of diminution such that at the depth of 150 feet below the surface the intensity of the vertical component of the pressure at the outer face becomes nearly equal to what it is at the same depth in the outer face of the dam across the Furens—viz., 107 feet of masonry or about $6\frac{1}{2}$ kilogrammes on the square centimetre.

Tension to be avoided.

11. I have kept in view another principle, not referred to by the French authors—viz., that there ought to be no practically appreciable tension at any point of the masonry, whether at the outer face when the reservoir is empty, or at the inner face when the reservoir is full. Experience has shown that in structures of brickwork and masonry that are exposed to the overturning action of forces which fluctuate in amount and direction (as when a factory chimney is exposed to the pressure of the wind), the tendency to give way first shows itself at that point at which the tension is greatest. In order that this principle may be fulfilled, the line of resistance should not deviate from the middle of the thickness of the wall to an extent materially exceeding one-sixth of the thickness. In other words, the lines of resistance when the reservoir is empty and full respectively, should both lie within, or but a small distance beyond, the middle third of the thickness of the wall.

Horizontal curvature of wall.

12. As regards the effect of giving the wall a curvature in plan, convex towards the reservoir, I look upon this as a desirable and in many cases an essential precaution, in order to prevent the wall from being bent by the pressure of the water into a curved shape concave towards the water, and thus having its outer face brought into a state of tension horizontally, which would probably cause the formation of vertical fissures and perhaps lead to the destruction of the dam. I consider, however, that calculations of stability which treat the dam as a horizontal arch are so uncertain as to be of very doubtful utility; and I would not rely upon them in designing the profile. In fixing the radius of horizontal curvature, I consider that the engineer should be guided by the form of the gorge in which the dam is to be built, making that radius as short as may be consistent with convenience in execution, and with making the ends of the dam abut normally against the sound rock at the sides of the gorge.

Summary of conditions to be fulfilled by Profile.

13. The conditions which have been observed in designing the accompanying profile may be summed up as follows :—

A. The vertical pressure at the inner face not to exceed 160 feet of masonry;

B. The vertical pressure at the outer face not to exceed 125 feet of masonry at the point where it is most intense, and to diminish in going down from that point;

C. The lines of resistance when the reservoir is full and empty respectively to lie within or near to the middle third of the thickness of the wall. Those are limiting conditions, and do not prescribe exactly any definite form.

In choosing a form in order to fulfil them without any practically important excess in the expenditure of material beyond what is necessary, I have been guided by the consideration, that a form whose dimensions, sectional area, and centre of gravity under different circumstances are found by short and simple calculations is to be preferred to one of a more complex kind when their merits in other respects are equal; and I have chosen logarithmic curves for both the inner and the outer faces.

Logarithmic Curves chosen.

14. The constant subtangent common to both curves (marked A D in the drawing) is 80 feet; this bears relations to the vertical pressure which are stated in the Appendix.

Rules as to thickness.

The thickness C B at 120 feet below the top is 84 feet; and of this one-fourteenth, A C = 6 feet, lies inside the vertical axis O X, and thirteen-fourteenths, A B, 78 feet, outside that axis. The formula for the thickness t at any depth x, below the top, is as follows :—

$$t = t_1 e^{\frac{x-x_1}{a}}; \qquad (1.)$$

or in *common* logarithms

$$\log t = \log t_1 + 0{\cdot}4343 \frac{x-x_1}{a}; \qquad (1A.)$$

in which a denotes the subtangent (80 feet) and t_1 the given thickness (84 feet) at the given depth (120 feet) below the top. The thickness at the top is 18·74 feet.

15. In the profile, horizontal ordinates are drawn at every 10 feet of depth from the top down to 180 feet, and their lengths, from the vertical axis O X to the inner faces respectively, are marked in feet and decimals. In each case those ordinates are respectively one-fourteenth and thirteen-fourteenths of the thickness. Intermediate ordinates at intervals of 5 feet can easily be calculated, if required, by taking mean proportionals between the adjacent pairs of ordinates at the intervals of 10 feet.

Horizontal Ordinates.

16. The sectional area of the wall from the top down to any given depth is found by multiplying the constant subtangent (a = 80 feet) by the difference ($t - t_0$) between the thickness at the top and at the given depth; that is to say

Sectional areas.

$$\int_0 t\,dx = a\left(t - t_0\right) \qquad (2.)$$

17. The vertical line through the centre of gravity of the part of the wall above a given horizontal plane stands midway between the middle of the thickness at the given horizontal plane and the middle of the thickness at the top of the wall; and thus have been found points in the curve marked "Line of Resistance, Reservoir Empty."

Line of Resistance when Reservoir is empty.

