CHAPTER - 4
SURVEY AND INVESTIGATION

Detailed survey and investigations such as topographical surveys, geological & geotechnical investigations for the borrow areas, construction material and foundation treatments, socio-economic studies, ecological and environmental impact assessment and seismo-tectonic studies for the above two dams and the two tunnels have been carried out by NWDA in order to examine technical feasibility of the scheme.

4.1 Topographical survey

The topographical surveys at proposed dam sites and along the alignment of the link tunnels were started by NWDA during April, 1994 and completed during March, 1998. The entire length of the tunnel from Bhugad to Khargihill and Khargihill to Pinjal shall pass through very steep hilly terrain and dense forest of Western Ghats. Other special surveys and investigations through specialised agencies were continued beyond March,1998 as consultancy works. The various items covered in topographical surveys are detailed below:

4.1.1 River surveys

a) River Damanganga

River survey had been carried out along the fair weather deep channel of river Damanganga across which Bhugad dam is proposed. The longitudinal section along the Damanganga river has been surveyed for 3 km downstream and 24 km upstream of the proposed Bhugad dam site upto RL 170 m. Besides, longitudinal section has also been surveyed for its major tributary viz. Bilia Nalla for a length of 6 km. Altogether 33 numbers of cross sections have been surveyed along the rivers at 1000 m interval.

b) River Vagh

River survey had been carried out along the fair weather deep channel of river Vagh (a tributary of river Damanganga) across which Khargihill dam is proposed. The longitudinal section along the Vagh River has been surveyed for 3 km downstream and 19 km upstream of the proposed Khargihill dam axis upto R.L. 168 m. Besides, longitudinal section had also been surveyed for its major tributaries viz. Landi river for a length of 9.0 km and Val river for a length of 10 km. Altogether, 41 numbers of cross-sections had been surveyed along the rivers at 1000 m interval.

c) River Pinjal

River surveys had already been carried out along the river Pinjal across which Pinjal dam is proposed by Government of Maharashtra. The longitudinal section along the river Pinjal for a length of 8 km had been surveyed by NWDA to fix the position of out portal after verifying and correcting the RL near Ene village shown in toposheet. Three cross-sections across the river at the dam site and eight numbers of cross-sections at interval of 1000 m along the longitudinal section of the river had been surveyed.

4.1.2 Reservoir surveys

Reservoir survey for the reservoir at Bhugad was carried out by NWDA during the year 1984. The survey for the reservoir at Khargihill was carried out by W.R.I. Division, Palghar, Government of Maharashtra on behalf of NWDA during the year 1984.

The Bhugad reservoir at the proposed FRL 163.87 m, has a submergence area of 1903 ha out of which 916 ha lies in Maharashtra and 987 ha in Gujarat.

The Khargihill reservoir is proposed across Vagh river (a tributary of Damanganga river) near village Behadpada of Mokhada taluka of Thane district of Maharashtra State. The Khargihill reservoir, at the proposed FRL of 154.52 m, has a submergence area of 1558 ha.

Due to change of Khargihill dam axis as suggested by Geological Survey of India (G.S.I.), Nagpur later in the year 1997 and some discrepancies noticed in Khargihill reservoir map prepared by the Palghar Division, the Khargihill reservoir map has been prepared afresh with the help of toposheets and river longitudinal section and cross section were surveyed by NWDA.

4.1.3 Head works surveys

a) Bhugad dam site

The dam site has been selected across Damanganga river near village Bhugad of Peint taluka of Nasik district where the river channel is narrow (flanked on the right bank by steep rock cut slopes (40º) and on the left bank by an undulating and hummocky topography rising at moderate slopes (20º) and a deep gorge exists so that the length of the proposed reservoir will be shorter and a deeper reservoir will be formed. A shorter dam is preferred to a longer because of its lower cost. A deeper reservoir is preferred to a shallow one because of lower cost of land submerged per unit capacity and lesser evaporation losses because of the reduction in the water spread area.

