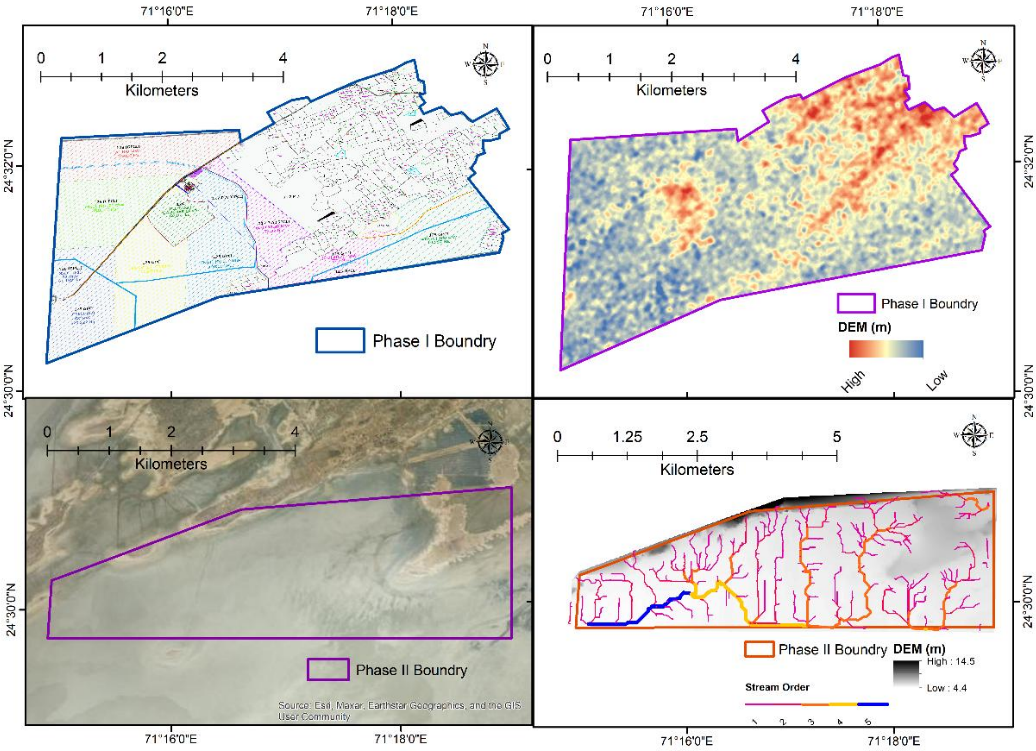
IITR Cons. Project No.WRD-6026/24-25 **Final Report**

To Study & Carry out Hydrology Survey and Flood Assessment/Disaster Management at Proposed GPCL- 700 MW Raghanesda Ultra Mega Solar Power Park Phase-II at Village Raghanesda, Taluka-Vav, Dist-Banaskatha (Gujarat)

Sponsored by

GUJARAT POWER CORPORATION LIMITED, UDHYOG BHAVAN, SECTOR-11, GANDHINAGAR, GUJARAT



Submitted by

Prof. Ashish Pandey (P.I.) and Dr. U.C. Chaube (Consultant)

DEPARTMENT OF WATER RESOURCES DEVELOPMENT AND MANAGEMENT
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE (UTTARAKHAND)-247667, INDIA
E-mail: ashish.pandey@wr.iitr.ac.in

July 2025

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ROORKEE (UTTARAKHAND)-247667, INDIA
E-mail: ashish.pandey@wr.iitr.ac.in

July 2025

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EXECUTIVE SUMMARY

M/s GPCL has issued a LOA to IIT Roorkee vide letter dated 1.10.2024 for the following work stating therein the scope of work and the terms and conditions acceptable to IIT Roorkee.

"To study and carryout hydrological survey and flood assessment/disaster management at proposed GPCL-700MW Raghanesda Ultra Mega Solar Power Park, phase II at village Raghanesda,Taluka-Vav, District Banaskatha (Gujarat). "

The Radhanesda Solar Park is located about 271 km from Ahmedabad in North West direction. The Raghanesda Solar Park Phase II(RSPP-II) is spread over 1206 ha south of the existing RSP Phase I. The study consists of two parts:

Part A: Control of Flooding and Waterlogging in Phase II area
Part B: Management of Flood Disaster

REVIEW OF PREVIOUS TWO STUDIES OF PHASE I

In the past, two studies of phase I (1407 ha) of the solar park have been carried out by IIT Roorkee. A brief review of these two studies is given in i) Annexure I for the first study carried out in 2016, and ii) Annexure II for the second study carried out in 2023.

First Study (Annexure I): DEM based topographic study of the area was carried out. Frequency analysis of 1-day annual maximum rainfall series was carried out. Isopluvial maps of the area were analysed. Design depth of flooding in the vicinity of the plant has been based on 310 mm (24 hr rainfall corresponding to 50 year return period as obtained by isopluvial maps). Focus of the study was to raise FGL in various blocks to control external flooding. Earth cut and fill analysis was done, and FGLs were worked out. Internal drainage in each block was designed. Water demand during the construction and operation stages was estimated. The primary source of water is the Gadsisar branch canal of Sardar Sarovar Narmada Nigam Limited (SSNNL). Surface and groundwater quality tests show higher values than the WHO and BIS standard limits, and therefore, the water is unacceptable for drinking purposes. For further details, refer to Annexure I and the IIT Roorkee report of 2016

Second Study (Annexure II): During the intervening period, an earthen embankment (16.394 km) along the boundary of the phase I area was constructed. The solar park experienced flooding in the July and August months of 2022 and then again in June 2023(Biparjoy Cyclone). Considering the inadequacy of pumps in rapid dewatering and the resulting rise in water level inside plant areas. The embankment had to be cut by developers at 12 locations due to heavy waterlogging in solar plants. FGLs recommended in the earlier study (2016) were used as a guide to approximate the safe levels in developers' plots to avoid flooding. The design depth of flooding was again worked out. Considering land development within the solar park, it was recommended that solar panels, roads, electric cables, etc., should be around 0.6 m above the finished grade level.

Measures to control flooding in each developer's plot (box culverts, pipe outlets with stop logs) were spelled out. Several other specific recommendations for each developer's plot were made. For further details, refer to Annexure II and the IIT Roorkee report of 2023.

PHYSICAL FEATURES AND FIELD VISIT TO PHASE II STUDY AREA

Field visits were conducted from 18.1.25 to 21.1.25 by the IIT Roorkee team, along with the Engineers of GPCL and SECL. A meeting was held in the Gandhinagar office of Gujarat Power Corporation Ltd (GPCL) on 18th January 2025. M/s GPCL briefed about the flooding that took place in the solar park area in 2023 and 2024. A brief discussion took place about the existing flood embankment on the boundary of the phase I park area, bank cutting, and planning of box culverts in the embankment. Visual depiction of the Phase I embankment and site condition of the Phase II area is given in photographs in Chapter 2.

The widening (9m top width) and strengthening works (retaining wall at toe of embankment on either side) are in progress. Table 2.6 in Chapter 2 provides the location and size of box culverts in the phase I embankment. This includes 6 box culverts on the south side embankment (5 culverts of 3 cells, each having a width of 8.6m, and 1 box culvert of 6 cells having a width of 8.6m. Each cell has 1.5m×3.0m size.

Phase II area is South of the Phase I area. There is a 50 m buffer zone between the southern boundary of Phase I and the northern boundary of Phase II. The digital elevation model study of the Phase II area has been discussed in Chapter 3. Spot levels were provided by GPCL for the area within the boundary of Phase II land. ARC-GIS software was used to prepare the DEM. Stream network has been generated, and boundaries of sub-catchments have been delineated. Since observed topographic data were not available for the area surrounding the phase II boundary, SRTM data was downloaded, and a stream network in the vicinity area was also generated.

RAINFALL ANALYSIS AND DEPTH OF FLOODING

1-Day annual maximum rainfall series was constructed for Banaskantha for 54 years (1971-2024), and EV Type I probability distribution was applied. 1-day rainfall has been converted to 24-hour rainfall using a factor of 1.15 as per guidelines of the Central Water Commission (Flood Estimation Report for Luni Sub Zone-1a). Isopluvial maps for subzone 1a of the Luni subzone are available for 24-hour rainfall of 25-year, 50-year, and 100-year return periods. The 24-hr rainfall values of 25 years, 50 years, and 100 years return periods (as per isopluvial map) and those derived from the frequency analysis of 1-day annual maximum rainfall data of 54 years at Banaskantha are compared

Analysis of 2-day maximum annual rainfall:

India Meteorological Department (IMD) has developed a new daily gridded rainfall data set all over India at a spatial resolution of 0.25° × 0.25° (approximate 25 km × 25 km). Twelve years of daily rainfall data (2012 to 2023) for the grid in which the Radhanesda Solar Park area lies has been obtained from the IMD website. This data has been used to prepare an annual 2-day max. rainfall series. For the same period (2012 to 2023), frequency analysis of 2-day annual maximum rainfall data at Banaskantha has also been carried out.

Design depth of flooding in Phase II area :

Considering future land development in phase II of the solar park, adopting a 2-day rainfall of 586.34 mm is recommended as the design depth of flooding inside the solar park. Solar panels, roads, electric cables, etc, should be around 0.6 m above the finished grade level.

DESIGN FLOOD IN PLOTS OF PHASE I AND SUB-CATCHMENTS OF PHASE II

The solar plants GSECL(F2), ENGIE SJVNL, and TPREL have box culverts through which the stormwater will be let out on the south side. This runoff needs to be carried safely to the low-lying area in the southwest corner side so that the phase II area is protected from the phase I runoff entering into phase II.

Similarly, storm runoff from the tributary sub-catchments of the Phase II area needs to be safely carried to low-lying areas beyond the west side of Phase II.

Therefore, it is necessary to estimate the design flood in solar plant areas (at the location of box culverts) of Phase I and in the sub-catchments of Phase II.

Basis for estimation of design floods. Floods corresponding to a 25-year return period, such as storm rainfall, are taken as a design flood. The modified Rational method is used to estimate flood. Design flood in the catchment (2.5708 km^2) of a nala lying in the upland beyond the North-East side of phase I has been estimated in the previous study (IITR 2023). This flood has been used to work out specific discharge (flood discharge per unit area). The specific discharge value is then used to calculate flood discharge in bunded plant areas of GSECL(F2), ENGIE, SJVNL, and TPREL of phase I and in sub-catchments of phase II on a contributing area basis.

Specific flood discharge: Specific discharge corresponding to 25 year flood from the catchment of 2.5708 km^2 is calculated as 3.54 m^3/sec/ km^2 or 0.0354 m^3/sec/ha.