18. Supposing the reservoir filled to the level of the top of the wall, the moment of the pressure exerted horizontally by the water against each unit of length of wall from the top down to a given depth (x) is found by multiplying the weight of a cubic unit of water by one-sixth of the cube of the depth; and if we take, for convenience, the weight of a cubic unit of masonry as the unit of weight, and suppose the masonry to have twice the heaviness of water, this gives us, for the moment of horizontal pressure,

Moment of pressure of water.

$$M = \frac{x^3}{12} \quad \text{(3.)}$$

19. The moment of horizontal pressure, expressed as above stated, being divided by the area of cross-section above the given depth, gives the horizontal distance at the given depth between the lines of resistance with the reservoir empty and full respectively; that is to say

Line of Resistance when Reservoir is full.

$$\frac{M}{\int t\, d\, x} = \frac{x^3}{12\, a\, (t - t_0)} \quad \text{(4.)}$$

and thus have been found points in the curve marked "Line of Resistance, Reservoir Full."

20. In the preceding formulæ, the pressure of the water against the inner face of the wall is treated as if it were wholly horizontal (as in the investigations of M. Graeff and M. Delocre). In fact, however, that pressure, being normal to the inner face of the wall, has a small inclination downwards; and therefore contains a small vertical component, which adds to the stability of the wall. The neglect of that vertical component is an error on the safe side.

Vertical component of water pressure neglected.

21. To find the mean intensity of the vertical pressure on a given horizontal plane in the masonry, expressed in feet of masonry, divide the sectional area by the thickness at the given plane; that is to say

Intensity of Vertical Pressure in Masonry.

$$\int \frac{t\, d\, x}{t} = a\left(1 - \frac{t_0}{t}\right) \quad \text{(5.)}$$

To find the greatest intensity of that vertical pressure, according to the ordinary assumption that, it is an *uniformly varying stress*, in other words, that it increases at an uniform rate from the face furthest from the line of resistance to the face nearest to that line, the mean intensity is to be increased by a fraction of itself expressed by the ratio which the deviation of the line of resistance from the middle of the thickness bears to one-sixth of the thickness; that is to say, let p denote that greatest intensity, expressed in feet of masonry, and r the deviation of the line of resistance from the middle of the thickness; then

$$p = a\left(1-\frac{t_0}{t}\right)\left(1+\frac{6r}{t}\right) \quad \text{(6.)}$$

When that deviation is appreciably greater than one-sixth of the thickness, the preceding rule is no longer applicable, but this case, as already explained, ought not to occur in a reservoir wall.

The assumption on which the rule is based, of an uniform rate of variation of that component of the pressure which is normal to the pressed surface, is known to be sensibly correct in the case of beams, and is probably very near the truth in walls of uniform or nearly uniform thickness. Whether, or to what extent, it deviates from exactness in walls of varying thickness is uncertain in the present state of our experimental knowledge.

Profiles for different depths.

22. The range of different depths to which the same profile is applicable without any waste of material extends from the greatest depth shown on the drawing, 180 feet, up to 120 feet, or thereabouts. For depths between 120 feet and 80 or 90 feet or thereabouts, the waste of material is unimportant. For depths to any considerable extent less than 90 feet, the use of a part of the same profile gives a surplus of stability. For example, if the depth be 50 feet, the quantity of material is greater than that which is necessary in the ratio of 1·4 to 1, nearly. For the shallow parts, however, at the ends of a dam that is deep in the centre, I think it preferable to use the same profile as in the deep parts, notwithstanding this expenditure of material, in order that the full advantage of the abutment against the sides of the ravine may be obtained. In the case of a dam that is less deep in the centre than 120 feet, the following rule may be employed: Construct a profile similar to that suited to a depth of 120 feet, with all the thicknesses and ordinates diminished in the same proportion with the depth. The intensity of the vertical pressure at each point will be diminished in the same proportion also; but this does not imply waste of material; the whole weight of the material being required in order that there may be no appreciable tension in any part of the wall.

(Signed) W. J. MACQUORN RANKINE.

59, *Vincent Street, Glasgow, 9th February* 1871.

APPENDIX E.

MATHEMATICAL PRINCIPLES OF THE PROFILE CURVES.

1.—Principles relating to all forms of Profile.

Let t, as before, be the thickness of the wall in a horizontal plane at the depth x below the top; then taking the weight of a cubic unit of masonry as the unit of weight, the weight of each unit of length of the wall above that plane is expressed by

$$\int_0^x t\,dx$$

In order that there may be no appreciable tension at the outer edge of the given plane when the reservoir is empty, nor at the inner edge when it is full, the centre of resistance of that plane ought not to deviate from the middle of the thickness by more than about one-sixth of the thickness; inwards when the reservoir is empty, outwards when it is full.

