Chapter 4
Surveys and investigations

4.1 General

Surveys and investigations provide field data required for planning and designing of various components of a water resources development project. A project can be designed optimally and economically, only when the necessary field data of specified standards are available. As such, NWDA has taken up extensive field surveys and investigations in the project area for collection of the data required for the preparation of Detailed project report (DPR) of Godavari (Inchampalli) - Cauvery (Grand Anicut) link project as per the guidelines contained in “Terms of Reference for preparation of Detailed Project Report of Inter basin water transfer proposals” approved by Ministry of Jal Shakti. These guidelines are by and large in harmony with the updated guidelines for preparation of DPR of Irrigation and Multipurpose Projects of Ministry of Jal Shakti issued subsequently in 2010.

Detailed surveys and investigations such as topographical surveys, geological, geophysical & geotechnical investigations including foundation investigations i.e. drilling bore holes at identified major CD/CM structures, tunnels etc for obtaining rock cores; Construction materials investigations; Geotechnical investigations (soil) including borrow area surveys; Command area surveys etc., have been undertaken departmentally as well as through various specialized organisations in order to examine the feasibility of the project.

The Godavari (Inchampalli) - Cauvery (Grand Anicut) link project takes off from the proposed Inchampalli barrage across Godavari river and falls into Cauvery river at Grand Anicut. It utilizes the services of the existing Musi reservoir, Nagarjunasagar reservoir on Krishna river and Somasila reservoir on Pennar river enroute. The link project comprises the following three components:

1. Godavari (Inchampalli) - Krishna (Nagarjunasagar)

2. Krishna (Nagarjunasagar) – Pennar (Somasila)
3. Pennar (Somasila) - Palar- Cauvery (Grand Anicut)

The survey and investigations were carried out for all these components and the respective feasibility reports were prepared and circulated to the concerned states, based on which the present DPR is prepared.

4.2 Topographical Surveys

Topographical surveys have been complied with the "Guidelines for preparation of detailed project reports of irrigation and multipurpose projects" of Ministry of Jal Shakti, Govt. of India, 2010, to the extent applicable.

The Great Trigonometrical Survey (GTS) Bench Marks (BMs) of Survey of India (SoI) located in the vicinity of link canal have been transferred and connected at various locations along the canal alignment by conducting double tertiary (DT) leveling. Adequate number of temporary bench marks (TBMs) at different locations along the alignment were established with reference to the above GTS Bench Marks. The submergence map of the Inchampalli pond is shown at **Plate 4.1.**

4.2.1 Canal

The centre line of the link canal marked on 1:50000 scale toposheets of Survey of India, is transferred to the ground by measuring the bearings of the alignment on the toposheets and then setting them on ground with the help of compass/ theodolite. The topographical surveys by conventional methods for a length of about 221 km of the main canal i.e. from Warangal –Mulug road to its out fall point, (Nagarjunasagar reservoir), out of the total length about 299.26 km and for the lead canal of length about 21.85 km were taken up and have been completed by NWDA. The initial reach of about 78.35 km i.e. from its off-take point in the foreshore of Inchampalli reservoir to Warangal - Mulug road crossing was not approachable since the alignment of the canal in this reach is passing through dense and protected forests and is highly

infested by extremist activists. Hence, it was decided that the topographical surveys and contour mapping of the entire canal and the intermediate reservoirs proposed along the alignment should be carried out by aerial photogrammetric techniques as a pilot project and the work has been awarded to NRSC.

Along the centre line of the link canal so transferred to the ground, levels are taken at 200 m interval from RD 78.35 km to the tail end by double leveling. The double leveling carried out was checked for its accuracy by connecting to the GTS benchmarks available along the alignment. The condensed plan and L-section of the link canal alignment are given in **Plates 4.2.1 (1/12) to 4.2.1 (12/12).**

Cross sections are taken at 400 m interval along the alignment with levels at 100 m interval extending upto 200 m on either side of the alignment. Wherever appreciable change in topography is noticed, levels are taken at closer intervals.

Block leveling has been carried out at places where cross drainage works are proposed by forming 50 m or less interval grid lines to cover an area upto 300 m on either side of the centre line of the link canal along the stream and laterally upto the firm bank plus 100 m on either bank of the stream. Similarly, block leveling by forming 50 m interval grids was done at road/railway crossings along the alignment, covering an area upto 300 m on either side of the centre line of the link canal and 100 m either side from the centre line of the road/railway line.

Centre line stones of size 75 x 15 x 15 cm have been fixed all along the alignment at 500 m interval for the surveyed portion of the canal. In addition, centre line stones are also fixed along the alignment at road crossings and at important CD works and at all the turns/bends indicated by change in the bearings of the link canal alignment.

Similar topographical surveys have been carried out for the lead canal which is proposed to transfer water from Inchampalli–Nagarjunasagar link canal to Kakatiya canal stage – II. The condensed plan and L-section of lead canal alignment is given in **Plate 4.3**.

The reach wise strip contour plans and condensed L-sections of the link canal alignment connecting Inchampalli to Grand Anicut are given in **Plates 4.2.1 (1/12) to 4.2.1 (12/12), 4.2.2 (1/16) to 4.2.2 (16/16)** and **4.2.3 (1/21) to 4.2.3 (21/21).**

4.2.2 Cross drainage / cross masonry works

Levels were taken at places where cross drainage works are proposed by forming 50 m grid to cover an area upto 300 m on either side of the centre line of the link canal along the major/ medium size streams and laterally upto the firm bank plus 100 m on either bank of the stream. Similarly, levels were taken by forming 50 m grids at road/railway crossings along the centre line stones of size 0.15 x 0.15 x0.75 m, fixed all along the alignment at every 500 m. In addition, centre line stones were fixed along the alignment at road crossings, at locations of important CD works and at all the turns/bends at the change in the bearings of the link canal alignment.

4.2.3 Pump house, switch-yards etc.

Block levelling by conventional method has not been carried out by NWDA near the off-take point of the link canal pump house sites and intermediate reservoirs due to non approachability. However, the topographical surveys were entrusted to NRSC for the mapping of the area of the head works, area of the link canal and lead canal by aerial photogrammetry. NRSC has conducted grid survey of dam site (50 m grid basis) covering the upstream upto 250 m and downstream upto 500 m from the dam axis. (contour interval – 0.5 m for plain areas and 2 to 5 m for hilly areas). Grid survey for intermediate reservoirs namely Peddavagu, Lower Tummalagutta and Upper Tummalagutta have also been taken up by NRSC.