Table 5.3 Design flood in the solar plant areas of Phase I

Solar plant	Plot area (ha)	Specific flood m^3/sec/ha	Flood, m^3/sec	Cumulative flood
TPREL	192.57	0.0354	6.817	6.817
SJVNL	176.2	0.0354	6.237	13.054
ENGIE	380.0	0.0354	13.452	26.506
GSECL(F2)	129.6	0.0354	4.588	31.094
Phase I End channel to outfall				31.094

Design flood in sub-catchments of Phase II: At present, plot boundaries within Phase II area are not demarcated. Therefore, flood discharge at the outlets of sub-catchments has been estimated as shown in the table below.

Table: Design flood discharge at the outlets of sub-catchments

Sub-catchment	Area (ha)of sub-catchment	Specific flood m^3/sec/ha	Flood m^3/sec	Cumulative flood
1	129.2	0.0354	4.574	4.574
2	161.55	0.0354	5.719	10.293
3	192.46	0.0354	6.813	17.106
4	186.31	0.0354	6.595	23.701
5	115.38	0.0354	4.084	27.785
6	302.15	0.0354	10.696	38.481
7	88.2	0.0354	3.122	41.603
Phase II End channel to outfall	1175.24			41.603

LAYOUT OF MAIN DRAINS

In chapter6 , control of flooding and hydraulic design of the main drains in Phase I and Phase II are discussed. **It is important to note that only technical possibilities have been explored in this report.**

The figure below shows the layout of the main drains of Phase I and Phase II and the location of outfalls

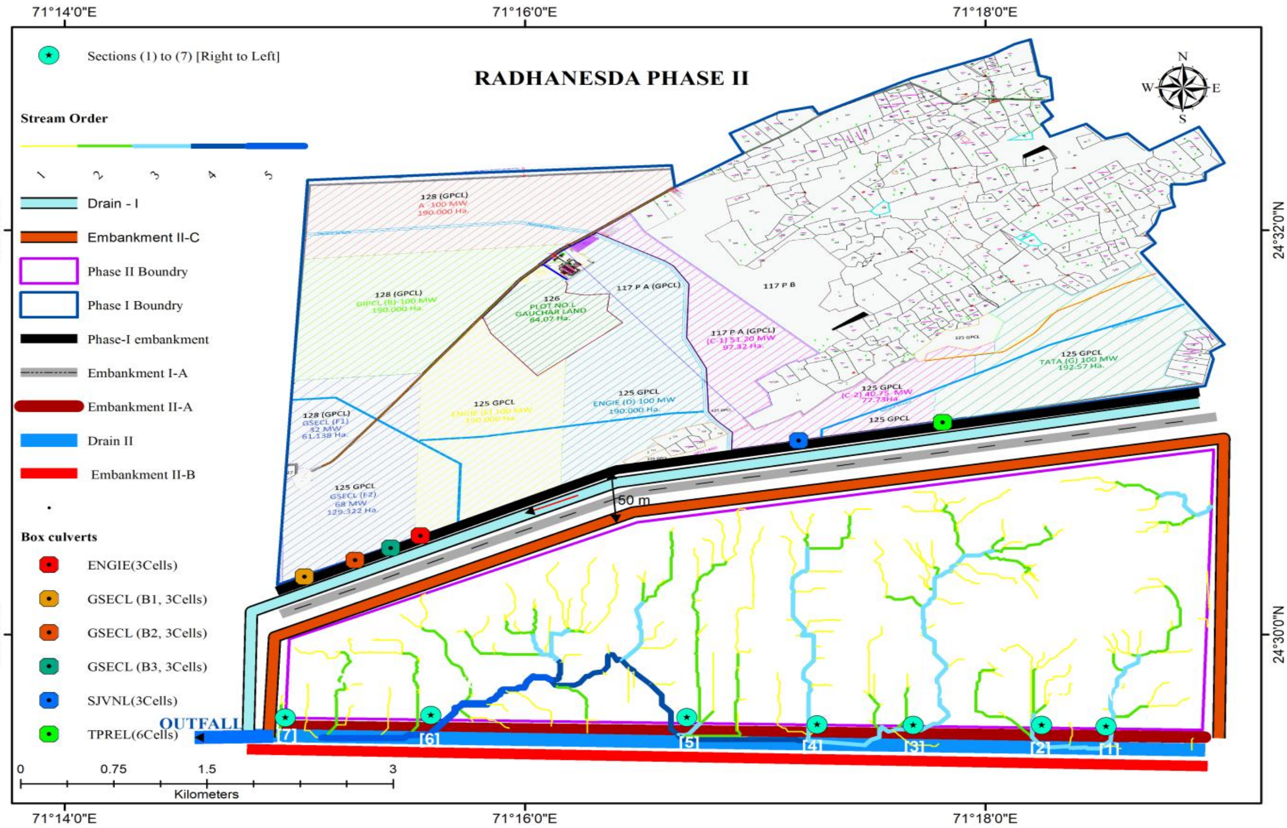

Figure 5.2 Location of six box culverts in Phase I and outfall of seven Nalas in Phase II

<u>Flood Control and Main drain on the south side of phase I:</u> In the area drainage study of phase I (IIT Roorkee 2022), a peripheral embankment around the boundary of the solar park phase I was discussed. The solar plants GSECL(F2), ENGIE SJVNL, and TPREL have box culverts through which the stormwater is let out on the south side. This runoff shall be carried safely to the low-lying area in the southwest corner side by the main drain aligned in an east-west direction along the embankment. Hence, the Phase II area is protected from the Phase I runoff entering into Phase II. The peripheral embankment on the south boundary of phase I is being widened and strengthened, and six box culverts are being provided in this embankment (figure 6.1). Figure 6.2 shows a plan view of the Phase I box culvert location, widened embankment, retaining walls, main drain, buffer zone, and north side embankment of Phase II.

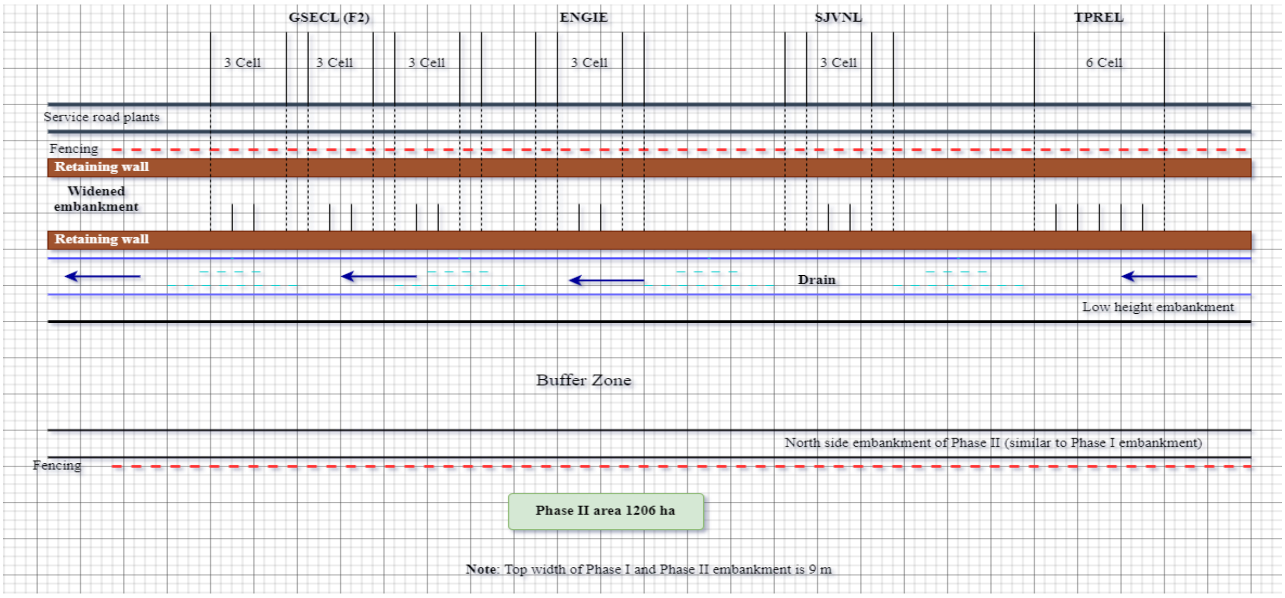

Figure 6.2 Plan view of phase I box culverts, embankment, retaining walls, drain, buffer zone

<u>**Flood Control and Main drain on the south side of Phase II:**</u> The Phase II area has natural topography at present. The general slope of the Phase II area is in the south and southwest directions (see Chapter 3). It is proposed to provide a peripheral embankment along the phase II boundary to protect it from external flooding (figure 6.1). Further, a drain along the southern boundary (similar to that in phase area(figure 6.3)is proposed to carry stormwater from the phase II area to the low-lying area on southwest side so as to protect the solar plant coming up the south of the phase II area.

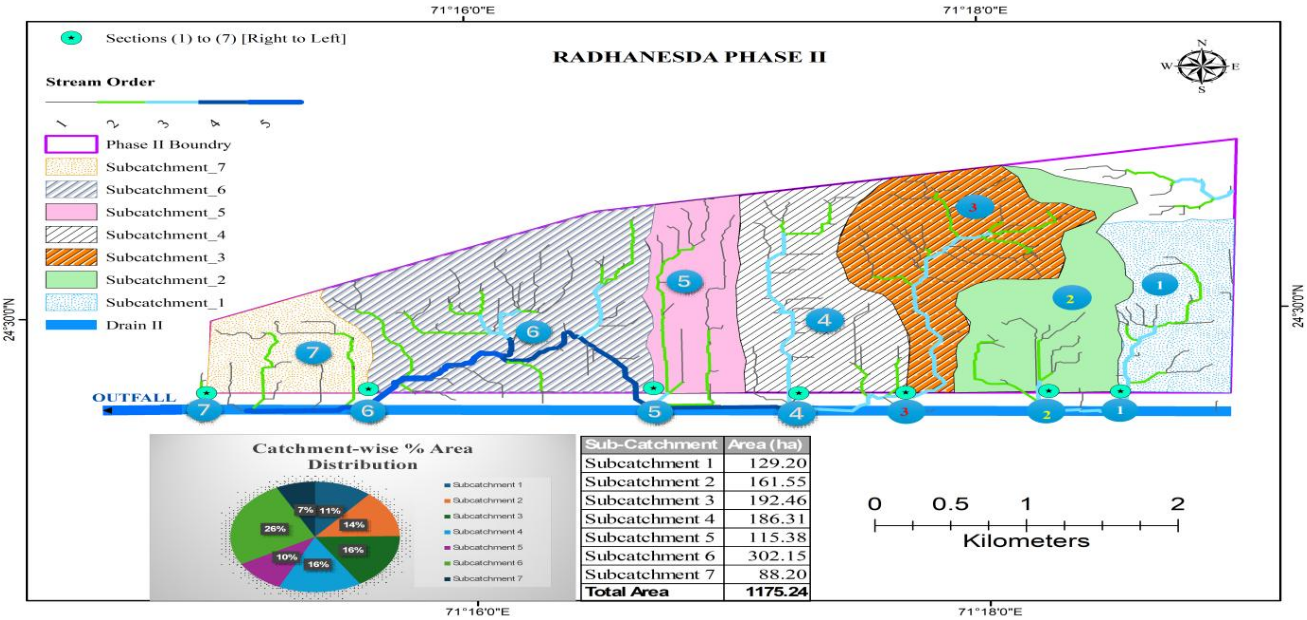

Figure 6.3 Seven sub-catchments and outfalls on the main drain in the phase II area

Raising the Formation Grade level (FGL) to Achieve Adequate Slope of Land

<u>Phase I Area:</u> Land development works in the phase I area have already been carried out; hence there is no scope for raising the formation grade level of plots. The solar plants GSECL(F2), ENGIE SJVNL, and TPREL have box culverts through which the flood water will be let out on the south

side. As discussed in section 6.1, six box culverts are now being provided in the peripheral embankment (Figure 6.1) to carry flood water into a drain aligned in an east-west direction along the embankment.