Let y denote the deviation of the centre line of the thickness of the wall outwards from a vertical axis O X; so that $y - \frac{t}{2}$ and $y + \frac{t}{2}$ are the coördinates of the inner and outer faces of the wall respectively; and when $x = 0$, let $y = y_0$.

The line of resistance when the reservoir is empty, cuts the horizontal plane at the depth x in a point vertically below the centre of gravity of the part of the wall above that plane; and in order that the weight of the wall may be thrown as far inwards as is consistent with there being no appreciable tension at the outer face when the reservoir is empty, the deviation of that line of resistance from the middle of the thickness of the wall, ought not materially to exceed one-sixth of the thickness; hence, if r' be taken to denote the inward deviation in question

$$r' = y - \frac{\int_0^x y\,t\,dx}{\int_0^x t\,dx} = \text{or} < \frac{t}{6}\text{ nearly} \quad \text{..............................(A}$$

Let w be the ratio in which the masonry is heavier than water. Then the moment of the horizontal pressure of the water above the same plane on each unit of length of wall is

$$M = \frac{x^3}{6\,w}$$

The vertical component of that pressure is neglected, as explained in the body of the report. The extent to which the centre of resistance at the given horizontal plane is shifted outwards by the pressure of the water is,

$$r' + r = \frac{M}{\int_0^x t\,d\,x} = \frac{x^3}{6\,w\int_0^x t\,d\,x} \quad \text{.................................... } \textbf{(B)}$$

in which r denotes the outward deviation of the line of resistance from the middle of the thickness when the reservoir is full, and the condition that the centre of resistance when the reservoir is full is not to deviate from the middle of the thickness by more than about one-sixth of the thickness, is expressed by the following formulæ, in which r denotes the outward deviation.

$$r = \frac{\frac{x^3}{6\,w} + \int_0^x y\,t\,d\,x}{\int_0^x t\,d\,x} - y = \text{or} < \frac{t}{6} \text{ nearly} \quad \text{................ } \textbf{(C)}$$

The formulæ A and C express the condition that there shall be no practically important tension in the masonry at any horizontal plane.

Let p' and p be the vertical pressures at the inner and outer faces respectively at the depth x; and P′ and P the limits which those pressures are not to exceed. Then we have as another pair of equations to be satisfied

$$p' = \left(1 + \frac{6\,r'}{t}\right)\frac{\int_0^x t\,d\,x}{t} = \text{or} < P' \quad \text{.............................. } \textbf{(D)}$$

$$p = \left(1 + \frac{6\,r}{t}\right)\frac{\int_0^x t\,d\,x}{t} = \text{or} < P \quad \text{.............................. } \textbf{(E)}$$

II.—*Principles relating to the Logarithmic Curve Profile.*

As a means of satisfying the equations of condition to a degree of approximation sufficient for practical purposes, let the inner and outer boundaries of the profile be all three logarithmic curves with the vertical axis O X for their common asymptote, and having one common constant subtangent a. It may be remarked that one reason for adopting the logarithmic curve is its giving a thickness at the top of the wall sufficient for the formation of a roadway; and that another reason is, its giving values to the intensity of the pressure at the outer face below the point of maximum pressure, which diminish as the latter increases. Let the ratio borne by the deviation y of the centre line of the thickness from the vertical axis to the thickness t be expressed by

$$C = \frac{y}{t}$$

Then we have the following equations :—

$$t = t_o e^{\frac{x}{a}}; \quad \text{(F)}$$

$$y = c\,t = c\,t_o e^{\frac{x}{a}}; \quad \text{(G)}$$

$$\int_0^x t\,d\,x = a\,t_o\left(e^{\frac{x}{a}} - 1\right) = a\left(t - t_o\right) \quad \text{(H)}$$

$$r' = \frac{t_o}{2}\left(e^{\frac{x}{a}} - 1\right) = c\,\frac{t - t_o}{2} = \frac{y - y_o}{2}; \quad \text{(K)}$$

$$r = \frac{x^3}{6\,w\,a\,(t - t_o)} - \frac{c\,(t - t_o)}{2} = \frac{x^3}{6\,w\,a\,t_o^2\left(e^{\frac{x}{a}} - 1\right)} - \frac{C}{2}\left(e^{\frac{x}{a}} - 1\right) \ldots \text{(L)}$$

$$p' = a\left(1 - e^{-\frac{x}{a}}\right)\left\{1 + 3\,C\left(1 - e^{-\frac{x}{a}}\right)\right\}; \quad \text{(M)}$$

$$p = a\left\{1 - e^{-\frac{x}{a}} - 3\,c\left(1 - e^{-\frac{x}{a}}\right)^2\right\} + \frac{x^3 e^{-\frac{2x}{a}}}{w\,t_o\,2} \quad \text{(N)}$$