4.2.4 Tunnel

A tunnel of length 9.15 km has been proposed between RD 86.35 and RD 95.50 km where the link canal passes through the ridge between Godavari and Krishna basins. Block levelling has been carried out by

forming 50 m grid lines extending upto 250 m on upstream and 250 m on downstream of inlet and exit of tunnel, extending upto 500 m on either side of the centre line of the tunnel. Levels at 200 m interval were taken for the complete length along the centre line of tunnel.

4.2.5 Command area

The link canal caters to the ongoing command areas proposed by under the Kakatiya canal stage–II of the SRSP stage-II and Srisailam left bank canal. Necessary command area surveys have been carried out by the designated State Govt. agencies. In addition, new command area of about 80000 ha is proposed under the Gottimukkala feeder branch. However, command area surveys are not carried out for this new area by NWDA as part of the present study, which will be carried out during pre-construction stage. The details are discussed in Chapter 8. The command area was measured from toposheets of scale 1:50000 procured from Survey of India (SOI). Generally, these maps were utilised for marking the layout of branch canals network in the command area. However, as sample survey, small patches of the command area are surveyed to design distributary network and to find the cost of command area development.

4.3 Soil conservation, archaeological and mineral surveys

It is envisaged to construct two intermediate reservoirs at RD 13.5 (Peddavagu), RD 26.5 Thummalagutta (Lower and Upper). Archaeological and mineral surveys and surveys for soil conservation as required in case of these reservoirs were not undertaken as these reservoirs are very small in size and were proposed as balancing reservoirs to take advantage of the topography along the canal and also as the alignment is not passing through the mineral and archaeological sensitive areas.

4.4 Geological investigations

The Geological Survey of India (GSI) was entrusted with the work of preparation of preliminary geological report of the link canal to derive

19 the general geology of the link. The report has been finalised by the GSI after extensive field investigations by their Geologists, of the areas along the alignment of link canal and the lead canal. Geological mapping of the proposed tunnel alignment and link alignment were carried out during the investigations.

The geological inferences of the above investigations, as enunciated by the GSI in their report are enumerated in the following paras.

4.4.1 Godavari (Inchampalli) to Krishna (Nagarjunasagar) Reach –I (RD 0.0 km to RD 299.256 km)

a) Link alignment

Broadly, the Inchampalli barrage–Nagarjunasagar link canal passes through three major geological domains, viz.

i) Gondwana Supergroup of rocks comprising pebbly / feldspathic Stand Stones, Ferruginous Sandstones, Siltstones, Shales and Dolomitic Limestones; and Sandstones belonging to Penganga group of rocks, collectively occupy the initial reach from chainage 0 to 55 km.

ii) Grey to dark grey coarse to very coarse-grained Granodiorite of Peninsular Gneissic Complex, between chainage 55 km and 102 km.

iii) Generally leucocratic, fine to medium grained Granite gneisses and Magmatities which contain xenoloths of older metamorphics, from chainage 102 km to the end point of the canal i.e. 299.26 km. Dolerite, Pegmatite and Quartz intrusive bodies were observed only at a few places, mostly in the granitic suite of Peninsular Gneissic complex.

b) Tunnel

A 16 m dia and 9.15 km long free flow tunnel with its invert levels at + 191.90 (inlet) and 190.07 m (outlet), is proposed between R.D. 86.35 and RD 95.50 km, in view of the deep excavations

likely to be involved which are of the order of 50 to 60 m. The tunnel alignment, in general, is covered with soil and scree material. The excavated dug well sections in the inlet portions, middle reaches and exit portions have exposed 9 to 11 m of weathered to moderately weathered and compact Granodiorite beneath a thin over burden of top soil cover and deeply decomposed kankar dominant soil.

c) Lead canal

The alignment of lead canal connecting the link to the Kakatiya canal is also located in a Granodiorite terrain. The sub-surface scenario is more or less the same i.e. weathered rock extending down to 11 to 13 m depth in general below 1 to 2 m thick overburden. Formation of embankment by filling in a major portion of the canal alignment is required.

d) Conclusions of GSI investigations

The preliminary evaluation of the data indicates that the sub-stratum is weathered down to depths ranging between 10 m and 15 m, below the ground level in general, irrespective of the two major rock types viz, Granodiorite and Granites and its variants, of the Peninsular Genissic Complex that would form the canal medium. Fresh rock is interpreted to be available below 10 m to 15 m and at 17 m depth, in different stretches.

Two to three sets of moderately close to widely spaced vertical to sub-vertical joints and sub-horizontal sheet joints dissect the rock mass.

Barring the top 1m to 2 m of overburden and deeply disintegrated rock which is almost transformed into soil, the underlying weathered to highly weathered horizon with high incidence of kankar that extends down to 4 m to 5 m depth, and the weathered to moderately weathered granite rock zone that was observed to a depth of 10 m to 15 m, in almost all the dug well sections, all through the canal alignment, were observed to stand with near vertical to vertical stable slopes.

Fresh Granodiorite will be the tunnelling media at the proposed 16 m dia and 9.15 km long free flow tunnel with its level of 191.90 m at the inlet and 190.07 m at the outlet in between RD. 86.35 and RD 95.50 km. The sub-surface along the tunnel alignment will be in a weathered to moderately weathered rock, down to 11 m to 15 m depth, followed by fairly fresh to fresh and hard Granodiorite.

The stream / river courses are covered with transported sandy overburden. The weathered bedrock is likely to be available below 5 m to 6 m depth, in general, along the minor stream courses while, it is likely to be available at a depth of 10 m to 12 m along the major river courses.

On the basis of the preliminary Geotechnical evaluation, it is considered that no sub-surface explorations are necessary along the major part of the I-N link canal alignment excepting to explore the proposed tunnel reach and aqueduct sites along the water courses crossing the canal alignment.

The study included the (i) geological mapping of the alignment in 1:50000 scale (ii) study of open wells available in the vicinity (iii) preparation of tentative geological section along the proposed alignment based on surface geology and available well data (iv) detailed study of river crossings where major cross drainage structures have been proposed (v) study of alignment based on photo interpretation and available geological maps. Accordingly, the GSI submitted a report with the following inferences (paras 4.5.1 to 4.5.4) drawn from the study. However the evaluation as enunciated for the reach upto Kinnerasani crossing (RD 70.60 km) is only based on aerial photo study, examination of imageries, existing geological maps and data base available with GSI since the reach was not accessible.