Phase II Area: Land development works in phase II area are yet to be carried out. Phase II area is more flatter than Phase I area. **Technically it is** possible to achieve adequate slope of land in east to west direction by earth filling so that the main drain could receive flood water as **gravity flow from phase II blocks**(to be developed) . It is suggested to provide formation grade level of 5.5m in the west, southwest parts and gradually increased upto 6.0 m in the central part and higher than 6.0 m in eastern part of the phase II area. However , for this purpose soil from outside the phase II area may have to be borrowed for filling. The topography of the Phase II area is explained in Chapter 3.

It is important to note that only technical possibility of earth filling has been considered here for control of flooding, drainage by gravity flow and the hydraulic design discussed below. Other possibilities are briefly stated in section 6.7.

DRAIN DESIGN CONSIDERATIONS

Site Constraints

The depth of flow in the drain cannot be increased beyond a certain limit (say 0.9m flow depth of cell in box culvert). The man drains receive stormwater (as gravity flow) from the flat land of phase I and phase II at nearly the same level as that of the drain bed level.

The soil is fine-grained clayey sand. Side slopes of the trapezoidal section have to be kept gentle. It is proposed to keep the side slope as 1v:1.25h.

Retaining walls at the toe of embankments would provide stability to embankment slopes and also would protect slopes (particularly the inner side) from erosion due to water flow in main drains.

Design Considerations

- **i.** A return period of 25 years has been considered in drainage design. Specific discharge (flood discharge per unit area of catchment) is calculated as 0.0354 m^3/sec/ha for 25 year return period (see sections 5.1 and 5.2 of chapter 5)
- **ii.** Concrete-lined main drains of trapezoidal shape are proposed.
- **iii.** The channel section is worked out such that the required section factor and achieved section factor for the trapezoidal section are nearly the same.

Design Discharge I pre and post-project Condition

The topography of Phase II land is plain. The land use in the project area will be modified during post-project conditions. However, the net effect of changes in land use, land cover, and topography in post-project conditions shall be negligible. Part of the area covered by roads, buildings, solar panels, etc., will cause more storm runoff. On the other hand, the flat land (clayey sand) and obstruction of flow by roads would increase the opportunity time for infiltration, and hence, storm runoff shall be reduced. The flood generated by storm rainfall is expected to be the same as for pre-project conditions.

Hydraulic Design of Channel Sections

A trapezoidal section is proposed for the main drains. The side slope is taken as 1V:1.25H

Manning's roughness coefficient(n) is taken as 0.016 for the concrete-lined channel.

Bed slope: Bed slope of 0.00026 (1:3850) has been considered for the main drain, considering flat topography.

Depth of flow in a channel section: A resistance formula proposed by Robert Manning for uniform flow in an open channel is used.

The bed width and depth of flow in the concrete-lined trapezoidal section are worked out in the tables below for the main drain in Phases I and II.

Table 1 Phase I Main drain design

(Longitudinal slope s=0.00026, Manning coeff=0.016; side slope 1V:1.25H)

Sl. No.	Location box culvert	Carrying Capacity(Q) m^3 /sec	Section factor $(Qn/(S)^{1/2)}$	Bed Width (m)	Depth (m)	Section factor achieved
1	TPREL	6.817	6.764	5.50	1.10	6.723
2	SJVNL	13.054	12.953	8.50	1.40	12.318
3	ENGIE	26.506	26.301	12.00	1.75	25.713
4	GSECL(F2)-1	27.653	27.439	12.00	1.82	27.285
5	GSECL(F2)-2	28.800	28.578	12.20	1.85	28.507
6	GSECI(F2)-3	31.094	30.854	12.50	1.90	30.524

Table 2: Phase II main drain design

(Longitudinal slope s=0.00026, Manning coeff=0.016; side slope 1V:1.25H)

Sl. No.	Sub catchment	Carrying Capacity(Q) m^3 /sec	Section factor $(Qn/(S)^{1/2)}$	Bed Width (m)	Depth (m)	Section factor achieved
1	subcatchment1	4.574	4.539	5.60	1.00	4.568
2	subcatchment2	10.293	10.214	7.20	1.40	10.134
3	subcatchment3	17.106	16.974	8.50	1.70	16.447
4	subcatchment4	23.701	23.518	10.45	1.85	23.804

Phase II-Section of Embankment and Drain at Location 7

Figure 6.4 shows a section of the embanked drain at location 7 that corresponds to the final outlet of stormwater from the Phase II area. The inner side embankment would also have a 9m wide service road. Its design is similar to the widened embankment of Phase I. The outer side embankment need not be as high as the inner side embankment as the main purpose is to protect the drain and phase II area from flooding.

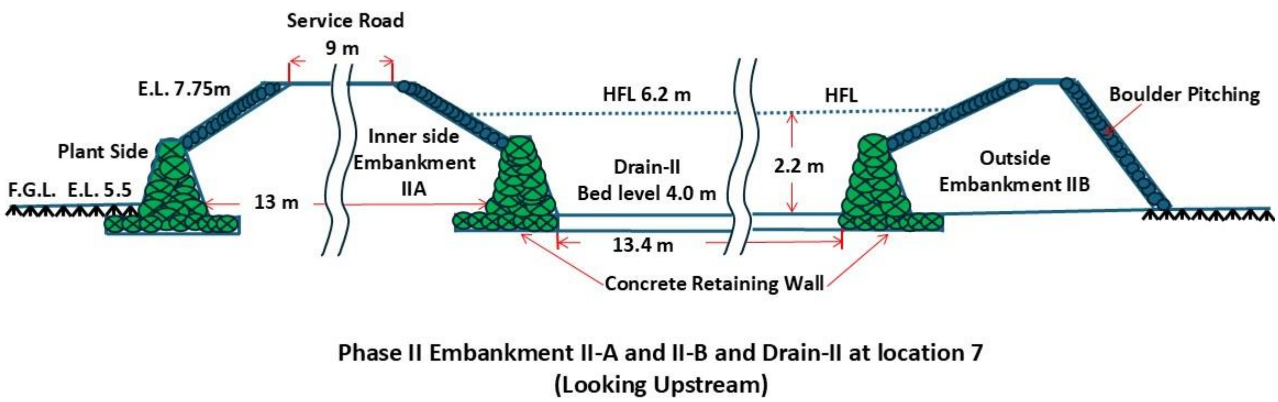

Figure 6.4 Section of an embanked drain at location 7 in Phase II

ALTERNATIVE TO EARTH FILLING IN PHASE II AREA

There are two other possibilities if earth filling is to be avoided.

First Possibility:

A peripheral embankment is provided around the phase II area (as stated in section 6.2). No outlets are provided in the peripheral embankment. The top level of internal roads shall be 0.6 m above natural ground level.

In the rainy season, the soil is completely saturated; therefore, whatever rain falls over the area would cause internal flooding and waterlogging. Design depth of flooding in solar park is 586.34mm (or 0.58634 m) as explained in section 4.4 of chapter 4. The Phase II area is 1206 ha. Therefore, volume of storm water that would get accumulated inside the area is 7.0713million cubic meters.

The design (probable maximum) storm water volume of 7.0713 MCM inside the phase II area shall have to be pumped out by installing a large number of high horsepower pumps. Rainfall and hence volume of storm water are random variables over the years. Hence actual quantity of storm water volume to be pumped out shall be different in different years.

Second Possibility:

A peripheral embankment is provided around the phase II area (as stated in section 6.2). Outlets (pipe and/or box culverts) on the south side embankment are provided. Location and size of these outlets would depend on the layout of the blocks and the layout of internal roads. The top level of the road shall be 0.6 m above natural ground level.

The invert level of the outlets shall be the same as the natural ground level at these locations. These outlets would be able to drain storm water only when the depth of water in the vast flat land in the vicinity of Phase II is lower than the storm water level inside the blocks. The rainwater in the vast flat land is likely to recede slowly, and hence it may take several days to drain out the floodwater from the phase II area.

PART B: MANAGEMENT OF FLOOD DISASTER

Management of flood disaster in the phase II area is discussed in the following four chapters

Chapter 1of Part B: Extreme Rainfall and wind-related risks and Adaptation Measures for solar plants

This chapter introduces the need for flood disaster management plans for solar parks. Whereas flood disaster management plans have been developed for dams and embankments in the country, not much attention has been given to the preparation of flood disaster management plans for solar parks in the country. Extreme rainfall and wind-related risks to solar plants are elaborated. This is followed by a discussion on various possible adaptation measures for a. Solar PV generation plant; b. Battery and energy storage systems (BESS); c. Distribution grid upgradation; d. AC and DC Power Risk and Adaptation Measure

A checklist for disaster preparedness during the operation stage of the solar power project has been included in this chapter.

Chapter 2 of Part B: Warning of storms, lightning, and an action plan

This chapter covers salient features of thunderstorms and associated weather phenomena and guidance for early warning and communication, keeping in mind existing gaps, challenges, and opportunities. Thunderstorms, squalls, hailstorms, dust storms, and lightning are defined to appreciate the meaning and differences in these weather phenomena.

The role of the India Meteorological Department in forecasting and issuing alerts/warnings is discussed. ‘Now Casting’ type of forecast has a lead time/validity of 3 to 6 hours, whereas short to medium-term forecast has a lead time/validity of 1 to 5 days. The weather bulletin of IMD provides information on i) intensity of rainfall, ii) spatial distribution of weather phenomenon, iii) emergency situation, and iv) evacuation. A list of weather websites. Also included.

A brief discussion on lightning is made. Banaskantha district is relatively less prone to lightning incidents than other parts of Gujarat.

The dissemination strategy of warning messages and the importance of review of the early warning system are discussed. The reliability of EWS and forecasting performance for storms and weather-related phenomena – in terms of hits, missed incidents, and false alarms for different thresholds – must be evaluated periodically.

Even though alertness is needed during the entire monsoon season, there could be a critical period when preparedness should be at its peak. Weekly rainfall at Radhanesda (grid rainfall) from 1st July to 30 September in each year from 2012 to 2022 has been compared. It is seen that relatively higher rainfall is received from 15th July to the end of August each year. Even though floods may occur at any time during monsoon, the period from 15th July to the end of August may be considered more vulnerable to flooding. The solar plant developers and disaster management team need to keep a close watch for severe storms during this period.

