

FINAL REPORT
ON
AUGMENTATION OF BOMBAY CITY'S
WATER SUPPLY
(April 1948)

VAITARNA-CUM-TANSA-SCHEME
(PART I & II)

BY

N. V. MODAK, ESQR. C.I.E., J.P.,
B.E., M. Inst. C.E., M.I.E. (Ind.), M.I.M.&Cy.E., F.R. San. I., &C.,
Special Engineer, Bombay Municipality.

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—APPENDICES.—

(to be published separately)

VAITARNA-CUM-TANSA SCHEME

FINAL REPORT—APRIL 1948.

Reference: Corporation Resolution No. 472, dated the 7-7-47.

This Report is divided in three parts:—

PART I—deals with the general aspects of the whole scheme.

PART II.—describes in details the major component parts of the scheme.

PART III—contains appendices.

PART I.

In the 'Interim Report' submitted by me in February 1947, I had shown that it would be in the interest of the Corporation to take up for immediate execution, the Vaitarna-cum-Tansa Scheme as a first step in the augmentation of the City's Water Supply, in preference to the Bhivpuri Scheme recommended by the Experts. The Vaitarna-cum-Tansa Scheme, as outlined by me on the data then available, aimed at bringing into the City a total combined supply of 160 million gallons per day from the two sources (Vaitarna and Tansa). The scheme comprised mainly of the following works:—

(1) Constructing a high masonry or concrete dam on the Vaitarna river to impound a useful storage of 17,000 million gallons, with the full supply level of the reservoir at about 480 T.H.D. so as to obtain a supply of 50 million gallons per day therefrom.

(2) Driving a tunnel, about five miles long, of adequate carrying capacity, between the intervening hills to divert a part of the monsoon flow of the Vaitarna river into the Tansa lake, to keep it filled upto its new full supply level of 422 T.H.D.* on 1st October of every year, so as to enable a supply of 110 million gallons per day being drawn from the same during the dry weather.

(3) Laying a new 72" diameter steel pipe line from the outlet well of the Tansa lake upto Powai—a distance of 40 miles—to carry a supply of 40 million gallons per day to increase

* The levels in T.H.D. are obtained by adding a constant viz. 80.25 feet to the mean Sea level.

the total carrying capacity of the conduits to 160 million gallons per day as given below :—

	m.	g. p. d.
(i) Existing two 72" dia. pipe lines (40 million gallons, per day each).		80
(ii) New 72" dia. pipe line	...	40
(iii) Existing duct (after reconditioning). The supply conveyed by the same, at present, is only 20 million gallon per day.		40
		160

The Corporation having agreed with my views, sanctioned funds (a) to carry out further survey work and (b) to collect more data, both geological and hydrographical, for preparing designs, plans and schedule of quantities for the various items of the scheme to enable tenders being invited for the same.

2. The Survey work was accordingly taken in hand on 1-4-47 and the major portion thereof was completed on or about 20-6-47. The remaining survey work was commenced after the monsoon of 1947 and completed by the end of the same year.

The main items covered by the survey, with comments on the results obtained, are detailed below :—

(1) Investigating alternative sites for the dam on the downstream side of the site 'D' (*vide* Index Plan, Appendix I), as this site is devoid of a natural site for a waste weir.

Investigations show that no suitable site on the downstream side of the site 'D' is available for locating a dam which can be said to possess more advantages than the site 'D' especially in regard to the location of the waste weir. There is therefore no other alternative, but to locate the dam at the site 'D' and to make the best of this site by adopting a type of the waste weir, most suited, to meet local conditions.

(2) Investigating more convenient alignments for the three sections of the tunnel to shorten its length and to obtain as many faces as possible for commencing the work thereon simultaneously for expeditious completion.

The alignment for the three sections of the tunnel has been slightly altered. The total length of the three sections will now be about 21,600 feet. The first section will extend from the Vaitarna river to the Balvant Nalla, the second from the Balvant Nalla to the Tasu Nalla, and the third from the Tasu Nalla to the Bell Nalla. (Tansa end).

The tunnel will have to be driven from six faces. Additional points for commencing the work on the tunnel are not available. The first face will be at the starting point in the left bank of the Vaitarna river. There will be two faces each in the Balvant and the Tasu Nallas and one face in the Bell Nalla. (Tansa end).

(3) Fixing the most suitable alignment for the new pipe line by the side of the existing ones and for refixing the existing trolley track in a new position.

The new pipe line from the Tansa lake will be laid to the west of the existing pipe lines upto Kapurbawdi and to the east from Kapurbawdi to Powai, on the embankment at present occupied by the trolley track. This track will be shifted from its present position and relaid on a new embankment to be formed in continuation of the existing embankment of the trolley track.

(4) Extending the existing cross drainage works to suit the new pipe line and the trolley track in the new position.

It is found that some of the existing cross drainage works are deteriorating and are in need of heavy repairs. Provision for rebuilding the deteriorated works will be made in the estimates of the new pipe line along with the extensions required.

(5) Fixing suitable routes for the two trunk inlet mains from Ghatkopar and Powai to carry the additional supply to the existing and proposed service reservoirs in the City, for distribution to the various zones of supply.

The most suitable alignment for one of the trunk inlet mains will be along the existing 57" Tansa mains upto Bandra and thence across the Mahim Creek upto the Mori Road Level crossing. A bridge will be required across the Mahim Creek, which will be located slightly to the east of the existing railway bridge. A suitable route for the second inlet main will be from Ghatkopar along the existing 48" main upto the Futka Tank and thence upto the Bhandarwada Hill Reservoir, *via* the proposed 100 feet Wadala Road and Reay Road.

(6) Selecting a suitable site for a balancing reservoir at Ghatkopar near the syphon head at altitudes of 305 and 270 T.H.D. (a) to improve the pressure in the distribution system serving the Northern parts of the City and (b) to enable water being supplied therefrom at reasonable pressure to the areas at present lying outside the City limits, but likely to be included within the extension of the Bombay Municipal limits in the Greater Bombay Region.

A suitable site for constructing a covered reservoir of about 12 million gallons capacity with its F.S.L. at 305 T.H.D. is available near the Ghatkopar syphon head. This reservoir will have to be fed from the 'duct' situated in its close proximity. It will not be necessary to construct this reservoir so long the Greater Bombay Plan does not materialise. It, being centrally situated, will be able to serve the areas commanded by the same with economical sizes of pipe lines at adequate pressures. If, in course of time, the duct is thrown out of operation this reservoir can be fed by laying another pipe from the end of the proposed new main at Powai, along the route of the existing 60" chord line.

A reservoir of about 25 million gallons capacity with F.S.L. at 270 T.H.D. can also be constructed on the hill situated to the East of the Horse-shoe valley. It can be fed from a point on one of the pipe lines from the Tansa lake, near Powai, by laying a new pipe of adequate capacity therefrom by the side of the existing 60" chord line. Though this reservoir would be more suited to feed the low-lying areas of Chembur and Mahul, it would be unable to supply water with economical sizes of pipes to high level zones. Due to this drawback, a reservoir with F.S.L. at 305 T.H.D. near the Ghatkopar syphon head would be more suitable and satisfactory.

(7) Selecting sites for temporary bunds on the Vaitarna river and the Tasu Nalla for impounding sufficient quantity of water at the end of every monsoon for the use of the supervising staff and labour to be employed on the works and also for constructional purposes, during the period the work on the Scheme is in progress.

A suitable site on the upstream side of the site 'D' has been selected for building the temporary masonry bund of 30 feet height above the river bed. The work on the bund upto a height of 20 feet has been completed. The bund will be raised to its ultimate height after watching the effect of the monsoon of 1948. This

caution is necessary as correct information regarding the depth of flood likely to pass over it was not available when the bund was designed. A temporary bund has also been constructed on the Tasu Nalla of 10 feet height. Sites for camps have also been selected and temporary buildings are under construction. The various works are shown on the accompanying plan (Appendix II).

(8) Determining the alignment of new service roads and running longitudinal sections therefor, for giving access to the site of the dam and to the working faces of the tunnels for transporting machinery materials and labour.

The alignment of the road for giving access to the site of the dam will follow more or less the route of the existing Khardi-Pareli Road. The roads for giving access to the faces of the tunnels in Balvant and Tasu Nallas are shown on Plan (Appendix II). The face of the tunnel in the Bell Nalla will have to be approached from the Tansa lake. It can also be approached by the service road to be constructed along the pipe line intended to carry water of the Vaitarna Reservoir to the City, independently of the Tansa lake, from the end of the tunnel in the Bell Nalla.

(9) Determining the quantity of rubble, metal, earth work etc. required for widening the existing Khardi-Pareli Road and for extending the same upto the site of the dam so as to render it sufficiently wide, strong and safe for the transport of machinery and materials from Khardi Station of the G. I. P. Railway (North-East line) to the sites of the various works.

After determining the quantities of earth work, metal and rubble required, the earth work has been done departmentally and the work of soling and spreading metal will be started in September of this year. Tenders for the supply of materials for these roads were invited and the work has been entrusted to one of the contractors with the sanction of the Standing Committee.

(10) A survey of 'materials' such as stone, sand, etc. required for the construction of the dam.

Materials required for the construction of the dam are stone sand, hydraulic lime and cement. Stone of good quality, in abundance, can be obtained from quarries to be opened within a reasonable distance mostly on the upstream side and partly on the downstream side of the site selected for the dam. The following statement gives a rough idea of the probable sites for quarries:—

Statement showing probable quarry sites.

Serial No.	Zone.	Distance from Dam site.	Quality of rock.	Size of quarry.	Elevation of quarry R.L.S. in T.H.D.	Type of approach suggested.	REMARKS.
1.	Upstream—Right Bank.	4 Furlongs approximately.	Big size boulders suitable for all types of materials such as metal, Khandkies, headers, etc., easy for hand blasting.	400' to 600' long, 30' to 50' high.	Between R.L.S. 450 and 550.	Trolley line on the same bank.	
	Do. ...	5 Furlongs approximately.	Solid rock easy for hand blasting capable of giving all types of material.	100' to 200' long, 20' to 30' high.	Between R.L.S. 340 and 400.	Do. do.	} They will be useful in the first two seasons.
	Do. ...	6 Furlongs approximately.	Do. do. ...	600' to 1,000' long, 40' to 50' high.	Do. ...	Do. do.	
2.	Upstream—Left Bank.	2 Furlongs approximately.	Solid rock—rather hard for hand blasting good for stone metal only.	200' to 300' long, 25' to 30' high.	Between R.L.S. 360 and 400.	Trolley line on the right bank to be used with siding across the river bed.		Road or trolley line on the left bank will be very costly.
	Do. ...	3 Furlongs approximately } 6 Furlongs approximately }	Do. do. ...	Many quarries of varying sizes can be opened.	Between R.L.S. 340 and 400.	Do. do.	Do. do.
3.	Downstream—Right Bank.	2 Furlongs approximately.	Solid rock and big size boulders easy for hand blasting capable of giving all types of material.	400' to 600' long, 40' to 50' high.	Between R.L.S. 450 and 550.	Trolley line on the same bank.	
4.	Downstream—Left Bank.	6 Furlongs approximately.	Solid rock but of inferior quality good for stone metal only.	50' to 100' long, 20' to 30' high.	Between R.L.S. 450 and 500.	Roadway can be constructed to join the approach road to Dam site under construction at present.	Will be useful throughout the period of construction.
	Downstream—Left Bank.	7 Furlongs approximately.	Do. do. ...	100' to 200' long, 30' to 40' high.	Between R.L.S. 550 and 600.	Do. do.	

As sand would be required in large quantities, it may not be possible to collect it from one place, but it may have to be obtained from several places. The nearest place from where it can be obtained is the Vaitarna river itself, near Tilsa Village, situated at a distance of about 10 miles on the downstream side of the site for the dam. Sand from this site was used in the construction of the Tansa dam. A kutcha cart track connecting the site of the dam and the village Tilsa exists. But it will not be suitable for running motor lorries for transporting the sand unless its surface is improved and its width increased to at least 12 feet. The cost of constructing a 12 feet wide road, along the kutcha track may amount to about Rs. 4 lakhs. It will be necessary to construct this road as sand in fairly large quantities and at a reasonable rate can be obtained from this place. The quantity of sand likely to be obtained from this source is estimated at about 60,000 brass against about 80,000 brass required for the dam. Another source, from where sand can be obtained is the Bhatsa river near Shahapur, a distance of about 25 miles from the site of the dam. Sand from this river is being used at present by the contractors working at the Tansa dam on the automatic falling shutters. In case the quantities of sand likely to be obtained from the two sources fall short of the requirements, it may be necessary to use 'stone grit' as a substitute for sand. Before deciding upon the use of this material, it would be ascertained whether it would not be more economical to obtain sand from Mumbra if adequate facilities for transport are given by the G.I.P. Railway authorities.

Hydraulic lime can only be obtained from Nasik district. It will not be required if the dam were built in 'cement concrete' or of masonry in 'cement mortar' instead of in hydraulic lime mortar. The use of cement mortar would help in speeding up the construction of a masonry dam.

Machinery and equipment required for driving the tunnel and for constructing the dam, will have to be transported from the Khardi station of the G.I.P. Railway via Khardi-Pareli Road, a distance of about 13 miles from Khardi-station or from Bombay via Bombay Agra Road, which meets Khardi-Pareli road at mileage 65. This road belongs to the District Local Board, Thana. The Khardi Pareli Road is of water-bound construction and is in a very unsatisfactory condition. The Local Board spends only about Rs. 2,000 per annum on its maintenance. This road, being important from the point of communications, has been included in the

Road Programme of the Bombay Province for being treated with a permanent mode of construction. But it has not been given priority in the programme drawn up for the next five years. There being no bridge on the Vaiterna river this road is not used during the monsoon to go to Pareli, which is situated on the other bank of the river. When the dam is constructed, it will help in maintaining communications between Khardi and Pareli during the monsoon also. To accomplish this end, a 28 feet wide road-way will be provided on the top of the dam. If the surface of the Khardi-Pareli road was improved immediately, it would help considerably in transporting speedily and at less cost materials, machinery and labour required for the execution of the Scheme. It would be in the interest of the Corporation to agree to share a portion of the cost of permanent construction of this road and to induce Government to include it in their Road Programme of the next five years. If the Municipality were to bear the whole burden of treating this road with a permanent mode of construction, the cost involved would be out of proportion to the advantages to be gained. Negotiations are therefore being opened with the Government of Bombay with a view to finding out whether they would agree to include this road for permanent mode of construction in their programme for the next five years.

(11) Fixing sites for temporary camps and laying pipe lines thereat to convey water impounded by the temporary bunds referred to in item (7).

The sites selected for the camps and for the storage tanks are shown on Plan (Appendix II) along with the pipe lines.

(12) Investigating the feasibility of laying a pipe line from the tunnel end on the Tansa side (near Bell Nalla) to convey the supply from the Vaiterna reservoir directly to the City independently of the Tansa lake.

This investigation was necessary. The weak point in the Vaiterna-cum-Tansa Scheme is that the waters of the Vaiterna reservoir have to be let into the Tansa lake for being conveyed to the City. This makes Vaiterna reservoir entirely dependent on the Tansa lake and due to this, full advantage of the head available in the Vaiterna reservoir cannot be made use of to increase the carrying capacity of the new pipe line to be laid and of the two existing 72" pipe lines from the Tansa lake. When an old work like the Tansa

Lake, which has served the City for 50 years is being connected with a new one, both the works (old and new) should not be interdependent, but should be capable of functioning independently of each other, as and when required. The survey has since shown that an independent connection can be established between the Vaitarna reservoir and the existing outlet mains from the Tansa lake, from the end of the tunnel on the Tansa side, by laying a pipe line about $6\frac{1}{2}$ miles in length, skirting more or less the water-spread of the Tansa lake. The feasibility of such an independent connection will naturally necessitate modification in the original scheme as regards the useful storage to be provided on the Vaitarna reservoir and the size of the pipe line to be laid therefrom for conveying the additional supply to the city.

3. To enable work being started on the main items of the Scheme, such as, foundations of the dam, **Sanction of the Corporation obtained for Preliminary Works.** driving of tunnel etc., an estimate amounting to Rs. 25,70,800 for carrying out preliminary works such as, the construction of temporary bunds, construction of access roads to the tunnel and the site of the dam, clearing of the dam site, etc., was submitted to the Corporation for sanction and they were requested to allot funds for the same. Corporation's permission was also requested to invite quotations for the major items of the work as soon as the designs, detailed plans and schedule of quantities and specifications for the same were completed to hasten the commencement of the work which under the ordinary procedure would have been considerably delayed, as tenders for the works can only be invited after detailed plans and estimates for the Scheme are sanctioned by the Corporation and funds for the same are allotted. The Corporation under their Resolution No. 728, dated the 25th September 1947 sanctioned funds for the preliminary works which are now in progress. The Corporation also empowered the Municipal Commissioner to invite quotations for the main items of the Scheme before funds were allotted. Accordingly, tenders for the tunnel, earth-work, embankment for the pipe lines, manufacture and supply of pipe lines and bridges across the Tasu and Balwant Nallas to support the open portions of the tunnel have already been invited and some of them have been received and are being scrutinised. The Schedule of Quantities for the 72" dia. pipe line was also prepared and an indent for the same was placed with the Director General of Supplies, Government of India, and he was requested to release steel in accordance with the programme framed for

the item of the work. The Government of India, however, has cautioned that the Corporation should move very slowly in this matter as they were doubtful whether large quantities of steel required for this project could be made available immediately or in the course of the next two years, because steel of indigenous manufacture not being available, it will have to be imported from America. It has been further pointed out that against the requirements of the Government of India for the current quarter of 1948 of over one lakh tons of steel, they have been able to get from U.S.A. only 1,200 tons.

4. The work on the 'Bore Holes' was started in June 1947 and is still in progress. As the survey work progressed, it was realised that the provision of 1,300 R.ft. made in the sanctioned estimate for the survey work for this purpose would not be sufficient and that additional bore holes were necessary at both the flanks and a little away from the abutments. A few bore holes along the line of the tunnel were also considered necessary. Standing Committee's sanction was, therefore, obtained for taking additional bore holes to the extent of 1,200 R.ft. (*vide* Standing Committee Resolution No. 1653, dated the 17th December 1947). The work on these bore holes is in progress.

The positions of the bore holes, so far driven, and the strata met with at each bore hole are shown on Plan Nos. $\frac{V.T.14}{23-2-48}$ i $\frac{V.T.7}{22-7-47}$ (Appendix III). The results of the bore holes show that (a) the foundations for the dam for the portion covered by the river bed may have to be taken at least 10 to 15 feet deep into the exposed rock; (b) the talus and boulders on the right bank of the river vary from 15 to 30 feet and those on the left bank from 5 to 35 feet. Good rock for founding the flanks of the dam being available at these depths, the foundations for them need not extend more than 10 to 15 feet deep into the rock.

In order to obtain expert advice regarding the suitability or otherwise of the site finally fixed for the construction of the dam and the reservoir-basin, from the geological point of view, Dr. B. C. Roy of the Geological Survey of India was requested, last year, to inspect the alternative sites for the dam, which were then proposed to be investigated. The note of inspection sent by him included comments on the two alternative sites suggested in the Interim

Report *vide* para. 17, page 23. He could not make any reference in his note to the site 'D', which was then proposed to be discarded in case better facilities for the location of the waste weir were available at the two alternative sites referred to above. In his note of inspection, Dr. B. C. Roy wrote *inter alia*, "The dam sites are wholly located on trap rocks in the form of bedded flows. Barring precipitous cliffs or plateau tops, the flanks of the river in the hill slopes are generally covered by surface boulder and talus deposits whereby the various flows are not distinguishable. Considerable amount of stripping would be needed to get an idea of the different varieties of lava beds that would be encountered along the dam alignment."

* * * * *

"The river bottom or valley floors, however, show thinly bedded compact and massive traps with fine vesicles. These slices under microscope, show an intergranular texture. Some amount of slabiness of the traps due to fine laminations or sheet jointing, varying from a few feet upto 10 feet in thickness is particularly seen along both embankments. These sheet joints are likely to affect the dam foundation and favour seepages. They, however, appear to be only superficial features, which are not likely to continue laterally for great distances."

* * * * *

"The rock at the foundation at the river bed is fresh and sound and is not liable to decomposition into unstable minerals but the foundation may have to be taken down to say, 20 feet from the surface."

"Basalts are capable of standing about 1,000 tons of weight per square foot and therefore the foundation rock may be considered sound enough to bear the proposed structure. Representative samples of rocks obtained during stripping and exploratory works, however, should be tested for crushing strength."

* * * * *

There should not be much difference from the geological point of view between the site 'D' and the two alternative sites inspected by Dr. Roy last year. Yet, in order to make certain that the site 'D' is as good as the other two sites, from a geological point of view, Dr. Roy was requested to inspect the same, as well as the alignment of the tunnel, this year, when the work on the bore holes had sufficiently advanced. Accordingly, Dr. Roy inspected the Vaitarna river in the region of the dam on 4th March 1948. During this visit, Dr. Roy was shown the positions of the bore holes as also

the cores obtained therefrom. He was furnished with detailed information of the cores as regards their depth below ground level, etc. He was shown a part alignment of the tunnel on the Vaitarna side as well. On the next day, i.e., 5th March 1948, he was shown the alignment at the tail end of the tunnel on the Tansa side. He was also given particulars of the trial pits taken on the Tansa side, last year, along this alignment. Dr. Roy expressed satisfaction with the results obtained. He does not think that there should be any apprehension regarding the suitability of the rock for the foundations of the dam and the waste weir and also for driving the 'tunnel'. He is also of opinion that the rock exposed in the bed of the river at the site of the dam would not be seriously affected by a sheet of falling water through a height of 200 feet to 250 feet, if it were decided to locate the waste weir in the central portion of the dam covering the river bed. Dr. Roy has since sent a short note of inspection done by him in March 1948, which is embodied in Appendix IV. Grouting under pressure in the foundations of the dam may have to be resorted to, to make them water tight and to prevent 'uplift'. Provision for grouting under pressure has been made in the estimate of the dam. In order to minimise the possibility of uplift, the design of the dam also provides for the construction of drainage galleries in the heart of the dam and for laying a sufficient number of drains therefrom to drain away the seepage water.

5. While the survey and the work of taking bore holes were in progress, it was necessary to estimate first the maximum flood discharge to be provided in the design of the waste weir as the quantity of flood discharge and the length available for the waste weir would decide the type of the waste weir most suited to satisfy local conditions. The characteristics of a river in respect of maximum, minimum and total flows for various periods can only be accurately determined if a series of gaugings extending over several years are available, and these too, to be of the greatest value, must include the periods of high floods as well as of draughts. Although the Vaitarna river is being gauged at the site of the dam for the past 18 years, records for only 15 years are available, as those pertaining to the years 1932, 1938 and 1939 are missing. Besides, the periods, cover years of good rainfall and not of scanty rainfall. The gaugings consist mostly of the total daily rainfall during 24 hours and the level of water in the river at the end of every 24 hours at the site of the dam. However, for the years 1933 and 1934, additional information as

regards the hourly fluctuations in the level of water in the river during the day only at two points of the river (one at the site of the dam and the other situated at a distance of about 2,400 feet on the downstream side of it) has been recorded. The gaugings are incomplete inasmuch as they do not give any information regarding the intensity of rainfall, its duration and the surface slope of the flowing water in the river for different depths of flow. Mere record of the rise in the water level at the end of 24 hours at one point of the river is not in itself sufficient to draw any inference regarding (a) the maximum water level that might have been reached during this interval at any hour of the day or night, due to abnormal floods and (b) the velocity attained for any particular depth of flow. It appears that at one time an attempt was made to record the velocity by using floats, for small depths of flow not exceeding 11 feet. No reliable inference can, however, be drawn from these observations as regards the velocity attained for higher depths of flow reached. According to the records, the maximum depth of flow in the river was as much as 31.5 feet on 1st July 1941 and the total daily rainfall recorded on that day was 13". Maximum flood discharge must have occurred on that day, but information regarding the surface slope of water for the depth of flow of 31'-6" not being available for that day, its extent cannot be worked out. Fortunately, for the years 1933 and 1934 records of surface slopes of water for different depths of flow are available (*vide* appendix IVA). The maximum depth of flow in these years was 26 feet. In order to find out the velocity for a depth of flow of 31'-6", a curve showing the velocity for various depths of flow was plotted (*vide* Appendix V) from the records available for 1933 and 1934 and the velocity for the maximum depth of 31'-6", recorded in 1941, was extra-polated. As the difference between the maximum depth of flow attained in 1941 and that attained in the year 1933 to 1934 is only 5'-6" (31'-6" - 26'), it may not be unreasonable to use the velocity as found out from the curve, for calculating the flood discharge for a maximum depth of 31'-6". The velocity for the depth of 31'-6" works out to 14.8 feet per second and the maximum flood discharge with this velocity works out to 90,000 cusecs.