4.4.2 Krishna (Nagarjunasagar) to Pennar (Somasila) Reach –II (RD 299.256 km to RD 692.276 km)

a) Link canal

The present proposal of the project is to have powerhouse at the toe of the dam and at the head of the Krishna (Nagarjunasagar) - Pennar (Somasila) link component. At this site also, no rock outcrops are

noticed. The ground level at the proposed powerhouse site would be around 162 m while the deepest foundation level for the powerhouse would be around 127 m. Thus a maximum depth of 35 m of excavation would be involved to reach the bottom most level in the powerhouse. From the sub-surface exploratory data available from the Nagarjunasagar dam site, it is expected that the excavation for the proposed power house might pass through 2 to 3 m thick soil at the top, below which predominant quartzites with sub-units such as thin bedded quartzites and shaly quartzites might occur between RL 162 m and 144 m, and massive quartzites in between RL 144 m and 128 m.

These rock types belong to Srisailam formation of the Cuddapah Super Group. They are predominantly horizontally bedded. These quartzites overlie the basement granites (Archaeans) as recorded in the foundations of the Nagarjunasagar dam, at about EL 109 m.

Excepting open vertical joints likely to be present in the quartzites in the top horizons below the soil cover, the excavation, if done with proper slopes, can be expected to pose no major problems regarding slope stability. Detailed assessment of the geological conditions at the proposed powerhouse site can be made at the pre-construction stage by undertaking subsurface exploration.

b) Tunnel (RD 302.786 km to 304.101 km)

Massive quartzites are exposed as small patchy outcrops and also as blocks/boulders mixed with reddish brown soil over most of the area along the proposed alignment of the tunnel. The quartzites are pale brown and buff coloured, and are medium to fine grained. They are horizontally bedded except for minor undulations. Two prominent sets of vertical joints trending in N 750 W – S 750 E and N.E. – S.W., directions are present in the quartzites besides bedding joints. However, the following joint sets, which are less prominent, are also present**:**

Sl.No.	**Strike**		**Dip**
i)	N100 to 300W – S100 to 300E	:	Vertical
ii)	N – S	:	Vertical
iii)	E – W	:	Vertical
iv)	N 200 E – S 200W	:	80^0 towards N 70^0W

The proposed tunnel is considered feasible in the context of improved present day techniques in the support system which are available today. However, in view of non-uniform thickness and distribution of various sub-units present within the quartzites, a detailed sub-surface exploration by means of bore holes would be necessary in order to prepare a dependable geological section based on which the tunnel level itself can be decided and tunnelling conditions can be prognosticated. Such a programme of drilling can be mounted and taken up during the pre-construction stage. The geological map of area along Pasuvemula tunnel and powerhouse is shown in **Plate 4.4.**

4.4.3 Pennar (Somasila) to Palar reach under Reach-III (RD 692.276 km to RD 906.951 km)

The link canal in this reach initially cuts across the steep easterly dipping quartzite with phyllite inter calations of Bairenkonta Formation. The canal passes through talcose phyllities, micaceous schists and granite gneisses of Peninsular Gneissic Complex running almost collateral and closely to the eastern margin of Cuddapah basin, which has a thrusted contact with the basement rocks of Archaean age. Thereafter, upto RD 881.786 km it passes in basement gneisses, schists and other acid and alkali intrusive rocks with NNW-SSE to ENE-WSW trending foliation with easterly dips of more than 60^{o}. In this reach, the rocks are inferred to have weathered to depths varying from 10 to 18 m from surface as observed from the local open wells. It was opined that execution of the proposed canal in this reach is feasible.

4.4.4 Palar to Cauvery (Grand Anicut) under Reach-III (RD 906.951 km to RD 1210.841 km)

Out of the 303.89 km in this reach, 227.93 km length of the canal passes through Archaean terrain (75%). Of this, 44.20 km (19.39%) of canal length will be completely in cutting, 68 km (29.83%) of canal length will be completely in filling and 115.73 km (50.78%) will be partly in cutting and filling.

Preliminary geo-technical appraisal studies carried out have revealed that no major adverse geological features encountered along the alignment and the proposed alignment is suitable prima facie. Since, the canal falls in the zone–II and III of the seismic zonation map of India as per IS 1897-1984 and number of low to moderate intensity earthquake events have also occurred in the study area, necessary seismic coefficients have to be provided in the construction stage for canal in general and structures in particular.

4.4.5 Foundation investigations along barrage

The Irrigation & C.A.D Department, Govt. of Andhra Pradesh had prepared "Inchampally Joint Project" Report in June, 1988. The para from that Report pertaining to the foundation investigations along dam which is also the location of the proposed barrage is given below.

The drilling operations for the Inchampalli project were done during the years 1955, 1965, 1966 and 1981 to explore the rock levels and taking out the cores of the foundation rock in the bed of Godavari at the site proposed for earthern dam, at spillway and non overflow dam. Exploratory work was done on a large scale at the sites proposed for the dam and spillway. Several trial pits were also excavated for making rapid preliminary assessment of rock levels and analysis of the soil samples. 43 diamond drill boreholes were drilled in the river bed and flanks along the alignment and also along the lines, 300 m upstream and 75 m downstream of the axis to establish the bed rock levels. Out of 43 boreholes drilled, 24 nos along the axis, 12 nos on upstream, 6 nos on downstream. The total depth drilled in the overburden is 139 m and in the rock is 782 m.

According to the logs observed, the overburden consists of alluvium with pebbles and cobbles, gravel and clay. The left abutment and ridges of the river channel have steep slopes at about 80º. The rest of the exposed river section is rocky and jagged. The right bank is terraced with steep side slopes. The top of the bank for 5 chains is quite flat and covered with 1 to 3 metre thick of alluvium. The rest of the banks and right abutment have a gentle slope but the latter rises at steep angle from 65 chain. This section is also covered by the rock talus except between

chains 50 to 60 where the rocks are exposed to rock types encountered in the boreholes are phyllites quartizites and silt stones.

Disturbed soils in situ and U.D. sample in clay were collected and got tested in APERL Hyderabad for their physical and engineering properties. The clay soil met with is of CH and SC type. Water permeability tests were also conducted in diamond drill boreholes to establish the water tightness of the foundations.

15 nos of diamond boreholes were drilled along the alignment upstream and downstream and abutments of spillway channel. The total depth drilled in overburden is 9 m and in rock is 374 m. Water permeability tests were conducted in the boreholes to establish water tightness of foundation rock. According to the logs observed rock is available in the river bed and there is no overburden. The spillway is located in the river bed.

16 nos of diamond core bores were drilled along the alignment downstream and abutments of the non overflow dam. The top depth of overburden is 36 m and rock is 259 m. Water permeability tests were conducted in the bore holes to establish water tightness of the foundations. The overburden consists of clay.