When the values given above are substituted in the expressions of conditions, A, C, D, and E, the formulæ obtained are of a kind incapable of solution by any direct process. They can, however, be solved approximately without much difficulty by the process of trial and error; and such is the method by which the dimensions of the profile sent with the report have been obtained; the constants employed being $w = 2$; $P' = 160$ feet; $P = 125$ feet. The general nature of the process of approximation followed may be summed up as follows. By making $\frac{d\,p}{d\,x} = 0$, an equation is obtained involving the value of $\frac{x}{a}$ which makes p a maximum. That equation shows that as a first approximation to that value we may take $\frac{3}{2}$. This first approximation is inserted in equation K; and by making $r' = \frac{t}{6}$ there is deduced from the equation an approximate value of c. Then, in equation M, by inserting the approximate values of $\frac{x}{a}$ and of c, and making $p' = P$ (the limit of p), there is obtained an approximate value of a; and by making $r = \frac{t}{8}$ in equation L, an approximate value of t_o. The several first approximate values being then inserted in $\frac{d\,p}{d\,x} = 0$, there is obtained a corrected value of $\frac{x}{a}$, which is found to be about $\frac{11}{8}$; and thence, by means of equation N, the actual maximum value of p is computed, and found to fall slightly within the prescribed limit. Finally, as a test of the approximations, equations K, L, M, and N are applied to a series of values of x extending from the top to the bottom of the wall. As to the degree of approximation obtained, the greatest values of p' and

p are respectively 154 feet and 124 feet, instead of 160 feet and 125 feet; and there are, as the drawing shows, some small deviations of the lines of resistance beyond the middle third of the thickness; but not sufficient to be of practical importance.

The following table contains some additional values of the vertical pressure at the outer face, at and near the point where it is more intense:—

Depths, feet;	90	100	110	120	130
Vertical pressures, feet;	114	122	124	122	117

(Signed)

W. J. MACQUORN RANKINE.

Glasgow, 18th February 1871.

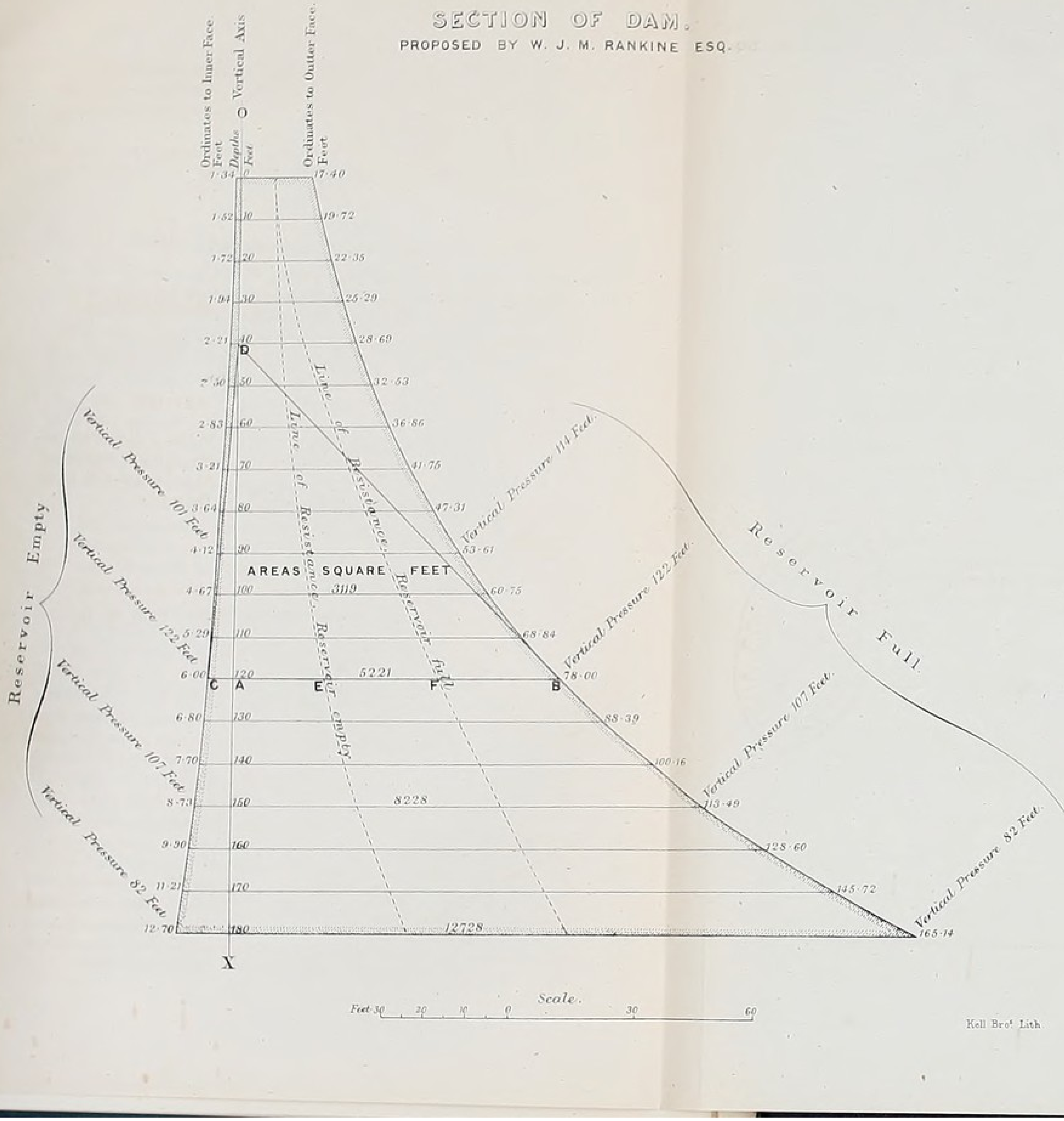
ADDENDUM TO SECTION 3 OF REPORT.