Chapter 3 of Part B: The Biparjoy cyclone, its impact on Raghanesda solar park, and lessons learnt

A very Severe Cyclonic Storm, “Biparjoy” (pronounced as “Biporjoy”), occurred in June 2023 over the Northeast Arabian Sea. The Biparjoy cyclone is illustrated through IMD bulletin number 76 issued on 15th June 2023, at 2030 hrs IST (Cyclone Warning for Saurashtra & Kutch Coasts). The IMD bulletin contained detailed information on the following:

- Heavy Rainfall warning: Places where heavy to very heavy rainfall, light to moderate rainfall would occur on15th June,2023 on 16th and 17th June, 2023
- Wind & gale warnings along & off Saurashtra & Kutch coasts (Kachchh, Devbhumi Dwarka, Porbandar, Jamnagar, Rajkot, Junagarh, and Morbi districts) including Gulf of Kutch, Wind Warning for South Rajasthan
- Sea condition (rough, very rough) along & off Saurashtra& Kutch coasts:
- Storm Surge Warning:
- Expected damage area (towns, cities, districts)
- Fishermen Warning & Action Suggested Total suspension of fishing operations over the northeast and adjoining east-central Arabian Sea till 15th June.
- Mobilize evacuation from coastal areas of Saurashtra and Kutch (Kachchh, Devbhumi Dwarka, Porbandar, Jamnagar, Rajkot, Junagarh, and Morbi districts).

- Preparatory actions before the cyclones.

Post Landfall Outlook for Banaskantha District: Light to moderate rainfall at most places, with heavy to extremely heavy rainfall at isolated places very likely over Banaskantha and Patan on 16th June.

For State Government Agencies: The list of affected villages with corresponding estimated wind speed, flood level, and surge height can be seen in the Web-DCRA &DSS Application (https://webdcra.ncrmp.gov.in/). The concerned States/UTs can generate and download the list of affected villages through the distinct Tab named ‘*Affected Villages*’ under the MOST AFFECTED DISTRICTS panel at the bottom right provided in the Real Time Cyclone Impact Forecasting dashboard of the Web-DCRA & DSS Application.

Chapter 4 of Part B: Safety of the flood embankment and buildings

An earthen embankment along the boundary of phase I of Radhanesda Solar Park has been constructed over a length of 16.394 km. It is being widened now, and box culverts are being provided in this embankment. In the present study, a similar embankment is proposed in phase II of the solar park to control flooding from the outside.

The material requirement for regular and emergency maintenance is given. Emergency measures for the flood embankment (Seepage/leakage, scouring, sliding, settlement, breach) are explained with the help of sketches and diagrams.

Protection of buildings against inundation effects is discussed. An inundation intensity scale for damage to houses on a broad basis is proposed.

Structural changes for the buildings in Radhanesda Park are suggested.

PART A

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

India lies in the high solar insolation region, endowed with huge solar energy potential. Most of the country area has about 300 days of sunshine per year with annual mean daily global solar radiation in the range of 4 – 6 kWh/m^2/day.

Large-size projects have the potential to bring down the cost of Solar Power. The ***Ministry of New and Renewable Energy (MNRE) of the Government of India*** has rolled out a plan to set up 25 solar parks, each with a capacity of 500 MW and above, thereby targeting around 20,000 MW of solar power installed capacity.

A solar park is a concentrated zone of development of solar power generation projects and provides developers with an area that is well characterized, with proper infrastructure and access to amenities, and where the risk of the projects can be minimized. Solar Park also facilitates developers by reducing the number of required approvals.

In this context, Gujarat Power Corporation Limited (GPCL) has been playing the role of developer and catalyser in the solar power generation sector in the state of Gujarat. Several solar parks are in the process of being developed in Gujarat. GPCL has already set up a) India's first-of-its-kind Gujarat Solar Park at Village Charanka, Taluka Santalpur, District Patan, and b) Radhanesda Solar Park (RASP) Phase I of 700 MW capacity near Radhnesada village, Taluk Vav, Dist. Banaskantha.

Radhanesda Solar Park (RASP) phase II is spread over a 1206-hectare area. It largely falls under the eastern part of Rann of Kutch. The area has been affected by flooding during the monsoon season and continued water logging during the non-monsoon season.

M/s GPCL approached IIT Roorkee to conduct a hydrological study of the planned expansion over a 1206-hectare area (termed phase II) in the south direction of the existing Radhanesda solar park. Based on correspondence between M/s GPCL and IIT Roorkee, M/s GPCL has requested IIT Roorkee to take up the study of the phase II area as stated below:

"To study and carryout hydrological survey and flood assessment/disaster management at proposed GPCL-700MW Raghanesda Ultra Mega Solar Power Park, phase II at village Raghanesda,Taluka-Vav, District Banaskatha (Gujarat). "

M/s GPCL has issued an LOA to IIT Roorkee vide letter no GPCL/PD/RSP/IIT-R/1198/60847 dated 1.10.2024 stating therein the scope of work and the terms and conditions acceptable to IIT Roorkee.

1.2 SCOPE OF STUDY ASSIGNED TO IIT ROORKEE

The study consists of two parts. The scope of study for part A and part B is as given below.

Part A: Control of Flooding and Waterlogging in Phase II area

1. Site visit for acquaintance with field problems of water logging and drainage in phase II area, collection of field data and discussion with project authorities.
2. Review of previous two studies of Phase I carried out by IIT-Roorkee.
3. Review of performance of existing arrangements to control external flooding, waterlogging and flood drainage in Phase I area during monsoon season of 2023,2024 and 2025.
4. Digital elevation model study of phase II area and vicinity area to understand topography, stream network, low and high grounds. The topographic survey data of the study area shall be provided by the GPCL. However, in the absence of the recent topographic data open source data i.e. SRTM,ASTER etc. data may be used
5. Identification and analysis of causes of flooding in phase II area during monsoon season and water logging during monsoon and non monsoon seasons.
6. Analysis of design storm rainfall and design flood level/magnitude in phase II area and vicinity.
7. Planning of structural measures for control of external flooding in phase II area.
8. Layout and design of internal drainage and outfall . Depending upon modified topography (formation ground levels) within phase II area and existing topography in vicinity, possible alternatives such as a) surface drainage by gravity, b) collection sump and pumping out facility to control waterlogging, c) combination of a) and b) etc. shall be examined.
9. Submission of draft and final report and presentation to GPCL (if required)

Part B: Management of Flood Disaster

1. Review of flood disaster management measures adopted in phase I area and at other locations in hydro meteorologically homogeneous region and performance thereof during recent severe storms.
2. Analysis of extreme Storms and warning system in the region
3. Recommendations on flood disaster mitigating measures specific to the phase II solar Park
4. Submission of draft and final report and presentation to GPCL (if required)

1.3 ENVIRONMENTAL SETTING OF THE SITE

The Radhanesda solar park is located about 271 km from Ahmedabad in North-West direction. The Index map is shown in Figures 1.1, Figure1.2, and Figure1.3. The basic environmental settings of the solar park are given in Table 1.1.

Table 1.1 Environmental Setting of Radhanesda solar park

S. No.	Particulars	Details
1	Plant location	Radhanesda village
2	Site Coordinates	As given in figure 1.1
3	Nearest highway	SH-63/127 at 8 km and NH-15 at 42 km
4	Nearest railway station	Bhabhar 77 km
5	Nearest Airport	271 km from Ahmedabad in North West direction.
6	Nearest village	Radhenesda
7	Nearest town/City	Tharad at 42 km
8	Reserved (RF) /Protected Forests	There is no forest range or any other type of eco-sensitive area in the near vicinity of the site.
9	Nearest International border	The international border with Pakistan at about 28 km

The site is accessible via NH 15 and other major roads (figure 1.2). These are:

- NH-15 till Tharad from Radhanpur
- SH-63 towards the west from Tharad. This is two lane road paved road passing through Dhima and Tadav villages and converging to SH- 127 thereafter, approximately a distance of 35 km
- Two laned SH-127 till Baradavi village for approximately 8 km
- Moving towards the west thereafter travelling for 8 km to reach Radha Nesda passing through Kundaliya village