In working out the flood discharge, the velocity has been arrived at by using Chezy's formula $V = C\sqrt{RS}$ —with value of $C = 72$ for hydraulic mean depth of 20.7 feet and that of the coefficient of rugosity 'N' equal to 0.035. The velocity was also

worked out by using Manning's formula and there is a slight difference between the results obtained by the use of this formula and those obtained by the use of Chezy's formula, but, on the whole, the results obtained may be said to be practically the same.

As pointed out previously, the period covered by the gaugings of the Vaitarna river covers mostly good years. The maximum flood of 1941 may be assumed as the highest known flood, because on 1st July of that year, Tansa lake was also replenished at an average rate of 22,000 cusecs. On that day, the level of water in the Tansa lake rose by 11 feet in 24 hours from 403.8 T.H.D. to 414.10 T.H.D. During the hours of 10.25 to 11.20 P.M. dated the 1st July 1941 Tansa lake was replenished to the extent of 864 million gallons, which is equivalent to an input of 42,000 cusecs.

There can therefore be no doubt that the maximum flood discharge to be assumed in designing the waste weir cannot be less than the calculated discharge, of 90,000 cusecs for 1941. It is always advisable to make a liberal provision in the design of a waste weir for passing additional floods than actually observed, because if the waste weir falls short of the requirements, a disaster would be caused. It is therefore customary to check up the observed or calculated discharge with that given by some formulae evolved in this behalf from the actual observations of the flood discharge of several catchments. It should however be remembered that as the maximum flood discharge depends upon several factors, such as, the intensity of the rainfall, its duration, the condition of the catchment whether saturated, wet or dry, the shape of the catchment whether long, bell-mouthed or fan-shaped—the total rainfall not only on the day of the occurrence of the maximum flood but on a day or days immediately preceding, no formula can be evolved which would make allowances for all of them. The Engineer has therefore to use his judgment in selecting the formula for 'checking up' purposes.

In the past, Engineers in the Bombay P.W.D. used to make the following allowances in estimating the maximum flood discharge, for average catchments.

Catchment area in square miles ...	0.5	5-10	10-25	25-75	75-150	Over 150.
Runoff in inches per hour ...	2.00	1.5	1.25	1.00	0.75	0.5

According to the above, the maximum flood discharge for the Tansa catchment works out to 34,000 cusecs and that for the

Vaitarna catchment to 56,000 cusecs. The above allowance is for 'average catchments'. Vaitarna is not an 'average' catchment but it is a ghat catchment with certain peculiarities. It runs north-south and east-west while the ghat catchments generally run easterly from the ghats. The rainfall in the ghats is very high while it is comparatively small at a distance of about 20 to 30 miles away from the ghats. The precipitation on the other hand in the Vaitarna catchment is more intense and simultaneous than that in the ghat catchments. The average total rainfall of the past fourteen years at the site of the Vaitarna dam is 105" and the average rainfall at Igatpuri—a distance of about 30 miles on the upstream side of the site of the dam is 135", but the maximum at Igatpuri in 1931 was as high as 259.89" while the total rainfall in 1941 amounted to 122.36 inches. Due to this, the run-off per hour would naturally be much more than that of 0.5" per hour for an 'average' catchment. On the basis of the actual rate of input into the Tansa lake the figure of flood discharge works out at the rate of $1\frac{1}{2}$ " run-off per hour against 1" allowed for in the above table. On the same analogy, if the runoff per hour of 0.5" were increased to 0.75" it would give a figure of 84,000 cusecs for the Vaitarna catchment which is less only by 6,000 cusecs than that calculated from the velocity curve for a maximum depth of flow of 31'-6", reached in the Vaitarna river, in the year 1941.

The Hydro-Dynamic Research Station of the Government of India at Khadakwasla, near Poona, has, after a long series of observations of actual floods in western India, developed formulae for 'Extra-ordinary flood runoff' under two categories—(1) for Normal Single Catchments and (2) for 'Multiple' or 'Fan' Catchments. These formulae are known as 'Inglis's' formulae. Tansa catchment is definitely 'fan shaped'. The maximum flood discharge for Tansa catchment with the Inglis formula for 'Fan shaped' catchments, works out to about 50,000 cusecs against the actual input into the Tansa lake in the year 1941 at the rate of 42,000 cusecs. Similarly the actual observed flood discharge flowing over the waste weir of the Tansa dam is reported to be 35,000 cusecs on 20th July 1894 and on that day, the flood passed over the entire length of the dam also. Allowing for the moderation of the flood intensity by the flood absorption capacity of the lake, the actual flood intensity may work out to about 50,000 cusecs corresponding to that arrived at from the formula for a 'fan' catchment.

Vaitarna catchment is neither 'fan shaped' nor 'normal single'. A part of it upto a distance of about 15 miles from the site of the dam is 'Normal single' while the remaining portion is definitely 'fan shaped' (*vide* appendix No. VI). The discharge for Vaitarna catchment, taking it as 'fan-shaped' and as 'normal single', works out to 92,000 and 74,000 cusecs respectively. As the rainfall in the Vaitarna catchment is intense and simultaneous, it will be advisable to design the waste weir for the maximum flood discharge based on the Inglis's "Fan catchment" formula as the quantity of flood discharge calculated in the year 1941 is only less by about 2,000 cusecs than that arrived by this formula:

It is again a matter for further consideration whether the discharge of 92,000 cusecs as worked out from the Inglis formula would take care of the catastrophic floods due to any possible cyclones or cloud bursts. No special provision for cloud bursts seems to be necessary because a cloud burst is a local phenomenon and it is not likely to occur at the same time over the whole length of river upto the site of the dam which is over 45 miles. Two sluices each of 5,000 cusecs capacity are to be provided in the body of the dam. They may be useful in passing floods in excess of 92,000 cusecs if they can be operated at the right moment.

Rao Bahadur B. L. Modak who was consulted in regard to the suitability of the syphon spillway agrees with me that the waste weir should be designed for the flood discharge arrived at by the use of Inglis formula for a 'fan shaped' catchment.

Opinion of Mr. K. K. Framji, the Director of the Hydro Dynamic Research Station at Khadakwasla was sought in regard to the maximum flood discharge to be provided. He is of the opinion that "Having due regard to safety as to economy, it will be advisable to design the spillway for a flood discharge of 92,000 cuses. If a discharge higher than 92,000 cusecs is ever obtained, it will" be for a very short duration and be so rare an occurrence that it may not be worth providing spillway capacity for it; the water level in the lake would, in such an event, temporarily rise above the designed H.F.L. 535.00 but as a free-board of not less than 10' has been proposed to be provided, it does not appear essential to provide a floodway for more than 92,000 cusecs."

The reasons given by him for arriving at this conclusion can be seen in Appendix No. VIA.

6. The next consideration is, what should be the type of the waste weir and what would be the economical depth of flow over its crest to pass a flood discharge of 92,000 cusecs.

Factors Which influence the choice of the type of the Waste Weir.

The choice of a waste weir depends upon (1) the total length available, (2) its location in reference to the dam—whether in the centre or at the flanks; (3) the maximum flood discharge to be passed; (4) the depth of flood over its crest, *i.e.*, the difference between the Full Supply Level of the reservoir and the High Flood Level; (5) the contours and nature of the ground both on the upstream and downstream of the dam (as they determine the extent of excavation in different strata for the approach and tail channels) (6) the extent of the protective works necessary for preventing scouring of the river bed and the banks on the downstream side and (7) its adaptability for increasing the storage in stages at reasonable cost.

The three principal types of waste weir are (1) the ordinary overflow; (2) side channel and (3) syphon spillway. Each of them can be used singly or in combination.

The ordinary overflow type.—This type of waste weir falls under two heads (1) Broad-crested weir with a flat crest and (2) a weir with 'Nappe' or 'Ogee' shape. It may be located in the centre or at the flanks to suit local conditions. With this type of waste weir, the capacity of the reservoir can be increased in future either by raising the dam (if provision for the same is made in its design from the beginning) or by erecting automatic falling shutters on its crest.

Side channel waste weir.—This weir is not constructed parallel to the dam but at right angles or at an obtuse angle thereto. In this type of waste weir, the flood waters overflow into a side channel. The side channel is connected with a tail channel and the water received therein is let into the river on the downstream side of the dam through a chute. This type of waste weir is resorted to, if adequate length is not available along the length of the dam to pass the estimated maximum flood discharge at reasonable depth. With this type of waste weir contents of the reservoir between F.S.L. and H.F.L. can be made available for use by erection of gates on its crest.

Syphon spillway.—This type is suited to positions where the difference between the Full Supply Level and High Flood Level of

the dam (the depth of flood over the crest of the waste weir) is required to be kept to a minimum. It can pass the flood discharge with a depth of flow of only about 2 feet. Its adoption therefore reduces considerably the cost of the dam especially where the flood discharge to be dealt with is considerable and the length available for an ordinary over-flow weir is limited. It helps in quickening the completion of the scheme as the quantity of masonry in the dam is reduced in proportion to the reduction in its height. Alternatively, it secures a larger storage in the reservoir for the same height of the dam. The extent of land submerged at the H.F.L. is also reduced due to the difference between the H.F.L. and the F.S.L. being only 2 feet. This incidentally helps to keep down the cost of land acquisition where rich agricultural lands have to be acquired. It has, however, certain drawbacks, some of which are given below:—

(1) It fixes the limit of utilisation of the source and the ultimate height of the dam, because it is not possible to raise the dam (unless it is originally designed for this purpose) at a later date. When such raising is done, the syphons already constructed must be scrapped and replaced by new ones at a higher level.

(2) The difference between the H.F.L. and F.S.L. being restricted to about 2 feet only, any catastrophic flood of even short duration cannot be absorbed by the reservoir as its flood absorption capacity is much less than that available in a reservoir provided with an overflow weir.

Overflow Waste Weir.

7. The detailed surveys have shown that the maximum length available for locating an over flow weir in the central portion of the dam is only 300 feet and about 500 feet if the weir is located at both the flanks.

Length of Waste Weir available for different types at site 'D'.

300 feet and about 500 feet if the weir is

Side-Channel Waste Weir.

The total length available for a side channel weir is 800 feet (400 feet on each flank) for a reservoir with the Full Supply Level at 480 T.H.D. (i.e., about 170 feet above the bed of the river). For a reservoir with its F.S.L. higher than 480 T.H.D., a sufficient length for a side channel weir at a reasonable cost, cannot be obtained.

Syphon Spillway.

A length of 300 to 400 feet can be obtained for a syphon spillway on the left flank to suit any F.S.L. ranging between 480 to 535 T.H.D.

Economical depths of flow.

It was originally contemplated that, if possible, the location of the waste weir in the central portion of the dam should be avoided because the effect of a large sheet of falling water through a depth of about 200 feet was considered to be detrimental to the foundation of the dam unless heavy protective works were provided. With this end in view, the feasibility of adopting either an over-flow waste weir at the flanks, a syphon spillway or a side channel weir was investigated. The investigations showed that as far as the over-flow waste weir on two flanks was concerned, if the F.S.L. of the lake was to be maintained at 480 T.H.D., as suggested in the Interim Report, the most economical depth of flow for passing a flood discharge of 92,000 cusecs was 18 feet for a length of 500 feet. For the same Full Supply Level, the economical depth of flow for a side channel waste weir [total length 800 feet (400 feet on each bank)] was found to be 10 feet. The alternative estimates for a syphon spillway showed that though its adoption would increase the storage by about 22 per cent., for the same height of the dam, its cost was practically the same as that of a flank or a side channel waste weir.

Central Spillway advisable for F.S.L. of the Reservoir above 480.00 T. H. D.

For an impounding reservoir with the F.S.L. higher than 480 T.H.D., it would be economical to locate the waste weir in the central portion of the dam covering the river bed. The length available for locating such a waste weir will be about 300 feet including piers and the depth of flow over its crest to pass a maximum flood discharge of 92,000 cusecs will be about 20 feet. In calculating the depth of flow, the flow likely to be absorbed in the lake while the reservoir level is rising from the crest of the waste weir to the H.F.L. has been neglected. Similarly the value of 'C'* for the waste weir has been assumed at 3.9 but according to some observers, it is likely that it may go down to, 3.4 due to the depth of flow being excessive, viz., 20 feet. In that event the depth of flood for the same length of weir would be 22 feet. In case it is decided to erect automatic gates on the waste weir to impound additional quantity of

* C = Co-efficient of discharge in formula $Q = clh^{3/2}$.

water, the cost of the gates would be heavy as the economical height of such gates is reported to be only 20 feet. To allow for erection of automatic gates and the reduction in the co-efficient of discharge from 3.9 to 3.4 it would be therefore desirable to increase the length of the waste weir from 300 feet to 360 feet. It would be possible to get this length by cutting the river banks further. The increase in the length will naturally increase the cost of the waste weir.

The potential energy created in the water by the raising of the dam, develops into kinetic energy, as it flows to meet the river bed downstream and unless effective measures are taken to destroy this energy, it spends itself by creating deepest scours on its course, very often undermining the structure of the dam itself. The geological investigations have since shown that the rock exposed in the bed of the river at the site of the dam is not likely to be affected seriously by the sheet of falling water, and therefore, the cost of protective works in the form of either a roller bucket or a sloping apron will be moderate and reasonable. There will be a further advantage in locating the waste weir in the centre, as it can serve as a temporary waste weir also for passing the floods during construction. In the case of other types of waste weirs, special provision for passing the floods during construction has to be made, involving considerable expenditure. With a central spillway, there will be a difference of 20 feet between the Full Supply Level and the H. F. L. of the reservoir. The whole structure of the dam will have, therefore, to be made strong enough to withstand the pressure corresponding to the H.F.L. so attained. This will add considerably to the cost of the dam, because when the height of a dam exceeds a particular height, the cost per foot height is much more than that for lower heights. In order to reduce the cost of the dam and waste weir, the device of the automatic gates is sometimes resorted to. By this device the same storage can be obtained but by lowering the crest of the waste weir below the F.S.L. to the extent of the depth of the flood. If the crest of the waste weir is not lowered, an additional storage equivalent to the contents of the lake between F. S. L. and the top of the gates is obtained. (*vide* appendix XIV A)

Instead of using automatic gates, the same object can be achieved by resorting to a syphon spillway built in the body of the dam if its cost is found to be the same as that of an ordinary over flow waste weir in conjunction with automatic gates.

It is evident from the foregoing that no decision can be taken in regard to the choice of the waste weir until the extent of the storage

(both initial and ultimate) to be created on the Vaitarna river is determined and the method of building it *viz.*, whether in one or more suitable stages is fixed.

8. The creation of a useful storage of 17,000 million gallons was suggested in the Interim Report because it was found that the existing three conduits from the Tansa lake [two 72" dia. steel pipes and the duct (as it stands today)] were incapable of conveying to the city a supply of 110 m.g.p.d. from the Tansa lake which would be available in a good year of rainfall in its catchment, when the work on the automatic falling shutters is completed and even in a lean year when the tunnel connecting the Tansa lake and the Vaitarna reservoir is driven. An additional pipe line therefore from the Tansa lake was necessary to convey the supply in excess of the total carrying capacity of the existing conduits. A pipe line of a smaller size would have served the purpose, but such a pipe line would not have proved economical in the long run. It was, therefore, considered desirable that the size of the new pipe line should be the same as that of the existing pipe lines and that sufficient storage should be created on the Vaitarna river to provide an additional supply required for utilising the new 72" pipe line to its full capacity under the available head.

Calculations were, therefore, made to find out the maximum carrying capacity of the four conduits [three pipe lines of 72" dia. and the duct (after it was reconditioned)] with the available head, which worked out to 160 m.g.p.d. As the supply available from the Tansa lake would be only 110 m.g.p.d., a useful storage capable of giving a supply of 50 m.g.p.d. (160—110) was required to be created on the Vaitarna river. To secure a daily supply of 50 m.g.p.d. after allowing for losses by evaporation and absorption in the reservoir, a useful storage of 17,000 million gallons (*vide* Appendix No. VII) on the Vaitarna river was necessary. The contours showed that this storage could be obtained with the F. S. L. of the reservoir standing at 480 T. H. D. (please *vide* para 17, sub-para 5 and 6, pages 22 and 23 of the Interim Report). Besides, no details of the waste weir in regard to its length, location and the maximum flood discharge to be passed could be worked out at the time of the Interim Report as the final site of the dam was not then fixed, but it was believed that better sites for the dam could be obtained within a stretch of about $1\frac{1}{2}$ miles on the downstream side of the site 'D.'

The information on these points to suit the site 'D' has not been given in the reports of the Hydraulic Engineer and the notes of the Experts. Information regarding the co-relation between the yields of the two catchments was also lacking. It was also believed that there was no feasibility of using the Vaitarna reservoir independently of the Tansa lake as a reference to such a vital factor is not to be found both in the reports of the Hydraulic Engineer and the notes of the Experts. As pointed out previously (para 2, page 8), this was one of the weak points in the Vaitarna-cum-Tansa scheme and this was the reason why a policy "of not laying all eggs in one basket" had to be inunciated in determining the storage to be impounded on the Vaitarna reservoir. It would not have been worthwhile to recommend a large storage on the Vaitarna reservoir, though the river had great potentialities, when there was no alternative route to convey the water so stored, directly to the City, independently of the Tansa lake.

9. The detailed survey has now shown that the waters of the Vaitarna reservoir could at a comparatively small cost be conveyed to the City independently of the Tansa lake. Again, the circumstances regarding the population and the demand of the public for additional water have undergone considerable changes since the drafting of the Interim Report. There has been a large influx of refugee population in the city. There was not the faintest idea of such a sudden increase in the City's population at the time of writing the 'Interim Report.' Further, the Vaitarna-cum-Tansa Scheme, as then outlined, was only a first step in the augmentation of the City's water supply to increase the total supply from 115 m.g.p.d. (in good years) to 175* m.g.p.d.; and it was intended to undertake either Kalu-Shahi or Bhiwpuri Scheme immediately after the completion of the Vaitarna-cum-Tansa Scheme, as the immediate requirements of the city both for domestic and industrial purposes were estimated at 236 m.g.p.d. (vide page 5 of the Interim Report). In view of the changed circumstances, the original scheme will require modifications, especially in regard to the storage to be provided.

Vehear and Tulsi lakes can be depended upon to give a supply of 16 m.g.p.d. This leaves a balance of 220 m.g.p.d. It must,

* This is inclusive of the dependable supply of about 15 m. g. p. d. from Vehear & Tulsi Lakes,

therefore, be investigated whether the site selected for the location of the dam in the Vaitarna-cum-Tansa Scheme can be developed so as to obtain a dependable supply of 220 m.g.p.d. therefrom in all lean years and three consecutive dry years. If the investigations show that a supply of 220 m.g.p.d. can be economically obtained from this source it may not be necessary to undertake the execution of the Bhivpuri or Kalu-Shahi Schemes at least for the next 20 years.

10. The storage likely to be impounded by the dam at the site 'D' to give a dependable supply of 220 m.g.p.d. will in the first instance be governed by the physical conditions of the gorge itself. As far as the river is concerned, it has great potentialities. Its yield at the site of the dam in a year of good rainfall in its catchment may be as high as 1,40,000 million gallons. It is, however, to be seen whether a dam to impound such a large storage can be built economically and that whether the reservoir so formed will be adequately replenished in lean and three consecutive dry years as well as in a driest year like 1899. The gorge is very narrow and has a peculiar form. The bed width of the river thereat is about 175 feet. Both the banks are very steep rising from 310 T.H.D. (Bed of the river) to 610 T.H.D. in a length of about 1,500 feet, ending in a plateau at the top of an altitude of 640 T.H.D. on the right bank and 620 T.H.D. on the left bank.

Taking these physical factors into consideration, it appears that the economical development of this source must be restricted to the H. F. L. of the reservoir being maintained between 555 and 540 T. H. D. because the banks of the river become steeper beyond these levels and the additional storage likely to be obtained by exceeding the H.F.L. of 540 T.H.D. would not be commensurate with the cost to be incurred on the additional height of the dam. The useful storage likely to be obtained with H. F. L. or F. S. L. between 535 and 540 T. H. D. as found out from the contours shown on the topo sheets will vary between 46,000 and 50,000 million gallons. It must therefore be ascertained whether the reservoir, if constructed to impound a useful storage of 46,000 or 50,000 million gallons would be adequately replenished by the yield from the Vaitarna catchment, in lean years, three consecutive dry years and in a driest year like 1899, after diverting the requisite quantity into the Tansa lake through the tunnel to make up the deficiency in the yield of the Tansa catchment in such years.

The actual yield of the Tansa catchment was about 12,000 million gallons in the year 1899. On the co-relation ratio, as worked out in para 12, the yield of the Vaitarna catchment in such a year would be about 42,000 million gallons. In two consecutive dry years like 1904 and 1905, the actual yield of the Tansa catchment was 18,000 million gallons. To keep Tansa lake filled up to its new F.S.L. of 422 T. H. D. a total yield of 36,000 million gallons is required (above 387* T. H. D. level). In the consecutive dry years like 1904-1905, a yield of only 18,000 million gallons will have to be diverted into the Tansa lake from the Vaitarna reservoir to keep it filled by 1st of October. The yield of the Vaitarna catchment in corresponding dry years is estimated at about 64,000 million gallons. Deducting from this, 18,000 million gallons required for replenishing the Tansa lake, the net quantity available for storage in the Vaitarna reservoir would be about 46,000 million gallons. To obtain this storage, the F. S. L. of the reservoir, as judged from the contours shown on the topo sheets, has to be kept at 535 T. H. D. This appears to be the limit of the useful storage likely to be obtained from the Vaitarna river at the site selected for the dam, from the point of economy, physical considerations of the site and the yield of the river in two consecutive dry years. The F. S. L. of 535 T. H. D. can either be built by constructing an overflow waste weir with its crest at 515 T. H. D. and providing automatic gates of about 20 feet height above it or by constructing a syphon spillway in the body of the dam with the F. S. L. of the reservoir at 535 T. H. D. and the H. F. L. at 537 T. H. D.

There is another reason why the works to be constructed now must be capable of being developed to obtain a useful storage of 46,000 million gallons either from the very commencement or in stages. No suitable sites for constructing an additional reservoir or reservoirs on the upstream side of the site of the dam are available. The only site for a reservoir is the one situated at a distance of about 30 miles on the upstream side of the site 'D.' If a reservoir were constructed at this site, it is doubtful whether the water impounded therein can be conveyed to the impounding reservoir at the site 'D,' by conduits and even if such a course were feasible, the cost of laying the conduits would be very heavy. The only economical way to convey water so stored would be to let it run along the bed of the Vaitarna river for being admitted into the Vaitarna reservoir at the site 'D.' As the water has to travel over a distance of 30 miles, it

* Lowest level of draw off of Tansa Lake.

will not only get contaminated on its way, but a major portion thereof, would be lost by absorption and evaporation. This will necessitate the provision of a filtration plant to improve the quality of the Vaitarna water, if the Vaitarna reservoir is used independently of the Tansa lake. On the other hand, if both (Tansa and Vaitarna) are used in combination as contemplated, the supply of the Tansa lake will have also to be filtered. This would involve not only heavy capital expenditure, but would add considerably to the recurring cost.

11. For these reasons, the works to be constructed now at the proposed site must be capable of being developed to derive the full benefit of the storage likely to be obtained with F. S. L. of the reservoir standing at 535 T. H. D. The total storage with F. S. L. at 535 T.H.D. will be about 54,000 million gallons as worked out from the contours shown on the topo sheets, out of which 8,000 million gallons being below 422 T. H. D. will be dead storage and the remaining 46,000 million gallons will be the useful storage. The actual contents will be known after the contour survey, which is now in hand, is completed.