Surveys and Investigations for Bhugad dam were completed by NWDA during the year 1994. However, Geological Survey of India, Nagpur after investigating this site suggested one alternate dam axis for Bhugad dam site in addition to the old dam axis. Altogether 31 numbers of cross sections had been surveyed for preparation of grid plan in the vicinity of Bhugad dam site at horizontal interval of 50 m. With the help of the longitudinal section, cross-section and spot levels, the contour plan with a contour interval of 4 m covering the dam site was prepared.

b) Khargihill dam site

The dam site has been selected across Vagh river near village Behadpada of Mokhada taluka of Thane district, where the river channel is narrow (flanked on the right bank by steep, rock cut slopes (45º) and on the left by an undulating topography formed by alluvial fill rising at moderate slopes (30º) and a deep gorge exists so that the length of the proposed dam will be shorter and a deeper reservoir will be formed. A shorter dam is preferred to a longer one because of its lower cost. A deeper reservoir is preferred to a shallow one because of lower cost of land submerged per unit capacity and lesser evaporation losses because of reduction in the water spread area.

G.S.I.,Nagpur had suggested two alternate dam axes for Khargihill dam site in addition to the old dam axis. Altogether 22 numbers of cross-sections had been surveyed for preparation of grid plan in the vicinity of Khargihill dam site at an interval of 50 m. In addition, 3 cross sections were also taken for saddle dam portion at village Vavar near Khargihill site. With the help of longitudinal section, cross-section and spot levels, the contour plan with a contour interval of 4 m covering the dam site was completed.

4.1.4 Tunnel surveys

The topographical surveys of the Bhugad-Khargihill and Khargihill-Pinjal tunnels, for the lengths of 16.85 kms and 25.70 kms respectively, had been carried out by NWDA and the alignment was firmed up by GSI, Nagpur after their investigations.

i) Tunnel alignment between Bhugad and Khargihill reservoirs

Three alternate alignments for the tunnels were considered by NWDA keeping the intake at RL 118.19 m and out portal at 102.78 m. The alignments were geologically examined by Geologists of G.S.I., Nagpur for working faces to reduce the haulage of tunnel muck and expedite the tunnelling operation in faster pace. A modified alignment for the Bhugad-Khargihill tunnel from intake portal to Garmal village having a length of 6.899 km and after a kink at Garmal hill (RL 370 m) it is aligned from Garmal to Nangarbari having a length of 9.951 km connecting the two portals located at 1.8 km upstream of Bhugad dam axis on left bank (Intake portal) and outlet portal near Nangarbari at Val river on right bank near the confluence of Vagh and Val river in Khargihill reservoir.

The Bhugad-Khargihill tunnel is aligned across Bapanvihir plateau, chain residual hills at Garmal and Chaura. The ground levels on the tunnel route vary from RL 370 m to RL 145 m with RL 170 m at Hirapada nala and RL 195 m at Ojharkhed nala.

Chaining, compassing and survey of longitudinal section along the tunnel alignment for a length of 16.85 km have been carried out and cross sections at every 100 m interval having distance of 250 m either side of the tunnel alignment have been surveyed. Using the above survey data the contour plan and longitudinal section of the tunnel alignment has been prepared. Three adit approaches each of 2 km, 2 km, 1.5 km length from Ranapada to Damanganga river, Garmal hill to Damanganga river and Khathvadpada to vagh river have been suggested.

ii) Tunnel alignment between Khargihill and Pinjal

Three alternative alignments for the tunnel were considered by NWDA keeping the intake at RL-104.25 m and out portal at 86.78 m. These alignments were geologically analysed by Geologist of GSI, Nagpur and finally keeping in view the length of the tunnel and need for additional working faces to reduce the haulage of tunnel muck and expedite the tunnelling operation in faster pace, a modified alignment for the Khargihill-Pinjal tunnel with a FB of 218º from intake to Khand village and after a kink at Khand hill (RL 398.5 m) it is aligned with FB of 184.30º from Khand to Akhar further after a kink at Akhar hill (297.405 m) it is aligned with FB of 146.30º connecting the two portals located at 12 km upstream of Khargihill dam site on left bank and at 1.25 km SW of village Bejpada (Intake portal) and out portal near village Ene at Ene nalla. The tunnel alignment is proposed to pass through hilly region with surface contour averaging more than RL 400 m.