Should it be resolved to insert, in the face of the wall, headers or long bond stones, with or without projecting ends to form corbels, as in the dam of the River Furens, these stones ought to be laid with their lengths *not horizontal,* but *normal to the face of the wall.*

Correction in Report.

In Section 22, for 120 feet, read 110 feet.

W. J. M. R.


SECTION OF DAM.
PROPOSED BY W. J. M. RANKINE ESQ.
Ordinates to Inner Face Feet
Depths Feet
Vertical Axis
O
Ordinates to Outter Face Feet
AREAS SQUARE FEET
3119
5221
8228
12728
Line of Resistance. Reservoir full.
Line of Resistance. Reservoir empty.
Reservoir Empty
Reservoir Full.
Vertical Pressure 101 Feet
Vertical Pressure 122 Feet
Vertical Pressure 107 Feet
Vertical Pressure 82 Feet
Vertical Pressure 114 Feet
D
C
A
E
F
B
X
Scale.
Feet 30
20
10
0
30
60
Kell Brod Lith

APPENDIX F.

MR. BLANDFORD'S REPORT ON ROCK SYPHONS.*

On the characters of the Rocks near Bombay, through which it is proposed to cut reversed syphons for the supply of water to the town, and the facilities and difficulties which may probably be presented.

I. The questions referred to me, if I understand, are the following: It is proposed to connect a reservoir at Tansa with Bombay by a conduit about fifty miles long, cut and, for the most part, tunnelled in the rock. The greater portion of the channel will be through hills above the general level of the country, and the water will run along its slight incline naturally, but it is proposed to connect these parts of the channel by reversed syphons, bored through the rock beneath the bottom of the valleys between the hills.

1. Is it certain, or probable, that the rock, at a depth of 50 to 100 feet below the depression in question, will be found sufficiently impervious to prevent the water, which will exert a pressure of from 20 to 125 lb. to the square inch, from escaping through holes or fissures ?

2. Would any particular route take the syphons through rocks free from fissures ?

II. The first question, as put, assumes a very unfamiliar form. The idea of rock syphons is, so far as I know, quite novel; and it is consequently very difficult to give any answer. But I think that, for most practical purposes, inasmuch as all fissures which would allow the escape of water must communicate with the surface, it may fairly be assumed in most cases, at all events, wherever the syphons are below the depth at which water would be found in wells, that the escape would take place through crevices which would let water into the tunnels whilst the latter are being excavated, the only difference being that the pressure of the water in the syphons being much greater, the leakage would exceed the influx. If, then, the question be put in this form—in making the syphons, is it probable that water will be met with, and in what quantity ?—it presents a problem common in ordinary mining operations, but to which there is still some difficulty in giving

* The notes on Mr. Blandford's paper are by me—H. Tulloch.

an exact reply, in the present instance, because no deep excavations have been made in the traps, and the railway and other tunnels are usually on the sides of hills, in a position which furnishes but imperfect evidence as to the amount of water which would be met with beneath valleys.