Details of boreholes drilled on the right flank

Sl. No	B.H. No.	Location with reference to dam axis	Year in which reported	G.L.	Recovery %	Total depth (m)	Thickness of overburden (m)	Thickness of weathered rock	Fresh rock begins at depth	Lithology, Structure and remarks
1	20	39.00	1965-66	-	-	22.86	3.66	11.88	15.54	Phyllites
2	1	40.00	1964-65	91.23	-	22.48	5.03	-	-	Soft weathered phyllite. Fresh rock not encountered.
3	13	42.00	1981-82	92.17	-	24.00	1.00	10.00	11.00	Grey Phyllite
4	2	44.00	1964-65	93.52	-	30.33	4.57	-	-	Weathered phyllites. Fresh rock not encountered.
5	14	46.00	1981-82	96.36	-	20.00	5.95	-	-	Weathered phyllites. Fresh rock not encountered.
6	15	48.00	1981-82	99.75	-	17.00	5.30	-	-	Fresh rock not encountered.
7	3	49.00	1964-65	101.5	-	22.57	2.90	-	-	Weathered phyllites. Fresh rock not encountered.
8	16	51.00	1981-82	105.6	-	11.00	3.60	-	-	Disintegrated phyllite powder. Fresh rock not encountered.
9	4	54.00	1964-65	113.1	Nil to 40%	17.42	2.13	-	-	Fragmentary core of weathered quartzite and quartz vein. Fresh rock not encountered (may be shear zone)
10	17	55.00	1981-82	114.4	Nil	16.00	5.20	-	-	Disintegrated phyllite powder. Fresh rock not encountered.
11	18	58.00	1981-82	118.3	Nil	16.00	3.28	-	-	Disintegrated phyllite powder. Fresh rock not encountered.
12	5	60.00	1964-65	123.1	Nil	30.48	1.50	-	-	Soft, talcose phyllite, fresh rock encountered.
13	6	64.00	1964-65	131.1	Nil to 30%	30.48	2.74	-	-	Disintegrated phyllite. Fresh rock not encountered.

Details of trial pits dug of right flank

Sl. No	Trial pit at chainage	Present depth of trial pit	Source	Lithology, Structure and remarks
1	40	5.03	1965-66 report	Soft disintegrated phyllites below a soil cover of 2.9m
2	44	4.50	1964-65 report	Soft disintegrated rock below soil/gravel cover of 1.52 m
3	48	1.00	Observed during 1985-86 F.S.	Laterite
4	49	2.90	1964-65 report	Soft disintegrated phyllite below soil/gravel cover of 1.68 m
5	50	1.00	Observed during 1985-86 F.S.	Laterite
6	51	0.50	Observed during 1985-86 F.S.	Laterite
7	52	1.00	Observed during 1985-86 F.S.	Laterite and white broken quartzites
8	54	2.13	1964-65 report	Weathered, broken, sheared quartzite & quartz veins from surface.
9	56	2.00	Observed during 1985-86 F.S.	Weathered, disintegrated, talcose phyllite below a soil cover of 0.5 m.
10	58	5.00	Observed during 1985-86 F.S.	Soft, disintegrated phyllite exposed below a soil/ bouldery cover of 0.5 m.
11	60	5.64	1964-65 report	Weathered, soft, talcose phyllite below a cover of 1.52 m.
12	64	5.18	1964-65 report	Weathered, talcose phyllite below an overburden of 2.74 m.

4.5 Geophysical investigations

To derive the sub-surface profile of the formations along the link alignment beyond RD 78.35 km, Geophysical investigations of the link canal have been assigned to **National Geophysical Research Institute, Hyderabad**. The objective of NGRI is to carry out geophysical investigations along the Godavari (Inchampalli) – Krishna (Nagarjunasagar) link canal alignment by conducting Vertical Electrical Soundings (VES) at 1.00 km interval to a depth extending to a little beyond the bed level of the canal, to determine the sub-surface lithology and to estimate the depth of bed rock. The investigations covered a length of about 221 km along the main canal starting from RD 78.35 to RD 299.26 km where it outfalls into Nagarjunasagar reservoir and around 21 km along the lead canal i.e. canal interconnecting the link and Kakatiya canal of Sri Ram Sagar Project. These investigations helped in ascertaining the estimated quantities of earth work accurately. The sub-surface profiles as reported by NGRI along the link canal and lead canal are shown in **Plates 4.2.1(1/12) to 4.2.1 (12/12) and 5** respectively**.** The geophysical investigations for the reach between Somasila and Grand Anicut was carried out by Mysore University. The depth of the sub-surface strata profiles given by these institutions were used for computing the earthwork involved at different strata.

4.6 Construction materials investigation

Necessary borrow / quarry area surveys have been carried out for construction materials such as soils for embankments, fine aggregate and coarse aggregate etc. The locations of quarries and borrow areas are shown in **Plates 4.5 (1/8) to 4.5 (3/8).**

Necessary borrow area/quarry surveys have been carried out for construction materials such as (i) soils for embankments by Andhra University, Visakhapatnam, Andhra Pradesh Engineering Research Laboratory (APERL), Hyderabad & NIT, Tiruchirapalli (ii) fine and coarse aggregates by JNTU college of Engineering, Hyderabad, APERL, CSMRS etc. The location of quarries/ borrow areas are shown in **Plate 4.5 (4/8) to (8/8).**

4.7.1 Soils

Borrow Area Survey along the link canal alignment form part of the studies required for the feasibility report. For this purpose, the work of carrying out the borrow area surveys along the proposed link alignment was entrusted to **Andhra University, Visakhapatnam, Andhra Pradesh**.

The objective of this survey is to carry out the borrow area Survey along the link canal alignment at selected locations identified as potential borrow areas in the vicinities of embankment reaches between R.D 78.35 km and RD 299.26 km of the link canal. Representative bulk soil samples from the trial pits excavated have been collected in the potential borrow areas and laboratory tests have been conducted in order to ascertain their suitability for the construction of canal embankment.

Soil samples have been collected from trial pits excavated in the potential borrow areas at 500 m interval in general or change of strata. The number of soil samples to be collected for carrying out laboratory investigations have been decided based on inferences arrived by the visiting field party in consultation with NWDA. The following tests have been conducted in the laboratory for obtaining the required soil parameters.

a) Grain size analysis
b) Atterberg limit
c) Proctor density
d) Specific gravity
e) Direct shear
f) Triaxial shear
g) Chemical analysis

The required borrow areas have been identified along the entire length of the alignment. Fourteen soil samples pertaining to the reach from Kinnerasani to Nagarjunasagar have been collected and tested in, Andhra University, Visakhapatnam. The test results indicate that soils from most of the identified borrow areas are generally suitable for

embankment. It is estimated that about 29.34 x 10^6 m^3 of earth is available from these identified areas. The average lead is around 2 km**.**

Thirty five borrow areas have been identified along the entire length of the reach from Nagarjunasagar to Somasila from which soil samples have been collected and tested in Andhra Pradesh Engineering Research Laboratory (APERL). The test results indicate that soils from most of the identified borrow areas are generally suitable for embankment. Out of 35 soil samples, 4 nos. in CH, 7 nos. in CI, 6 nos. in CL, 1 no. each in GC, GM & GM-GC, 13 nos. in SC and 2 nos. in SM. Use of CH soil in embankment is to be avoided. It is estimated that about 35.75 x 10^6 m^3 of earth is available from these quarries. The average lead is around 10 km.