Chaining, compassing and survey of longitudinal section along the tunnel alignment for a length of 25.70 km had been carried out and cross-section at every 100 m interval having distance of 250 m on either side of tunnel alignment had been surveyed. Using the above survey data, the contour plan and longitudinal section of tunnel alignment had been prepared. Five adit approaches each of 2.1 km, 2.0 km, 0.25 km, 1.0 km & 1.25 km from Hatheri to Vagh river ,Velichapada to Domihiri river, Akhar to Shenkari nathi, Pathardi village to Jawhar river and Dongerpada to Jawhar river have been suggested.

The cast-in-situ bench marks had been constructed at important points such as dam axis, inlet, outlet portals of the tunnel etc.

4.2 Other specialised surveys through outside agencies

Specialised investigations/studies were got done through outside agencies as described in following paragraphs.

4.2.1 Geological and foundation investigations

There are important structures such as dams, saddle dam and tunnels in the proposed Damanganga-Pinjal link project. In order to know the characteristics of the foundation strata of the dams and the tunnelling media and to find preliminary construction material and quarry sites it was essential to carry out geological and foundation investigations. The geological investigations at the Bhugad & Khargihill dam sites and at their reservoirs and tunnels interlinking these reservoirs were entrusted to the Geological Survey of India, Nagpur.

The exploratory drilling work as suggested by G.S.I.,Nagpur to know subsurface geology at both the dam sites to find out foundation grade level and water tightness of bed rock and on both the tunnel alignments to know the tunnelling media was entrusted to Government of Maharashtra through their Mechanical Circle, Irrigation Department, Pune.

4.2.1.1 Photogeological interpretation

GSI, Nagpur studied the aerial photographs of the project area, adjoining dam axis with the help of mirror stereoscope and tried to have general idea of major structural features of rocks, such as fault, dykes, shear zone, major joints, fractures etc. in the vicinity of dam axes and along the tunnel alignment. This Photogeological interpretation was followed by ground truth verification.

4.2.2 Geological investigation

Since idea developed regarding structural features of rock from photogeological interpretation had its limitations, geological investigations were carried out in detail for the two dams. The basic purpose of these investigations was to find out type of rock in the area, major joints, shear zone, faults, fractured zone and also to know some of the properties of rock through laboratory testing. These investigations had been grouped into two classes namely surface & sub-surface geological studies.

(a) Surface geology

To study surface geology, visual inspection of the surface area on either side of both the Bhugad and Khargihill dam axes was carried out by the Geologists and shots were taken at all those points which were having some important geological features. The purpose of taking shots was to find location and reduced levels of the points having important features so that these can be correlated while preparing geotechnical maps.

The tunnel grade is around RL 120 m and is overlain by horizontally disposed basaltic flows reaching upto RL 400 m. As the surface mapping was not likely to give any indication about the rock grade of tunnelling media, it was decided to observe sections along the different rivers and nalla sections intersecting the tunnel alignment or very near to it.

Studies on surface geology for following items have been done.

i) Surface geological mapping of Intake and outlet portal of Bhugad to Khargihill tunnel link and Khargihill to Pinjal tunnel link.
ii) Surface geological mapping of both Bhugad and Khargihill reservoirs.
iii) Surface geological mapping of different rivers and nalla sections intersecting the tunnel alignment or very near to it.