III. It may be stated at once that if such a thing exists as an absolutely impervious rock, it is a rare exception. Besides certain argillaceous beds, there are but very few through which water does not percolate in larger or smaller quantities, and few, if any, of the rocks found in the neighbourhood of Bombay are free from fissures. The general character of these rocks is very variable, some beds being decidedly porous in consequence of cracks, while others are compact, and the character of each bed is by no means uniform, compact rocks passing into others of more open texture, and traversed by fissures, within very short distances. The question, as to whether water will be met with in making the syphons, may, therefore, I think, safely be answered in the affirmative, but the quantity to be expected is a much more difficult matter, and the distribution of the fissures, whether general or local, becomes a point of much importance, since there may perhaps be a saving in making the syphons, even although a portion of them may require lining.

IV. That the trap rocks are, as a rule, pervious to water, is shown by the general use, throughout the area composed of them, of wells in preference to tanks, both for the supply of water for drinking and household purposes, and for irrigation. It is true that the peculiarities of the black soil which generally overlies the traps, partly account for the latter, since many of the crops grown do not require irrigation, and consequently tanks are not an essential requisite for agriculture, as in the soils derived from the metamorphic rocks on which rice is the principal cereal grown; whilst the smaller supply of water obtained from wells suffices for the less extensive cultivation of sugar, tobacco, vegetables, &c., for which irrigation is chiefly employed. But I do not think that the paucity of tanks in the trap country is sufficiently accounted for by the peculiarities of the soil. There is certainly a widely-spread opinion that the rock is unfavourable, and ill suited to retain water, and that, consequently, dams upon trap rock are liable to fail in consequence of leakage taking place through the rock. How far this opinion is founded on actual experience I cannot say, but I know of one instance, and have heard of others, in the neighbourhood of Bombay, in which an attempt to store water by means of a dam was a failure, in consequence of the leakage through fissures in the rock.*

* If Mr. Blandford refers here to the tank built at Matheran, in which no water is retained, it must be remembered that the soil is laterite, a most porous stratum. This is trap, no doubt, but a very exceptional form of it, and one which does not

V. On the other hand, many tanks, some of them of large size, are scattered over the trap country, although they are far less numerous than elsewhere, and they afford valuable information, because they show that the trap rock is sometimes sufficiently free from fissures to retain water under pressure. In connection with this question, I have examined the three dams at the Vehar reservoir. At the most eastern of the three the leakage is now very small indeed, and may be entirely through the dam, but in the other two it appeared to me that in each case there was a larger flow of water 200 or 300 yards below the dam than in its immediate neighbourhood. This was especially the case at the small middle dam, and it seemed to me that the discharge must in this case be chiefly through the rock below the dam. At the same time the whole leakage is not large.

VI. It may be asked whether the fissures are not confined to the surface or to a small depth beneath it. Undoubtedly they are more open in this position, but except in cases where the rock has become disintegrated towards the surface, the cracks and joints in which fissures originate are nearly as numerous below as they are above.

VII. Wells afford another admirable illustration of the irregular texture of rock, the water-supply in spots distant but a few yards from each other being notoriously variable; and this is, I think, the case in

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occur in the valleys where the rock syphons would be situated. The reason why tanks are not constructed for irrigational purposes in the Concan is not because the soil is porous and will not retain water; the reason is that the slope of the country is so great. Unless very high dams are made, the quantity of water impounded is too small for use, and high dams cannot be made by the ryots, as the cost would be altogether beyond their means. Any one who is acquainted with the East of India will understand the force of this at once. In the Madras districts, the country is so flat, that a dam, 10 or 15 feet high, will often form a tank one or two square miles in area, and impound sufficient water for several hundred acres of paddy. The entire face of the country is covered with tanks, and very few of the bunds exceed 20 feet in height. In most of the tanks the water is not more than 10 or 12 feet deep. Now, in the Concan, what would be the amount of water which a dam, 12 feet high, would impound? The slope of the streams is so great that the water retained by such a bund would not suffice for a dozen acres. Another reason why tanks are dispensed with in the Concan is that the south-west monsoon prevails for a sufficient time to admit of paddy being matured while the rain continues. In Madras the ryots are compelled to make tanks, because the north-east monsoon, on which they are dependent for water, very often does not supply rain for more than ten or twelve days in the year, never for more than two months. No paddy could be matured in this short period. But around Bombay, rice is sown as soon as the monsoon commences, and the ryots depend on the rains during June, July, August, and September, for the growth of the crops. When the rains have ceased, the lands are still so saturated with moisture, due to the exceedingly heavy nature of the monsoon, that the paddy ripens without requiring any more rain. It is not due, therefore, to the porosity of the trap strata, but to the great slope of the country and to the continuance of the monsoon for four months, that tanks are not found in the Concan.

places in which the water in the wells appears to be derived from the rocks themselves, and not from soil overlying them.