It is considered that the part of earth excavated for the link canal could be used economically for forming embankments and for other filling works. 25 borrow areas were identified along the entire length of reach from Somasila to Grand anicut. Suitability of the earth from borrow area have been tested at National Institute of Technology, Tiruchchirappalli. The test results of soil samples collected from borrow areas are furnished in **Annexure 4.1.1 to 4.1.3.** The test results indicate that soils from most of the identified borrow areas are generally suitable for embankment. It is estimated that about 64.40 Mm^3 of earth is available from these areas. The average lead is about 500 m. The reach wise requirement and availability of earth is furnished in **Annexures 4.2.1 to 4.2.3.**

4.7.2.1 Fine aggregate

Consultancy for the construction materials survey and laboratory testing of coarse and fine aggregate samples for ascertaining their suitability as construction materials for the proposed structures along the canal alignment is awarded to the **Department of Civil Engineering, College of Engineering, Osmania University, Hyderabad**.

The objective is to carry out the construction materials survey and collection of fine aggregate samples from the identified prospective

quarry sites in the project area and testing the samples in the laboratory at Osmania University, Hyderabad to ascertain their suitability for use as coarse and fine aggregates respectively for the proposed structures along the Godavari (Inchampalli) – Krishna (Nagarjunasagar) link canal reach.

The following tests have been carried out for construction materials by Osmania University, Hyderabad.

i) Specific Gravity
ii) Grading & Fineness Modulus
iii) Silt & Clay content
iv) Organic Impurities
v) Petrographic analysis

Twelve sites have been identified as potential sand quarries for the entire length of the link canal from Warangal–Mulug road crossing to Nagarjunasagar. The details of sand quarry sites are given in **Annexure 4.3.** These have been identified in the rivers Hallia, Akeru, Vattivagu, Muneru, Palleru, Tettevai vagu, Musi etc. The lead varies from 5 km to a maximum of 50 km. Samples have been collected one each from each site and were tested in the laboratories of Osmania University for their suitability. The test results and availability of sand samples pertaining to identified sand quarries (Reach I) are furnished in **Annexure 4.3.1.** The total sand available from all the 12 quarries is about 41.24 Mm^3. The test results indicate that sand from most of the identified quarry sites are grossly homogenous and can be used for construction from 8 out of 12 quarries so identified.

Three sand quarries have been identified in the rivers Haliar, Konkeru and Musi from which sand can be obtained and used for the initially upto 210 km. The average leads from the above quarries are 70 km, 58 km and 77 km to the respective nearby reaches of the link canal. Another 8 sand quarries have been identified for the remaining portion of the canal with an average lead varying from 6 to 40 km from various quarries to the respective reaches. Among the 11 quarries, three representative samples were tested at APERL. The total sand is about

2.95 x 10^6 m^3**.** The test results of sand samples pertaining to identified sand quarries (Reach II) are furnished in **Annexure 4.3.2.**

12 probable quarry locations were identified along the entire length of the reach from Somasila - Grand Anicut surveyed by Central Soil & Materials Research Station (CSMRS) to ascertain the availability and suitability of the materials available from these quarries for use in the proposed construction works. These samples were collected and tested at CSMRS, New Delhi. The test results reveal that all the sand samples collected from all the 12 quarries conform to the specification requirements as per IS:383 – 1970 and can be used as fine aggregates in concrete. The test results and availability of sand samples pertaining to identified sand quarries (Reach III) are furnished in **Annexure 4.3.3.**

4.7.2.2 Coarse aggregate

The Department of Civil Engineering, College of Engineering, Osmania University, Hyderabad was engaged for providing consultancy for the construction materials survey and laboratory testing of coarse and fine aggregate samples for ascertaining their suitability as construction materials for the proposed structures along the canal.

The objective is to carry out the construction materials survey and collection of coarse aggregate samples from the identified prospective quarry sites in the project area and testing the samples in the laboratory at Osmania University, Hyderabad to ascertain their suitability for use as coarse and fine aggregates respectively for the proposed structures along the Godavari (Inchampalli) – Krishna (Nagarjunasagar) link canal project.

The following tests have been carried out for construction materials by Osmania University, Hyderabad.

i) Specific Gravity
ii) Water Absorption
iii) Aggregate Crushing value
iv) Aggregate Impact value
v) Los-Angeles Abrasion value

vi) Soundness Loss value (5 cycles)
vii) Petrographic analysis

Fifteen stone quarries have been identified in the vicinity of link canal, which cumulatively yield 76.32 Mm^3 of stone. The samples collected were tested in the laboratories of Osmania University. The average lead from different quarries varies from 5 km to 50 km to the respective canal reaches.

Fourteen stone quarries have been identified in the vicinity of reach from Nagarjunasagar to Somasila of link canal alignment, which cumulatively yield 59.8×10^6 m^3 of stone . Quarry No. 1 to 6 are in the vicinity of the existing NSRBC and stones from these quarries were used for the construction of NSRBC. Since the proposed link canal is close to the existing NSRBC, the same quarries can be utilised for the construction of the initial reach of N-S reach of the proposed link canal alignment. Four representative samples from the remaining 8 quarries were tested at APERL and were found generally suitable for the construction work. The average lead from different quarries varies from 9 to 36 km to the respective reaches.

The total requirement of coarse aggregate for various works of the reach from Somasila to Grand anicut is estimated to be 57.40 lakh m^3 .In all, 13 coarse aggregate quarries have been identified in the vicinity of the reach from Somasila to Grand anicut of link canal alignment, which may cumulatively yield more than the requirement. The samples from 13 quarries were collected and tested at CSMRS, New Delhi of which materials from 11 quarries are found generally suitable for the use as coarse aggregate in concrete for wearing as well as non wearing surfaces construction work. The samples of other two quarries are suitable for use in concrete for non wearing surfaces only. The test results of coarse aggregate samples pertaining to identified stone quarries are given in **Annexures 4.4.1 to 4.4.3.** Such coarse aggregate samples having crushing and abrasion value more than 30% should not be used in wearing surface as in canal lining or top surface in barrage floor/glacis. It is also suggested that the alkali reactivity test on coarse aggregate of all quarries should be tested. If found alkali reactive, then these

aggregate should be used with slag cement or micro-silica. or else the quarry's coarse aggregate is to be avoided.