(b) Sub-surface geology and exploration

Considering the geotechnical findings and layout of dam an exploratory programme consisting of 6 drill holes at Bhugad dam site and 12 drill holes at Khargihill dam site for varying depths from 25 m to 50 m was proposed. Out of the 6 proposed drill hole 1 drill hole at right bank on the Bhugad dam axis could not be carried out due to resistance from the local people. Out of the 12 drill holes on three alternate Khargihill dam axes and its saddle dam, only 5 drill holes could be completed and the remaining 8 drill holes could not be completed due to resistance from the local people. Assistance from local administration was sought but the local resistance from public prevailed in stopping further investigations at dam sites.

Exploratory drilling along tunnel alignment was initially proposed by G.S.I. at three locations namely the point of intersection of the tunnel alignment with Ranapada Nala, Hirapada Nala and Nangarbari Nala along the Bhugad-Khargihill tunnel and three locations namely the point of intersection of the tunnel alignment with Hateri Nala, Domihira Nadi and Shankeri Nadi along the Khargihill-Pinjal tunnel. However, subsequently Director, GSI, Nagpur reviewed the same and suggested only two drill holes along Bhugad-Khargihill tunnel namely at Ranapada Nala (depth 40 m) and at Hirapada Nala (depth 60 m) and 2 drill holes along Khargihill-Pinjal tunnel namely at Jawhar river (depth 124 m) and at Ene Nala (depth 82 m) and 3 additional drill holes near the outlet portal of the Khargihill-Pinjal tunnel to ascertain right location of the outlet portal.

4.2.3 Seismotectonic studies

The project area falls under zone-III as given in I.S. code 1983-1984 entitled "Criteria for earth quake resistant design of structures".

G.S.I., Nagpur suggested regional geological studies using remote sensing inputs for preparation of structural and tectonic map and reservoir area map with classification of reservoir rim slopes for taking up further competency studies. Regional Remote Sensing Service Station, Nagpur has done these studies.

The seismo-tectonic study of Damanganga-Pinjal Link Project suggests the existence of major lineaments that are seismically active. The lineaments are very deep in nature and may have resulted from the tectonics in this area after the eruption of Deccan Trap flows. The lineament fabric is governed by the major tectonic events that took place in this region as post Deccan Trap events. The intersection of lineaments particularly NW-SE and E-W lineaments seems to be sites of historical seismicity. Though the highest magnitude of the earthquake in this region has been 5.7, however such intersections may be loci of release of energy in the future.

Considering the above facts it is suggested that engineering structures near lineament intersections should be avoided. Dam site locations away by 20 km or more from major

lineaments are not likely to be affected by future seismicity, however this has to be confirmed after establishing the relationship of major lineaments in terms of netectonic activity. Dam sites within a radius of 10 km from major lineaments should be studied extensively and constructed with due consideration of an earthquake with highest magnitude and nearest to the dam site in this kind of tectonic setting.

However, the other dams constructed in the adjoining region, for the last 10-15 years suggest that there is no risk of dam failure in this region due to earthquakes.

4.2.4 Foundation investigations of dams

The work of foundation investigations for the proposed Bhugad and Khargihill dams was entrusted to Central Soil and Materials Research Station (CSMRS), New Delhi.

The samples collected from exploratory drill holes at Bhugad and Khargihill dam sites (core samples) were sent to CSMRS, New Delhi for rock mechanics laboratory investigation. The following laboratory tests were carried out on the collected rock samples.

i) Compressive strength (confined and unconfined) test to know bearing capacity of rocks.
ii) Slake durability test to know water absorption percentage in rock.
iii) Water percolation test for establishing clay.

Salient findings of report :

Based on testing work on the rock cores recovered from the exploratory drills at the proposed dam sites, the following parameters are recommended for design.