RAGHANESDA PHASE 2: 1206 HA LAND FOR ULTRA-MEGA SOLAR PARK

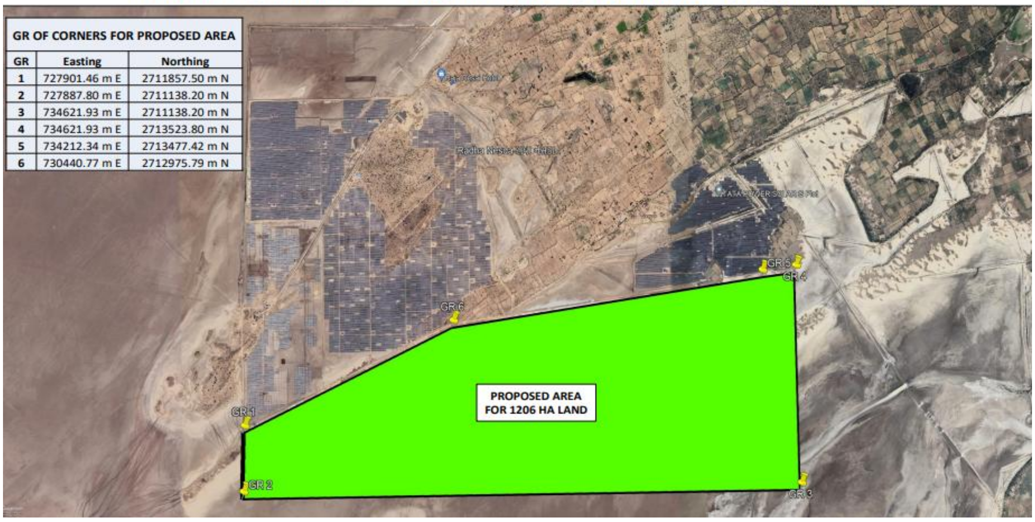

Figure 1.1 Coordinates of Raghanesda solar park Phase II

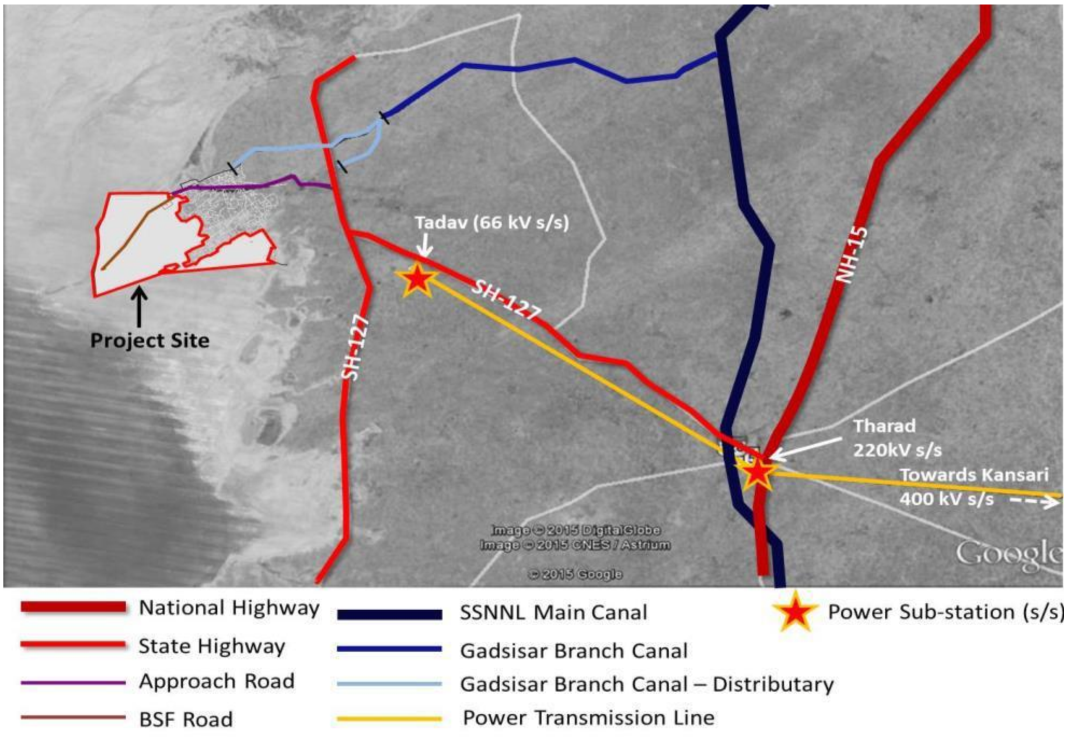

Figure 1.2 Road map from Tharad to Radhanesda solar park phase II

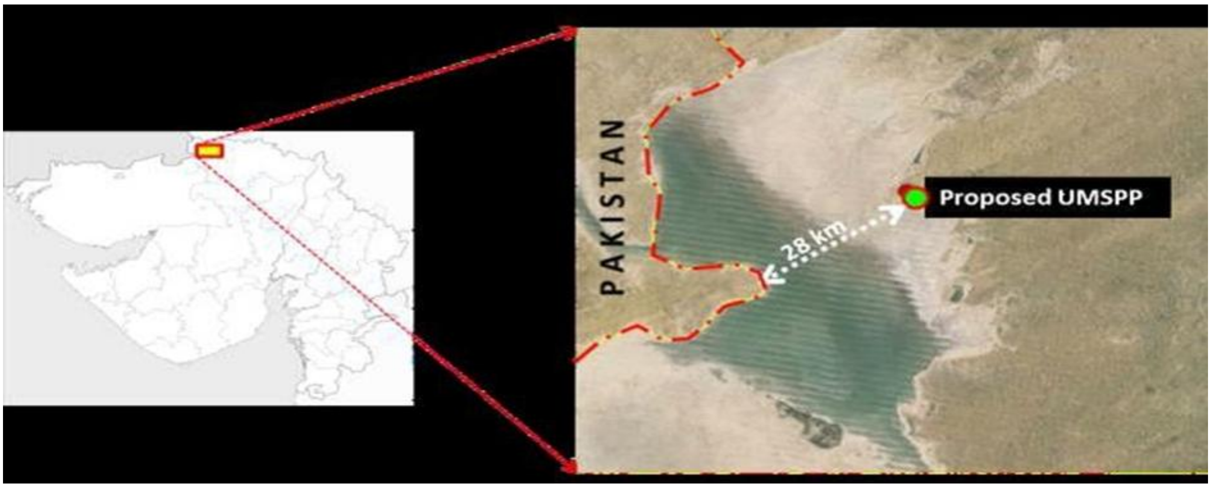

Figure 1.3 Location of Radhanesda solar park phase II with reference to International boundary

1.4 FIELD VISITS

Field visits were conducted from January 18, 2025 to January 21, 2025 by the IIT Roorkee team along with the Engineers of GPCL and SECL (Soler Energy Corporation Ltd).

Before proceeding to the site, a meeting was held in the Gandhinagar office of Gujarat Power Corporation Ltd (GPCL) on 18th January 2025.

M/s GPCL briefed about the flooding that took place in the solar park area in 2023 and 2024. A brief discussion took place about the existing flood embankment on the boundary of the phase I park area, bank cutting, and planning of box culverts in the embankment.
Visual depiction of site condition is given photographs.

1.5 DOCUMENTS AND DATA

Documents/Data given below have been, and relevant information has been utilized in this study:

i. IIT Roorkee Report of September 2016: Hydrological study of the proposed solar plant at Radhanesda, District Banaskatha, Gujarat**.**

i. IIT Roorkee Report of September 2023: Hydrological survey and flood assessment/disaster management at GPCL-700MW Raghanesda Ultra Mega Solar Power Park, village Raghanesda,Taluka-Vav, District Banaskatha (Gujarat).

ii. Flood Estimation Report for Luni Sub Zone-1(a) (93 pages) by Central Water Commission, Government of India, New Delhi (November 1993)

iii. Following data provided by GPCL

   (a) Location map of proposed phase II solar pant

   (b) Contour map of the plant area

CHAPTER 2

PHYSICAL FEATURES AND FIELD VISIT TO PHASE II STUDY AREA

2.1 LAYOUT PLAN OF PHASE I AND PHASE II

Figure 2.1 shows the layout plan of Phase I of Radhanesda Solar Park. In the past, two studies have been carried out by IIT Roorkee (IIT Roorkee 2016 and IIT Roorkee 2023). A brief review of these two studies is given in **i). Annexure I** for the first study carried out in 2016 and **ii) Annexure II** for the second study carried out in 2023.

Phase II of the Radhanesda solar park lies in south of and adjacent to phase I as shown in figure 2.2.

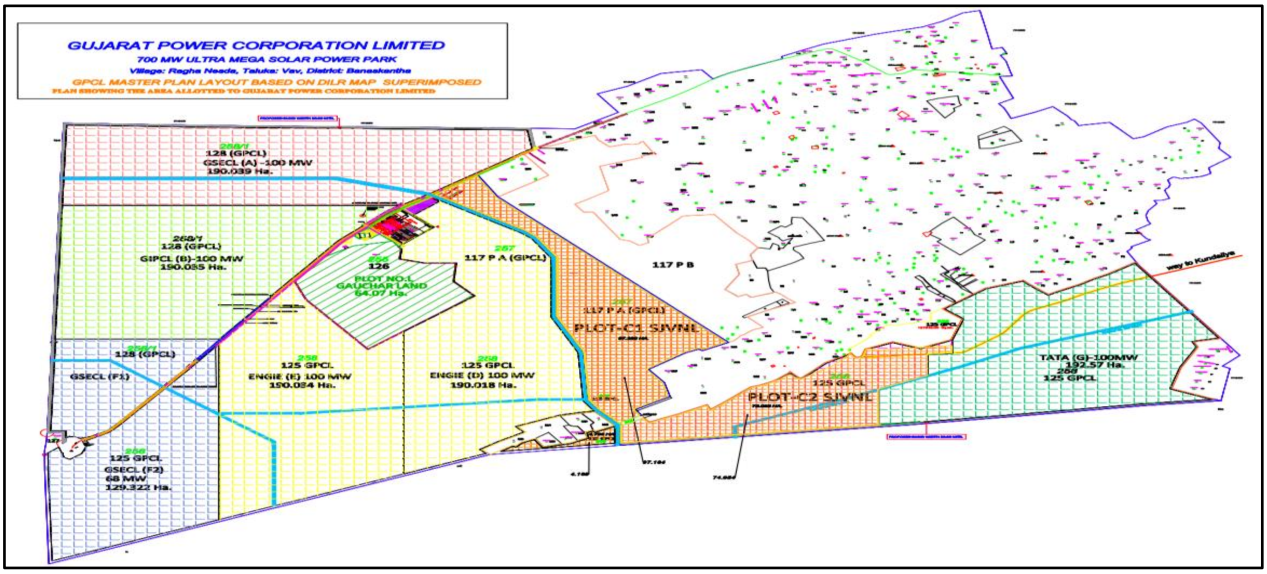

Figure 2.1 Layout plan of the phase I solar plants and the Upland area

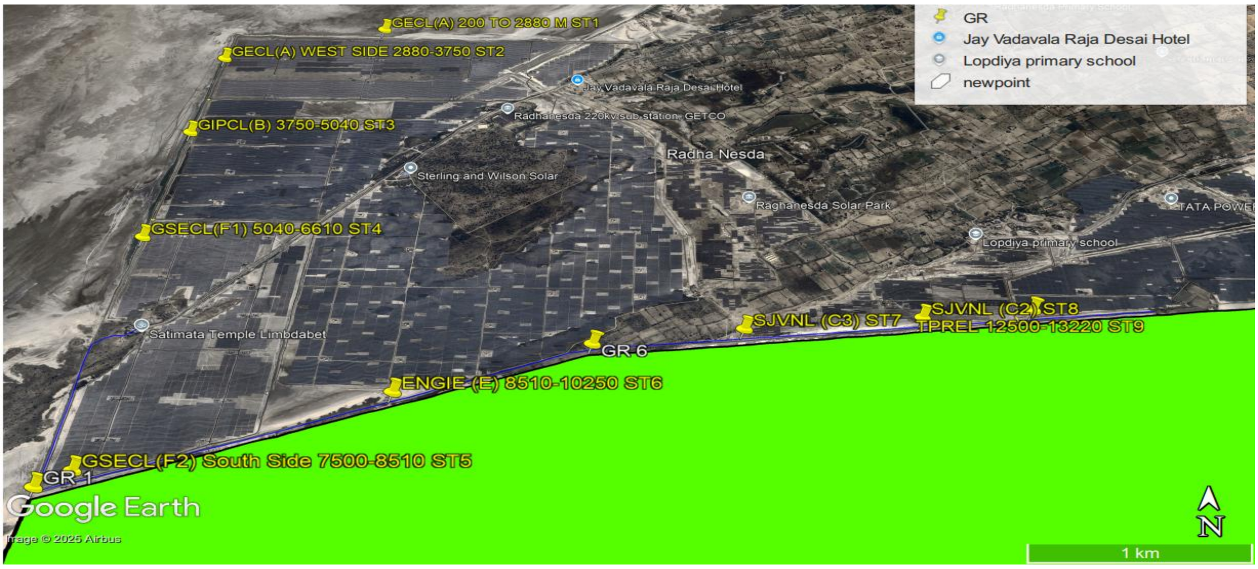

Figure 2.2 Layout plan of the Phase II area south of Phase I plants and the Upland area

Raghanesda phase II 1206 ha land (green colour) with coordinates of corners is shown in Figure 2.3. Table 2.1 shows the coordinates of six corner points of the Phase II land.