Storage available with the ultimate F.S.L. of the Vaitarna reservoir at 535 T.H.D.

Provision for Silting up.

The dead storage of 8,000 million gallons should be sufficient to take care of the silt that may be brought into the reservoir as it equals 15 per cent. of the total storage of 54,000 million gallons. (46,000 plus 8,000).

Information regarding the rate of silting in the Tansa lake is not available. But it is reported that the silting in the past fifty years has been negligible and that it has not materially reduced the contents of the lake. Whatever silting has occurred has been in the upper reaches of the Tansa river and not in the lake itself. Dr. Roy's opinion was sought regarding the provision to be made for silting up in the Vaitarna reservoir. He opined that looking to the geological formation of the river stretch, there is no likelihood of the Vaitarna reservoir silting up, as most of the silting, if at all it takes place, will occur in the upper reaches of the river. Besides, any tendency towards silting up may to some extent be checked by operating, during the early part of the monsoon, the two sluices to be provided in the body of the dam for flushing out the washings

brought down at the commencement of the monsoon to maintain the purity of the supply.

**Water spread of the Vaitarna Reservoir with
F. S. L. at 535 T. H. D.**

Due to the steep banks of the river the water spread of the new reservoir, with F. S. L. standing at 535 T. H. D. at the end of the monsoon, as worked out from the topo sheets, will be about 4.60 square miles against 7.5 square miles of the Tansa lake at its new F. S. L. 422 T. H. D. As the water surface exposed to the sun and air will be less in the case of the Vaitarna reservoir, it is likely that the losses due to evaporation will be slightly less than those occurring at the Tansa lake, *viz.*, at the rate of .02 feet per day equivalent to a total loss of about 6,000 million gallons during the whole year. On this basis, the total loss per annum in the case of the Vaitarna reservoir has been assumed at 4,000 million gallons for its ultimate useful capacity of 46,000 million gallons in working out the net daily supply available therefrom.

The longest length of the lake as judged from the topo sheet would be about 10 miles against that of 4 miles for the Tansa lake. The Vaitarna reservoir will be slightly bigger than the Tansa lake as the latter's useful contents would amount to 34,000 million gallons (between 422 and 387 T. H. D.) against 46,000 million gallons of the proposed Vaitarna reservoir (between 535 and 422 T. H. D.). A considerable portion of the forest land would be submerged in the spread of the Vaitarna reservoir but no villages will be affected. The compensation to be paid for the forest land would be somewhat heavy, as, at the present time, the cost of timber has gone up considerably.

12. The next step is to ascertain the extent of the daily combined supply that can be made available with

The extent of the daily supply that can be made available with a useful storage of 46,000 million gallons on the Vaitarna reservoir, will depend upon the correlation ratio between the two catchments.

a useful storage of 46,000 million gallons in the Vaitarna reservoir from both the sources (Vaitarna and Tansa) in all years of good, bad and indifferent rainfall in their respective catchments. The combined daily supply will also be governed by the carrying capacity of the tunnel connecting the Vaitarna reservoir to the Tansa lake. Unless day to day yields of the two catchments are worked out for 'critical' years, in which the yield is comparatively small due to scanty rainfall, the combined daily dependable

supply likely to be made available cannot be estimated. No information regarding the rainfall in scanty years like those of 1904, 1905, 1906 etc., is available for the Vaitarna catchment. The yield for such years has therefore to be worked out by establishing a co-relation ratio between the Vaitarna catchment and any other similarly-situated catchment after observing the behaviour of the rainfall in the two catchments for the years for which records exist. Tansa and Vaitarna catchments can be said to be similarly situated. There is a great similarity between their rainfalls for the past fifteen years *i.e.* for the years during which the Vaitarna river has been gauged. The records of the Tansa catchment extend over a period of 50 years and they cover both lean and good years of rainfall. The critical years from the point of yield are the three consecutive dry years of 1904, 1905 and 1906; lean years of 1911, 1918 and 1929 and the driest year of 1899, which occurs once in 200 years. The records maintained at the Tansa lake consist of the rainfall and the fluctuations in the level in the lake at the end of every six hours.

Major Tulloch while preparing the Tansa project had assumed that the average rainfall in the catchment of the Tansa lake would be about 136" and that about 60 per cent. thereof would be available for 'storage.' He had at that time taken the catchment area of the Tansa lake at 45 square miles against the actual area of 52.5 square miles. The average rainfall recorded at the Tansa lake during the past fifty years works out to 95". In 1911, at the time of reporting upon the 'duplication scheme' of the Tansa lake, the Engineer in-charge wrote "the average rainfall during the last 25 years is 94.24 inches and the 'flow off' varied from 29 to 53 percent of the rainfall and can be taken as 50 per cent so that the actual ultimate yield of this catchment can now be definitely ascertained." He put the ultimate yield at 33,000 million gallons and he also estimated that the dependable supply from the Tansa lake would not exceed 78 m.g.p.d. The average 'flow off' or 'run-off' of the last fifty years works out to 60 percent of the average yearly rainfall and in the year 1899 it amounted to only 40 percent of the total rainfall of 40". Assuming the 'flow off' or 'run-off' of 60 per cent, the average yield of the Vaitarna catchment works out to 1,50,000 million gallons and with a 'run-off' of 40 per cent. it works out to 1,00,000 million gallons. In a year like 1899, with a 'flow off' of 40 per cent. of the total rain of 40" (the same as observed in Tansa catchment) the yield works out to about 42,000 million gallons. This yield

together with carry over may be adequate to fill the Vaitarna reservoir to its ultimate F. S. L. of 535 T. H. D if even in such a year steps are taken to prevent any water from going to waste by over flow over the waste weir.

In order to establish a co-relation ratio between the yields of the two catchments, the yield of the Vaitarna river on some typical days of every year during the period of 15 years were plotted on a graph along with those actually observed at the Tansa lake on the corresponding days (*vide* Appendix No. VIII). The graphs showed that upto a daily yield of 1,500 million gallons in the Tansa catchment, the co-relation was in the proportion of 1 to 4 i.e. on the corresponding day, the yield of the Vaitarna was 6,000 million gallons. Co-relation in daily yields in excess of 1,500 million gallons could not be established as the number of days on which the yield exceeded 6,000 million gallons at the point of gauging is very small, during the 15 years the Vaitarna river is being gauged. To find out the co-relation ratio between the yields of the two catchments in excess of 1,500 million gallons, the total yearly yield of the two catchments for the corresponding 15 years was worked out and it gave an overall ratio of 1 to 4.75 (*vide* Appendix No. IX) which appears to be rather on a higher side. The ratio on the basis of the areas of the two catchments, works out to 1 to 3.3 (catchment area of the Tansa river 52 square miles and area of Vaitarna catchment 173 square miles) and with an allowance for an average rainfall of 95" in Tansa, against 105" in the Vaitarna, the ratio may be taken as 1 to 3.5. This ratio of 1 to 3.5 has been assumed in estimating the yield of the Vaitarna catchment in lean years to err on the safe side. It corresponds to a run-off of 60 per cent. of the total average rainfall. The extent of the daily supply available from the two sources will depend upon this ratio. If this ratio is found to be more, there will remain a large 'carry over' in the lakes in lean years which would be useful to tide over the following lean years.

13. As regards the tunnel its capacity must be adequate to divert the requisite quantity of water from the Vaitarna river into the Tansa lake to keep it filled at the end of the monsoon after replenishing the Vaitarna reservoir itself. If the tunnel were made of a very large capacity, it would prove costly and at the same time, it would tend to hasten the overflow on the waste weir of the Tansa lake, which is not desirable especially in years of scanty rainfall. On the other hand if the tunnel were made of a smaller carrying capacity, it may not

be able to keep the Tansa lake filled at the end of the monsoon as a large quantity of water in excess of its carrying capacity would run to 'waste' over the waste weir of the Vaitarna reservoir.

The most economical section for the tunnel has, therefore, to be worked out. Different sections varying in sizes, such as 10' x 8', 12' x 8', 13' x 10' and 15' x 10', both lined and unlined were tried for three consecutive dry years like 1904, 1905 and 1906 and it was found that a 10' diameter horse* shoe section, lined, having a carrying capacity of 500 million gallons per day at a head of about 60' would be capable of keeping the Tansa lake filled at the end of the Monsoon in three consecutive dry years. The invert level of the tunnel at the tail end on the Tansa side will be kept at 417.90 T.H.D., i.e., about 5' below the new F.S.L. of the Tansa lake. The invert level at the starting point on the Vaitarna reservoir will be the same as the new F.S.L. of the Tansa lake, viz., 422 T.H.D.

The tunnel will consist of three sections. Section No. 1 from Vaitarna end will be 8,850' long; Section No. 2 will be 1910' long between Balwant and Tasu Nallas, and Section No. 3 will be 10,840' long between Tasu and Bell Nallas making a total length of 21,600'. The tunnel will however emerge above ground level at the Balwant and Tasu Nallas where 10'-6" diameter steel pipes supported on masonry bridges will be used. The total length of the steel pipes will be 1,000' (470' in Balwant Nalla and 530' in Tasu Nalla.) The tunnel will have an intake channel about 300' long at the Vaitarna end and its bed width will be about 30'. The off-take channel will be 35' wide at the bottom with suitable side slopes and its length will be about 3,000'. The off-take channel will convey Vaitarna waters from the end of the tunnel into the Tansa lake.

The carrying capacity of the tunnel with different levels of water in the Vaitarna Reservoir will be as follows :—

Water level 480 T.H.D.	...	500 million gallons per day.
" 500	" ...	570 " "
" 515	" ...	625 " "
" 535	" ...	685 " "

The details of the tunnel are given in the specifications prepared for the scheme (Appendix X). Tenders for its execution have since been received and they are being scrutinised.

* This section incidentally is found to be most economical from the construction point of view also.

14. The following tables 1 to 5 will give an idea of the combined daily supply likely to be obtained in critical years with different useful storages as per graphs of daily yields (*vide* Appendix XA). They have been prepared on the correlation ratio of 1 to 3.5. The tables, in addition to the combined daily supply likely to be obtained from the two sources both in wet and dry weather, give information regarding (a) the quantity of water likely to run to waste over the waste weir of the Vaitarna reservoir during the monsoon period of such years, (b) the level of water in the Tansa lake as well as in the proposed Vaitarna reservoir on 1st of October of every year, (c) the supply available from the Vaitarna reservoir alone independently of the Tansa lake and (d) the 'carry over' in the lakes at the end of the hot weather, after allowing for losses by absorption and evaporation in the two reservoirs on the basis referred to in para. 11, sub-para 3. There is no 'carry over' left at present in the Tansa lake. Due to this, the daily supply that can be obtained from the same cannot be estimated till 1st of October, because it depends upon the level of water in the lake on that date. It is desirable that this drawback should be minimised as far as possible in the scheme now under consideration.

Table No. 1 is for a useful storage of 17,000 million gallons with F.S.L. of the lake at 480 T.H.D. It shows that in three consecutive dry years, like 1904, 1905 and 1906, if a combined supply of 160 million gallons per day were given during the monsoon period, the supply available for the consumption of the City in the dry season for the corresponding years will be 150, 130 and 142 million gallons per day respectively, without leaving any 'carry over' at the end of the hot weather. With this storage, it will also not be possible to maintain a supply of 160 million gallons per day during the hot weather, in years like 1911, 1918 and 1929. In a driest year like 1899, if a supply of 160 million gallons per day is given during the monsoon period, a supply of only 80 million gallons per day could be given in the dry weather and that too without leaving any 'carry over'. This clearly indicates that if a dependable combined supply of 160 million gallons per day is to be obtained in lean years, leaving aside the driest year like 1899, the Full Supply Level of the Vaitarna reservoir must be raised at least by 15', i.e., 495 T.H.D. (*vide* table No. 2.) This can be secured by keeping the crest of the waste weir at 475 T.H.D. and providing automatic gates 20' high on its crest.

With Full Supply Level of the reservoir at 495 T.H.D., the useful storage available will amount to 24,000 million gallons, as will be seen from the Table No. 2. It will be possible with this storage to maintain a combined supply of 160 million gallons per day both in the dry and wet weathers, in three consecutive dry years and in all lean years. The combined supply available in a driest year like 1899, will be 160 million gallons per day during the monsoon and 115 million gallons per day during the dry weather.

Table No. 3 shows the position of the supply with Full Supply Level at 500 T.H.D. impounding a useful storage of 26,000 million gallons. This storage will ensure a combined supply of 170 million gallons per day in all the lean years, including the three consecutive dry years and during the monsoon of a driest year like 1899, but of 110 million gallons per day in the dry weather following the monsoon of a year like 1899. It will leave some 'carry over' varying between 1,000 to 3,000 million gallons at the end of the dry weather, in all years, except in a year similar to 1899.

Table No. 4 shows the position of the supply with Full Supply Level standing at 515 T.H.D. impounding a useful storage of 34,000 million gallons. With this Full Supply Level a combined supply of 200 million gallons per day can be expected in all lean years and in three consecutive dry years. In a year like 1899, the combined supply during the wet weather will be 200 million gallons per day and in the hot weather 105 million gallons per day.

Table No. 5 shows the position of the supply with the ultimate Full Supply Level of 535 T.H.D. which can be obtained either by keeping the crest of the waste weir at 515 T.H.D. and erecting automatic gates of 20' height on its crest, or by providing a syphon spillway in the body of the dam with Full Supply Level 535 T.H.D. and H.F.L. at 537 T.H.D. With this storage, it would be possible to give a combined supply of 220 million gallons per day in three consecutive dry years and in all lean years. In a year like 1899, the supply during the wet weather will be 220 million gallons per day and in the hot weather, 115 million gallons per day. A deficiency of 5 million gallons per day may be experienced in a year like 1905 but it can be got over by utilising the contents below 387 T.H.D. of the Tansa lake. With this Full Supply Level, a 'carry over' varying between 4,000 and 5,000 million gallons, will be left at the end of the hot weather in lean years.

If the column regarding the quantity of water overflowing over the waste weir of the Vaitarna reservoir, is carefully studied it will be seen that the shortage in the daily supply is not due to the inadequacy of the yield in the Vaitarna river, at the site of the dam in such year but it is due to the inadequacy of the storage itself. The reservoir being small, cannot accommodate a large quantity of water which has necessarily to run to waste over the waste weir. Even in a driest year like 1899, the quantity running to waste will be about 6,000 million gallons with the Full Supply Level of the reservoir standing at 480 T.H.D. As the Full Supply Level of the reservoir is progressively increased, the quantity overflowing over the waste weir is correspondingly decreased and ultimately, with the Full Supply Level of the reservoir standing at 535 T.H.D. no overflow will take place in a year like 1899 and in years similar to those of 1904 and 1905, (For tables No. 1 to 5, *vide* pages 33 to 37 both inclusive)

TABLE No. 1.

USEFUL STORAGE ... 17,000 Million Gallons.

FULL SUPPLY LEVEL ... 480 T.H.D.

Year.	Rainfall in inches at Tansa.	Observed yield at Tansa in million gallons.	Calculated yield at Vaitarna in million gallons.	Quantity of overflow. M.G.		Position of lake level on 1st October in T.H.D.		Combined supply in m. g. p. d. that can be given during		Carry over left at the end of hot season. M.G.	Independent supply from Vaitarna. m.g.p.d.	REMARKS.
				At Vaitarna.	At Tansa.	At Vaitarna.	At Tansa.	Monsoon.	Dry Season.			
1899	... 40"	12,200	42,800	6,000	Nil.	422.0	416.5	160	80	Nil.	50	
1904	... 74"	19,200	67,600	16,600	500	476.5	422.0	160	150	Nil.	50	
1905	... 57"	18,300	64,000	19,700	Nil.	456.5	422.0	160	130	Nil.	50	
1906	... 76"	26,400	92,300	47,700	4,300	473.5	422.0	160	142	Nil.	50	
1911	... 69"	23,200	81,100	36,500	1,500	472.0	422.0	160	142	Nil.	50	
1918	... 61"	19,700	68,900	25,900	Nil.	459.25	422.0	160	125	Nil.	50	
1929	... 74"	22,300	77,900	30,000	1,100	480.0	422.0	160	150	Nil.	50	
1941	... 91"	53,900	2,15,600	1,90,500	10,500	480.0	422.0	160	150	Nil.	50	

TABLE No. 2.

USEFUL STORAGE ... 24,000 Million Gallons

FULL SUPPLY LEVEL ... 495 T.H.D.

Year.	Rainfall in inches at Tansa.	Observed yield at Tansa in million gallons.	Calculated yield at Vaitarna in million gallons.	Quantity of overflow. M. G.		Position of lake level on 1st October. in T. H. D.		Combined supply in m. g. p. d. that can be given during		Carry overleft at the end of hot season. M. G.	Independent supply from Vaitarna. m. g. p. d.	REMARKS.
				At Vaitarna.	At Tansa.	At Vaitarna.	At Tansa.	Monsoon.	Dry Season.			
1899	... 40"	12,200	42,800	800	Nil	444.0	422.0	160	115	Nil.	75	
1904	... 74"	19,200	67,600	12,300	2,500	492.5	422.0	160	160	3,700	75	
1905	... 57"	18,300	64,000	19,400	200	486.0	422.0	160	160	2,700	75	
1906	... 75"	26,400	92,300	41,700	4,400	490.0	422.0	160	160	2,500	75	
1911	... 69"	23,200	81,100	31,300	4,300	489.0	422.0	160	160	2,000	75	
1918	... 61"	19,700	68,900	22,600	200	488.5	422.0	160	160	2,000	75	
1929	... 74"	22,300	77,900	25,000	4,200	495.0	422.0	160	160	5,000	75	
1941	... 91"	53,900	2,15,600	1,83,500	16,400	495.0	422.0	160	160	5,000	75	

TABLE No. 3.

USEFUL STORAGE ... 26,000 Million Gallons.

FULL SUPPLY LEVEL ... 500 T.H.D.

Year.	Rainfall in inches at Tansa.	Observed yield at Tansa in million gallons.	Calculated yield at Vaitarna in million gallons.	Quantity of over flow. M.G.		Position of lake level on 1st October. in T.H.D.		Combined supply in m. g. p. d. that can be given during		Carry over left at the end of hot season. M.G.	Independent supply from Vaitarna. m.g.p.d.	REMARKS.
				At Vaitarna.	At Tansa.	At Vaitarna.	At Tansa.	Monsoon.	Dry Season.			
1899	... 40"	12,200	42,800	Nil	Nil	443.0	422.0	170	110	Nil	85	
1904	... 74"	19,200	67,600	13,560	1,260	497.25	422.0	170	170	3,000	85	
1905	... 57"	18,300	64,000	11,600	200	488.75	422.0	170	170	2,000	85	
1906	... 76"	26,400	92,300	37,000	4,300	494.5	422.0	170	170	2,600	85	
1911	... 69"	23,000	81,000	29,300	4,000	494.0	422.0	170	170	1,000	85	
1918	... 61"	19,700	68,900	21,300	100	493.0	422.0	170	170	1,000	85	
1929	... 74"	22,300	77,900	24,000	4,000	500.0	422.0	170	170	4,000	85	
1941	... 91"	53,900	2,15,600	1,71,800	13,000	500.0	422.0	170	170	4,000	85	

TABLE No. 4.

USEFUL STORAGE ... 34,000 Million Gallon..

FULL SUPPLY LEVEL ... 515 T.H.D.

Year.	Rainfall in inches at Tansa.	Observed yield at Tansa in million gallons.	Calculated yield at Vaitarna in million gallons.	Quantity of overflow. M.G.		Posit on of lake level on 1st October. in T. H. D.		Combined supply in m. g. p. d. that can be given during		Carry overleft at the end of hot season. M.G.	Independent supply from Vaitarna. m.g.p.d.	REMARKS.
				At Vaitarna.	At Tansa.	At Vaitarna.	At Tansa.	Monsoon.	Dry Season.			
1899	... 40"	12,200	42,800	Nil.	Nil.	437.75	422.0	200	105	Nil.	110	
1904	... 74"	19,200	67,600	2,400	1,900	512.0	422.0	200	200	2,000	110	
1905	... 57"	18,300	64,000	5,000	Nil.	498.75	422.0	200	195	Nil.	110	
1906	... 76"	26,400	92,300	25,400	3,400	510.0	422.0	200	200	1,000	110	
1911	... 69"	23,200	81,100	20,900	1,800	509.0	422.0	200	200	1,000	110	
1918	... 61"	19,700	68,900	13,300	Nil.	508.0	422.0	200	200	Nil.	110	
1929	... 74"	22,300	77,900	14,500	2,500	515.0	422.0	200	200	4,000	110	
1941	... 91"	53,900	2,15,600	1,64,700	14,500	515.0	422.0	200	200	4,000	110	

TABLE No. 5.
 USEFUL STORAGE ... 46,000 Million Gallons.
 FULL SUPPLY LEVEL ... 535 T.H.D.

Year.	Rainfall in inches at Tansa.	Observed yield at Tansa in million gallons.	Calculated yield at Vaitarna in million gallons.	Quantity of overflow. M. G.		Position of lake level on 1st October. in T. H. D.		Combined supply in m. g. p. d. that can be given during		Carry over left at the end of hot season. M.G.	Independent supply from Vaitarna. m.g.p.d.	REMARKS.
				At Vaitarna.	At Tansa.	At Vaitarna.	At Tansa.	Monsoon.	Dry Season.			
1899	... 40"	1,220	42,800	Nil.	Nil.	445.00	422.0	220	115	Nil.	110	
1904	... 74"	19,200	67,600	Nil.	3,500	526.25	422.0	220	220	4,000	150	
1905	... 57"	18,300	64,000	Nil.	100	510.75	422.0	220	215	Nil.	150	
1906	... 76"	26,400	92,300	11,000	4,400	530.5	422.0	220	220	6,000	150	
1911	... 69"	23,200	81,100	11,300	3,600	528.0	422.0	220	220	5,000	150	
1918	... 61"	19,700	68,900	1,650	Nil.	527.5	422.0	220	220	4,500	150	
1929	... 74"	22,300	77,900	4,000	3,400	535.0	422.0	220	220	9,000	150	
1941	... 91"	53,900	2,15,650	1,58,000	17,000	535.0	422.0	220	220	9,000	150	

15. The only conclusion that can be drawn from the study of the five tables is that the site selected for

Works to be constructed now must be capable of being developed to obtain a combined dependable supply of 220 m. g. p. d.

the location of the dam is capable of being economically developed for obtaining a combined supply of 220 m. g. p. d. from the two sources (Tansa and Vaitarna) with F.S.L. of the reservoir standing at 535 T.H. D. and a supply of 150 m. g. p. d. independently of the Tansa lake, if it (Vaitarna Reservoir) remains filled up to its F. S. L. of 535 T.H.D. on 1st of October. In a year like 1899, the dependable supply from the Vaitarna reservoir alone will be 110 m. g. p. d. Steps must therefore be taken to design the various component parts of the scheme in such a manner as to be capable of being developed with as little modifications as possible to obtain a useful storage of 46,000 million gallons if it is not intended to secure the same from the very commencement. But certain works like the tunnel including the in-take and off-take towers, will have to be constructed from the very commencement to withstand the pressure of the ultimate head of water to which they would be subjected when the F. S. L. of the reservoir is finally raised to 535 T. H. D. For the same reason, the embankments for the new pipe line or lines will have to be made sufficiently wide from the very commencement to accommodate the requisite number of additional pipe line or lines necessary for conveying the ultimate combined supply of 220 m. g. p. d. to the City. The existing trolley-track also will have to be shifted to a suitable position so as not to interfere with the laying of the additional pipe line or lines. The only work that can be carried out in stages would be the dam and the waste weir and that too can be done in only two stages. In the first stage, the crest of the waste weir will have to be built upto 495 T. H. D. to obtain a combined dependable supply of 160 m. g. p. d. in all years except a year like 1899. The depth of flow passing over the waste weir will be 23 feet instead of 20 feet due to the reduction in the value of co-efficient of discharge from 3.9 to 3.00. The top of the dam will be kept at 523 T. H. D. to maintain a free-board of 5 feet *i.e.* [the difference between the H. F. L. of the reservoir *viz.*, 518 T. H. D. (495+23) and the top of the dam.] In the second stage, the portion of the waste weir will be raised to 515 T. H. D. and it shall be given an 'ogee' shape to increase the value of the co-efficient of discharge from 3.00 to 3.90. Automatic gates 20 feet high will be erected on its crest to increase

the F. S. L. from 515 T. H. D. to 535 T. H. D. In this stage, a free board of 10 feet will be provided instead of 5 feet, suggested for the first stage; and the top of the Dam will be thus at 545 T.H.D. The extra cost involved in building up the F. S. L. to 535 T. H. D. from the very commencement will be about Rs. 44 lakhs. With this extra expenditure, an additional supply of 60 m. g. p. d. will be secured to the city and the suburbs. Additional expenditure over and above Rs. 44 lakhs will have to be incurred on certain items if the dam were built to its ultimate height in two stages and not from the very commencement as will be evident from the following :—

The bridge to be provided on the waste weir portion in the first stage will have to be removed when the top of the dam is raised to 545 T.H. D. in the second stage, for being re-erected in its new position. To enable this being done, the bridge will have to be made up of steel plate girders which will be costlier than a R. C. C. bridge. A plate girder bridge will be costlier to maintain as it will have to be painted at least every alternate year to protect it from weathering action. Other disadvantages of a minor nature are that the expenditure incurred on the parapet wall and the wearing coat of the roadway in the first stage will be wasted. Spindles of the under sluices will have to be lengthened in the second stage to suit the new height of the dam involving extra expenditure. The approach road connecting the Khardi-Pareli Road will have to be slightly re-aligned and modified to suit the increased level of the top of the dam in the 2nd stage.