VIII. The trap rocks of the neighbourhood of Bombay may be roughly divided into three groups, each comprising numerous varieties. All the different forms pass into each other in places. The groups are:—

IX. (1) Basalt and its allies; hard dark-coloured rock, containing very little, if any, agate zeolite. These beds vary greatly in fineness of texture, but are rarely coarse-grained, although one variety is porphyritic, and contains tabular crystals of felspar. The basaltic forms of the traps are seen forming hard belts on the hill-sides, which usually weather out precipitous scarps. They are always more or less jointed, but the cracks are not wide, except near the surface. These rocks may in places prove nearly impervious, but the extensive jointing is a very unfavourable character; as a rule, they disintegrate very slowly.

X. (2) Amygdaloidal traps. This group comprises a wider series of variations than the last, and, in one form or another, makes up the greater portion of the traps. The beds included in it are softer, less fine-grained as a rule, and less uniform in composition than those of the basaltic group; and they contain more or less zeolite or agate. In places the latter minerals are dispersed in small nodules throughout the rock; sometimes they form elongate vertical pipes; and in places they occur in large veins, traversing the rock in all directions. In the latter case the trap is usually somewhat disintegrated and altered in chemical composition. This last form of rock is thoroughly pervious; not only would it allow the water to pass out of the syphons, or even of the rock channels, but in the former the quantity of water poured in during excavation would be a most serious impediment to the work, and involve large expenditure in pumping. The other forms of amygdaloid vary much in the extent to which they are fissured; as a rule, they are less jointed than the basaltic rocks, and those which are of compact texture, as is frequently the case, would, I am disposed to believe, generally retain water even under pressure. All the different kinds pass into each other, and it is most probable that all the beds are permeable in places. The amygdaloidal traps are, as a rule, more liable to decompose than other kinds, and, near the surface, they usually pass into the soft rock known throughout the Mahratta country as moorum. This is well known to be pervious to water—indeed, its disintegration is due to the action of water upon the rock from which it is produced. The depth to which disintegration extends is most variable, and as irregular as most other characters of these capricious formations. Some beds are solid and apparently unaltered at the surface, others are decomposed to a depth of 40 or 50 feet, perhaps even deeper, and on hill-sides I have often seen unaltered compact beds resting upon others which were quite soft through disintegration.

XI. (3) Breccia, or volcanic ash. There is but little of this rock to the east of Tannah in the Concan, but it is largely developed in Salsette and Bombay. It varies *ad infinitum* in colour, but is more often light than dark, and consists of angular fragments varying in size and character, in a somewhat fine, rather argillaceous matrix. As a rule, it is compact and not much fissured, but some of the beds are not only extensively cracked, but even traversed by large open channels, two or three feet in diameter; such at least is the case at Koorla, where an extensive quarry exists close to the railway-station.

XII. It will, I think, be evident from what I have stated above, that I am obliged to infer from the known character of the rocks that there will be considerable leakage from the syphons, sufficient in all probability to cause them to fail entirely, but that at the same time I am disposed to think that the most serious leakage will be local, and it may be obviated by "tubbing," or some other form of lining, or by substituting pipes. The question then is whether the proportion of lining necessary will be such as to increase the cost of the rock syphons to a limit at which there will no longer be any advantage in carrying them out. As to the necessary amount of lining, any estimate I could give would be a mere guess, and consequently worthless. I suspect it would vary in proportion in every syphon.

XIII. There are two or three points and possible difficulties to which I ought to draw attention before leaving this part of the subject. I have already mentioned one risk, that of meeting with disintegrated rock, or moorum, at a greater depth than usual. This is more likely, perhaps, in the vertical shafts at the end of each syphon than beneath the valleys, but I do not in either case consider it as very probable.

XIV. The next point is more important. In the proposed syphons beneath the creeks which separate Bombay from Salsette, and Salsette from the mainland, it is possible that quicksand may be encountered under the creeks themselves, or under the alluvial land upon their banks. This can, of course, be ascertained previously by borings made at a short distance from each other.

XV. Another risk, at the same places, is that the rock may be extensively permeated by salt water. Indeed, this may be the case wherever the syphons are below the level of the sea, for salt water was found in deepening the Baboola tank,* at Byculla, in the centre of

* Perhaps Mr. Blandford, in writing this, was not aware that the sea at one time extended almost up to the Baboola tank. Only since the erection of Governor Hornby's Embankment, known now as the Breach Vellard, has the sea been prevented from flooding this part of the town.

Bombay Island, and the water of this tank has never since been fit for drinking purposes. Unless the rock be saturated with salt over a considerable area, this, of course, would not produce any serious effect, after the fresh water had traversed the channel for a short time.