Identification and Water-Related Properties (Average)

Rock Type	Dry Bulk Density (Kg/m^3)	Saturated Bulk Density (Kg/m3)	Grain Density (Kg/m^3)	Water content at saturation (%)	Apparent Porosity (%)
Amygdular Basalt	2,628	2,695	2,769	2.65	6.65
Fine grained Massive Basalt	2,942	2,959	3,000	0.57	1.47
Medium grained Porphyritic Basalt	2,791	2,842	2,889	1.84	5.15

Triaxial Shear Strength Parameters

Rock Type	C, Mpa	Angle of Shearing resistance
Amygdular Basalt	5.5	36
Fine Grained Massive Basalt	30	41
Medium Grained Porphyritic Basalt	10	47

Uniaxial Compressive Strength (Saturated)

Rock Type	Uniaxial Compressive Strength (Saturated)
Amygdular Basalt	50/80 Mpa
Fine Grained Massive Basalt	115 Mpa

Medium Grained Porphyritic Basalt	55 Mpa

Deformability Characteristics (Saturated)

Rock Type	E, Gpa	Poisson's Ratio
Amygdular Basalt	35.55	0.19
Fine Grained Massive Basalt	75	0.25
Medium Grained Porphyritic Basalt	37	0.22

Slake Durability Index

Rock Type	I cycle, %	II cycle, %
Amygdular Basalt	93.33	89.60
Fine Grained Massive Basalt	99.35	98.98
Medium Grained Porphyritic Basalt	97.70	97.34

Note: The above values of engineering parameters are for intact rock specimens, whereas the values may be entirely different for the rock mass, because of various reasons like the presence of fault, discontinuities, folds gouge materials etc.

4.2.5 Construction material survey

For construction of concrete spillway and masonary dam sand, coarse and fine aggregate, rubble etc. will be required whereas for construction of earthen dam suitable soils for hearting and casing zones and other materials such as sand and gravel for filter will be required. Keeping these facts in view necessary construction material surveys have been conducted as suggested by CSMRS, New Delhi.

(i) Soils

For earthen dam portion, hearting and casing materials are required. In general it was observed during investigation that impervious soil required for the hearting material is available near dam sites. As per suggestion of CSMRS party a number of trenches in the borrow area of Bhugad dam had been made and 23 nos. of disturbed soil samples from the pits had been collected in the presence of CSMRS field party. Similarly, a number of trenches in the borrow area at 1.0 km d/s of Khargihill dam axis on right side and at 4 kms u/s side of dam axis near village Vangani had been made and 27 nos. of disturbed soil samples from the pits had been collected and all above 50 nos. of soil samples were tested at CSMRS, New Delhi.

The Mechanical Analysis Test results indicate that the tested soil samples in general, are dominated by finner fractions with particular reference to silt sizes followed by fine and medium sand sizes.

The Plasticity Index values of the tested soil samples of borrow area arrived at, based on Atterberg Limits tests, indicate that the samples in general possess medium to high plasticity characteristics and as such expected to undergo large deformation on loading.

The Triaxial shear test results show that the tested soil samples likely to exhibit good shear strength subject to the condition that these materials are compacted upto 98% of proctor compaction (MDD).

The consolidation and compressibility characteristics of borrow area soil samples in general possess medium to high compressibility characteristics. In view of above, during

construction appropriate quality control measures have to be followed with particular reference in achieving the density & moisture content. The values of the coefficient of permeability computed based on consolidation test results indicate that the soil samples possess impermeable characteristics.

The results of the Laboratory Permeability Test conducted on selected borrow area soil samples confirm that these materials have impermeable characteristics.

(ii) Rubble Masonry

There are massive quantities of basalt exposed above RL 220 m on right bank reservoir rim of Bhugad reservoir. Another major dyke tending in N to W directions and exposed in the right bank of the river between SW of village Kas and SW of Mohpada would offer congenial quarring condition at Bhugad reservoir.

For Khargihill reservoir rubble coarse aggregate in massive basalt units exposed in Lendi river section near village Dhadhri (10 km SW of Khargihill dam site) can be used. About 8,85,000 cubic metres rubble stone is available near project site while only 64,522 cubic metres rubble masonry is required.

(iii) Crushed Rock Aggregate

For concrete aggregate the basalt rock boulders/shingles forming shoal and bars on the river bed in vicinity to Dam sites could be used. The supplementary requirements may be obtained from rubble quarry sites.