16. With the increase in the useful storage capacity from 17,000 million gallons to 46,000 million gallons, the most economical way of conveying the supply of 220 m.g.p.d. to the suburbs and the city. The new pipe line of 72" dia., suggested in the Interim Report, will not be adequate to carry the total supply to the city in conjunction with the existing conduits. It will therefore be necessary to find out the most economical manner by which the total combined supply of 220 m. g. p. d. can be conveyed to the city. The minimum carrying capacity of the conduits from the two reservoirs will depend upon the lowest levels reached in them at the end of the hot weather. The lowest level to which the Vaitarna reservoir can be drained at the end of the hot weather will be about 422 T. H. D. while the

lowest level reached in the Tansa lake is 390 T. H. D. under the existing conditions (without the erection of automatic gates). It should be possible, with the increased storage proposed to be impounded in the Vaitarna reservoir, not to permit the level of the Tansa lake to go down below 399 T. H. D. at the end of the dry weather because of the 'carry over' that would be left in the two reservoirs (Tansa and Vaitarna) at the end of the hot weather. Due to the possibility of an independent pipe line being laid from the Vaitarna reservoir to connect up with the existing conduits from the Tansa lake, the pipe line from the Vaitarna reservoir will work with an additional head of 32 feet (422-390 T. H. D.). Due to this, the carrying capacity of the pipe line to be laid independently from the Vaitarna reservoir will be considerably more than what it would be if the water of the Vaitarna reservoir were all allowed to be admitted into the Tansa lake and drawn upon therefrom, through the existing and the new conduits. Due to the maintenance of a higher water level in the Tansa lake by about 9 feet (399-390), the carrying capacity of the existing conduits will also be increased. The maintenance of a higher water level in the Tansa lake at the end of the hot weather will also be helpful in getting over the difficulty, which is at present experienced, in the reduction in the carrying capacities of the existing pipe lines from the Tansa lake due to their touching the hydraulic grade line at Pivli and Mohili cuttings when the water level in the Tansa lake goes below 390 T. H. D. In the scheme outlined in the Interim Report, it was proposed to lay the new 72" pipe line about 10 feet lower than the existing 72" pipe lines in these two portions to keep it below the hydraulic grade line with the water level in the Tansa lake standing at 390 T. H. D. This would have involved cutting in rock which would have to be done by 'chiselling,' as it would not have been safe to resort to 'blasting' in the close proximity of the existing pipe lines. With the lowest water level standing in the Tansa lake at 399 T. H. D. at the end of the dry weather, the carrying capacity of each of the existing two 72" pipe line will be increased by about 3 m. g. p. d. The actual quantity carried through the existing conduits in the four years

1944-1947 with the lowest water level reached in these years is tabulated below:—

Year.	Date.	Lake Level.	57"E	57"W	60"	Duct.	Total.
1944.	June						
	6	394.13	27.7	22.6	25.3	14.8	90.4
	7	393.97	27.8	22.3	25.7	16.1	91.9
	8	393.83	27.8	22.1	26.1	17.6	92.6
	9	393.84	27.8	22.0	25.9	17.9	93.6
	10	394.01	28.1	21.1	27.0	18.0	94.2
1945	June						
	13	390.30	27.6	20.0	23.5	16.9	88.0
	14	390.14	27.7	20.7	24.1	15.3	87.8
	15	390.06	27.5	20.5	24.5	14.0	86.5
	16	390.25	27.6	20.8	24.3	12.3	85.0
	17	390.23	27.7	20.7	24.1	11.9	84.4
1946	June						
	16	390.62	28.7	22.1	23.3	19.5	93.6
	17	390.52	28.7	21.1	22.3	19.0	91.1
	18	390.38	28.5	21.2	21.7	22.7	94.1
	19	390.40	28.5	22.4	23.1	21.4	95.4
	20	390.46	28.4	22.9	22.8	20.5	94.6
1947	June						
	27	390.05	28.2	17.1	21.1	15.7	82.1
	28	389.90	28.1	16.1	21.0	15.6	80.8
	29	389.75	27.4	16.7	21.9	15.2	81.2
	30	389.60	27.9	16.6	21.3	15.5	81.3
	July						
	1	389.58	26.3	12.0	18.3	15.6	72.2
2	389.54	27.4	15.4	21.6	13.2	77.6	
	3	390.08	27.3	16.2	21.9	11.5	76.9

If a 72" pipe line were laid from the end of the tunnel upto Powai, a distance of about 46½ miles to convey a part of the supply of the Vaitarna reservoir directly to the city to connect up with the mains feeding the Malabar Hill Reservoir, its carrying capacity, in the beginning, will be 47 million gallons per day which would be reduced to 41.50 million gallon per day at the end of the next 20 years as by that time the co-efficient of rugosity would

increase due to 'age'. Conveying a part of the supply of the Vaitarna reservoir directly to Powai would also improve the carrying capacity of the Tansa East Main, if it were utilised to feed the service reservoirs at Bhandarwada and those to be constructed here after at Rowli and Worli Hills. By this dual supply, partly from the Tansa lake and partly from the Vaitarna reservoir, the carrying capacity of the duct will not be affected and it will continue to give a supply of 20 million gallon per day so long it is not reconditioned and of 40 million gallons per day when reconditioned. Thus with a new pipe line of 72" dia. laid between the Vaitarna reservoir and Powai, the total carrying capacity of the conduits both new and existing, with the water level in the two lakes standing at their lowest *viz.*, 422 T.H.D. in the case of Vaitarna and 399 T.H.D. in the case of Tansa at the end of the hot weather will be 147 million gallons per day as given below :—

	m. g. p. d.
New 72" pipe line (connected to Vaitarna Reservoir)	47
East Tansa Main	... 40
West Tansa Main	... 40
Duct (in its present condition) :	... 20
	147

This capacity will fall short by 13 million gallons per day for a total supply of 160 million gallons per day and by 73 million gallons per day for a supply of 220 million gallons per day. When the duct is reconditioned, the supply will increase to 167 million gallons per day only. A fourth pipe line would therefore have to be laid by the side of the new 72" pipe line when the supply to be conveyed to the City has to be increased to 220 million gallons per day. There is no room for accommodating a 4th pipe line on the two Kasheli bridges constructed in 1925-26 in connection with the Tansa quadruplication scheme. Room for accommodating only one pipe line has been left on these two bridges. To accommodate a 4th pipe line, new bridges will have to be constructed across the Ulhas creek. As the duct will be reconditioned, the existing bridges, across the Ulhas creek which are showing signs of deterioration, will also have to be strengthened and perhaps re-built involving very heavy expenditure. Further, the cost of acquisition

of land for accommodating the 4th pipe line will be heavy as some areas along the pipe line have been fully developed. It would not therefore be an economical proposition to provide for laying a fourth pipe line but it would be simpler and cheaper if the size of the proposed pipe line was suitably increased from the very commencement to convey a supply of 220 million gallons per day in conjunction with the existing conduits, preferably without having to rely upon the duct in course of time. Our objective should be to do away with the duct and replace it if necessary by a reinforced concrete pipe when the prices of materials and wages of labour go down. Because, the retention of the duct, after all, as judged from the present-day water works practice is not advisable as it tends to promote growth of weeds and trees in its bottom and sides which have the effect of impairing the quality of water flowing through it. If the duct were replaced by a reinforced concrete pipe, its carrying capacity will remain the same *viz.*, 20 million gallons per day. To arrive at the most economical size of the pipe to meet the requirements, several sizes were tried and it was found that a 96" dia. welded steel pipe will serve the purpose admirably. The carrying capacity of a 96" dia. pipe line laid directly from the end of the tunnel upto to Powai—a distance of 46½ miles—for being connected with the mains feeding the Malbar Hill Reservoir will be 110 million gallons per day in the beginning with the water level in the Vaitarna lake standing at its lowest and 100 million gallons per day at the end of 20 years' service. A general plan showing the carrying capacities and the hydraulic grade lines of the new and the existing pipes is enclosed (Appendix X-A). The total supply conveyed to the City by a 96" pipe line along with the existing two 72" dia. pipe lines and the duct in its present condition will be 210 million gallons per day as detailed below :—

	m. g. p. d.
Tansa East (72")	... 40
Tansa West (72")	... 40
New 96' dia.	... 110
Duct	... 20
	<hr style="width: 100%; border: 0.5px solid black;"/>
	210
	<hr style="width: 100%; border: 0.5px solid black;"/>

It must, however, be remembered that the whole of the supply of 220 million gallons per day would not be required to be taken

straight into the heart of the City but a part of it will be utilised on the way for the use of the suburbs and the Greater Bombay Region and consequently the three pipe lines would be capable of conveying a total supply of 220 million gallons per day as the loss of head due to friction will be reduced owing to the reduction in the load in lower portions of the pipe lines which are required to carry a total discharge of 220 million gallons per day. With the growth of industries round about Kalyan, in the area specially allotted to heavy industries, a supply of 10 to 20 million gallons per day may have to be given to this region. Similarly, a supply of 3 to 5 million gallons per day may be given to the Municipalities of Kalyan, Thana and the village Panchayat of Dombivli. When a supply to the extent of about 15 to 25 million gallons per day is thus given, it will not only reduce the load on the pipe line to that extent but it would also be helpful in bringing some revenue by the sale of water which can be utilised in defraying a part of the interest and sinking fund charges on the loan to be raised for the scheme. The proper distribution of the 220 million gallons per day will be—170 million gallons per day to the City proper and 50 million gallons per day for the suburbs—(please *vide* page 5 para 4 of the Interim Report). With a 96" pipe line, the duct can be done away with, in course of time when certain parts of the existing 72" dia. steel pipes are required to be renewed. If instead of renewing the 72" pipe line, a part thereof were replaced by a 96" pipe, the total supply of 220 million gallons per day can be taken to the City without the help of the duct. This point should not be lost sight of, at the time when the existing 72" pipes due to their having finished their useful life are required to be renewed.

It may be questioned whether the steel required for a larger size pipe line would be available when the greatest difficulty is being experienced in obtaining the steel required for a 72" dia. pipe line. The answer is that it will not be necessary to lay the whole length of 96" pipe line from the very beginning right upto Powai for obtaining the same supply *viz.*, 160 million gallons per day intended to be conveyed to the city with a 72" pipe line after reconditioning the duct. The steel required for the 72" pipe line 40 miles long will be about 30,600 tons. For obtaining an independent supply from the Vaitarna reservoir, an additional length of 6½ miles will be required. The steel required for 46½ miles of 72" dia. pipe line would be about 35,000 tons. With the same steel, a 96" dia. pipe line can be laid from the end of the tunnel

upto a distance of $28\frac{1}{2}$ miles. When this pipe line is laid and the water level of the Vaitarna reservoir reaches 495 T.H.D. a combined supply of 160 m.g.p. will be assured for the whole year, by cross connecting it with the existing 72" pipes, as detailed below :—

	m. g. p. d.
New 96" dia. pipe line $28\frac{1}{2}$ miles long connected to 72" Tansa West.	65
Tansa East (72")	55
Duct after reconditioning	40
	160

If on the other hand, the dam of the Vaitarna reservoir was built to its ultimate height from the very commencement to impound a useful stroage of 46,000 million gallons (F.S.L. 535 T.H.D.) a supply of 160 million gallons per day can be made available to the City by laying $36\frac{1}{2}$ miles of 96" pipe line and cross connecting with Tansa West Main without reconditioning the duct. This will require an additional quantity of steel to the extent of about 10,000 tons.

If the idea of reconditioning the duct to obtain from it a supply of 40 million gallons per day is given up, it should be possible to utilise the 20 miles of 48" dia. C.I. pipes from one of the syphon lines of the duct which are lying idle for the last 20 years without giving any service. Their cost at the present market rates will be roughly Rs. 80 lacs and they can be utilised in the City proper for improving the distribution system of which the City is in dire need. It will also not be necessary to incur an expenditure of about Rs. 80 lacs at the present rates on reconditioning the duct. The duct can be made to function in its present condition by carrying out a few repairs to the same to maintain a supply therefrom of 20 million gallons per day. Thus the combined saving to the extent of $1\frac{1}{2}$ crores of rupees accruing from the use of C. I. pipes from the syphons and not reconditioning the duct can well be utilised for raising the dam to its ultimate height and increasing the size of the pipe line from 72" to 96", because if this work were done in one single stage it will cost much less than what it would do if it were carried out in different stages as it will save duplication of machinery and staff.

Experience of Tansa lake has shown that the development of this source in stages has cost the Corporation much more than

what it would have cost, had the works in connection therewith been carried out to their ultimate capacity from the very commencement. The total expenditure so far incurred on the Tansa lake and the pipe lines therefrom amounts to Rs. 7.45 crores for obtaining a dependable supply of 78 million gallons per day as calculated by the then Hydraulic Engineer in 1911 and 64 million gallons per day as estimated by me. A part of the expenditure that will be incurred in connection with the Vaitarna water supply scheme is legitimately chargeable to the Tansa scheme as one of its objects is to stabilize the Tansa supply and to obtain from the Tansa lake a daily supply of 110 million gallons per day in all the years irrespective of the behaviour of the rainfall in the Tansa catchment. In order to attain this end, the minimum works required would be the construction of a weir on the Vaitarna river with its crest at about 431 T.H.D. (estimated to cost about Rs. 80 lakhs at the present rates), driving of a tunnel of 140 Sft. area capable of discharging 500 million gallons per day with a head of 20 ft. (estimated to cost not less than Rs. 2.20 crores) and laying a pipe line 48" in dia. to convey the additional supply so stored to the City (estimated to cost Rs. 2.98 crores). Thus the total cost debitable to the Tansa works for stabilizing its supply to the extent of 110 million gallons per day and conveying the same by laying an additional pipe line of 48" dia. would be Rs. 5.98 crores (Rs. 0.80 + Rs. 2.20 + Rs. 2.98). Adding to it the cost of Rs. 7.45 crores already incurred, (including the cost of automatic shutters), the total cost for ensuring the supply of 110 million gallons per day will be Rs. 13.43 crores. On this capital cost, the cost of water per 1000 gallons works out to annas 4.25.

There is another reason why a 96" dia. pipe line should be laid from now. It is always desirable to have excess carrying capacity in the inlet mains to the service reservoirs of the City. This end can only be secured by laying from now a 96" dia. pipe line instead of a 72" dia. pipe line as originally suggested even if the storage in the initial stages is restricted to ensure a supply of 160 million gallons per day for the City in all years except in the dry year like 1899.

17. If the total supply of 220 million gallons per day were to be conveyed to the City from the Tansa lake only, the existing outlets in the Tansa lake will be found to be inadequate and they will have to be suitably enlarged to give a total discharge of at least 300 million gallons per day to allow for

No additional outlets in the Tansa dam may be necessary to start with.

sufficient stand by in case of any outlet getting choked or being put out of operation for repairs.

As, out of the total supply of 220 million gallons per day, a large quantity to the extent of 110 million gallons per day will be conveyed through the Vaitarna reservoir directly to the City, the outlets in the Tansa lake should have a total capacity of 110 million gallons per day with sufficient allowance for stand by especially when the water level in the Tansa lake goes down.

There are ten outlets in the Tansa dam discharging into the outlet well." They are as follows:—

Level..	No. of outlets	Total area
380 T.H.D.	... 2 outlets.	11.50 sq. ft.
390 "	... 1 "	5.75 "
400 "	... 1 "	5.75 "
405 "	... 2 "	11.50 "
410 "	... 2 "	11.50 "
415 "	... 2 "	11.50 "
	Total area	... 57.50 "

These outlets being connected with the outlet well, a further head of about 3 feet, is lost in the well.

There will be no difficulty in obtaining a discharge of 220 million gallons per day from the higher outlets so long as the water level in the lake does not go below 400 T.H.D. It is only when the water level in the lake goes below 400 T.H.D. that the existing outlets at 380 T.H.D. will be found to be inadequate to pass the required discharge. The discharging capacity of the existing two outlets at 380 T.H.D. is 63 m.g.p.d. with water level in the lake standing at 387 T.H.D. and that in the outlet well at 384 T.H.D. A new outlet at 375 T.H.D. is being driven to accommodate a 48" dia. steel pipe. The discharging capacity of this new outlet when ready will be about 70 million gallons per day (under similar conditions of head viz., water level in the lake at 387 T.H.D. and in the outlet well at 384 T.H.D.) making a total of 133 million gallons per day i.e., about 25 per cent. more than the required discharge of 110 million gallons per day.

Two new openings at 395 T.H.D. are being made in the Tansa dam to accommodate the rising mains from the pumps to be installed on the potoons in the lake (through which the contents of the

Tansa lake below 385 T.H.D. are to be pumped in a year of scanty rainfall if it occurs while the Vaitarna-cum Tansa scheme is under construction). These two outlets with the water level in the lake standing at 399 T.H.D. will have a discharging capacity of about 140 million gallons per day. The discharging capacity of the outlets from the Tansa dam should be equivalent to at least 220 million gallons per day with the water level in the lake standing at 399 T.H.D. to enable the whole supply being drawn through the same in an emergency i.e., when the mains laid directly from the Vaitarna reservoir are closed down for repairs. It is, therefore, desirable to have another outlet 48" dia. size in the Tansa dam at 375 T.H.D., the work on which may have to be started next year. The total discharging capacity of the two existing outlets at 380 T.H.D. and the two outlet at 375 T.H.D. one under construction and one to be made later on will be about 200 million gallons per day which will be sufficient to maintain the full quota of supply to the City in an emergency even when the water level in the Tansa lake is at its lowest.

18. If the useful storage of 46,000 million gallons is created

Advantages to be gained by creating a useful storage of 46,000 million gallons from the very commencement.

from the very commencement, it will result in securing the following advantages:—

(1) Both the sources, Tansa and Vaitarna can function independently of each other, in case of emergency.

(2) A 'carry over' of nearly 9,000 million gallons will be available at the end of the hot season of a year of good rainfall to tide over a following bad year.

(3) The extra head available in the Vaitarna Reservoir could be utilised with advantage in increasing the carrying capacity not only of the independent pipe line to be laid therefrom, but also of the existing pipe lines from Tansa lake due to the maintenance of a higher water level therein, at the end of the hot weather.

(4) It will do away with the necessity of making additional outlets in the Tansa dam at 360 T.H.D. to enable the lower contents of the Tansa lake below 380 T.H.D. being utilised by pumping.

(5) The daily supply that could be obtained from the two sources even in three consecutive dry years and all lean years will not be less than 220 million gallons per day, while that in a year like 1899, it would amount to 165 million gallons per day throughout the year, provided steps are taken to curtail it as soon as some

indications of a draught are known.

(6) The Vaitarna Reservoir independently of Tansa,* on the strength of its own storage capacity can give a uniform supply of 150 million gallons per day in all good and lean years, except in only a worst year like 1899, when the supply would be 110 million gallons per day.

(7) A large quantity of water flowing over the waste weirs of the Tansa lake and the Vaitarna Reservoir could be diverted through the existing and the new pipe line into the Vehar lake in good years and stored therein to obtain an additional supply therefrom to the extent of about 4 million gallons per day, because the carrying capacity of the new 96" dia. pipe line with the water level in the Vaitarna Reservoir standing at 535 T.H.D. (F.S.L.) will be about 140 million gallons per day and that of the two 72" dia. pipe lines from the Tansa lake with F.S.L. at 422 T.H.D. will be about 90 million gallons per day. Vehar lake on account of its inadequate catchment area does not fill normally, but the water level therein stands on an average about 8 feet below its F.S.L. at the end of the monsoon as estimated from the actual records of its water level for the past ten years.

(8) No expenditure need be incurred on reconditioning the duct, but it may be done away with altogether, by laying in lieu thereof a reinforced concrete pipe or by stopping its use altogether, by replacing a few lengths of the existing 72" pipes by 96" dia. pipes when the former are due for renewal due to 'age'.

(9) If decision is taken not to recondition the duct at any future date, but to allow it to function in its present condition with necessary repairs, about 20 miles of 48" C. I. pipe line can be released from the syphons immediately for being used for improving the distribution system in the City as these pipes are lying idle for the past 20 years and it would not be advisable to continue them to do so for another 20 years, when at the present moment there is dearth of steel and C. I. pipes. The cost of the pipes so released at the present market rates will be about Rs. 80 lacs.

(10) It may be possible in the future when the duct is finally scrapped (a) to utilise 20 miles of 50" dia. lock-bar steel pipes for extending the distribution system in the suburbs for the Greater Bombay Region and (b) to save the expenditure on the reconstruction of the bridges on the Ulhas River, carrying the existing syphons. The bridges are already showing signs of deterioration and heavy

* In case of Tansa lake is thrown out of commission.

expenditure will have to be incurred in reconditioning or strengthening them if they are to be retained as a permanent part of water works system.

(11) The cost to be incurred in lowering the existing pipe lines and the new pipe line at Mohili and Pivli cuttings will be saved as due to maintenance of higher water level in the Tansa lake, the hydraulic grade line will always remain above the pipe lines.

(12) No additional outlets may be driven in the Tansa dam immediately to increase the discharging capacity of the existing outlets below 385 T.H.D. to 220 million gallons per day, because with an independent pipe line from the Vaitarna Reservoir a supply equivalent to about 110 million gallons per day can be conveyed to the City independently of the Tansa lake.

(13) The supply to be obtained being 220 million gallons per day it would meet the requirements of the City for the next 20 years without having to go in for any other scheme. A total supply of 160 million gallons per day from the two sources as originally contemplated (Tansa and Vaitarna) will certainly not be adequate to meet the requirements of the citizens for the next 20 years due to the unprecedented growth in the City's population. Besides, the Vaitarna-cum-Tansa scheme of 160 million gallons per day capacity was only considered as the first step in the augmentation of the City's water supply and it was intended to undertake either the Bhivpuri or Kalu Shai schemes after the former was completed. Even with the execution of a 160 million gallons per day Vaitarna-cum-Tansa scheme, the hardship and inconvenience at present caused to the citizens due to the inadequacy of the water supply, will continue till an additional supply is made available for the City by harnessing other sources.

Though the present moment is not the opportune time for carrying out large works due to prices of materials and wages of labour having gone up, the augmentation of the City's water supply does not brook delay. It must be proceeded with, at whatever cost, as on its execution, hinges the health and sanitation of the City. Besides, no one knows when the prices will go down. In a water supply scheme, the various component parts are so inter-dependent that some of them have to be constructed from the very commencement to fit in with the ultimate utilisation of the source. As pointed

out previously, in the present case it is only the dam that may not be constructed to its ultimate height at the very commencement but its foundations and the structures must be made strong enough to withstand final stresses to which it would be subjected when raised to the ultimate height.

19. With decision to construct all the works from the very commencement to obtain a combined dependable supply of 220 million gallons per day, the choice of the waste weir will necessarily lie between the ordinary overflow waste weir (in conjunction with automatic gates) and a syphon spillway. The automatic gates are objected to by some engineers on the following grounds :—

What type of waste weir would be suitable if the schemes were developed from the very commencement to secure an ultimate supply available therefrom.