Figure 2.3 Raghanesda phase II 1206 ha land (green colour) with coordinates of corners

Table 2.1 Coordinates of six corners of phase II area

GR CORNERS FOR THE PROPOSED AREA		
GR	Easting	Northing
1	727901.46 m E	2711857.50 m N
2	727887.80 m E	2711138.20 m N
3	734621.93 m E	2711138.20 m N
4	734621.93 m E	2713523.80 m N
5	734212.37 m E	2713477.42 m N
6	730440.77 m E	2712975.79 m N

2.2 FLOOD EMBANKMENT OF PHASE I

An earthen embankment along the boundary of phase I of the solar park has been constructed over the length of 16.394 km. The embankment has been constructed to control flooding of the solar park from the outside. The layout plan of the embankment is shown in Figure 2.4. The embankment has pipe outlets and has been cut at several laces. These are now being replaced by box culverts in the embankment. The flood embankment and the box culverts on the south side are particularly relevant for the Phase II study as stormwater from the Phase I area would enter the Phase II area that needs to be controlled.

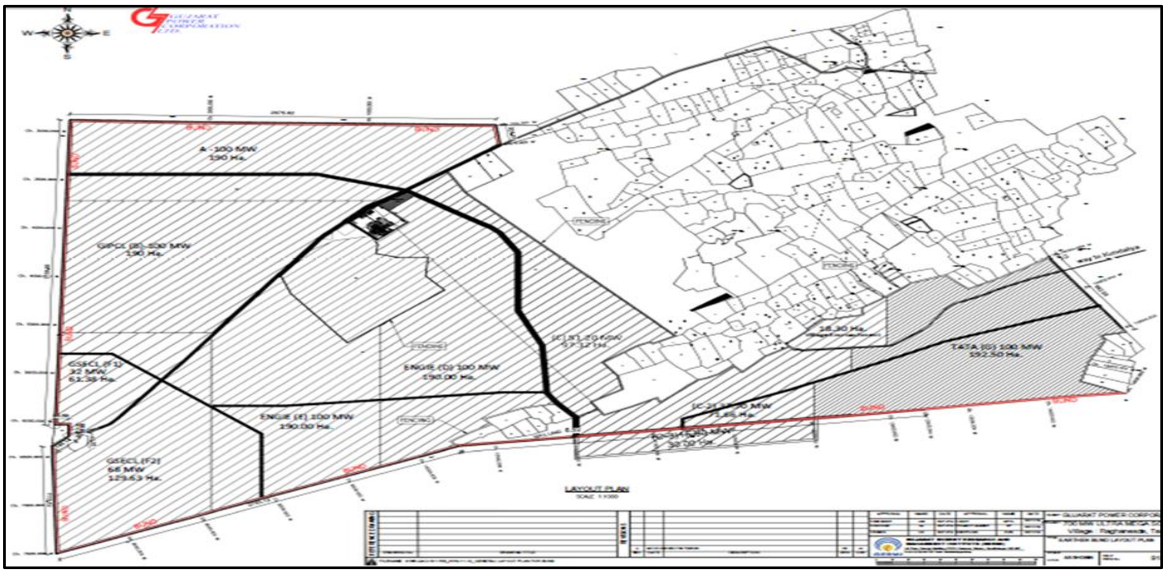

Figure 2.4 The layout of the embankment around the Phase I area

The longitudinal section of the flood embankment for the first 6 km (from chainage 0 to 6000m) is shown in Figure 2.5, for the next 6 km (from chainage 6000m to 12000m) is shown in Figure 2.6, and for remaining 4.394 km (from chainage 12000 m to chainage 16394.5 m) is shown in figure 2.7. Typical cross-sections of the embankment are also shown in Figure 2.8. A stormwater drain has been constructed (sloping in the north-to-south direction) on the west side of GSECL(A), GIPCL, and GSECL(F1) plots, as shown in Figure 2.7. The typical cross-section of the embankment and drain is shown in Figure 2.8.

The Cross Section of the embankment has varying heights along the boundary according to the varying natural ground level. The top level and top width are kept the same throughout the length. The top width is 3.5m. The height of the embankment varies from 0.495 m to 4.973 m. Table 2.2 shows some typical dimensions of the earthen embankment. The side slope is 2H:1V on the inner side (park side) and outer side (Luni basin side) all around the length.

Table 2.2 Typical dimensions of the flood embankment

S. No.	Type	Height (m)	Base width(m)	Top width(m)
1	Type I	0.493	5.472	3.5
2	Type II	0.999	7.496	3.5
3	Type III	1.997	11.488	3.5
4	Type IV	2.998	15.492	3.5
5	Type V	3.992	19.468	3.5
6	Type VI	4.973	23.392	3.5

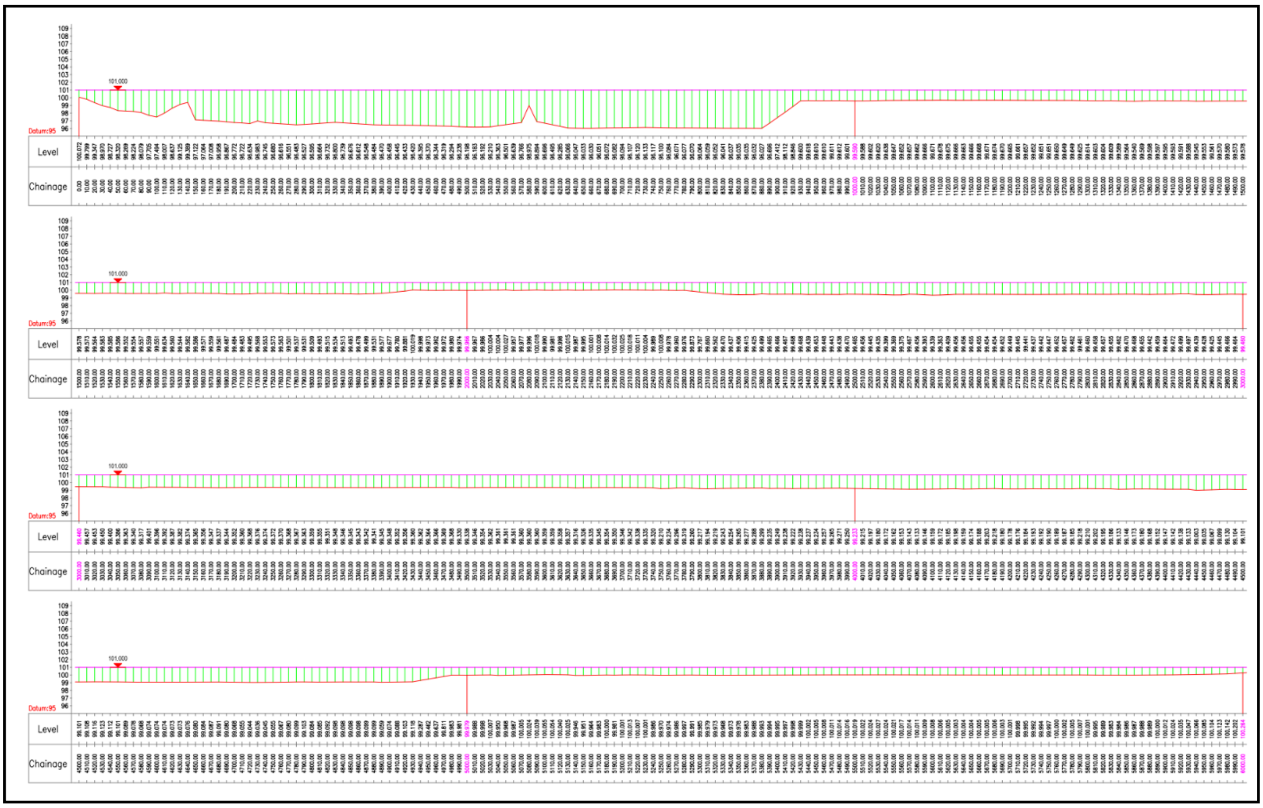

Figure 2.5 Longitudinal section for the first 6 km (from chainage 0 to 6000 m)

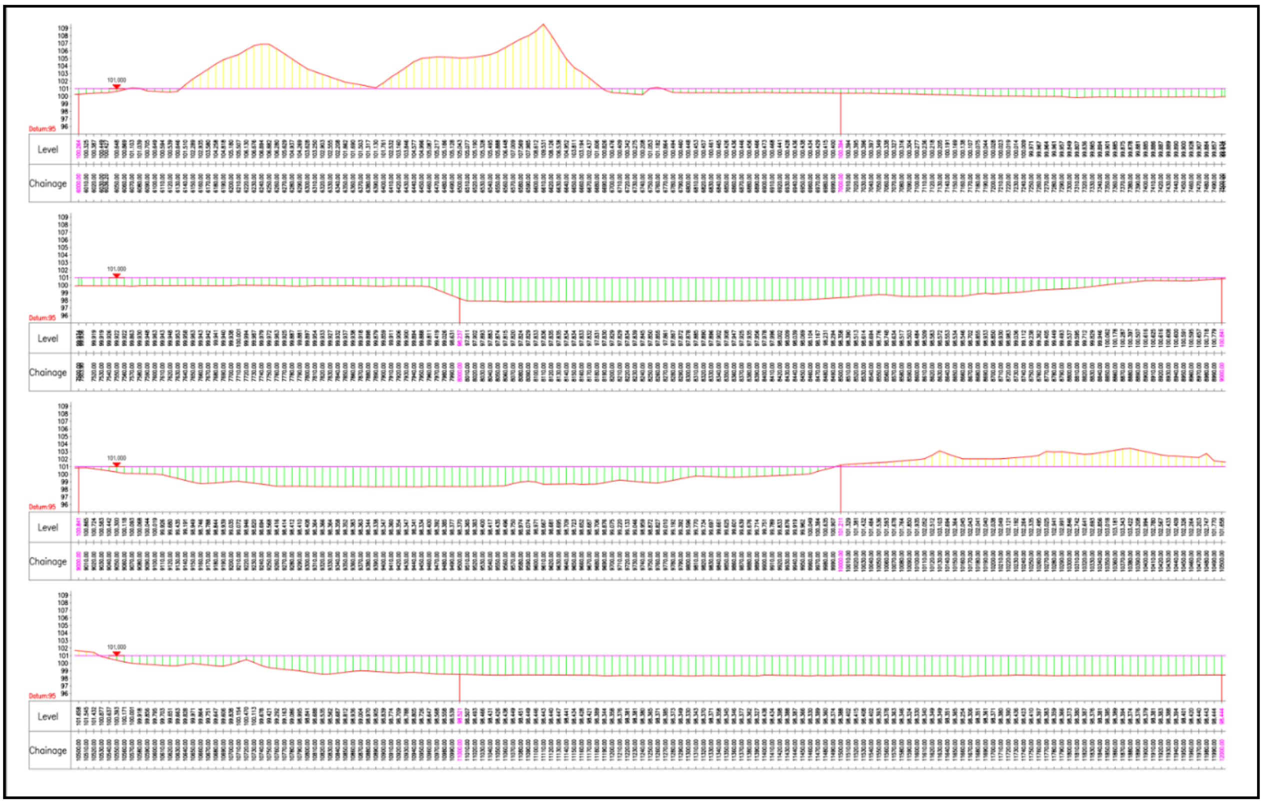

Figure 2.6 Longitudinal section for the next 6 km (from chainage 6000 m to 12000 m)