XVI. Wherever small fissures are met with and no lining employed, there will be a tendency to a constant, though doubtless, in general, a very slow increase in leakage, from the fissures being enlarged by the disintegration and removal of their walls. It is true that the same cracks will have contained water previously, but it was nearly or quite at rest, whilst the pressure exerted, after the syphons are filled with water, will keep up a constant flow. In most instances the increase of leakage will be so very slow as to be unimportant, but there will always be a risk of the formation of fresh leaks.

XVII. I am informed that in the estimates of cost nothing has been especially allowed for pumps and pumping.* I may be mistaken, but I must point out that, judging from mining operations in general, I should expect this to prove a very serious item; indeed, I am inclined to believe that the expense and delay to the work of excavation involved in meeting with large quantities of water is one of the most serious difficulties likely to be met with in the whole scheme. This is especially the case in the long syphons near Bhewndi and Koorla. It is not probable that tunnels eight or nine miles in length can be made through such rocks as the traps, and at a considerable depth below the water-level of the country (which is, throughout large portions of the tract, close to the surface), without somewhere intersecting springs of large size. It should be borne in mind that freedom from fissures in one syphon, or part of one syphon, is no guarantee of equal immunity in the next or in the remaining portion of the same; all that is known of the rocks would lead me to anticipate irregularity in this matter.

XVIII. The general conclusion at which I arrive, therefore, in answer to the first question put, is that the trap rocks are, as a rule, fissured, and often extensively fissured, but that portions are less pervious, and although I cannot assert that these latter are suited for rock syphons, they may be. That the whole syphons will resist without lining I entirely disbelieve, but what proportion may require lining is a question which can only be ascertained by trial. In making the syphons when once below the general water level of the country, the amount of

* No estimate has been taken out of the cost of rock syphons. As the reader is aware, my proposition merely extends to the making of an experiment whether rock syphons will answer. In the estimates of the cost of all the various projects submitted by me, I have allowed in every case for taking the water across the valleys in iron pipes. Mr. Blandford was not aware, perhaps, that at least eight miles of rock syphon on the Tansa line of channel would be above the general level of the water in the country, and that, therefore, in them at all events, no water would occur.

water met with in the workings will probably bear a definite proportion to the loss by escape, but will be less in quantity. In some instances it will probably be so large as to necessitate the substitution of pipes for that portion of the syphon.

XIX. To the second question proposed—viz., the best route for the syphon—I can say very little. All that I have hitherto stated applies to any scheme for supplying water to Bombay by the system proposed by Captain Tulloch, and equally generally I may add that, with the exception of the more jointed forms of the basaltic beds, which must, however, I think, be traversed occasionally, whatever the route selected, and such very open beds as the Koorla breccia, which I am disposed to look upon as local and exceptional, and therefore easily to be avoided, there is but little room for selection amongst the traps. It is really almost a matter of chance as to what may be the precise character of the rock at any particular point. I can see no especial objection to any part of the route between Tansa and Tannah; so far as Bhewndi the beds are horizontal, and the rock to be traversed by the syphons, so far as can be judged from surface examination, appears to be a tolerably compact form of amygelaloid. The depth proposed—50 feet—would, I should think, in most cases suffice to carry the syphon through rock which has not undergone disintegration. A few very inexpensive borings in the rice-fields would ascertain this point, and I should certainly recommend their being made at the Yewayee Syphon.

XX. West of Bhewndi, and throughout Bombay and Salsette, the rocks are no longer horizontal, but inclined to the west at angles varying from 3° to 10°, the usual dip being about 5° (1 in 11). As far as the Tannah Creek the rocks appear to differ but little from those to the eastward, but both in Salsette and Bombay there is considerable prevalence of breccia. I am still disposed to consider this rock as locally favourable and less pervious than most other forms of the traps, but it has been very little quarried. In any case the neighbourhood of the Koorla railway-station should be avoided, which may be easily done by taking the syphon farther to the west. The remaining portion of the ground in Bombay Island appears unobjectionable; at least, I can suggest no probable improvement from altering it. If, on sinking shafts, the ground be found unfavourable, a change of about a quarter of a mile to the east or west will, almost throughout Bombay Island, bring the syphon into a different rock.

XXI. In conclusion, I must express my fear that this is a very unsatisfactory report; but in truth the project is so novel, the rocks so notoriously uncertain, and the means available for judging of their permeability by water so inadequate, that it is with much hesitation that I venture to express any opinion whatever on the chances of Captain Tulloch's scheme. Briefly, my belief is that without lining or pipes the longer syphons will almost certainly fail, and the shorter ones probably; that lining throughout will not be necessary, but that the proportion essential can only be ascertained by trial.

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