(1) The gates, being mechanical contrivances, may fail to function at the right time resulting in a catastrophe.

(2) A large recurring expenditure per annum is required to be incurred in keeping them in good condition.

(3) There is a tendency for leakage through their sides and the bottom and due to this, a large quantity of water may run to waste.

As pointed out previously, if an over flow waste weir is adopted its crest will have to be kept at 515 T.H.D. and the F.S.L. of 535 T.H.D. could be obtained by using gates of 20 feet height. With a syphon spillway, the F.S.L. of the reservoir will have to be kept at 535 T.H.D. and the H.F.L. at 537 T.H.D. as a depth of 2 feet is required for the operation of the syphons.

Before taking a decision as regards the type of the waste weir it would be advisable to carry out experiments at the Government of India Hydro-dynamic Research Station at Khadakwasla both on the overflow waste weir and the syphon spillway to ascertain which type would be most suitable and economical. The Research Station will also have to be requested to carry out experiments on the protective works necessary for preventing the dam being undermined by the fall of a large mass of water through a height of nearly 250 feet and for determining the value of "C" for working out the required length of the weir. Mr. Framji, the Director, Khadakwasla

* Value of coefficient of discharge in the formula $Q = clh^{3/2}$.

Research Station, is agreeable to carry out the necessary experiments and to give us the results as early as possible so that by the time the work on the dam is started, the decision regarding the type of the waste weir could be taken. A provision of Rs. 50,000 has been included in the estimate of the dam and the waste weir for carrying out the experiments.

20. It is now to be seen whether, from a financial point of view, also, the execution of the whole scheme for obtaining immediately a dependable combined supply of 220 million gallons per day can be justified. The criterion to be used in this connection will not be the total cost of the various schemes, but the cost of water per 1000 gallons obtainable therefrom. In order to estimate the cost of water per 1000 gallons under each scheme, its cost as a whole must be first worked out. It is difficult at the present moment to estimate with any degree of accuracy the cost of the various items included in the scheme when the market is unstable and prices of materials and wages of labour show a tendency towards soaring up and the output of labour has gone down considerably. There is also a dearth of essential materials like cement and steel and other materials like petrol, fuel oil etc. There are thus several unforeseen items the cost of which cannot be worked out. The costs worked out here may be said to be relative. They are intended mainly for the purpose of comparing the costs of water per 1000 gallons under each scheme.

Cost of a scheme for giving an ultimate combined supply of 160 million gallons per day as originally suggested.

If the scheme as originally contemplated *viz.*, of obtaining a combined dependable supply of 160 million gallons per day were to be executed without any allowance for future development, the F.S.L. of the reservoir will have to be maintained at 495 T.H.D. (*vide* table No. II) and not at 480 T.H.D. as originally suggested. This F.S.L. can be built up either by keeping the crest of the waste weir at 475 T.H.D. and providing automatic gates thereon to increase it to 495 T.H.D. or by using a syphon spillway. In the case of the latter, the F.S.L. of the lake will be at 495 T.H.D., but its H.F.L. will be at 497 T.H.D. and the top of the dam will be at 507 T.H.D. against 505 T.H.D. in the former case.

The cost of the two alternatives is tabulated below :—

Items.	Scheme No. I	Scheme No. II
	F. S. L. 495 with 20 feet high automatic shutters (Central spillway).	F. S. L. 495 with syphon spillway.
	Rupees in lacs.	Rupees in lacs.
Cost of survey work ...	3.37	3.37
Preliminary works (Revised) ...	37.17	37.17
Acquisition of land ...	12.00	12.00
Dam and waste weir ...	311.87	272.75
Tunnel ...	209.04	209.04
72" pipe line from Tansa to Powai (40 miles) ...	456.00	456.00
Reconditioning duct ...	77.52	77.52
Reinstating the missing syphons ...	11.68	11.68
	<u>Rs. 1,118.65</u>	<u>1079.53</u>
Say Rs.	11.20 crores	10.80 crores.

(Vide item 2 and 3 of Table)

The cost of water per 1,000 gallons after taking into consideration the expenditure of Rs. 7.45 crores already incurred on Tansa works, will be at As. 4.10 and As. 4.00 for schemes Nos. 1 and 2 respectively.

The total cost of the scheme as now estimated is much more than that of Rs. 6.9 crores mentioned in the Interim Report. The estimate of Rs. 6.9 crores included a provision of Rs. 88 lakhs representing half the cost of the trunk inlet mains to the existing service reservoirs as worked out by the Special Officer (Survey). The difference between the original rough estimate and that now framed is about Rs. 5.17 crores [Rs. 11.20 crores less (Rs. 6.91—0.88) crores]. The excess is attributable to the following:—

Item.	Cost in lacs of Rupees.		
	Dam.	Tunnel.	Pipe line.
Extra quantity of cement required viz 49,000 tons at Rs. 105 per ton due to the increase in the F. S. L. of the reservoir from 480 to 495 T.H.D. and also due to inadequate length available for the waste weir	51.45	...	...
Increase in the price of cement 29,600 tons at Rs. 40 per ton	9.84	...	2.00
Increase in the rate of steel from Rs. 220 to Rs. 410 per ton for 30,600 tons	...	...	56.14
Additional quantity of steel for 96" pipe line on Kasheli bridges 3,300 tons at Rs. 410 per ton. This was not included in the original block estimate. This provision is now considered necessary to maintain the full supply to the City in an emergency arising due to the collapse of the old bridges on the Ulhas river at Kasheli	...	...	13.65
Extra depth of foundations for the dam as a result of the bore holes	7.09	...	...
Extra for lining of the tunnel as a result of bore holes along the alignment of the tunnel	...	35.00	...
Extra for excavation in tunnel. The size of the tunnel has to be increased to keep the Tansa lake filled on 1st October in three consecutive dry years	...	91.00	...
	68.29	126.00	73.67

Item.	Cost in Lacs of Rupees.			
	Dam.	Tunnel.	Pipeline	
	B. O.	68.29	126.00	73.67
Additional Works on dam.				
Rollerbucket and protective works on the down-stream side of the dam.	10.55			
Extra for grouting the foundations	7.20			
Inspection and drainage galleries	3.70			
Drains	1.22			
Contraction joints	1.56			
Reinforcement for the spillway	0.21			
Extra for causeway	1.00			
Bridge on the dam	4.47			
Gunniting the upstream face of dam	3.74			
Cost of experiments	0.50			
Automatic shutters	20.00			
Arrangement for passing the floods during construction	5.00			
Other minor items like the roadway, parapets etc.	1.10			
	60.25	60.25	...	
Extra items on Tunnel			...	
Reinforcement in lining	3.00			
Masonry	2.40			
Pitching	1.00			
Bridges	3.60			
Pipe line 10'-6"	5.50			
Adits and shafts	28.00			
Extra for intake and offtake	8.00			
	51.50	...	51.50	
Extra item on pipe line			...	
Chairs under the pipeline	...	...	8.90
		128.54	177.50	
			82.57	
			Rs. 388.61.	
Extra for acquisition of land (increase in cost due to increase in the price of timber)			Rs. 10.40	
			Rs. 399.01	
			Say Rs. 4 crores	

After deducting Rs. 4.0 crores from the difference of Rs. 5.17 crores, there still remains an excess of Rs. 1.17 crores which works out to about 19.5 per cent. and is due to the increase in the cost of other materials, fabrication and labour, etc.

Cost of diverting the waters of Vaitarna river into the Tansa lake to ensure a supply of 110 million gallons per day therefrom including the cost of conduits for conveying the supply to City.

(Ultimate Capacity=200 m.g.p.d. only)

If, on the other hand, the dam were constructed to a height of 431 T.H.D. with provision for its being raised to an ultimate height of 515 T.H.D. just to divert the monsoon waters of the Vaitarna river into the Tansa lake, to ensure a supply of 110 million gallons per day, therefrom, the cost of the scheme allowing for a pipe line of 48" dia. to convey the supply to the City in excess of the carrying capacity of the existing conduits will be Rs. 7.97 crores, with a pipe-line of 72" dia. the cost will be Rs. 9.55 crores and with a pipe line of 96" dia. the cost will be Rs. 11.63 crores as detailed below:—

	Scheme No. I 48" pipe. Rupees in crores.	Scheme No. II 72" pipe. Rupees in crores.	Scheme No. III 96" pipe. Rupees in crores.
Cost of the dam ...	2.90	2.90	2.90
Cost of tunnel ...	2.09	2.09	2.09
Cost of pipeline (40 miles long).	2.98	4.56	6.64
	7.97	9.55	11.63

The cost of water per 1,000 gallons after allowing for the cost of Rs. 7.45 crores already incurred on Tansa Works works out to annas 4.95, 5.46 and 6.2 for schemes Nos. I, II and III respectively. Such a Scheme however will prove costly in the long run as compared with other Schemes described in this report and hence it requires no further consideration.

The cost of the works for obtaining a combined dependable supply of 220 million gallons per day from the very commencement with automatic falling shutters or with a syphon spillway will be Rs. 16.00 and Rs. 15.50 crores respectively as tabulated below

Rough cost of the
ultimate scheme.

	With automatic gates. (Rupees in lacs).	With syphon spillway. (Rupees in lacs).
Cost of survey work	... 3.37	3.37
Preliminary works	... 37.17	37.17
Acquisition of land	... 25.00	25.00
Dam, waste weir and gates	... 4,71.18	4,31.00
Tunnels	... 209.04	209.04
96" dia. pipeline from end of tunnel to Powai 46½ miles	... 790.81	790.81
Quarters, Store houses, Offices	... 10.00	10.00
Miscellaneous item	... 52.07	52.07
	15,98.64	15,58.46
Say	...Rs. 16 crores;	Rs. 15.50 crores.

(Vide items 6 & 7, 12 & 13, 14 & 15 of table).

The difference is due to the cost of the syphon being less than that of the waste weir portion with gates.

Note.—The details of the syphon are not worked out. The cost of a syphon to be constructed in the body of the dam is taken to be Rs. 20 lacs on a very rough basis.

Comparison with Bhivpuri Scheme for obtaining a supply of 60 million gallons per day and 100 million gallons per day.

The cost of the two Bhivpuri Schemes, one of bringing a supply of 60 million gallons per day and the other of 100 million gallons per day as estimated in the Interim Report was Rs. 7.82 (8.7—0.88*) and Rs. 13.35 (14.7—1.35*) crores respectively. With the execution of the former scheme the dependable supply would have amounted to 124 million gallons per day (64 from Tansa and 60 from Bhivpuri). With the execution of the latter, the dependable supply would have amounted to 164 million gallons per day. The cost of the 60 million gallons per day scheme according to the present rates will be about Rs. 11.50 crores and that of the 100 million gallons per day after making an allowance of Rs. 2½ crores for diverting the waters of the

* Cost of Trunk inlet mains.

Bhama river into the Andhra lake, which feeds the Bhivpuri Power House will be about Rs. 21 crores as detailed below :—

	60 m. g. p. d. Bhivpuri Scheme (in crores)	100 m. g. p. d. Bhivpuri Scheme. (in crores)
	Rs.	Rs.
Steel pipe line	6.00	12.40
Roadways	0.69	0.70
Shifting high tension pylons	0.03	0.03
Earth work	1.24	1.92
Balancing reservoir at Bhivpuri	0.90	1.08
Rolling stock for transport	0.03	0.04
Building structures	0.38	0.41
Telephone system	0.02	0.03
Bridges, culverts, etc.	0.41	0.46
Tunnel	0.51	0.51
Coagulation and chlorination plant	0.16	0.16
Ghatkopar reservoir	0.40	0.40
Land and building acquisition	0.11	0.15
Pej Nala Scheme	0.62	...
Chembur reservoir	...	0.61
	11.50	18.90
(For diversion of waters of Bhama river)	...	2.50
		21.40
Say Rs. ...		21.00

(Vide items 4, 5, 8, 9, 10 11 of table)

If it was possible to complete the 160 million gallons per day Vaitarna-cum-Tansa scheme at Rs. 6.03 (6.91-0.88*) crores the cost to be incurred for increasing the supply to 220 million gallons per day by executing the 60 million gallons per day Bhivpuri scheme would have been Rs. 7.82 crores as per rates included in the Interim Report making a total of Rs. 13.85 crores. Thus by spending an additional amount of only about Rs. 2 crores over the original estimates, a supply of 220 million gallons per day would be made available from the Vaitarna-cum-Tansa Scheme.

* Cost of trunk inlet mains.

Cost of water per 1,000 gallons for different schemes.

The following table gives at a glance the cost of water per 1,000 gallons for different schemes :—

Serial No.	Scheme	Assured supply in million gallons per day.	COST.		Cost per 1,000 gallons in Annas.	Remarks.
			Capitals in crores.	Annual in lakhs.		
1.	Pick-up weir at Vaitarna and tunnel to Sta. Bilise	110	5.98+7.45	106.7	4.25	The top of pick-up weir at 431 T.H.D.
2.	Vaitarna and Tansa	160	11.20+7.45	150.1	4.1	With automatic gates.
3.	Do.	160	10.80+7.45	147.1	4.00	With syphon spillway.†
4.	Bhivpuri	60	11.5	105.8	7.7	
5.	Pick-up weir and Tansa and Bhivpuri	110+60=170	5.98+7.45+11.5	212.5	5.47	
6.	Vaitarna and Tansa	220	16.00+7.45	188.7	3.75	With automatic gates.
7.	Do.	220	15.5+7.45	184.5	3.68	With syphon spillway.
8.	Tansa, Vaitarna and Bhivpuri	110+50+60=220	7.45+11.20+11.5	255.9	5.1	With automatic gates.
9.	Tansa, Vaitarna and Bhivpuri	110+50+60=220	7.45+10.80+11.5	252.9	5.00	With syphon spillway.
10.	Bhivpuri	100	21	193.2	8.5	
11.	Pick-up weir and Tansa and Bhivpuri	110+100=210	5.98+7.45+21	299.9	6.25	
12**	Vaitarna (Independent)	110	16.00+2.2*	147.94	5.90	With automatic gates.
13**	Do.	110	15.5+2.2	143.94	5.75	With syphon spillway.
14**	Vaitarna (Independent)	150	16+2.2	147.94	4.32	With automatic gates.
15**	Do.	150	15.5+2.2	143.94	4.21	With syphon spillway.
16.	Tansa (Dependable)	64	7.45	57.5	3.94	
17.	Do.	78	7.45	57.5	3.24	
18.	Do.	94	7.45	57.5	2.68	In good years.

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Note: (1) Sinking fund and maintenance cost is calculated at—

- (a) 7.7 percent. on Tansa Works.
- (b) 8.2 percent. on Vaitarna Works.
- (c) 9.2 percent. on Bhivpuri Works.

Vide page No. 71 of the Interim Report—February 1947.

** (2) A credit of 2.2 crores is given towards the cost of one 72" pipe line.

** (3) The Vaitarna reservoir with F.S.L. 535 T.H.D. if directly connected to the Tansa Mair will give a daily supply of 150 million gallons and 110 million gallons in good and driest year like 1899 respectively. The cost per 1,000 gallons is worked out on this basis.

† As the details of the syphon spillway have not been worked out, it is assumed in the above estimates that the cost of a syphon spillway in general, be about Rs. 40 Lakhs less than that of an overflow weir with automatic gates.

21. There is another way by which the capital cost of the scheme can be compared according to the reliable supply available from each source. The cost for a reliable supply of 64 million gallons per day from the Tansa lake works out to Rs. 4,050 per million C.ft. while that for obtaining a reliable supply of 110 million gallons per day from the Vaitarna reservoir in dependently of Tansa lake works out to Rs. 6,300* and Rs. 5,750** per million C.ft.

For a total reliable supply of 220 million gallons per day from both the sources (Vaitarna and Tansa) the cost works out to Rs. 6,000* and Rs. 5,720** per million C.ft.

On the basis of the supply available in good years, *viz.*, of 94 million gallons per day the cost per million C.ft. for Tansa, works out to Rs. 2,940 and that for a supply of 150 million gallons per day from the Vaitarna Reservoir works out to Rs. 4,800* and Rs. 4,360.** The Tansa works were executed in normal times while the Vaitarna reservoir will be constructed when the prices of materials and wages of labour have reached their erst-while maximum. (For details of the cost *vide* Appendix XI).

22. It was pointed out in the Interim Report, para. 26 page 41, that along with the execution of the Vaitarna-cum-Tansa Scheme, the work of improving the water distribution system to distribute the additional supply evenly, uniformly and at adequate pressure to all the inhabitants of the City irrespective of the locality in which they live, should be taken in hand simultaneously along with the main scheme. It was further pointed out that the work of remodelling the existing sewerage system to take care of the additional supply that would be brought into the city should also be taken in hand immediately. A separate report regarding the latter has already been submitted to the Corporation and it is hoped that the Corporation will approve of the recommendations made therein and pass orders to start the work immediately on the same, according to the priority laid down in that report to enable the whole work of remodelling being completed in about 5 to 6 years' time.

* With automatic gates.

** With Syphon Spillway.

A report on measures for improving the supply to the existing and the proposed service reservoirs by providing additional inlet trunk mains of adequate capacity is also being submitted separately. It has been recommended in this report that the inlet trunk mains to be laid now would be capable of dealing with an initial total supply of 176 million gallons per day (160 million gallons per day from Tansa and Vaitarna and 16 million gallons per day from Vehar and Tulsi) and of 236 million gallons per day ultimately (220 from Vaitarna and Tansa and 16 from Vehar and Tulsi). This course is suggested because it would prove more economical in the long run. If a small size pipeline to meet the initial requirements is laid, it will have to be duplicated in the very near future and the cost of duplication would be heavy. Another reason why this course has to be followed is that there is no room in the existing main roads to accommodate two or three additional pipe lines of large size as they (roads) are already congested with underground public utility services such as water mains, gas mains, electric cables, sewers, storm water drains, telephone lines, etc. Further, if the roads are broken twice to accommodate an additional pipe line or lines, the cost of restoration of the road surfaces would be heavy, because most of them are treated with permanent mode of construction.

In the separate report on improving the supply to the service reservoirs by laying additional mains, it has not been possible for me to include therein improvements to the internal distribution system and to the outlets from the existing and the proposed service reservoirs for lack of adequate data for preparing such a scheme. It is, therefore, suggested that the Hydraulic Engineer should be requested to make necessary recommendations regarding the improvements to the internal distribution system after collecting the necessary data. If the work of improving the internal distributing system along with the enlargement of the outlets from the existing and the proposed service reservoirs is not taken in hand simultaneously with the execution of the Vaitarna-cum-Tansa Scheme, the citizens occupying upper floors of the tall buildings will not get material benefit by the additional water that would be brought into the city. What is really wanted is a 'Master Plan' for the distribution system and a programme giving priorities for executing the works included therein. The expenditure incurred in the course of the last 10 years in simply enlarging the mains of small sizes without a 'Master Plan' does not appear to have helped much to remove the hardships.

of the citizens occupying upper floors of tall buildings. The re-modelling of the distribution system and the enlargement of the outlets from the existing reservoirs should have been done in 1925-26 when the supply brought into the city from the Tansa lake, as a result of the completion of the Tansa quadruplication scheme, was nearly doubled. The same outlets have to carry the additional supply with the result that the velocity in them increases considerably and the pressure drops, because the loss of head due to friction in a pipe line varies directly as the square of the velocity. The existing outlets do carry a large quantity of water but at a lower pressure and consequently the residents on the ground floors of the buildings are more benefitted than those occupying upper floors.

23. As far as I can see, additional mains in the following localities are considered necessary:—

Internal distribution
system—immediate needs.

- (1) Two new outlets of a fairly large size from the Malbar Hill Reservoir to make up the deficiency in the supply to the zones of Kalbadevi, Dhobi Talao and the Colaba area.
- (2) A separate outlet of a small size for the Tardeo area which is at present given direct supply from the tail end of the 48" old Tansa main.
- (3) Two new outlets from the Bhandarwada Hill Reservoir to improve pressures particularly in the Dongri area which is situated at a high level, some places being at 120 T. H. D. while the F. S. L. of the Bhandarwada Reservoir is at 195 T. H. D.
- (4) A new pipe line of 60" dia. to improve the supply to the areas abutting Lady Jamshedji Road, Gokhale Road (North) etc., in 'G' Ward. This main will probably start from Mahim and will have to be continued upto Worli Naka *via* the Globe Mill passage. It can very well be made to act as an inlet main to the proposed Worli reservoir by extending it in the North upto Powai.
- (5) A 48" main from Futka tank in the proposed 100 feet Wadala Road right upto Bhandarwada Hill Reservoir *via*, Sewri, to improve the supply to 'F' Ward. This main also, when extended upto Ghatkopar, will act as an additional inlet main to the Bhandarwada

Hill Reservoir to which an additional inlet is absolutely necessary.

24. As per permission granted by the Corporation under their resolution No. 728, dated the 25th September 1947, detailed estimates for the various items of the major scheme will be submitted for sanction one by one as tenders for the same are received. So far, tenders for the following works have been invited after completing the detailed plans and estimates and schedule of quantities for the same :—

Detailed estimates can be submitted after the receipt of tenders for the various items.

- (i) Construction of the tunnel ;
- (ii) supply and fabrication of the pipe line ;
- (iii) Preparation of the embankments for accommodating the additional pipe line referred to in (ii) above.

The only major tender which remains to be invited is for the dam. A tentative design for a cement concrete dam with F. S. L. at 535 T. H. D. has been completed together with the necessary specifications. As soon as the Corporation decide whether the scheme should be restricted to obtain an ultimate supply of 160 m. g. p. d. as originally suggested or whether full advantage should be taken of this source to obtain a combined dependable supply of 220 m. g. p. d., tenders for the dam will be invited.

25. The rough estimates given in para. 21 page 67 have been prepared only for the purpose of comparing the cost of the various alternatives to enable the Corporation to take a decision ; but these estimates will have to be revised according to the rates that will be quoted by the tenderers if the work is to be carried out by contract. It is likely that the work being of an intricate and specialised nature involving the use of special machinery and equipment and the difficulty of getting them in time, only a few firms may come forward to carry out the work. As the work is to be spread over a period of five years, it is likely that the contractors might quote higher prices to cover any unforeseen rise in respect of the wages of labour and prices of materials. They would also take into consideration the difficulty at present experienced in getting materials like petrol diesel oil, cement, steel, Llasting powder etc. which are essential for the speedy execution. No one at this stage can predict what the

Contractors likewise to quote high rates to cover unforeseen increases in the prices of materials and wages of labour. If prices quoted are high, the work should be carried out departmentally.

position regarding the above would be in the course of the next 4 or 5 years. The rates on which the rough estimates in para. 21 are based have been worked out in consultation with persons dealing with this type of work according to the prevailing market rates. If there are prospects of the situation regarding wages of labour and the availability of materials etc., like petrol, diesel oil, cement and steel being eased in the course of the next four or five years, the Corporation will be well advised to make up their mind to carry out major items of the work departmentally or by negotiating with the firms who tender for the work on the basis of actual cost plus a certain percentage for profit. Such a procedure will be advantageous both to the Corporation as well as to the contractors, because they will not in that case include a large provision in their tender to meet the cost of the unforeseen items.

26. This scheme is of a great magnitude. It comprises works like driving a tunnel, construction of a concrete dam and fabrication of a pipe line of a larger diameter than 72". So far, a pipe line of more than 72" dia. for a longer length than as now proposed has not been laid in this country, as far as I am aware. If full advantage of the advance and the research that has taken place in the realm of the engineering science dealing with driving tunnel, the construction of a concrete dam and manufacture and laying of pipe line of large size, is to be taken, it will be in the interest of the Corporation to get the designs and specifications, for the concrete dam, scrutinised by competent Engineers who have specialised in the design and construction of high concrete dams. There may be hardly a few men in India who have experience of the construction of a concrete dam of 250 feet height. The only concrete dam so far constructed in this country, as far as I know, is the Mettur dam in Madras. It is a composite dam consisting of masonry and concrete and not a wholly concrete dam. The Government of India have under their consideration the construction of a high concrete dam for Kodi and other projects and they have engaged the services of an Expert from America, Dr. Savage, the well-known Engineer in the geology of dam foundations. He is likely to visit India shortly as per his terms with the Government of India and it is suggested that his advice should also be taken regarding the geology of the foundation of the dam when he visits India. So far, the opinion expressed by the Expert from the Geological Survey of India regarding the

Desirability of getting the designs checked by Experts.

suitability of the site of the dam and the river basin as a whole for being developed as an impounding reservoir is favourable.