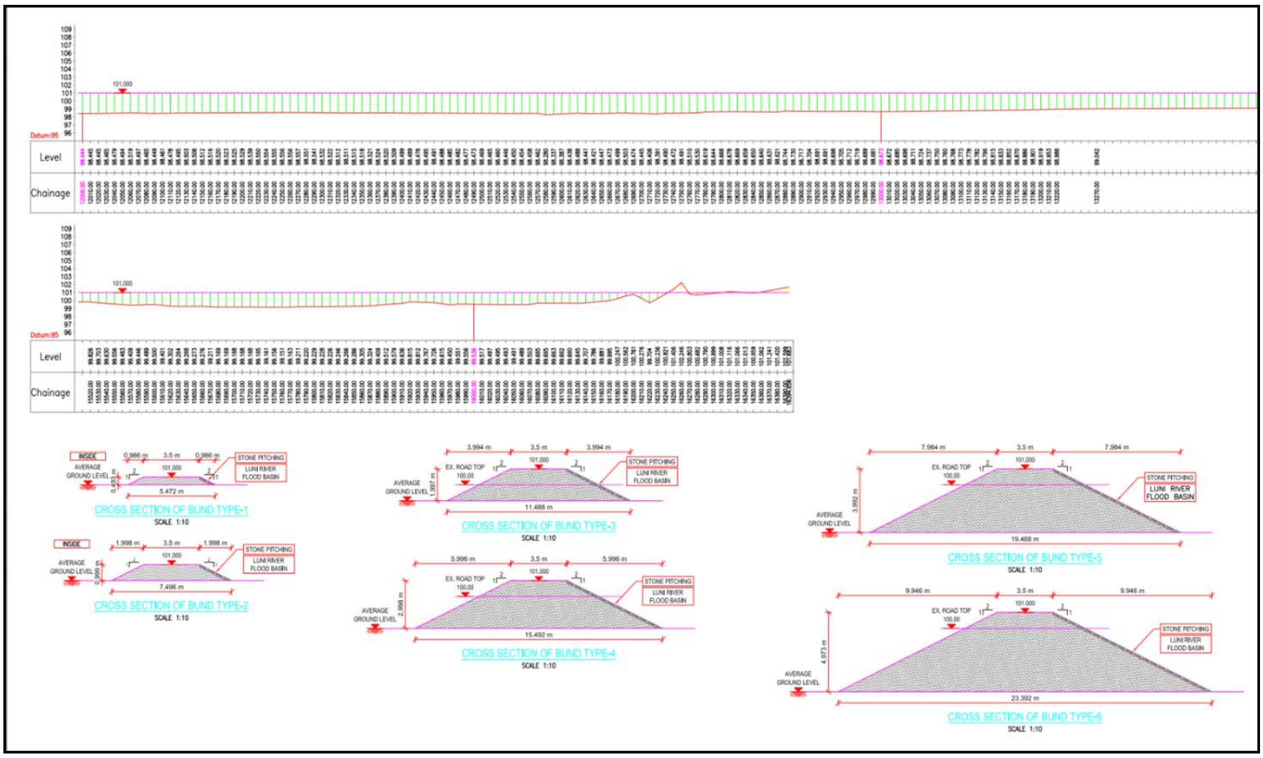

Figure 2.7 Longitudinal section for remaining 4.394 km (from chainage 12000 m to chainage 16394.5 m)

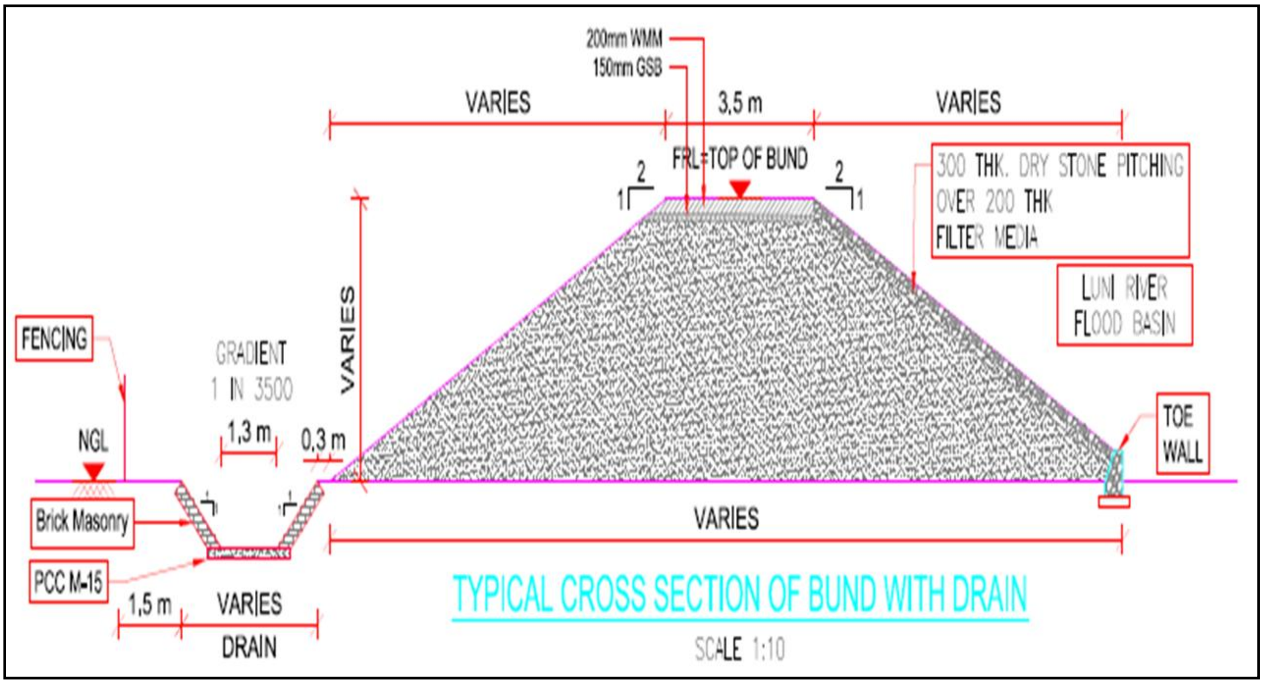

Figure 2.8 Typical section of embankment and drain

2.3 FLOODING OF PHASE I AND PHASE II AREA IN JUNE 2023

The "BIPAREJOY CYCLONE" struck the solar park from 14/06/2023 to 17/06/2023. The "Biparjoy Cyclone", known for its intensity and destructive force, struck the regionwith unprecedented ferocity. The cyclone brought forth strong winds, torrential rainfall, and turbulent atmospheric conditions, leading to a series of adverse impacts on the solar park. The entire park area was waterlogged with sluggish drainage. Table 2.3 below shows the daily rainfall recorded at the automatic weather station (AWS) inside the GIPCL plant. There was very heavy rainfall on 16th June (176.2 mm) and on 17th June 2023(73.8 mm).

Table 2.3 Daily Rainfall in June 2023

Date	Rainfall (mm)	Date	Rainfall(mm)
01-06-2023	0	14-06-2023	0.4
02-06-2023	0	15-06-2023	61
03-06-2023	0	16-06-2023	176.2
04-06-2023	18.4	17-06-2023	73.8
05-06-2023	0	18-06-2023	0
06-06-2023	0	19-06-2023	0
07-06-2023	0	20-06-2023	0
08-06-2023	0	21-06-2023	0
09-06-2023	0	22-06-2023	0
10-06-2023	0	23-06-2023	0
11-06-2023	0	24-06-2023	0
12-06-2023	0	25-06-2023	0
13-06-2023	0		

(Source: Data supplied by the site in charge of the GIPCL plant)

The Intensity of rainfall was very high from 12:00 AM on 16 June 2023 to 2:00 PM on 17th June 2023, as shown in Table 2.4. There was 393 mm of rainfall during 6 hours (2 AM to 8 AM on 17th June), with the highest intensity recorded as 89.4mm/hour from 5 AM to 6 AM on 17th June.

Table 2.4 High-Intensity rainfall (mm/hour) on 16 June 2023 and 17th June 2023

16-06-2023	12:00 AM	23.2
17-06-2023	1:00 AM	24
17-06-2023	2:00 AM	27.6
17-06-2023	3:00 AM	57.8
17-06-2023	4:00 AM	73.4
17-06-2023	5:00 AM	60.6
17-06-2023	6:00 AM	89.4
17-06-2023	7:00 AM	66.6
17-06-2023	8:00 AM	45.2
17-06-2023	9:00 AM	31

17-06-2023	10:00 AM	28.2
17-06-2023	11:00 AM	39.4
17-06-2023	12:00 PM	26.8
17-06-2023	1:00 PM	36.2
17-06-2023	2:00 PM	33.6

(Source: Data supplied by the site in charge of the GIPCL plant)

2.4 CUTTING OF EMBANKMENT TO LET OUT THE PONDED WATER IN SOLAR PARK

Considering the inadequacy of pumps in rapid dewatering and the resulting rise in water level inside plant areas, the phase I embankment had to be cut by developers (Photo 2.1). The embankment was cut at two locations on 18 August, 22 and at 5 locations on 23rd August 2022. as shown in Table 2.5. Again, due to heavy waterlogging caused by the Biporjoy cyclone, from 14 June to 17 June 2023, the embankment was cut at 7 locations, as shown in Table 2.5.