4.7.3 Bricks

Soils of suitable quality for manufacture of bricks and tiles for use in building construction are available along the entire length of canal alignment. Warangal, Suryapet and Nalgonda towns are famous for good quality bricks. Gopalapuram village near Pamur in Prakasam district is famous for good quality of bricks.

It was observed during field surveys that sufficient quantity of bricks of desired quality could be obtained from nearby areas along most of the length of the canal alignment.

4.7.4 Cement and steel

Cement manufactured by reputed companies located in the vicinity at Warangal, Suryapet and Nalgonda is proposed to be used. Cement and steel can be received at the railway stations located near the canal alignment i.e Warangal, K.Samudram and Nalgonda and transported to the site of construction.

Cement plants by reputed companies are located in the vicinity at Karampudi, Pidiguralla, Arakkonam, Uthiramerur and Ariyalur. Cement and steel as per project requirement can also be received at the railway stations located near the canal alignment i.e. Kottagudem, Khammam, Miryalaguda, Macherla, Pidigurala, Vinukonda, Kurichedu, Donakonda, Ongole, Singarayakonda, Kavali, Kovur, Nellore, Venkatagiri, Srikalahasthi, Tiruttani, Arakkonam, Kancheepuram, Tindivanam, Tirukoilur, Ulundurpettai, Vridhachalam, Ariyalur and Tiruchchirapalli and transported to the site of construction.

4.8 Soil Surveys - mapping of existing landuse / land cover and irrigability

4.8.1 Soil

Government of erstwhile A.P. has got conducted the soil surveys of SRSP command area through NRSC. Hence, NWDA has not taken up

the soil surveys for this command area under Inchampalli–Nagarjunasagar link canal. The details of soil and land irrigability classification of command under SLBC available from Government of Andhra Pradesh are taken in this report. The details are discussed in Chapter–8. For the present DPR, the soil surveys of the proposed command area under Gottimukkala feeder branch have not been carried out. Soil map of the command area is appended as **Plate-4.6**. Red earths, red sandy soils, clay loamy soil, brown clay loamy soil, black clay loamy soil, alluvial soil and black cotton soils etc. are the predominant soils available in the command. No systematic soil survey, land use/land cover and irrigability status of the command area has been carried out at present. However, as per the details available from Department of Agriculture, Government of Tamil Nadu, the soils in the proposed command area in the reach from Somasila to Grand anicut are mainly falling under five soil classification groups viz., Haplustalfs, Rhodustalfs, Ustifluvents, Chromusterts and Ustropepts. Reach wise soil map of the command area is appended at **Plate 4.6.1 (1/3 to 3/3) to 4.6.3 (1/ to 3/3).**

4.8.2 Land use/ land cover mapping

The work of preparation of thematic maps of i) existing land use/land cover and ii) soil and land irrigability of the entire new command area of 168017 ha of reach between Nagarjunasagar and Somasila was entrusted to the National Remote Sensing Centre (NRSC), Hyderabad. The NRSC has utilised LISS-II data obtained through Indian Remote Sensing Satellite (IRS-1B) for the thematic mapping of the command area. In addition to the thematic mapping, NRSC has also done studies for the land evaluation for crop suitabilities and incorporated the same in the report. The thematic maps of the land use/land cover and land irrigability prepared and supplied by the NRSC were utilised for planning of the command area. Irrigable tracts of land were delineated and demarcated on 1:50000 land irrigability maps which facilitated reliable identification of the irrigable area under each of the branch canals.

4.8.3 Land use classification

The land use/ land cover classification details of the command area of the link canal are generated from the satellite remote sensing data. The taluk wise area falling within the command has been computed after accounting for the forest areas, from the toposheets (Scale 1:50000) procured from Survey of India.

4.8.4 Land irrigability classification

Land irrigability classification is further grouping of the irrigable soils into land irrigability classes considering the slope, sub-surface grading, drainage, depth of water table below ground level etc. Land suitable for irrigation is grouped under classes 1 to 4 according to their limitations. Lands not suitable for irrigation are grouped under classes 5 and 6.

Soils in the proposed command area are mainly falling under four orders viz. Inseptisols, Alfisols, Vertisols, and Extisols. About 63% of the gross command area is covered by Inseptisols, 26% by Alfisols, 8% by Vertisols and the remaining 3% by Extisols. **Table 4.3** shows physiography and soil classification in the proposed new command area enroute in the N-S reach of the link canal.

The available soils of the command area grouped according to the physiographic units have been classified into soil irrigability classes considering various soil characteristics such as soil depth, texture, permeability, moisture holding capacity, sub-surface cover, salinity, subsoil drainage, erosion status etc.

Table 4.3

Physiography and soils in the proposed command area enroute the Godavari (Inchamapalli barrage) - Cauvery (Grand Anicut) link canal

Soil Mapping unit	Soil Classification	Area (km^2)
C	LANDSCAPE OVER COASTAL ALLUVIUM	

C1	Coastal plane	Fine undertic Ustochrepts	27.425
C2	Back swamps	Fine Aquic Ustochrepts	7.975
C3	Beach ridges	Typic Ustipsaments	5.775

G LANDCAPE OVER GRANITE/GRANITIC-GENISSES/ SCHITST / PHYLITES

G1	Residual hills/Inselbergs	Loamy-skeletal lithic/typic Ustochrepts	107.325
G2	Pediment		
G2.1	With moderate erosion	Loamy-skeletalTypic Ustochrepts Loamy-skeletal Typic Rhodustalfs	287.025
G2.2	With severe erosion	Loamy-skeletal Typic Ustothents Loamy-skeletal Typic Ustochrepts	103.425
G3	Buried pediment		
G3.1	Nil to slight erosion	Fine Typic Haplusters	
G3.2	Moderate erosion	Fine Loamy Typic Ustochrepts Fine Vertic ustochrepts	41.775
G4	Weathered pediplain		
G4.1	Nearly level	Fine typic Rhodustalfs	230.440
G4.2	Gently sloping		
G4.2.1	With slight erosion	Fine loamy typic Haplustalfs Fine Typic Rhodustalfs/ Haplustalfs	636.150
G4.2.2	With moderate erosion	Loamy-skeletal Typic Ustochrepts Fine loamy Typic Haplustalfs	622.725
G4.2.3	With severe erosion	Loamy-skeletal Typic Ustochrepts	104.425
G5	Buried pediplain		
G5.1	Nearly level	Fine Typic Haplustalfs Fine Vertic ustochrepts Fine Typic/Vertic ustochrepts	280.900