(iv) Sand

The Damanganga river with its steep gradient does not have sand vicinity except for small quantity. However, for stable supply of sand the dependable source is the beach sand from the coastal area located at a distance of approximately 100 km. Sand samples were taken out in grid pattern after having trenches from Daman beach, Devka beach and Jampore beach and tested at CSMRS, New Delhi.

The Salient findings of the investigation report for the construction material survey and laboratory testing of rock and sand samples received from CSMRS, New Delhi are as under:

Coarse Aggregate

In all, 8 rock samples were collected from 3 rock quarries for assessing their suitability for use as coarse aggregate in concrete. Based on the results of physical tests conducted on the representative rock samples collected from various quarries, the suitability of different rock quarries for coarse aggregate to be used in concrete is indicated as below :

Suitability of coarse aggregate for both wearing as well as non-wearing surfaces

The following quarries have been found to be suitable for coarse aggregate in concrete for both wearing as well as non-wearing surfaces :

(i) Rock quarry near Dhadri village
(ii) River bed material of river Landy
(iii) Boulder materials of Damanganga river

Although it can be seen from the physical test results that rock quarries conform to the specification requirements as per IS 383-1970 for use as coarse aggregate in concrete for wearing as well as non-wearing surfaces. However, the petrographic examination shows presence of Iron Oxide ranging from 3% to 22%. The presence of Iron Oxide has been identified to be susceptible to initiate pitting effects when it comes in contact with water leading to durability problems. It is, therefore, suggested that the deleterious effect is required to be examined by conducting Mortar-Bar extension test at the pre-construction stage investigation of the project.

Since the coarse aggregate contains high percentage of Iron oxide and is liable to pose durability problem in concrete, these coarse aggregate with high content of Iron oxide may, however, be used in the hearting of the spillway structure beyond the gallery portion of the dam leaving at least 2 m cover around the periphery of the structure. The cover portion and the concrete lining of the tunnel may be constructed using good quality coarse and fine aggregate material to be explored from the new quarries.

Fine Aggregate

In all, 21 sand samples were collected from 3 beach sediment quarries for assessing their suitability for use as fine aggregate in concrete. Based on the results of physical tests conducted on these sand samples, the organic impurities are either absent or within allowable limits as per IS : 383-1970 specifications. The silt and clay content for all 21 samples ranges from 0.5 to 16.55% and only 8 samples fall within the permissible limit of 3.0% as per BIS specifications. The remaining 13 samples do not fall within the permissible limit as prescribed by BIS specifications. Out of 21 samples, the fineness modulus for 19 sand samples fall between 2.62 to 4.27 and indicate that the sand samples are coarse grained and the remaining 2 sand samples fall under fine grained.

Even though a few of the sand samples fulfill the requirements of physical tests as specified in the BIS-383, the petrographic examination of 9 representative samples from the three identified beach sediments, revealed higher content of Iron oxide and shell fragments ($CaCO_3$) which are commonly known for their deleterious effect on concrete strength and durability. Hence, it may be concluded that the sand samples from all the identified beach sediments may be dispensed with and crushed sand made of the rock can be utilized as replacement to natural sand only after ascertaining its physical and mechanical properties.

In view of long haulage distance it will be required to run a pilot test on rock crushing using basalt at site at pre-construction stage.

v) Cement

The nearest cement factories for the dam sites are located in Surat and Thane districts. The cement manufactured from these factories can be transported to dam and colony sites through Valsad, Vapi, Dahanu and Thane by rail. Later the cement bags collected at Valsad can be transported to Bhugad dam site by road, whereas cement bags collected at Vapi, Dahanu and Thane can be transported to Kahrgihill dam site by road.

vi) Steel

Steel procured from outside can be collected at Valsad, Vapi and Dahanu road /railway stations for further transhipment by road to the construction sites.

vii) Other materials

Apart from above, there will be many other items such as asbestos, CGI sheet, coal tar, wood, paint etc. which will be required for construction of temporary sheds, approach roads etc. All such items are available at Dharampur, Vapi and Jawhar.