I could only think of the Associated Consulting Engineers who are at present helping the Corporation in the valuation of the Tramway undertaking to be a suitable firm for checking up the designs of the various works and suggesting improvements with a view to economy where necessary. I also contacted the Cement Marketing Company of India and requested them whether they would suggest the name of any suitable Engineer who would check up the calculations and the specifications for the dam prepared by me. Mr. Batliwala, the Acting Chief Engineer of the Concrete Association of India, has informed me that they would get the design and specifications checked by an Expert in England and that they have already contacted him and are communicating with him.

The terms and conditions on which the Associated Consulting Engineers are prepared to do the work for us on the retaining fee basis are given in their letter dated 27th February 1948, (Appendix XII). They are agreeable to do the work on a minimum payment of Rs. 18,000 per annum. Any cost incurred in connection with the Municipal work in excess of the annual minimum fee would be charged for by the firm on the time basis as set out by them in their letter under reference. It is earnestly requested that Corporation should give this matter their serious consideration. If the Experts are engaged for checking up the designs and specifications, the execution of the work will not be delayed as it will take at least one season before the foundations of the dam are exposed and by that time the experts would have advised regarding the modifications etc., required in the design of the dam. The superstructure of the dam could then be built either according to the design now suggested or that modified by the Experts.

27. I may further suggest that the Corporation should send abroad two or three young and energetic young Engineers abroad for a period of at least 6 months. Desirability of sending young Engineers abroad for a period of at least 6 months.

existing and under construction. The knowledge obtained by personal visits would be very helpful in organising or supervising the execution of the scheme as a whole, as well as that of its component parts—the dam and the waste weir, automatic shutters, the tunnel,

pipe fabrication etc. If three Engineers are sent for a period of six months, the cost to be incurred is not likely to exceed Rs. 50,000 which is negligible compared with the advantages to be gained. These Engineers can return back by December 1948 when the execution of the scheme is expected to start in full swing. The knowledge gained by personal visits to similar works under construction abroad will be very helpful in executing the works especially departmentally, if it is found necessary to do so, due to high prices being quoted by the tenderers or even when the work is entrusted to a contractor or contractors.

28. A chart showing the personnel required for organising and supervising the work during the period of construction is attached herewith (*vide* Appendix XIII). The staff shown in this chart must be conversant with the nature of the work that they would be required to supervise and organise. Staff to the full extent as shown in the chart is expected to work for a period of 3½ years and probably half the staff might have to be engaged for a period of about two years, because, in the beginning a full complement of the staff may not be necessary. The total cost to be incurred is estimated at about Rs. 60 lacs which is less than 5 per cent. of the total cost of the scheme. On a work of this magnitude, the usual practice of the P. W. D. is to incur expenditure on the supervising staff to the extent of 10 per cent. of the estimated cost of the works.

29. Another request that I would like to make to the Corporation is to give the same powers to the Municipal Executive as those enjoyed by the Chief Engineers of the Provinces to enable him to push the work to speedy completion. The powers of the Municipal Commissioner to-day are so restricted that a considerable time is spent in obtaining sanctions. If the work is to be carried out departmentally, there is more reason why this should be done, otherwise, the departmental work will suffer due to lack of powers and it may not be possible to complete the scheme within the stipulated period not on account of inability or incapacity of the staff but because of the delays in obtaining the requisite sanctions. The Municipal Act, may be suitably amended only for the execution of this scheme.

30. The whole scheme can be completed in about 5 years' time as originally estimated in spite of the additional work involved in the dam. The dam of 250 feet height should not take more than three working seasons to complete. The period required for the completion of the tunnel, embankment of the pipe line would be about three working seasons. The fabrication of the pipe line will however depend upon the quantity of steel released from time to time for this purpose by the Government of India. Even if the work on the pipe line is extended by another two years due to the non-availability of the steel plates, the scheme will begin to give relief to the citizens after the tunnel is completed and as the work on the pipe line and the dam progresses as is shown in the table on the following page :—

Time required for completion and the benefits likely to be derived by the City, as the dam and the pipe line advances.

The table showing how the City will be benefitted with the progress in the laying of the pipe line and the construction of the dam.—

Serial No.	Position of dam (F.S.L.).	Position of tunnel.	Position of 96" pipe.	SUPPLY IN MILLION GALLONS PER DAY.			Total supply from Tansa and Vaitarna in million gallons per day.	Supply from Vihar and Tulsī in million gallons per day.	Grand total in million gallons per day.	REMARKS.
				From Vaitarna.		From Tansa.				
				96"	72" W	72" Duct. East.				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	
1	400 T.H.D....	Complete ...	6½ Miles...	42	43	20	105	15	120	The discharges through the pipe lines have been worked on the lowest level, that may be reached at the end of the hot weather, after bringing the quantity as shown in Column 5.
2	500 do. ...	Do. ...	16½ do. ...	50	47	20	117	15	132	
3	515 do. ...	Do. ...	21½ do. ...	57	50	20	127	15	142	
4	515 do. ...	Do. ...	26½ do. ...	60	52	20	132	15	147	*As the 96" pipe line will be completely laid i.e., 46½ miles, both the 72" East and West Tansa mains will be free to carry 40 million gallons per day each.
5	535 do. ...	Do. ...	26½ do. ...	65	52	20	137	15	152	
6	535 do. ...	Do. ...	36½ do. ...	80	60	20	160	15	175	
7	535 do. ...	Do. ...	46½ do. ...	110*	80*	20	210	15	225	

31. The scheme now recommended after studying the

Summary of the geological, topographical and hydrographical scheme recommended.

details may be summarised as under :—

(1) That it would be in the interest of the Corporation to utilise the Vaitarna Reservoir source to its most economical benefit compatible with the physical conditions obtained at the site of the dam.

This source can be economically developed to obtain the maximum useful storage of 46,000 million gallons by keeping its F. S. L. at 535 T. H. D. with 20' high automatic gates or by constructing a syphon spillway in the body of the dam. This storage will provide a good 'carry over' in years of good rainfall and would also be adequate to give a dependable combined supply of 220 m. g. p. d. in all lean years including the three consecutive dry years except in a year like 1899 which occurs once in 200 years. The supply available in such a year will be 220 m. g. p. d. in the wet weather and 115 m. g. p. d. in the dry weather.

(2) The development of the Vaitarna source to impound 46,000 million gallons would also enable the Vaitarna Reservoir to function independently of the Tansa lake, when it is thrown out of commission when so used, it would be capable of giving a uniform supply of 150 m. g. p. d. in all good and lean years, except only a driest year like 1899, when it will be reduced to 110 m. g. p. d.

(3) All the water stored in the Vaitarna Reservoir need not be transferred to the Tansa lake for being drawn upon through its outlet well for being supplied to the city but that a part of the supply equivalent to the carrying capacity of the new 96" pipe line could be conveyed directly to the city. With the lowest level of water at about 422 T. H. D., this pipe line, when new, will convey a supply of 110 m. g. p. d. and of 100 m. g. p. d. at the end of 20 years' service.

(4) The waters from the Vaitarna Reservoir could be transferred to the Tansa lake in such a manner as to maintain the lowest level of draw-off in that lake at the end of the hot weather not below 399 T. H. D. This will help to increase the carrying capacity of the existing pipe lines and would also get over the difficulty at present experienced of the two pipe lines touching the hydraulic grade line at Pivli and Mohili cuttings when the water level in the lake drops to 390 T. H. D.

(5) The waste weir will be designed to deal with a maximum flood discharge of 92,000 cusecs with a flood depth of 20' over its crest and in order that the co-efficient of discharge of the waste weir should be as high as possible, experiments will be carried out at the Khadakwasla Research Station to determine the most suitable 'ogee' shape for the waste weir to accomplish this end. The flood discharge of 92,000 cusecs has been arrived at, by the application of Inglis formula for a 'fan-shaped' catchment which compares favourably with the actual flood discharge estimated for the Vaitarna river from the velocity curve for a maximum flood depth of 31'-6" in the year 1941.

(6) Experiments will be carried out on the syphon spillway constructed in the body of the dam and an overflow weir with automatic gates at Khadakwasla Research Station to determine the more suitable type of the waste weir. The Station will also carry out experiments on the protective works necessary on the downstream side of the dam to prevent undermining of the foundations of the dam.

6. (a) In the words of Mr. K. K. Framji, the Director of the Hydro Dynamic Reserach Station at Khandakwasla, model experiments in respect of the following are required to be carried out :—

(1) To ascertain the most efficient profile for the waste weir or the syphon spilway, as the case may be and its coefficient.

(2) To ascertain the shape of the piers to obtain a high coefficient of discharge.

(3) To determine the shape of the side walls to deflect the discharge rushing out through the 8'×10' under-sluices (to be provided, alternatively, in the flanks or in the centre) into the tail channels.

(4) To find out the protective works necessary such as the size and shape of the dentated sill, or other dissipating devices on the downstream side of the spillway to dissipate the energy of the falling water to reduce the scouring on the downstream side to the minimum.

(7) The tunnel will have a maximum carrying capacity of 685 million gallons per day at Full Supply Level of the Vaitarna Reservoir standing at 535 T.H.D. It would be a 10' diameter horse

shoe type. It will be lined with cement concrete and the thickness of lining will depend upon the nature of the rock met with.

(8) The dam will be 250' high and will be built in concrete. It has been designed according to the modern technique in the design of such dams and provision for uplift has also been made therein though the foundation at the site of the dam can be said to be satisfactory. The dam will be provided with cut off walls (if necessary), galleries, drains, etc., to reduce the seepage of water and thereby minimise uplift. Grouting will also be resorted to, under the heel of the dam for the same reason, *viz.*, to prevent seepage and to minimise uplift.

(9) It will be economical in the long run to lay from the very commencement a 96" diameter pipe line $46\frac{1}{2}$ miles long—to convey the additional supply to the city. If this were done, it will not be necessary to recondition the duct. This will release about 20 miles of 48" C.I. Pipes for being used in improving the distribution system in the city.

(10) If the duct were done away with, a further length of 20 miles of 50" diameter lock-bar pipes will be released for being used in improving the distribution system in the city. This will only be possible when the time for renewing the existing 72" pipe lines, comes. It may be taken advantageous to replace some portions of the existing 72" pipe lines by a new 96" pipe line to increase the carrying capacity so as to close down the duct.

With the duct out of commission, it would not be necessary to incur heavy expenditure in strengthening or rebuilding the old Kasheli bridges supporting its syphons.

32. A rough idea of the financial implications involved by the execution of the scheme was given in Financial consideration. para. 28, sub-para. 5, 6 and 7 of the Interim Report (pages 44-45). At that time, the financial consideration was based on the estimated cost of the scheme, *viz.*, Rs. 6.9 crores for a total supply of 160 million gallons per day from both the sources Tansa and Vaitarna. As now the cost of the scheme will amount to Rs. 16 crores for a total dependable supply of 220 million gallons per day, it is necessary to review the position regarding the financial aspects of the scheme. As pointed out previously,* if the amount of 45 lakhs of rupees which at present remains surplus after meeting the cost of maintenance, establishment and debt charges on Water Works were to be utilised, it would be possible

*Vide p. 44 of the Interim Report.

with this amount to raise a loan of Rs. 7½ crores without additional liability on the Corporation. The question now remains how the interest and sinking fund charges on a loan of Rs. 8½ crores (16-7½) and the additional maintenance charges should be met with. Due to no building activities going on in the City at present owing to non-availability of essential building materials and the high cost thereof, it is doubtful whether in the course of the next 7 years new buildings will crop up which will bring substantial revenue by way of water tax on rateable value. The position regarding housing will certainly improve after a period of 4 to 5 years when a great slump in prices of building materials is expected. The collection of water tax on rateable value will considerably increase if the Greater Bombay Scheme is implemented and the Corporation undertakes to supply water to the regions included in the Greater Bombay Scheme and not to leave it to the Government as is being done at present. New buildings to the extent of nearly one lakh are immediately required if the citizens of Bombay and the suburbs are to be housed in comfortable and healthy surroundings. Assuming the average rateable value of the premises to be about Rs. 500 each, the total rateable value will be Rs. 5 crores and the water tax at 3¾ per cent. will be about Rs. 18.75 lakhs. If the suburbs are not included in the Bombay Municipal limits, we shall have to pay income-tax on the profit made by the sale of water and a large portion of this amount is likely to be taken away by Government by way of income-tax. As additional water supply will be brought into the city, the income likely to be derived by the sale of water to the industries in the neighbourhood of Kalyan area and in the suburbs close to the City as well as to the Local authorities on the way, will be considerable. It may be pointed out here that pipe lines of about 24" diameter size for a length of 8 to 10 miles will be required to be laid from suitable points on the trunk mains upto the town limits like Kalyan and Bhivandi and the cost of this item will be very small compared to the total cost of the scheme and the revenue that would be derived by giving such tapplings. It is roughly estimated that revenue likely to be derived by the sale of water by measurement on the assumption that the rate is kept only annas 8 per 1,000 gallons will be about Rs. 30 lakhs. The increase in the total income will therefore be about Rs. 45 lakhs which would be adequate to meet the interest and sinking fund charges on the balance of loan of Rs. 8½ crores and the additional maintenance cost due to completion of the Vaitarna-cum-Tansa scheme, bringing to the city a total dependable supply of 220 million gallons per day.

It may however be pointed out that at the end of the year 1954, a part of the loan at present outstanding against the water works will be wiped out to the extent of Rs. 2½ crores. The debt charges that are being paid on this loan amount to Rs. 30 lakhs which can then be diverted to meet the additional liability to be incurred. Thus, the amount of Rs. 30 lakhs likely to be made available from 1954 and Rs. 45 lakhs surplus already existing will be sufficient to defray the interest and sinking fund charges on a loan of Rs. 16 crores from 1954 onwards. If the development as suggested above does not take place, there will be some difficulty in making both ends meet in the initial stages of the scheme and it may be necessary during this period to raise the income on the rateable value by increasing the water tax from 3½ per cent. to 5 per cent. as was suggested in the Interim Report.

33. If you approve of the recommendations contained in
 Sanction of the Corporation required for. this Report, the Corporation may be approached to accord sanction to the following —

- (1) To create a useful storage of 46,000 million gallons from the very commencement on the river Vaitarna to obtain a combined dependable supply of 220 million gallons per day from the two sources (Tansa and Vaitarna) by laying a 96" pipe line in lieu of the 72" diameter pipe line originally proposed.
- (2) To carry out experiments at Khadakwasla Research Station at a total cost not exceeding Rs. 50,000 for ascertaining the most suitable type of waste weir (syphon spillway or an ordinary overflow weir with automatic shutters) and for the protective works required on the downstream side of the dam to prevent scouring.
- (3) To get the designs and specifications especially for the dam, scrutinised by Experts at a cost not exceeding Rs. 2 lakhs
- (4) To the staff as shown in the chart (Appendix XIII) being employed as and when required for the execution of the scheme.
- (5) To send three Municipal Engineers abroad to visit the works of tunnel and concrete dam construction and to study the methods followed in their execution so that they can be used in the speedy execution of the scheme.

(6) To give additional powers to the Municipal Executive similar to those enjoyed by the Chief Engineers of P.W.D. by amending the Municipal Act for the period of the execution of the scheme.

(7) To carry out the works departmentally or on the cost plus percentage basis by negotiating with the tenderers or other firms specialised in the particular type of work if the tenders received are found to be very high.

II PART.

CHAPTER I

DAM.

The site selected for the location of the dam has one great advantage *viz.*, that it reduces the length of the tunnel from the Vaitarna Reservoir to the Tansa lake. It has, however, one drawback. It is devoid of a natural site for a waste weir.

Introduction. In view of the feasibility of the waters of the Vaitarna Reservoir being conveyed to the city independently of the Tansa lake by an independent pipe line, it was considered desirable to take full advantage of the storage offered by the Vaitarna river at the site of the dam, instead of restricting it to 17,000 million gallons as originally contemplated. Investigations have since shown that the Vaitarna river at the site of the dam can be economically developed to create a useful storage of 46,000 million gallons above the invert of the tunnel, *viz.*, 422 T.H.D. It should be possible to obtain this storage by keeping the F.S.L. of the reservoir at 535 T.H.D. This F.S.L. may be maintained either by adopting a waste weir of the overflow weir type with its crest at 515 T.H.D. and erecting automatic falling shutters of about 20 feet height thereon, or by providing a syphon spillway with the crest of the syphons at 535 T.H.D. The final choice regarding the type of the waste weir will depend upon the result of experiments proposed to be carried out at the Hydrodynamic Research Station of the Government of India at Khadakwasla. If the syphon spillway is found to be more economical, the F.S.L. of the Reservoir will be kept at 535 T.H.D. and the H.F.L. at 537 T.H.D., as a margin of 2 feet is required for the priming of the syphons before they come into operation. The top of the dam must be raised higher than 537 T.H.D. to prevent waves etc., going over its top during the monsoon when the reservoir is overflowing. In this particular case, the waves are likely to rise about 5 feet over the H.F.L. This extra height, *i.e.*, the difference between the H.F.L. and the top of the dam is known as 'Free-board.'

(2) Free-board is usually determined by making rough calculations as regards the cost of the dam as a whole.

Free board and total height of the dam. In this particular case, it was found that for an overflow weir with automatic gates, a free board of 8 feet would be economical. It is however proposed to provide a free-board of 10 ft. The height of the top of the dam

with this free-board will be 545 T.H.D. The height of the dam above the river bed (310 T.H.D.) will therefore be 235 feet and adding thereto the depth of 15 feet in the foundations, the maximum height of the dam in the deepest portion will be 250 feet. It may appear at first sight that by keeping the free-board 2 feet higher than the economical height of 8 feet., the cost of the masonry in the dam would be increased. But calculations have shown that the additional masonry, covered by the extra 2 feet height of the dam will be largely compensated by the reduction in the width of the dam at lower levels which will reduce not only excavation for foundations and the masonry in the dam at lower levels but also the total uplift.

(3) The length of the dam including the spillway length of about 400 feet will be about 1700 feet which is the width of the gorge at the level corresponding to the top of the dam.

(4) The most economical width at the top of the dam to suit the maximum height of 250 feet would have been a little less than 24 feet. But taking into consideration the fact that the dam has to carry a roadway to connect up the two villages of Khardi and Pareli, it was considered necessary to increase the width to 28 feet for providing a carriageway of 20 feet and adequate footpaths on either side. The additional width required for increasing the width of the roadway could have been secured either by providing cantilevers or by corbelling out. But both the methods have not been followed in view of the shortage of steel and the difficulty of corbelling in plain cement concrete. The excess masonry in the dam due to the additional width of 4 feet, is also compensated considerably by the decrease in the width of the dam at lower levels involving less excavation.

(5) Dams are mainly classified under two heads, depending upon the way the water load is carried:—
Choice of the type of dam and final selection thereof.

(I) Arch dams, where horizontal water pressure is directly resisted by horizontal reactions at abutments.

(II) Gravity dams, where the sliding of dam due to horizontal pressure of water is prevented either by action of friction or shear, while the moment of the horizontal thrust is counteracted by the shifting of the position of the vertical reaction of foundation which provides the required moment of opposite type.

Gravity dams are again sub-divided into two classes :—

(1) Hollow dams where the horizontal load of water is transferred to a series of buttresses placed at intervals by means of arches, slabs, etc., spanning between two consecutive buttresses.

(2) Solid gravity dams, where at every elevation, every foot width of dam is subjected to uniform pressure and resists it by its weight alone.

(6) At first sight the steepness of the gorge naturally suggests an arch dam. An arch dam however is not usually found to be cheaper than a gravity dam unless its length is less than three times its height.

Arch dam not feasible.

Though this criterion is not fulfilled in the case of the Vaitarna dam, preliminary calculations based on the 'Thick Cylinder' theory were made for an arch dam and they revealed that the width of the dam at the foundation level would be about 340 feet. i.e., much more than the corresponding width for a gravity dam (whether built in concrete or in masonry). Besides, the length of an arch dam being the arc of the segment, is always greater than the length of the straight gravity dam which forms the chord of that segment. The arch dam has therefore to be ruled out.

(7) The next choice would be that of the hollow type gravity dam. It requires only about 40 to 45 per cent. of masonry as compared to that required for a solid gravity dam.

Hollow type gravity dam also not feasible.

This type of the dam has also to be ruled out, because, saving effected in materials would be more than offset by the heavy cost involved in the complicated shuttering required. Skilled supervision during construction would be necessary which it would be difficult to secure. Further, arrangements for passing the floods during construction, would present many difficulties. The number of hollow dams so far constructed in the world is small and sufficient experience has yet to be gained of their behaviour. However, a design for a hollow dam with F.S.L. at 480 T.H.D. was actually prepared but the idea of its adoption was thereafter abandoned because it was thought that it would be better after all, not to try a new type of design which has not been put to sufficient test.

(8) The next in order of consideration would be the solid gravity dam. This type of dam is more commonly used than a dam of any other type.

A solid gravity dam. Masonry dam also not feasible under peculiar circumstances.

Here also two alternatives present themselves (a) Masonry dam and (b) Cement concrete dam.

Masonry dams of 270 feet height have been successfully constructed in Bombay Province (for example, Bhandardara Dam on the Pravara). The masonry dam possesses certain advantages over the cement concrete dam—(1) its construction is simpler and requires hardly any machinery, (2) it requires less skilled labour and less supervision, (3) it can be constructed in ordinary hydraulic lime mortar, thus dispensing with cement of which there is a shortage at present. This advantage is obtained at the cost of extra time required for its completion. The overall cost of a masonry dam is less than that of a cement concrete dam even though the total quantity of masonry in a masonry dam exceeds that of a cement concrete dam, because, the cement concrete dam requires the necessary skilled supervision, special equipment, form work and very sound organisation. Drawing No. V.T./134, 3rd April 1948, shows a concrete dam super-imposed on a masonry dam. The following are some of the reasons why a cement concrete dam is considered preferable to an ordinary masonry dam :—

(1) There are prospects of getting required equipment and machinery.—

(2) The required skilled personnel having experience of such work are also available.

(3) The hydraulic lime required for a masonry dam is not available in the neighbourhood and will have to be transported to site from long distances.

(4) The time required for the completion of a masonry dam would be over 8 years while a cement concrete dam can be constructed in about 3 years provided, adequate steps are taken before starting the work to keep all the equipment and materials ready. Time is the governing factor, in our case and the cost is of no consideration. The city is in need of additional supply of water and it must be made available in the shortest time possible. Any delay in the execution of the scheme would

seriously affect public health. It may not even be possible to make available to the citizens a supply that is being given at present if the monsoon fails. Bombay has been fortunate in getting for the last ten years, good rainfall in the Tansa catchment. We may have to face a scanty year or a series of scanty years in the near future and if such years do occur, the supply available from the Tansa lake would be considerably less than what is available today. It is necessary to speed up the construction of the dam and the tunnel and to build the former, atleast to a height of 430 T.H.D. so that the waters of the Vaitarna could be diverted into the Tansa lake in lean years to keep it filled on first of October.

Under these circumstances, the choice naturally falls on a cement concrete dam of the solid gravity type.

(9) In working out the gravity section of the dam, the following assumptions have been made:—

Assumptions for design purposes.

(a) The completed structure will be a monolithic mass so that the stress conditions developed in the loaded dam would be essentially the same as calculated in the stress analysis.

(l) The weight of concrete in the dam will be 150 lbs. per cu. ft.

(c) The dam will be subjected to the maximum uplift of 50 per cent. at the heel decreasing uniformly to zero at the toe.

(d) The coefficient of friction between concrete and concrete and also between concrete and foundation rock will be 0.65.

(e) The inclined compressive stress should not exceed 50,000 lbs. per square foot; while the inclined tensile stress should always be less than one pound per square inch.

(f) The average shear stress should never exceed the figure of 350 lbs. per square inch.

(g) The factor of safety for the resultant shear friction to be limited to the minimum figure of 5.