G5.2	Gently sloping	Fine Loamy Typic ustochrepts	171.225
G6	Valley fill		
G6.1	Salt affected		
G6.1.1	Moderate affected	Fine typic (Saline-Sodic) Ustochrepts	221.025
G6.1.2	Severe affected	Fine (Saline-Sodic) typic Ustochrepts	186.500
G6.2	Non Salt-affected	Fine Typic/vertic Ustochrepts Fine loamy Fluventic ustochrepts	600.400
L	LATERIC LANDSCAPE		
L1	Weathered pediplain		
L1.1	Nearly level	Fine loamy typic Rhodustalfs	57.200
L1.2	Gently sloping	Loamy skeletal typic Ustochrepts/ Ustrothents	54.950
		Total	**3766.690**

The final irrigability classification details of the command area in the N-S reach of the Godavari (Inchampalli) – Cauvery (Grand Anicut) link canal obtained by the above methodology are given in **Table 4.4.**

Table 4.4

Irrigability classification of the command area of the Godavari (Inchampalli) -Cauvery (Grand Anicut) link canal

Land irrigablity class	Characteristics	Limitations for sustained use under irrigation	Soil mapping units*	Area (lakh ha)
1	Nearly level, deep rooting zone, good permeability, favourable texture and moisture holding capacity.	Few limitations	-	-
2	Very gentle slopes,			

	less than ideal soil depth, texture and permeability, moderate salinity/ alkalinity, unfavourable topography and drainage conditions.	- Moderate - Limitations	C1,G3.1, G3.2, G4.1, G4.2.1, G4.2.2, G5.1, G5.2	- 2.03
3	Gentle slopes, unfavourable soil depth, texture and permeability, moderate to severe salinity/ alkalinity, unfavourable topography or drainage conditions	- Severe limitations	G2.1,G4.2.3, G6.2, L1.1, L1.2	- 1.10
4	Moderately steep slopes, unfavourable soil depth, texture, permeability, severe salinity, very unfavourable topography and drainage conditions	-Very severe limitations	-C2,G2.2, G6.1.1	- 0.33
5	Temporarily not suitable for sustained use under irrigation	-	-	
6	Not suitable for sustained use under irrigation	-	C3, G1, G6.1.2	- 0.30
			Total	**3.76**

*The alphabets C, G and L indicate different physiographic units of Coastal alluvium, Granite/Gneiss and Laterites and the numbers 1,2,3 etc. indicate sub-classes within the same physiographic unit.

4.8.5 Land evaluation for crop suitability

The land evaluation for crop suitability is the process of evaluating the potential of the land for growing specific crops. The land under each mapping unit is independently evaluated for the principal crops grown in the area, viz. paddy, cotton, tobacco, sunflower, chillies, and soyabean to assess their suitability or otherwise for sustained production. The Food and Agricultural Organisation (FAO) frame work which involves pragmatic classification was followed in the evaluation of the land in the command area in Nagarjunasagar-Somasila reach of the Godavari (Inchampalli) – Cauvery (Grand Anicut) link and recommendations on crop suitabilities for the classes of land found in the command area were also included in the report prepared by NRSC. The scheme of evaluation envisages two orders – one "suitable" (S) and the other "not suitable" (N). The suitability order is further divided into four classes viz, (S1) highly suitable without any limitations, (S2) suitable with slight limitations, (S3) moderately suitable with moderate limitations, and (S4) marginally suitable with severe limitations. The soil suitability rating for different principal crops grown in the area as assessed by NRSC and indicated in the report are presented in **Table 4.5.**

Table 4.5

Soil suitability ratings for principal crops grown in the command area

	Paddy	Cotton	Tobacco	Sunflower	Soyabean	Chillies
G1	N	N	N	N	N	N
G21	N	S4	N	S3	N	N
G22	N	N	N	S4	N	N
G31	S1	S1	S2	S2/S3	S1	S1
G32	S2	S2	S2	S2/S3	S1	S2
G41	S2	S3	S1	S2	S1	S3
G421	S2	S3	S1	S2	S1	S3
G422	S3	S4	S2	S3	S2	S4
G423	S3	S4	S3	S3	S3	S4
G51	S1	S1	S2	S2/S3	S1	S1
G52	S2	S2	S2	S2/S3	S1	S2
G611	S3	N	N	N	N	N

G612	N	N	N	N	N	N
G62	S1	N	N	N	N	N
L11	S2	S3	S2	S3	S3	S2
C1	S1	S3	N	S4	S3	S4
C2	S3	N	N	N	N	N
C3	N	N	N	N	N	N

S1= Highly suitable without any limitations;
S2= Suitable with slight limitations;
S3= Moderately suitable with moderate limitations;
S4= Marginally suitable with severe limitations; N= Not suitable.

4.9 Drainage survey

The proposed enroute command area is well drained by rivers/streams like Maner, Muneru, Akeru, Musi, Palleru, and Hallia and also by a number of major/minor drains. As such, the proposed command area is not likely to encounter any serious drainage problem. However, certain provisions are made in the estimate for providing drainage facilities in the command, though no detailed surveys were undertaken for the purpose. The available natural drainage system in the command area in the form of rivers, streams, nallas etc. is shown in **Plate-11**. Since the branch canals and major distributaries are planned as ridge canals, no major drainage problem is anticipated in the command area.

The proposed enroute command area is well drained by rivers/streams like Venkatagiri, Swarnamukhi, Arani Ar, Korttalaiyar, Cooum, Varahanadi, Palar, Cheyyar, Ponnaiyar, Gadilam, Manimuktha nadhi, Gomukha nadhi and Vellar and also by a number of major/minor drains. As such, the proposed command area is not likely to encounter any serious drainage problem. Since the branch canals and major distributaries are planned mostly as ridge canals, and adequate CD. Works are provided wherever necessary, no major drainage problem is anticipated. However, certain provision is made in the estimate for providing drainage facilities in the command utilising the information available on natural drainage system, though no detailed surveys were undertaken for the purpose.

4.10 Communication surveys

All the important structures of the Inchampalli – Nagarjunasagar link canal are approachable by pucca/kachcha roads. The National High way No. 9 and the Hyderabad–Guntur Railway line connecting Vijayawada pass through a part of the proposed command area. All the important villages/towns situated along the canal alignment and in the command area are well connected by telephone lines, power lines and wide network of roads. The major communications available in the area at present are shown in **Plate 11**. There can be further improvement in the communication system in the command area in the course of development in future. Inspection roads of major branch canals in the command area would lead to further improvement in the communication system.