4.3 Hydrological and meteorological investigation

There are four gauge and discharge sites on the river Damanganga maintained by Central Water Commission (CWC) and Government of Gujarat. The data of these sites were available for varying periods from 1974-75 to 1997-98. The availability of discharge data at these sites and catchment areas covered by them are given in Table - 4.2

Table 4.2
Availability of observed discharge at the G&D sites on Damanganga River

Sl. No.	Site	River	Catch-ment area (Sq.km)	Period of availability	Maintai-ned by	Remarks
1.	Nanipalsan	Damangang a	764	1991-92 to1996-97	CWC	**
2.	Ojarkheda	Vagh	690	1991-92 to1996-97	CWC	**
3.	Rakholi	Damangang a	1829	1961 to 1969	Govt.of Gujarat	Site closed
4.	Vapi	Damangang a	2233.19 2253.07	1974-75 to 1981-82 1981-82 to 1997-98	Govt.of Gujarat Govt.of Gujarat	The increase in catch-ment area is due to shift-ing of the site in the down stream.

***The Nanipalsan and Ojarkheda G&D sites were established in the year 1984 and 1974 respectively. However, the G & D data at these sites has been made available by CWC for the period for 1991–1992 to 1996-1997 only as the remaining data is inconsistent.*

Besides, Madhuban reservoir inflow data is also available for a period of 14 years (1988-89 to 2001-02). Hence, Vapi G&D site data has been used for developing unit hydrographs for the dam sites and estimation of design flood at the sites on proportionate catchment area basis.

Availability of rainfall data

There are 12 raingauge stations influencing the Damanganga basin upto Vapi G & D site. Out of these three raingauge stations influence the catchment upto proposed Bhugad dam site and 6 raingauge stations influence Vagh sub-basin upto proposed Khargihill dam site. Details of the periods of availability of the rainfall data of these stations are given in Table-4.3.

Table-4.3
Availability of rainfall data

Station	Period of availability
Peint	1901 to 1997 (except 1991)
Mokhada	1901 to 1997
Silvassa	1964 to 1997 (except 1996)
Harsul	1973 to 1996 (except 1988)
Rakholi	1967 to 1982
Vadoli	1967 to 1997
Vapi	1962 to 1997 (except 1996)
Khanvel	1966 to 1997
Dudhni	1966 to 1993 (except 1974 & 1977)
Raimal	1967 to 1988 (except 1985 & 1986)
Trimbak	1901 to 1996 (except 1961,1981, 1982, 1991 to 1993)
Jawhar	1955 to 1997

The period of availability of rainfall data of these raingauge stations vary. For generating long term monsoon rainfall data for these raingauge stations, the corresponding value of the nearest raingauge stations have been used by regression analysis. The best fit equations having least standard error with coefficient of correlation more than 0.7 have been selected for missing data generation.

4.4 Archaeological surveys

As discussed with Archaeological Survey of India authorities the reservoirs are not likely to submerge any historical monuments or structures of archaeological importance.

4.5 Communication surveys

The dam sites of this project are approachable through pacca/kachcha roads. Approach to these sites has been discussed in Chapter-7 "Reservoirs".

4.6 Agro-Economic, Socio-Economic & Environmental Survey

To assess environmental, ecological and socio-economic issues of the proposed link, NWDA engaged the consultancy services of M/S, Consulting Engineering Services (India) Pvt. Limited, New Delhi. Based on environmental, ecological and socio economic surveys conducted along the reservoirs and entire stretch of tunnel as well as data collected from primary and secondary sources, impacts on environmental, ecological and socio-economic components have been identified. For implementation of mitigation measures, proper Environmental Management Plan (EMP) has been suggested. All the guidelines given in National Policy on Resettlement and Rehabilitation (2003) would be followed to the project affected persons (PAPs).