Drawing Nos. V.T./125, dated the 23rd February 1948 and V.T./126, dated the 26th February 1948 show respectively the cross-sections of the dam for the abutment and the spillway section with their stability and stress analysis.

(10) It is proposed to grout rock lying under the upstream face of the dam even though provision for the whole uplift expected, has been made in its design. **Grout holes and cut-off trench.** Four lines of grout holes, each about 2" dia. size running along the heel of the dam at 12' centres are proposed. The distance between the consecutive lines will be 4 feet and the holes in alternate lines will be staggered. The first two rows as measured from the upstream face of the dam will be drilled to a depth not less than 25 feet below the foundation level of the dam and will be grouted with cement grout at a pressure of about 150 lbs. per square inch before the foundation concrete is laid. When the concrete for the dam has been deposited for a height of about 25 feet, the rows Nos. 3 and 4 as measured from the upstream face will be drilled through the concrete and rock to a depth not less than 50 feet below the foundation level and will then be grouted with cement grout at a higher pressure of about 200 lbs. per square inch. Wherever possible, holes in the fourth row will be drilled at an inclination towards the upstream side so as to intercept the three preceding lines of grout holes to form an impervious barrier in the bed rock.

In addition to the above precautions if the foundation condition so demands, a cut-off trench 10' x 10' will be provided under the heel of the dam and this trench along with the grouted rock will form a better barrier under the heel of the dam.

During the preliminary investigations, no major faults in the bed rock have been discovered. But if such a fault in the bed rock is encountered when the foundations are finally opened up, special treatment will have to be given thereto.

(11) The rock foundation for the dam shall be drained by a series of drain trenches 2 feet wide by 1 foot deep to be provided about 25 feet apart as shown on the drawing No. V.T./143/20-8-48. **Foundation drains.** These trenches will be filled up with broken stones to form a permeable path for any water if at all leaking into the foundations.

A line of 3" dia. holes drilled into the bed rock for a depth of about 25 feet below the foundation level along the above transverse drains is also being provided. These holes will intercept any water finding its way through or around the grouted curtain. The seepage water will be collected in the transverse drains through the vertical drains from where it will be led to the drainage gallery through 4"

dia. cement concrete pipes provided in the body of the dam at about 25 feet apart connecting the transverse foundation drain to the drainage gallery.

(12) 6" dia. porous concrete pipes placed at about 25 feet centres about 3 feet downstream of the axis of the dam, running vertically down and connected to the drainage galleries will be provided. These drains are planned to intercept and collect the water entering the portion of the dam between the upstream face of the dam and the drainage galleries through construction joints, though very little leakage in this form is actually expected.

Internal drainage system.

Drainage water pump. (Arrangements to be provided if foundation conditions demand such an extra provision).

(13) A 5 feet dia. shaft from the top of the central pier in the spillway will extend right down to R.L. 300.00 T.H.D. This shaft will be located alongside the inspection galleries in the spillway section of the dam. On completion of the works, if experience demands, an electrically operated 6" dia. vertical spindle pump will be lowered through this shaft and mounted over the drainage sump pit situated alongside the 314.00 T.H.D. elevation inspection gallery.

(14) Drawing Nos. V.T./143/20-4-48 and V.T./144/22-4-48 show the general arrangements of the inspection galleries which will be 5'-0" wide by 7'-0" high and will be provided in the interior of the dam at about 60 feet difference of levels, the lowest being at R.L. 314 T.H.D. Though these are being called inspection galleries, they will be useful not only for inspection but for draining, cooling and grouting the contraction joints. Each inspection gallery will extend from one bank of the river to the other and will be approachable from both the ends. These galleries will be provided with lighting and ventilation arrangements.

(15) Two under sluices each 8'-0" wide by 10'-0" high are being provided on either side of the central spillway. The main purpose of these sluice gates is to let go the first fill of the lake from the catchment area. The sluice gates will be located with their invert at 325.00 T.H.D. and each will be able to pass a maximum discharge of about 5,000 cusecs only when the reservoir is full. These gates will be operated

Under sluices.

electrically as well as manually. A curtain to go in front of either of these gates will also be provided to meet an emergency in case repairs to the main gates are necessary. The gates can be approached from the shaft by steel ladders provided for the purpose.

(16) After considering various alternatives such as, side channel spillway, syphon spillway and a central spillway with a high coefficient nappe-shape no decision has yet been taken in regard to the type of the spillway to be provided. It is being recommended that this matter should be investigated by the Khadakwasla Research Station and till the results of the syphon spillway as well as of an overflow spillway in conjunction with automatic gates are known, the final decision should not be taken. In case it is decided to go in for an ordinary overflow spillway in conjunction with automatic gates, 4 gates, each 20 feet high and 70 feet long will be required. If, on the other hand, a syphon spillway is found to be cheaper, it will have to be located in the body of the dam.

(17) The gates if erected will be of copper bearing M.S. Sections and will be counter-balanced with concrete counter-weights and will be float operated. Cement concrete floats are linked to the radial arms of the gates at about one third of the length of the arms. The concrete floats will be housed in chambers in the piers on each side of the gates. When the water in the lake reaches the level of 535.00 T.H.D. it will be admitted into two chambers, over weirs at 535.00 T.H.D. These chambers will be housed over the two 28'-0" wide piers on either side of the spillway. The water admitted into the weir chambers will flow into the float chambers. These float chambers will also be provided with escape pipes with control valves having indicators and locks. When the inflow into the float chambers exceeds the escape from them, the water level will rise within the float chambers thus making the floats buoyant. As the floats rise, the gates will be lifted till ultimately they are quite clear of the waterway.

On the floods receding and the lake level falling below 535.00 T.H.D., the escape from the float chambers will exceed the inflow into the weir chamber and thence into the float chamber; this, in its turn will result in lowering the water level in the float chambers and

falling of the floats and closing of the gates. As the weights of the floats will be considerable, they will keep the gates hard down on their sills properly staunched.

A further advantage of the gates of this type is that during the dry season, they can be lifted for complete examination, adjustment of staunching, painting etc., merely by closing the escape valves from the float chambers and filling them with water.

In case the choice falls on a syphon spillway, there will be about 6 batteries, each containing about 5 to 6 syphons each $10' \times 10'$.

(18) As aforesaid, model tests are necessary to determine the nappe-shape as would give the highest coefficient of discharge. Model experiments are also necessary to determine the shape of the side walls to deflect the discharge rushing out through the $8'-0" \times 10'-0"$ under sluices, into the tail channel. Experiments will also be required to determine the size and shape of the dentated sill at the downstream side of the spillway to dissipate the energy of the falling water to reduce the scour on the downstream side to the minimum.

(19) A water level indicator and recorder will be installed in a 2 feet diameter shaft alongside one of the $8'-0" \times 10'-0"$ sluice gates. This machine will be mechanically operated with an electrical transmitter to indicate and record the Vaitarna lake levels, at the control station at Tansa and in the Hydraulic Engineer's office in Bombay.

Each of the four Radial Gates will also be fitted with mechanically operated indicators, integrators and recorders for the purpose of keeping full records as to when each gate operated and the quantity of water spilled through it. These machines also will be electrically connected with the instrument panels at Tansa and in the Hydraulic Engineer's office in Bombay.

(20) The 20 feet roadway with 3 feet side pathways on either side will be the main link between the Agra Road on the East and Surat Road on the West. The roadway will be provided with $3'-6"$ high parapets which will be about 12" wide at top and will be provided with toe niches at bottom. The road surface will have a

wearing coat $4\frac{1}{2}$ " thick of 1:2:4 concrete. The roadway will be drained with 3" concrete pipes on to the downstream side.

The bridge over the spillway will consist of four independent spans each 70 feet long. It may be either a M.S. plate girder, or a R.C.C. slab and girder type, or a R.C.C. arch type. The bridge will be designed to class 'A' loading as prescribed by the Indian Road Congress, with 750 lbs./square inch compressive stress in concrete and 18,000 lbs./square inch tensile stress in steel. The beam ends will be supported on roller frames free to expand or contract. The road surface on the bridge will be given the same treatment as in the case of the roadway on the top of the dam. Thus a first class roadway having two traffic lanes with 'A' class loading will be provided across the Vaitarna Reservoir.

Construction of the Dam.

(21) A total excavation of about 35,00,000 cubic feet of earth mixed with boulders and about 22,00,000 cubic feet in rock will be required for the foundations of the dam. On the basis of the exploratory boring, it has been expected that no unusually large seams exist and the removal of 10 feet of top rock lying just underneath the overburden of earth and boulders will be sufficient to obtain a firm and good rock for the foundation throughout the length of the dam. The spoil from the foundations will be deposited along the banks of the river beyond a distance of 300 feet from the toe of the dam.

(22) The whole process of manufacture of concrete from the point of origin of raw materials to the finished product as laid in the dam, will be under strict control and laboratory testing. The concrete to be used in the dam will generally be of 1:3:6 mix by volume but this proportion may be varied, after laboratory tests with the actual materials, are carried out during the progress of the work to obtain a minimum crushing strength of about 1,400 lbs. per square inch (factor of safety=4) at the end of 28 days. The total quantity of cement concrete will be in the neighbourhood of 172,00,000 cubic feet.

(22a) The coarse aggregate will be crushed at site, out of the blue basalt trap rock for which quarries will be opened at site. Selected quality of stone

will be transported from the quarries to the crushing plant where the stone will be crushed and classified into four grades :—

Grade	I Fine	metal 1/4" to 3/4"
..	II Medium	.. 3/4" to 1 1/2"
..	III Coarse	.. 1 1/2" to 2"
..	IV Plums	3" to 6"

All the four grades of aggregate will be washed in order to remove all unsatisfactory materials. If any change in the grades of the aggregates as a result of laboratory test is considered necessary, it will be done during construction.

(22b) A large quantity of trap sand is available in the bed of the Vaitarna river about ten miles downstream of the site of the dam. This sand will be transported to the site of works by road transport. The sand will be screened and graded to give the fineness modulus of not less than 2.50 and not more than 3.00. The sand will also be washed clean to remove any objectionable matter. If sand in sufficient quantities is not obtained from the Vaitarna river, either crushed grit or else sand from Mumbra* may have to be used. It is felt that sufficient quantity of sand will be available from the Vaitarna river.

(22c) Water for aggregate washing will be pumped from that stored by the temporary bund constructed on the upstream side of the site for main dam, till the main dam rises above the top of the temporary bund. Water used for washing the aggregate will be as low in turbidity as possible.

(22d) The Cement Marketing Company of India have shown their willingness to supply the special Low-Heat cement required for making concrete. Negotiations in this behalf are still going on. Low-heat cement will be used in order to reduce the amount of heat generated during the curing process which facilitates the cooling of the concrete after it is placed in the dam.

* Mumbra is a railway station, 21 miles from Bombay on the Thana Creek and is a great source of sand.

The Low-heat cement will tentatively conform to the following specifications :—

The Chemical composition—

Loss on ignition not to exceed 3.00 per cent.

Insoluble Residue not to exceed 0.85 per cent.

Magnesia (MgO) not to exceed 5.00 per cent.

Sulphuric Anhydride (SO_3) not to exceed 2.00 per cent.

The Compound Composition—

Tricalcium Silicate (Ca_3S) not to exceed 40 per cent.

Dicalcium Silicate (Ca_2S) not to exceed 65 per cent.

Tricalcium aluminate (Ca_3A) not to exceed 7 per cent.

Tetracalcium aluminoferrite (Ca_4AF) not to exceed 20 per cent.

Fineness—

The specific surface to be not less than 1,700 nor more than 2,300 square centimeters per gram as determined by the Wagner turbidimeter.

Time of Setting—

The Cement not to develop initial set in less than 60 minutes and the final set within 10 hours.

Compressive strength—

The compressive strength of mortar at 7 days, (one day in moist air and six days in water) to be not less than 1,000 lbs. per square inch, and at 28 days, (one day in moist air and twenty seven days in water) to be not less than 3,750 lbs. per square inch.

Heat of Hydration—

Cumulative heat of hydration not to exceed 65 calories per gram at 7 days and 75 calories per gram at 28 days.

Water—

The water for making concrete will also be pumped from the same temporary lake from which water for aggregate washing will be taken.

From the information available so far, the water is suitable for mixing concrete but when the work progresses, it may be necessary to instal a filtration plant to remove objectionable impurities. However, under no circumstances, solids in water used for concreting will be allowed to exceed 50 parts per hundred thousand.

(22e) The total of about 172,00,000 cubic feet of cement concrete is to be laid for the construction of the dam. To complete the work in three years with 200 working days in a year, about 28,000 cubic feet of concrete must be laid per day. It is proposed that the mixing plant will consist of four rotary type concrete mixers. Each of these mixers will be of 42 cubic feet output capacity giving about 9,000 cubic feet of mixed concrete per 8 hours working day. Normally, three mixers will be working and one will be a standby.

The mixing plant will be a stationary one and mounted on the eastern side of the valley. Two mixers will form one unit and will have their own batching plant consisting of aggregate and cement storage bins. From the storage bins, materials will flow by gravity to the weighing mechanism installed directly beneath the bins. These weighing mechanisms will be simple in construction and operation and will have a simple correction device which will compensate for the moisture contents of the aggregate. The weight control mechanism upon which depends the uniformity of the batches, will consist of separate weigh beams for each, aggregate, cement and water. The moisture correction which will make accurate allowance for the moisture contents in the aggregate, will be carried out by adjusting percentage weights on the weigh beams. For this purpose, moisture determination scales will be supplied with the plant to obtain the moisture contents. Thus, the correct amount of cement, aggregates and water, including the water in the aggregate will be obtained in each mix.

(22f) The mixed concrete from the mixing plant will be transported to the point, by 2'-0" gauge trolley wagons, hauled by diesel engines, where it will be picked up by ropeway. Flat decked wagons will be used for this purpose.

Two rope-ways each of about 20 ton capacity with self-propelled travelling head and tail towers will be necessary. These rope-ways should be capable of dumping about 50 charges per 8 hour

working day at the farthest point. It is suggested that the hoisting speed should be about 200 feet per minute.

(22g) Large numbers of containers of special construction and design will be required. It is suggested that the general sizes, 200, 100 and 50 cubic feet, be adopted.

Containers.

(22h) The concrete will be laid in 50 feet \times 50 feet square blocks and in 5'-0" high lifts in one continuous operation of 8 hours. All along the forms and edges, the concrete will be vibrated by means of mechanical vibrators as the concrete is being deposited. As soon as the 5 feet lift is set but not later than 24 hours of its placing, the top surface will be thoroughly cleaned with water jet to remove the laitance and coating of mortar. However, care must be taken to ensure that no excessive mortar is removed and the green concrete is not injured in any way. After cleaning the surface, it will be kept moist with a layer of water till the next lift of concrete is laid on it. Immediately before concreting the next lift, the surface will be once again cleaned with sand blast and water jet. All inclined and vertical faces of concrete will be kept wet for 22 days from the date of concreting.

Placing of concrete.

(22i) Timber forms are to be used. However, these forms will be so made that they will be self-supporting and will provide vertical keys in the crosswise joints.

Forms.

(23) All the vertical contraction joints will be provided with water seals about 18" from the upstream and downstream faces of the dam. They will be either of 9" wide hollow-central triple bulb type made from especially treated rubber compound or 18 gauge annealed copper plates. Rubber and copper seals have been used at Gila, Boulder Canyon, Yakima, Kalamath and many other projects in U.S.A., organised by the Bureau of Reclamation, with great success.

Water seals.

(24) With American Engineers, who have built high concrete dams, the cooling of the dam by artificial means and thus contracting the concrete and opening up the vertical joints and then grouting them under high pressure has become a regular practice.

Cooling of the dam.

The purpose of artificial cooling, is to minimise the temperature rise from hydration heat of cement immediately after placing of concrete and to speed up the inevitable shrinkage so that the structure quickly reaches a constant size. During the entire cooling period, the mass structure shrinks and joints in the interior open up. The artificial cooling therefore speeds up the temperature change, firstly to cause the entire shrinkage while the concrete is relatively plastic, and thus secondly to open up the joints to their maximum limit which can then be grouted full before stresses from the load in the reservoir come on the structure. Thus, the full mass of the structure takes compression without internal movement.

It is an established fact that in the case of mass concrete structures, to hold the temperatures low, specially when the concrete is green, is very effective in controlling surface cracking. Without preartificial cooling, sudden drop in temperature on concrete surfaces, in winter months, produces marked temperature gradients at and near the surface of the concrete, such that the ultimate tensile strength of the green concrete is exceeded.

The Grand Coulee dam which is 540 feet above foundations, Shasta which is 560 feet high above the foundations, Owyhee Dam which is also 405 feet high and many other high dams have been cooled and grouted. In the case of Friant Dam built across the river San Joaquin in California and completed in the year 1943, a 238 ton capacity plant cooled and circulated water through small pipes spaced at $2\frac{1}{2}$ to 5 feet centres on 5 feet lifts of concrete. This dam is 300 feet high above foundations and about 3,430 feet long.

As pointed out before, the first condition of design is that the complete structure should be a monolithic mass so that the stress conditions developed in the loaded dam would be essentially as calculated in the stress analysis. It is therefore necessary to cool the dam artificially and to grout all the contraction joints.

(24a) One inch outside diameter thin walled M. S. tubing will be placed in the bottom part of each of the 5 feet lift. These pipes will be placed in coil, the distance between any two coils not exceeding 5'-0". Wherever the cooling pipes pass from one block to another, suitably designed expansion joints will be provided. These coils will be connected

Cooling Pipes.

to about 60 feet long header pipes placed vertically at suitable distances so that the total length of any of the 1" pipe coils does not exceed 1,000 feet. These header pipes will be placed along the line of inspection galleries and will terminate between two successive galleries. The inlet headers will be connected to the main refrigerant feed pipe running along the lower gallery in the section of the dam that is being cooled. The outlet headers will be connected to the main return refrigerant pipe running along the upper gallery of the section of the dam.

The vertical header pipe will be 3" diameter while the horizontal main refrigerant feed and return pipes will be 6" diameter, suitably insulated either with 2" thick cork or any other suitable material. These pipes will be provided with expansion joints at every 50 feet so that the joint is located opposite every crosswise construction joint in the dam. The cooling arrangements here suggested may have to be modified during construction but they have been mentioned here to give only a general idea of the equipment required.

(24b) The design of the cooling plants will be left to the contractors who specialize in this line of profession. The cooling will be carried out in two stages. The first stage will consist of circulating air-cooled water through the pipe system. The second stage will consist of circulating of refrigerated water through the same pipe system. The reduction in temperature will be obtained by air-cooled water to the maximum extent possible. In both stages, water will be pumped at the rate of not more than 4 gallons a minute and not less than 2 gallons a minute through each of the coils. It is proposed that the mass concrete will be cooled down to 45°F. Further investigations on the subject, however, are necessary before final decisions can be taken.

After cooling has been effected down to 45°F, the temperature will be maintained at that level for at least 48 hours, before final grouting is started and also throughout the process of grouting the contraction joints. The cooling will be done for two adjacent sections of 50 feet length between cross-wise contraction joints and extending throughout the width of the dam. The section taken for cooling will be about 60 feet high between two successive gallery elevations at a time.

It is estimated that two 100 ton refrigeration plants giving a total capacity of 200 tons of refrigeration will be ample when coupled up with a suitably designed cooling tower.

(24c) About 98 thermometers and 38 joint opening indicators will be inserted in the body of the mass concrete as the work progresses. These instruments will be of electrical resistance type. The terminals of the electrical conductors from these instruments will be conveniently located in the respective inspection galleries. A portable Wheatstone Bridge type instrument when connected to the terminals in the galleries will give the readings of the temperature of the concrete and the extent to which the construction joint has opened.

Grouting of construction joints.

(25) Strips 12" wide 18 gauge annealed copper sheet bent in "Z" shape will be embedded across the joints along the boundaries of each grout lift running vertically both upstream and down-stream faces of the dam so that a complete barrier is effected to attain the required pressure of grout within the joint.

Grout scales.

(25a) As work progresses, pipes will be embedded in the mass concrete for grouting the crosswise joints.

Grout Pipes.

At a distance of about 18" from the grout stop barrier, 1½" diameter header pipes at the top and bottom of the joint running across the dam from upstream to downstream face will be laid in the block to be grouted. These two header pipes are connected by ½" dia. pipes at 6 feet centres running vertically with grout-holes located in such a way that they are at a distance of about 12" above the 5 feet concreted lift surface. This set of piping will serve to grout the cross-wise joints.

(25b) Suitable vent holes with control valves will be provided on the downstream side to ensure proper venting of the joints as the grouting is being done.

(25c) Before grouting operation is started, the joints will be filled with water and allowed to be soaked for at least 24 hours. The grouting will

Grouting operation.

continue as slowly as possible. When the required quantity of grout as per calculations has gone in, a final pressure of 50 lbs. per square inch measured at top of the lift, will be applied to ensure that the grout penetrates into all crevices. Extreme care will be taken when applying this pressure. Low heat cement will be used for grouting purposes after it has been sieved through a 200 sieve. The grout mix will be in the proportion of 0.7 to 1 water to cement by volume in all the joints.

The whole design of the mass cement concrete dam depends on effective cooling and grouting of the construction joints. Therefore every care must be taken to ensure that the completed structure is a monolithic mass so that the stress condition developed in the loaded dam would be essentially as calculated in the stress analysis. To achieve this result, no efforts can be spared.

MAGNITUDE OF THE WORK.

(Vaitarna-cum-Tansa Scheme)

Excavation :

The excavation for the foundations of the dam will be as under :—

(a) Excavation in ordinary earth and loose material—17,500 brass.

(b) Excavation in murum and soft rock—17,500 brass.

(c) Excavation in hard rock requiring blasting—22,000 brass.

The labour for (a) and (b) will be about 2,000 labourers per day, for about four months and for (c) about 600 labourers per day, for two seasons.

Plant and Machinery :

The following machinery will be required :—

(a) Compressors 40 H.P. with necessary pneumatic drills, etc.—5 Nos.

(b) Pumps with 3" to 4" suction—10 Nos.

Concreting of the dam :

The quantity of concrete (1 : 3 : 6) will be about 172,000 brass (with 20 per cent. plums).

Materials for the concrete :

(a) Cement	...	1,20,000 tons
(b) Plum stones (if used)	...	34,400 brass
(c) Aggregate	...	1,52,000 Brass
(d) Sand	...	77,000 brass

Crushing programme :

A stone crushing programme of about 1,52,000 brass in four seasons will have to be arranged for. Its tipping should be on an average 220 brass per day for 175 working days in a year. Quarry arrangements for obtaining about 250 brass per day will have to be made.

Plant and machinery required for crushing :

About 14 Nos. of 20" x 9" Baxter make crushers each with 30 H.P. will be required. The capacity of each crusher for 10 hours working will be about 13 brass per day. The screening will give about 7½ per cent. fine metal which can be used as sand.

Sand :

Sand will have to be obtained from Tilsa—10 miles downstream of the dam site, either by lorry or a tram line by making a road. Arrangements will have to be made to collect and bring 100 brass of sand per day. A fleet of about 20 lorries will be required.

Labour :

The man-power required for construction of the dam will be roughly as follows :—

	Numbers per day.
(a) Quarries	... 1,300
(b) Crushers	... 800
(c) Sand collection	... 300

	Numbers per day.
(d) Breakers	... 300
(e) Mixers	... 650
(f) Casting and concreting	... 650
(g) Stores	... 100
(h) Miscellaneous, for trolley lines, attendants, drivers, mechanics, masons, carpenters, Bhisties, etc.	... 350
	4,450

In all roughly 5,000 workmen will be required daily at least for a period of 3 years.

CHAPTER II.

—TUNNELS.—

1. The work on the tunnel alignment is divided into three sections. The carrying capacity of the tunnel in each section is to be 685 million gallons per day with a maximum head of 118 feet.

**Total number of works
on Tunnel alignment.**

	Total length R.ft.
(1) 2 Nos. of approach and tail channels (30 ft. and 35 feet bed width respectively with a maximum depth of 50 feet)	... 3,300
(2) 3 Nos. of Horse-shoe type tunnels (concrete lined) of 10 feet diameter size	... 21,600
(3) 2 Nos. of 126" diameter steel pipes, 3/4" thick, supported on bridges	... 1,010

2. To facilitate construction, the entire work on the tunnel alignment is divided into three different parts.

**Division of work into
suitable tenders.**

- (1) Tunnel work proper, including the works of the two open channels and intake and offtake wells.