All the important structures of the Godavari (Inchampalli) – Cauvery (Grand Anicut) link canal are approachable by pucca / kachcha roads. The National High way No. 9 Hyderabad – Vijayawada road and the South Central Railway line connecting Khammam – Vijayawada pass through the north eastern part of the proposed command area. The National High way No. 5 and the South Central Railway line connecting Chennai and Vijayawada passes through the eastern part of the proposed command area. The National Highways No. 4 & 45 and the South Central Railway line connecting Srikalahasthi to Renigunta; Southern Railway line connecting Arakkonam to Tiruttani, Arakkonam to Katpadi, Villupuram to Tirukoilur, Salem to Vridhachalam, Vridhachalam to Ariyalur pass through the proposed command area. All the important villages/towns situated along the canal alignment and in the command area are well connected by telephone lines, power lines and wide network of roads. There can be further improvement in the communication system in the command area in the course of development in future. Inspection roads of major branch

canals in the command area would lead to further improvement in the communication systems.

4.11 Hydrological and meteorological investigations

All the hydrological and meteorological data available in various state and central organisations have been collected by NWDA for carrying out the water balance studies. The details of these stations are given in the following paragraphs.

There are four Gauge and Discharge stations nearer to the link canal in the basins connected with the link canal. The Perur G&D site on Godavari, Somanpalli on Maner, Damarcherla on Musi and Pondugala on Krishna river. In addition to the above, outflows of SRSP and Nagarjunasagar project are also available.

4.11.1 Runoff

There are a number of gauge & discharge stations on the main Godavari and Krishna rivers as well as on their various tributary rivers maintained by CWC and the respective States.

There are four gauge and discharge sites in the basin of streams between Gundlakamma and Pennar, out of which one site at V.G. Palem on Musi River is maintained by CWC and the remaining three sites at Palleru - Bitragunta Anicut, Rallapadu reservoir and Lower Upputeru Anicut are maintained by the Government of Andhra Pradesh. The required data of these stations have been collected.

There are three gauge and discharge sites viz. Somasila, Sangam Anicut and Nellore Anicut in the Pennar delta sub-basin, across Pennar river. All the three G & D sites are maintained by the Government of Andhra Pradesh. The Nellore G&D site is maintained by the Central Water Commission (CWC).

There are five gauge and discharge sites viz. Naidupeta, Tambarapakkam, Kesavaram Anicut, Vallur Anicut and Korattur Anicut in the basin area covered by the Streams between Pennar and Palar. The Naidupeta G & D site is maintained by Central Water Commission (CWC) and the remaining four G & D sites are maintained by the Government of Tamil Nadu.

There are ten gauge and discharge sites viz. Arcot, Magaral, Avarankuppam, Chengalpattu, Uthiramerur, Aliabad, Palar, Poini, Cheyyar and Thandarai in the Palar basin. The first four G & D sites are maintained by Central Water Commission and the remaining six sites are maintained by the Government of Tamil Nadu.

There are 21 gauge and discharge sites viz. Gummanur, Valavachanur, Villupuram, Kodalaiyattur, Sattanur, Krishnagiri, Nedungal Anicut, Pambar, Tumbalahalli, Sulagiri, Tirukoilur, Ellis Choultry Anicut, Soravanur Anicut, Willingdon reservoir, Memattur, Vridhachalam, Pelandurai, Toludur, Manimuktha reservoir, Gomukhi reservoir and Shatiatope Anicut in the basin covered by the Streams between Palar and Cauvery. The first four G & D sites are maintained by Central Water Commission and the remaining 17 sites are maintained by the Government of Tamil Nadu. In Cauvery basin, a number of G&D sites are set up by CWC and the State Govts. on the main river and its tributaries.

4.11.2 Climate

The summer season is from March to May, the monsoon is from June to December and the winter is from January to February in the vicinity of the command area. There are IMD stations at Khammam, Hanamkonda in the first Reach. There are three IMD observatories namely, Ongole, Nellore and Cuddapah in and around the command area in the reach between Nagarjunasagar and Somasila.

In the third reach between Somasila and Grand Anicut, there are five IMD observatories namely, Nellore, Chennai, Vellore, Cuddalore and Kallakurichi in the vicinity of command area. The data on rainfall,

temperature, relative humidity, wind speed, cloud cover, etc. are available at all these observatories.

4.11.3 Rainfall

There are several rain gauge stations located in and around command area. There are 25 rain gauge stations in and around the command area of the reach between Nagarjunasagar and Somasila. The rainfall data for these rain gauge stations are available for varying periods.

There are 28 rain gauge stations in and around the command area of the reach between Somasila and Grand Anicut. These are at Rapur, Venkatagiri, Srikalahasti, Pitchattur, Nagalapuram, Ponneri, Poondi, Tiruvallur, Poonamallee, Kancheepuram, Cheyyar, Uthiramerur, Chengalpattu, Tiruporur, Gingee, Marakkanam, Villupuram, Tirukoilur, Panruti, Ulundurpettai, Tittagudi, Vridhachalam, Shatiatope, Cuddalore, Cheyyur, Tindivanam, Puducherry and Vidur. The rainfall data are available for varying periods from 1901-02 to 2013-14.

4.11.4 Temperature

The monthly average maximum and minimum temperatures observed at Cuddapah observatory are 40.3^0 C in the month of May and 19.1^0 C in the month of December respectively

The mean daily maximum and minimum temperatures observed at Nellore observatory are 39.9^0 C in the month of May and 20.7^0 C in the month of January respectively. The mean daily maximum and minimum temperatures observed at Chennai observatory are 38.2^0 C in the month of May and 20.8^0 C in the month of January and for Vellore observatory are 39.1^0 C in the month of May and 17.8^0 C in the month of January. The same observed at Kallakurichchi observatory are 38.6^0 C in the month of May and 19.8^0 C in the month of January respectively.

4.11.5 Relative humidity

The maximum and minimum values of relative humidity observed at the three observatories in the reach from Nagarjunasagar to Somasila are 84% and 36% respectively.

The maximum and minimum values of relative humidity observed at the five observatories in the reach from Somasila to Grand Anicut viz. Nellore, Chennai, Vellore, Cuddalore and Kallakurichchi vary from 88% to 41% respectively.

4.11.6 Wind speed

The command area is influenced by winds from the south - west during the monsoon season. The maximum wind velocity is 11.6 km/hr in June and the minimum is 4.30 km/hr in December

The command area is influenced by winds from both south - west and north - east monsoon seasons. The maximum wind velocity is 10.2 km/hr in June and the minimum is 2.8 km/hr in October.

4.11.7 Cloud cover

The sky is heavily clouded during the south-west monsoon. During remaining part of the year, clear or lightly clouded sky prevails. The maximum cloud amount is 6.7 oktas in the month of July and minimum is 1.5 oktas in the month of March.