(2) Civil works, i.e., work of the two bridges on Balwant and Tasu Nallas, together with the works of providing C. C. chairs for steel pipe, deflection blocks, etc.

(3) The work of fabricating and laying steel pipes together with their appurtenances.

3. The quantities involved are as follows:—

Main items of tenders.

(A) Tunnel Work:—

(1) Excavation in open channel in earth and murum ...	40 lakhs C.ft.
(2) Excavation in open channel in hard rock ...	40 ..
(3) Excavation in tunnels proper ...	23.7 ..
(4) Lining of concrete 1 : 2 : 4 for good rock ...	5,250 brass
(5) Lining of concrete 1 : 2 : 4 for poor rock ...	950 ..
(6) Lining of portals ...	90 ..
(7) C. C. 1 : 3 : 6 for hollows outside lining ...	600 ..
(8) Steel required for reinforcement	6,000 Cwts.
(9) Coursed rubble masonry in cement	1,200 brass
(10) Pitching ...	2,000 ..
(11) Construction of Intake Well ...	1 Job.
(12) ,, Off-take well ...	1 ..

(B) Civil Works—(Balwant and Tasu Nalla Bridges).

(1) Excavation in Murum and Boulder in trenches ...	46,500 C.ft.
(2) Do. in rock ...	21,000 ..
(3) C. C. 1 : 4 : 8 foundation ...	20,700 ..
(4) Coursed rubble masonry in cement	98,800 ..
(5) Formation of embankment ...	6,20,000 ..

(6) R. C. Concrete	...	2,360 C.ft.
(7) 1 : 2 : 4 plain concrete in blocks	...	7,700 ..
(8) 1 : 3 : 6 Deflection blocks	...	7,000 ..
(9) Cut-stone work	...	970 ..
(10) Metalled road	...	10,600 S.ft.

(C) Pipe Line.

126" diameter steel pipe, 3/4" thick ... 1,010 R.ft.

Appurtenances—Manholes, Scour valves, Expansion joints, etc.

4. List of Building materials required :—

Quantities of Building materials required.

Serial No.	Item.	Tunnel work	Civil work	Pipes	Total
1	Cement	... 1,34,000 bags	11,000 bags.	...	1,45,000 bags.
2	Sand	... 3,200 Brass.	551 Brass.	...	3,751 Brass.
3	Metal	... 6,520 Brass.	420 Brass.	...	6,940 Brass.
4	Stone	... 2,700 Brass.	1,040 Brass.	...	3,740 Brass.
5	Steel	... 300 tons.	10 tons.	505 tons.	815 tons.

This excludes the materials required for intake and offtake arrangements and steel required for appurtenances of 126" diameter pipes.

5.—List of equipment and machinery required.

(1) Air compressors (about 300 C.ft. capacity each)	...	15 Nos.
(2) Drills of all types	...	40 "
(3) Jack hammers	...	12 "
(4) Drill sharpeners	...	3 "
(5) Grinders	...	3 "
(6) Air blowers	...	4 "
(7) Generating sets (about 250 K.V.A. capacity each)	...	6 "
(8) Tempering furnaces	...	4 "
(9) Mucking machines	...	8 "
(10) Tunnel trollies (40 C.ft. capacity Each)	...	100 "
(11) Tipping trollies	...	50 "
(12) Hoists	...	4 "
(13) Electric winches	...	2 "
(14) Air pipes 4" and 6" diameter	...	5 miles.
(15) Water pipes (various sizes)	...	10 "
(16) Ventilating fans (about 80 H.P. capacity each)	...	10 Nos.
(17) Ventilating pipes	...	4 miles
(18) Stone crushers	...	3 Nos.
(19) Trolley line—		
(a) 30 lbs./yd.	..	6 miles.
(b) 20 lbs./yd.	..	2½ "
(20) Diesel locomotives.	..	6 Nos.
(21) Bull-dozers	..	2 Nos.
(22) Other equipment such as concrete mixers and placers, workshop equipment such as lathes etc.		

The work will be carried out by day and night and the workmen will have to stay as near the work site as possible. At each tunnel face there will be in all about 200 labourers including 50 skilled labourers working in the tunnel.

6. The size of the tunnel, viz., 10 feet diameter, is small, leaving very little room for removal of muck. The length of two of the three tunnels exceeds 8,000 feet each, and there are hardly any sites where shafts or adits can be driven. The work will thus be found to be rather difficult and the progress will be slow. It is proposed that the work will be carried out all the year round including the monsoon season, in suitable daily shifts. With such programme, it is expected that the working days in a year will be about 300 at least and the daily progress on any tunnel, including work on both the faces will be 13 feet.

As the tunnel work is expected to be carried out simultaneously on all the three tunnels and as the longest length of a tunnel is 10,000 feet, the period required for completion of the work will be about 850 working days or a total period of 3 years on the basis of 300 working days in a year.

As the total period for completion of work will depend on the longest length between any two working faces, the period of 3 years may be further reduced if it be found possible to reduce the long lengths of tunnels Nos. 1 and No. 3 by driving shafts or adits and thus providing additional working faces.

CHAPTER III

PIPE LINE.

Cast Iron pipes are out of consideration because they give way without warnings; are heavy to handle, and difficult for repairs as they cannot be easily welded. For similar reasons, reinforced cement concrete pipes would also be not suitable. Further, they are not likely to prove economical as the cost of reinforcement required to be provided to make them sufficiently strong to withstand the internal water pressure, together with the cost of cement concrete will almost be the same (probably more) as that of a steel pipe.

1.—Choice of material for pipes.

Steel pipes may be used with cement concrete lining on (i) outside, (ii) inside or (iii) both outside and inside. Outside lining is suited to positions where the pipe line is buried underground. But in exposed positions, hair-cracks are developed in the lining due to variation in temperature, and minor settlements which take place

when the pipe line is laid. These hair-cracks harbour moisture which causes faster deterioration of the steel shell. For facility of maintenance, it is, therefore, desirable that the pipe line from Tansa to Powai should be laid above ground, and without outside lining. In some places the pipe line will have to be laid underground, for example, at road crossings, etc. The soil into which the pipe line has to be laid through is generally good but in some stretches it is saltish. In such positions, the steel shell of the pipe is likely to deteriorate very quickly. In such positions, the pipes with outside lining of concrete will be used.

The inside lining of cement concrete is helpful in maintaining a high and uniform discharging capacity even with age. It is also helpful in giving additional rigidity to prevent any tendency to collapse due to partial vacuum created inside the pipe line consequent upon a burst, or sudden closing of a valve, in the upper section. It is very doubtful whether the inside lining could remain without cracking as the embankment on which the pipe line would be laid is likely to settle unevenly. Besides, the circular section of the pipe line will not remain the same when buckling takes place and this would result not only in producing cracks in the inside lining but some of it might fall off. Welded steel and inside-lined steel mains have the same discharging capacities when the pipes are new. The discharging capacity of unlined steel pipes, however, decreases with age. The analysis of cost for inside-lined steel pipes and unlined welded pipes giving the same discharge after 25 years as that of inside-lined pipe was made, and it was found that an unlined welded steel pipe was more economical.

Having found that unlined steel pipes were more economical, the next step was to specify the type of joint. The 2—Joint for pipes. three principal classifications of steel pipes according to the type of joint adopted are: (1) fully riveted pipes, (2) girth riveted pipes, and (3) continuous interior pipes.

Class No. (1) viz., fully riveted pipes have been used for the 72" diameter existing Tansa mains. The efficiency of the double row lap riveted joints being limited to 70 per cent, this class requires a thicker shell, and consequently more metal for the same strength as compared to all welded pipes falling in class (3) above. (For the welded pipes an efficiency of 90 per cent is adopted for welded joints;

and where good welding is done, the strength of the joint is almost the same as that of the plate of the pipe). Moreover, the projections of the plate thickness and the rivet heads inside the pipe, hinder the flow of water and cause greater frictional losses. Consequently, the value of the co-efficient of discharge for such pipes has to be taken 18 per cent. lower than that for the fully welded pipes.

Class No. (2) viz., girth riveted pipes have not been so far used on a large scale. The lock-bar pipes used in the existing Vehar mains belong to this class. The discharging capacity of this class of pipes is about 14 per cent more than that of a fully riveted pipe.

Class No. (3) viz., continuous interior pipes include all welded steel pipes with no projecting rivet heads or plate thickness on the inside. The discharging capacity of this class of pipes is about 22 per cent more than that of a fully riveted pipe. This type of pipe possesses a further advantage of having a higher efficiency of joints, resulting in substantial saving in the thickness of shell plates. This class of pipe i.e., fully welded pipe is now-a-days being used on a large scale.

All welded steel pipes however would not be suitable for laying underground. The portion of the twin unlined steel mains running along the Mahalaxmi Race Course, laid during the Tansa Completion Works deteriorated within 2 years and it had to be immediately renewed. Owing to the corrosive action of the soil, many other sections of steel mains in the City have been found to have corroded badly, resulting in numerous leaks, and consequent loss of water. These had to be repaired at very heavy costs by guniting. In order to ensure long life without heavy expenditure for repairs, it is desirable that the pipes inside the City area, should be either (1) outside-lined all welded steel pipe or (2) cast iron pipes. The disadvantages of C. I. pipes have been already stated. The only advantage in favour of C. I. pipes is that they admit of easy service connections. Where a large number of service connections are not required to be made, outside-lined steel pipes deserve preference over the C. I. pipes.

It is necessary to select the most suitable formula for the discharge through the pipe line. At the time of designing the existing 72" diameter Tansa mains, Prof. Unwin was consulted in regard to the formula to be used for working out the discharge of these pipes.

3—Carrying capacity of pipes

For all riveted steel pipes, he recommended a value of 108 for 'C' in the Chezy's formula $V = CV_{rs}$, but rightly pointed out that this formula was unsatisfactory as a general formula, because of variations of 'C'. In his opinion, this formula was convenient and trustworthy when used as an interpolation formula after 'C' was determined from experiments on pipes of a given type of the same diameter working with the same velocity.

As the type of pipe now proposed for the third pipe line is different to that of the existing 72" pipe lines, Chezy's formula with value of 'C' as recommended by Prof. Unwin cannot be adopted.

A number of formulas have since been evolved, and the most reliable are those evolved by William Hazen and Scoby. William Hazen's formula is as follows :—

$$V = C r^{0.63} \times s^{0.54} \times 0.001^{-0.04}$$

where C is a constant depending upon the class of the pipe, 'r' hydraulic mean depth in feet and 's' hydraulic gradient.

This formula does not directly take into account the age of the pipe and its effect on its carrying capacity, but the value of 'C' is reduced according to the age of the pipe. The Committee appointed in 1935 by the New England Water Works Association Ltd. to determine the "Pipe Line Friction Coefficient", have scrutinized the available data on the subject and have given a trend curve for the age effect on the capacity of the pipes.

Scoby's formula evolved in 1930 based on 1,178 different observations carried out on 198 stretches of pipes covering all classes is as follows :—

$$V = \frac{H^{0.526} \times D^{0.58}}{K_s^{0.526}}$$

Where 'H' is fall in feet per 1,000 feet length, 'D' the diameter of the pipe in feet and K_s is a constant depending on the class of the pipe and its age.

Actual observations in 1946 on the existing 72" diameter Tansa mains showed that 'C' equalled to 99 for $V=3$ feet/second. This result agrees with Scoby's recommendation of $C=110$ for new pipes

of this type reduced by 10 per cent due to the age effect of 20 years. Scoby has pointed out that a factor of safety should be adopted in the design of the discharging capacities of pipes. It is difficult to fore-see the condition of pipes after 10, 20 or 30 years; and this is why occasionally wide divergence is found between computed and actual results.

The factor of safety as recommended by Scoby is as follows :—

(a) 5 per cent where water is known to be non-aggressive, when the pipe line is practically straight, and when the conditions of operations are such that no penalty attaches to a slight reduction in capacity.

(b) 25 per cent in case of very aggressive water, inferior coating, crooked alignment, flow laden with silt and at low velocity, and when penalty attaches to a slight reduction in capacity. For intermediate conditions an intermediate percentage should be adopted.

In working out the carrying capacity of a steel pipe, the most unfavourable condition of head and the condition of pipe after 25 years, have to be taken into consideration, so that the required discharge could be obtained even when the pipe line is old. In the calculations of the structural design of the pipe, the higher head to which it will be subjected, has to be taken into account. Normally, the highest head would be the maximum static head, namely the difference between F. S. L. of the Reservoir and the level at the lowest point in the pipe line such as at Kasheli in our case. It would not, however, be proper to consider this total head for designing the whole pipe line as it would result in making the lower portions of the pipe line (from Kasheli onwards to Powai) unnecessarily thick to withstand the maximum static head. There is loss of head due to pipe friction, and it is, therefore, desirable to design the pipe line for maximum internal pressure on account of the hydraulic gradient only, introducing such expedients in the design as would restrict the head to this limitation.

The steel selected has to have special qualities, and to be suitable for welding and hence a low carbon steel with 0.20 per cent of copper is generally specified. Its breaking stress should be 50,000 to 55,000 lbs. per square inch and the yield point 29,000 lbs. per

4—Properties of Steel to be used.

square inch. The working stress would normally be half of the yield point stress, reduced by 10 per cent for the efficiency of the welded joints but for occasional higher stresses caused by static water pressure, water hammer, etc., the limit may be increased to 0.8 of the yield point stress reduced by 10 per cent for the efficiency of welded joints.

Joints are proposed to be butt-welded. The efficiency of such joints is usually as that of the plate itself but to err on the safe side it is assumed as 90 per cent as stated above. The normal working stresses are, therefore, restricted to 13,104 lbs. square inch and extreme stresses to 21,000 lbs./square inch.

The thickness of the shell is guided more by the consideration of a partial internal vacuum consequent upon a burst than by the consideration of the internal pressure. Air valves have to be provided to allow air inside the pipe at the maximum rate at which the pipe can get empty in the event of a burst, and without creating such difference of pressure between the inside and the outside, as the shell thickness can be relied upon to withstand buckling. A minimum shell thickness of $3/8"$ assumed to have an allowance of $1/16"$ for corrosion, etc., shall have to be provided for on this account. This allowance of $1/16"$ in shell thickness over what is required to withstand the stresses, is essential to provide against future reduction of the thickness consequent to corrosion, so that the stresses will still be within the permissible limits even after many years.

A pipe line is subjected to the following stresses :—

(i) Circumferential stress due to internal pressure.

(ii) Longitudinal stress due to—

(a) pressure in pipe. This stress is always tensile and occurs when the Anchor Blocks at the sluice valves do not take up the longitudinal thrust. It may occur momentarily when a stretch of pipe line is tested or has to be flanged during maintenance.

(b) Beam action—This is due to weight of pipe and water when the pipe acts as a beam, when supported on chairs. For 96" and 72" dia. pipes, chairs are provided at 24' centres and for 126" dia. pipes at 30' centres.

(c) Slope of the pipe line.

(d) Temperature variations. Expansion joints allow the pipes to move freely over the lubricated bearings of the chairs when pipe expands or contracts, and this stress need not be taken into consideration.

(e) Force of friction at supports when the pipe tries to move due to temperature variations. This causes direct and bending stresses.

(f) Friction at the expansion joints exerting a force against movements due to temperature variations. This can be compressive or tensile depending upon the expansion or contraction of the pipe.

(g) The pressure of water on the annular areas of the spigot of the expansion joint. The stresses on this account are very small and are always compressive.

(h) Tractive force due to flow of water.

All the above stresses do not occur at one and the same time, and are not of the same sign. However, it is necessary to find out the maximum compressive and tensile stresses to which a pipe will be subjected under the most unfavourable combinations of the above stresses for two conditions *viz.*, (1) Pipe empty, (2) Pipe full, under normal working conditions.

Detailed calculations have been made in the above manner and it is found that $3/8$ " thickness of plate is suitable for 72" dia pipes, $1/2$ " for 96" pipes and $3/4$ " for 126" dia. pipes.

The effect of water hammer is to create a temporary head, due to sudden closure of valves. This stress will be for a temporary duration, and with the selection of slow closing valves, (closing time not less than 10 minutes) it is possible to limit the same to a very low figure. The total stresses including that due to water hammer have been kept within 0.8 of the yield point stress for steel plates further reduced to 90 per cent. to allow for the efficiency of welded joints as stated earlier.

It is necessary to provide a preservative coat for the steel pipe, line so as to prevent corrosion due to atmospheric effects. A coating on the inside will give a higher co-efficient of discharge for many years.

Bituministic enamel has been specified for the new pipe lines, as per latest practice.

The alignment of the new 96" dia. steel pipe line $\frac{1}{2}$ " thick from Tansa to Powai will be parallel to the existing two 72" dia. steel mains known as "East" and "West" mains. From Tansa to Kasheli, the new pipe line will be laid on the west-side of the existing mains. Over the South Kasheli Bridge, this pipe line will be laid on the east cantilever, from the point of view of structural stability of the bridge. It shall then continue on the east side of the existing mains upto Powai.

The pipe line will be spaced from the existing mains at the same distance as maintained between the two existing mains, i.e. about 3 feet apart. It will be laid above ground on concrete chairs fixed on the embankment at 24 feet centres. Wherever the pipe line dips underground, i.e. at the level crossings, etc., the underground portion will be either coated on the outside with R.C.C. of about 2" thickness or encased in a block of cement concrete not less than 6" thick.

The pipes will be of all welded construction. The factory joints to join a minimum of four strakes of the pipe each 6' long, or a total length of about 24' shall be of single 'V' butt type. The welding will be done by automatic machines. The field joints will be of the single 'V' butt type, but a sealing run of weld will be given from the inside of the pipe. The field welding will be done by oxy-acetylene flame, or shielded electric arc.

The longitudinal joints will be placed at 45° to the horizontal plane along the axis of the pipe and any two consecutive strakes shall have a break of joint to form 90° at the centre of the pipe.

As the new pipe line has to be laid parallel to the existing pipe line, the horizontal and vertical curves have necessarily to be almost equal to those of the latter. The positions of the appurtenances, cross connections, expansion joints, anchor blocks, etc., will almost be the same as those of the existing mains, for the facility of simultaneous maintenance.

Expansion joints will be provided along the pipe line, in general, at every 1000 feet interval, and also in addition, on either side of an anchor block where such one occurs.

The following is the list of appurtenances that will be fixed on
7—Appurtenances, this pipe line :—

Description.	Size.	Quantity. Nos.
Kinetic Air Valves	...	3"
Do.	...	8"
Do.	...	12"
Anti Vacuum Air Valve	...	12"
Scour Valves	...	18"
Do.	...	12"
Do.	...	9"
Do.	...	3"
Manholes	...	15"
Sluice Valves	...	36"
Cross connections with 24" sluice valves	...	24"
Venturi meter	...	1
Burst alarms	...	13
Pressure gauges	...	25
Pressure recorders	...	4
Expansion joints	...	228

The entire pipe line will require about 52,200 tons of steel plates, 6 feet wide \times 25' - 3 $\frac{1}{2}$ " long \times $\frac{1}{2}$ " thick, and the length of the pipe line will be about 40 miles.

The pipe line between Tunnel faces 2, 3 and 4, 5 along the tunnel line between the proposed Vaitarna reservoir and the Tansa lake, to cross over Balvant and Tasu Nallas respectively, will be 126" dia. steel pipe line, $\frac{3}{4}$ " thick, electrical arcwelded. The length of the two sections will be about 470 ft. and 530 feet respectively. The pipe line will be laid above ground on concrete chairs fixed on the embankment at 30 feet centres.

The pipes will be of all welded construction and the stipulations regarding factory and field joints applicable to 96" dia. steel pipes are also applicable to these pipes, but the joints will be of double 'V' butt type, due to the greater thickness of the pipe plates.

There are no vertical bends in this pipe line, which is practically horizontal. There are two horizontal bends one of 16° and the other of 20° .

Deflection anchor blocks of suitable sizes have been provided at these bends with an expansion joint on either side of each block. There will thus be 4 expansion joints in this pipe line. Two scour valves 12" size, have been provided one at Tasu and one at Balvant Nallas respectively for draining the entire pipe line if required. Four manholes, 15" size, 2 Kinetic Air Valves 12" size, one burst alarm, two pressure gauges, and two pressure recorders are also provided at suitable places.

The total length of this pipe line will be about 1,000 Rft. and will require about 455 tons of steel plates, 6 feet wide \times 33 $\frac{1}{2}$ feet \times $\frac{3}{4}$ " thick.

The 6 $\frac{1}{2}$ miles of pipe line from the tunnel end upto the Tansa lake will also be of 96" dia. steel pipes $\frac{1}{2}$ " thick. This pipe line will also be laid above ground on concrete chairs, fixed on embankment at 24 feet centres. The pipe line will be of welded construction and will be of exactly similar type to that from Tansa to Powai. The steel required for this pipe line will be about 7,930 tons plates, 6 feet wide \times 25'-3 $\frac{1}{4}$ " \times $\frac{1}{2}$ " thick.

As pointed out before, calculations have shown that the north bridge on the Ulhas creek will not require any strengthening to carry a 96" dia. pipe line as now proposed, though the space left on this bridge is for a 72" dia. pipe line.

The south bridge will not be capable of taking the 96" dia. pipe line in the place reserved on it for the 72" dia. steel pipe. It will require strengthening and the nature of the strengthening required has been fully investigated.

The bridges have been designed to carry a roadway 24' wide with arrangement for 2'-6" trolley track and also three steel pipe lines each 6 feet dia. The bridge is of "N" Girders 'through' type with cross girders. The "N" girders are placed 36 feet apart and cross girders are attached to the bottom booms of the same. The cross girders are extended on both sides by cantilevers, each 13 feet long. Thus, the overall length of the each cross girder is 62 feet.

As actually constructed, the central portion of cross girder carries one 6 feet dia. pipe line and a 24 feet roadway. The east cantilever carries the second 6 feet dia. pipe line. The west cantilever is at present unloaded and is meant to carry the third pipe line of 6 feet dia.

The following alternative combinations of the pipe lines over the bridge were examined from the point of view of structural stability for laying a 96" dia. pipe line in lieu of a 72" dia. pipeline.

East cantilever.	Central portion.	West cantilever.
(a) 8' dia. pipe.	6' dia. pipe.	6' dia. pipe.
(b) 6' Do.	6' Do.	8' Do.
(c) 6' Do.	8' Do.	6' Do.
(d) 8' Do.	6' Do.	8' Do.
(e) 6' Do.	8' Do.	8' Do.
(f) 8' Do.	8' Do.	6' Do.

The alternatives (c), (e) and (f) which have 8' dia. pipe on the Central Portion of the girder are ruled out, as maximum B.M. exceeds permissible limits.

Out of the remaining three alternatives, viz., (a), (b) and (d) which have 6 feet dia. pipe on the central portion of the girder, the first one, having 8' dia. pipe on the East Cantilever and 6' dia. pipe on the Central Portion and West cantilever is most suitable.

Due to road-load, the central portion of the cross girder is more heavily loaded on the west side support. Assuming 6 feet dia. pipe on the central portion and the west cantilever as per original design, the reaction at the West side support due to cross girder works out to 107.53 tons as per our calculations. In the alternative (a) the reaction at East supports of the cross girders works to just about the same. In view of the symmetrical design of the "N" Girders, it can be safely assumed that the same have been originally designed for the higher reaction at the west support. If this assumption is correct, the question of strengthening the "N" girders does not arise in case of alternative (a). Some portions of cross girders between supports require strengthening for shear only.

Messrs Rendel Palmer & Tritton, Consulting Engineers, London who were consulted in 1923, for the design of this Bridge, have been contacted and their advice has been sought for as regards the adaptability of the alternative (a). The reply of the said consulting

Engineers, has since been received and they have recommended the alternative (c) in preference to remaining 5 alternatives mentioned above.

Investigations, however, are now, being carried out to find out whether, in addition to laying the proposed 96" dia. main, one of the two existing 72" dia mains can also be replaced by a 96" dia. main, by incurring only a reasonable expenditure on strengthening the said bridge, so that the said bridge will finally carry two 96" dia. mains and one 72" dia. main.

END OF PART II.