Table 2.5 Details of Embankment Cuts made in August,22 and June,23

Name of plot	Number of Cuts	Date
GSECL-A	2	23.8.2022
GSECL-F1	2	18.8.2022
GSECL-F2	1	23.8.2022
SJVNL	1	23.8.2022
Tata-G	1	23.8.2022
GSECL-A	1	June,2023
GSECL-F1	1	June,2023
GSECL-F2	5	June,2023

Photo 2.1 Cutting of Embankment to drain out the ponded water inside the solar park

2.5 CULVERTS ON EXISTING EMBANKMENT (after widening of the embankment): M/s GPCL has identified 13 locations on the phase I embankment where box culverts shall be provided (table 2.6). Out of these 6 locations are on the southern part of the embankment that is adjacent to the northern boundary of phase II

Table 2.6 Box culverts proposed in phase I embankment

Total No. of Box Requires around bund periphery					
Annexure-A					
Sr. No.	**Plot Name and Chainage**	**Boundary**	**No. of Box Required**	**No. of cell in each box**	**Location provided (in term of co-ordinate) by the developers of the box suggested by IIT Roorkee.**
1	GSECL (A) 200 to 2880m	North	Nil	NA	NA
	2880 to 3750m	West	(2+1)=3	3	24° 32'30.6"N 71° 15'02.6"E
					24° 32'21.3"N 71° 15'01.8"E
					24° 32'14.7"N 71° 15'01.6"E
2	GIPCL (B) 3750 TO 5040M	West	2	3	24.535752,71.251214
					24.525615,71.250303
3	GSECL (F1) 5040 to 6610m	West	(1+1)=2	3	24° 31'10.5"N 71° 14'58.1"E
					24° 31'20.3"N 71° 14'58.7"E
	Total 7 no. of box having 6.6m width and 3 cell (1.5m*3.0m)				
4	GSECL (F2) 6610 to 7500m	West	Nil	NA	NA
	7500 to 8510m	South	(1+2)=3	3	24° 30'17.2"N 71° 15'02.8"E
					24° 30'22.1"N 71° 15'15.7"E
					24° 30'25.7"N 71° 15'25.0"E
5	ENGIE 8510 TO 10250m	South	1	3	24°30'29.34"N 71°15'32.74"E
6	SJVNL 10250 TO 12500m	South	1	3	24.515060,71.28648 As per HYDROLOGICAL SURVEY Report.
7	TPREL 12500 to 13220m	South	1	6	24°30'57.8"N 71°17'48.9"E
	5 box of 3 cell having width 8.6m and 1 box of 6 cell having width 8.6m. each size 1.5m*3.0m				

2.6 VISUAL OBSERVATIONS DURING 18-20 JANUARY,2025

The Phase II area was visited during 18-20 January 2025 as part of the Phase II study. Following works are in progress on the existing embankment

i) Removal of existing stone pitching on the outer slope of the embankment so that the embankment road could be widened

ii) Widening of the road by earth filling on the outer side of the embankment

iii) Stone pitching on the inner and outer slopes of the widened road

iv) Retaining wall on the inside of the existing embankment

v) Box culverts in the embankment

Visual observations of these works are depicted in photographs given in Photos 2.2 to 2.7

Photo 2.2. Removal of stone pitching on the outer slope of the embankment near GSCEL (plot 2 corner)

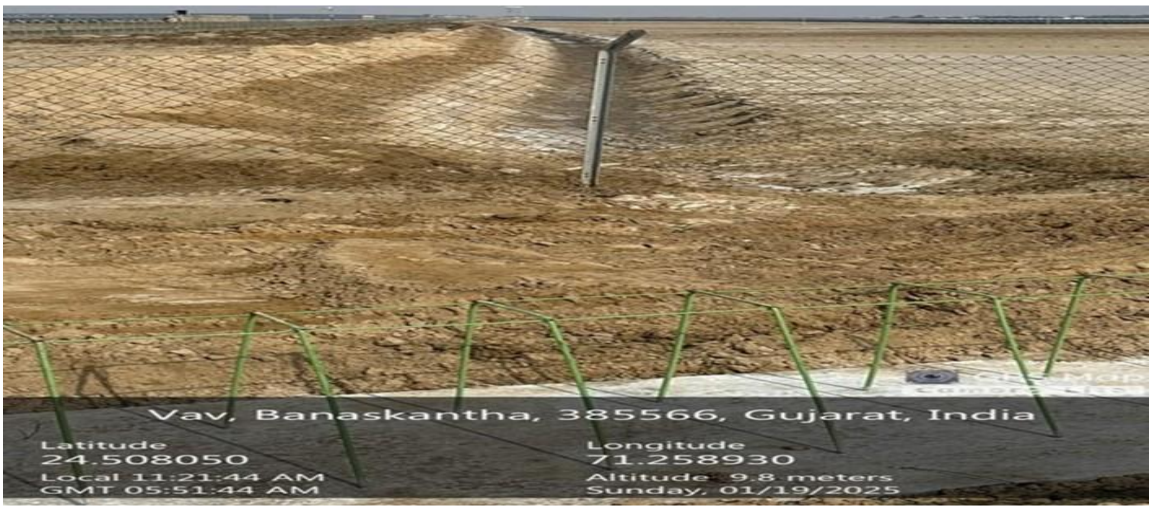

Photo 2.3 Drain outfall of Engie plot. Location of proposed box culvert

Photo 2.4 Water logged area downstream of proposed box culvert of SJVNL plot

Photo 2.5 Solar panels being water washed in SJVNL plot

Photo 2.6 Retaining wall being constructed on upstream (plant side) toe of peripheral embankment

Photo 2.7 The existing box culvert is on the peripheral road of the Tata solar plant.

The fencing shows the boundary of the Tata Solar plant. Parallel to it, a box culvert shall be provided in the embankment

Photo 2.8 View of the channel downstream of the box culvert of the Tata solar plant as seen from the peripheral embankment

BUFFER ZONE HAS HIGH LAND PATCHES

The fifty-meter buffer zone between the southern boundary of Phase I and the northern boundary of Phase II has patches of highland (Photo 2.9). It is proposed that a drain be provided south of and adjacent to the phase I embankment. This drain shall receive stormwater from TPREL, SJVNL, ENGIE, and GSECL(II) plots of phase I. The drain should be aligned in East-West direction following the natural gradient and bypassing the high patches of ground

Photo 2.9 The fifty-meter buffer zone between the southern boundary of Phase I and the northern the boundary of Phase II

PHASE II AREA: Phase II area as seen from south west corner. It is flat land without any vegetation. No natural drain in the area. Figure 2.10 shows the GPS location. The northwest side shows the embankment alignment of Phase I and the high land area outside phase I area

Photo 2.10 a. View of the Phase II area

Photo 2.10 b. Another view of the Phase II area

Photo 2.11 shows engineers from GPCL, SECL, Prof Ashish Pandey of IIT Roorkee, and Prof U C Chaube, Drainage Expert in the phase II area during the site visit.

Photo 2.11 Engineers from GPCL, SECL, Prof Ashish Pandey of IIT Roorkee, and Prof U C Chaube, Drainage Expert in the phase II area.

2.7 PHYSICAL CHARACTERISTICS

2.7.1 Geology and Seismic Zones: Geologically, the area is covered with a saline tract of brownish-grey silt, clay, sand, and murram at depth. The site falls in Seismic Zone IV, which indicates a High Damage Risk Zone. Therefore, developers need to take adequate measures while installing Solar Panels to ensure the least damage during an earthquake.

2.7.2 Soil: Surface geologic materials consist of clays and clayey sand and might have strata with hard clay mixed with highly weathered weak and fragmented rock from 5 m to 10 m from the ground surface.

Solar panels, along with shallow footings, are lightweight structures. The panels are independently supported on low-height columns. Damages that could occur to large, heavy structures due to liquefaction are unlikely in the case of solar panels. Also, with the presence of stiff to very stiff, fine-grained, cohesive nature of the subsurface materials in the area, the liquefaction effect can be from nil to insignificant. Bored cast-in-place piles may be considered to support solar panels so as to minimize the risk of liquefaction damage to the panels.

2.7.3 Climatic and Meteorological Conditions: The state of Gujarat is one of the best locations in India for solar power generation. Charanka Solar Park, having a capacity of 500+ MW, is at a crow-fly distance of about 30 km.

Local Weather Conditions: Weather is predominantly dry and arid. Key characteristics of weather for Deesa IMD station at a distance of about 102 km are depicted in Table 2.7.

Table 2.7 Climate and Meteorological Conditions

Sr. No.	Parameters	Details
1	**Solar Zone**	**5.8 – 6.0 kWh / sq.m.**
2	**Temperature**	
2.1	Average Daily Maximum Temperature	34.1°C
2.2	Average Daily Minimum Temperature	19.4°C
2.3	Highest Temperature	47°C
2.4	Lowest Temperature	5.2°C
3	**Rainfall**	
3.1	Annual Rainfall	578.8 mm
3.2	Number of Rainy Days	26.9days (sustained, torrential rainfall)
3.3	Relative Humidity	64%
4.1	Average Wind Speed	8.5 km/hr

Source: MK Soils, CCI Report, IMD data

IMD data indicates that the site receives maximum rainfall between July to August. In these two months, heavy downpours happen for only 8 to 9 days. On certain days, more than 200 mm of rainfall occurs within 24 hours. Limited periods of torrential rainfall, together with the low-lying nature of the topography, cause flooding during the monsoon periods and continued waterlogging in pockets even in non-monsoon months.

The water level could be 2 – 3 feet above the ground level during monsoon season. This is mainly due to the non-availability of a proper drainage network from the site.

2.7.4 Ecologically Sensitive Areas : There is no forest range or any other type of eco-sensitive area near the site. Moreover, at the site, the land parcels are barren and unfertile in nature. The prime reason for the lack of vegetation is arid weather and the salinity of groundwater.

2.7.5 Water Supply Infrastructure: Surface Water: Surface water reaches up to a distance of about 4 km from the site to Kundaliya village. SSNL Main Canal water is diverted towards the site from Gadsisar Branch Canal Offtake point at a distance of about 37 km from the solar park. The water flowing through the Gadsisar branch canal is further diverted towards Kundaliya village through a network of distributary canals of about 11 km.

There is an illegal drawing of water from the canal using diesel pumps for irrigation purposes.

Groundwater: Soil is heavily saline in nature, and the groundwater level is as low as 1.0 – 1.2 m from the ground level. This is a perched water table formed due to water logging in the monsoon season. The total dissolved salts of groundwater range around 500 ppm during monsoon; however, during the summer season, the level rises to about 3,000 ppm.

CHAPTER 3

DIGITAL ELEVATION MODEL STUDY

3.1 INTRODUCTION

The digital elevation model (DEM) is the digital representation (digital map) of the ground elevation data in meters. This digital map, a type of Digital Terrain Model (DTM), is raster data, meaning that it comprises equally sized grid cells, each with a unique elevation.

The projection and datum for a DEM may vary. The present study used polyconic coordinates (meters) to geo-reference all maps. The following data have been used for the DEM study:

i. Contour map of the plant area with a contour interval of 0.5 m.

ii. Geographic referencing points: These have been extracted from the features common in the toposheet and the map based on a recent topographic survey and georeferenced points provided by the GPCL.

iii. Plant layout map showing location and ground formation levels of various components of the Radhanesda Solar Power Project (Phase – II) (700 MW).

3.2 PREPARATION OF DIGITAL ELEVATION MODEL (DEM)

ARC-GIS software was used to prepare the DEM. Each contour was assigned to its value and converted into TIN. However, to prepare a digital elevation model (DEM), a 5m × 5m gridded spot-level dataset was used.

The extensive Digital Elevation Model has been generated by interpolating the spot-level data. The DEM of the study area is shown in Figure 3.1, and the variation in elevation from 4.0 m to 14.5 m is depicted through different colors. The DEM of the study area is a single-color intensity map in Figure 3.2.

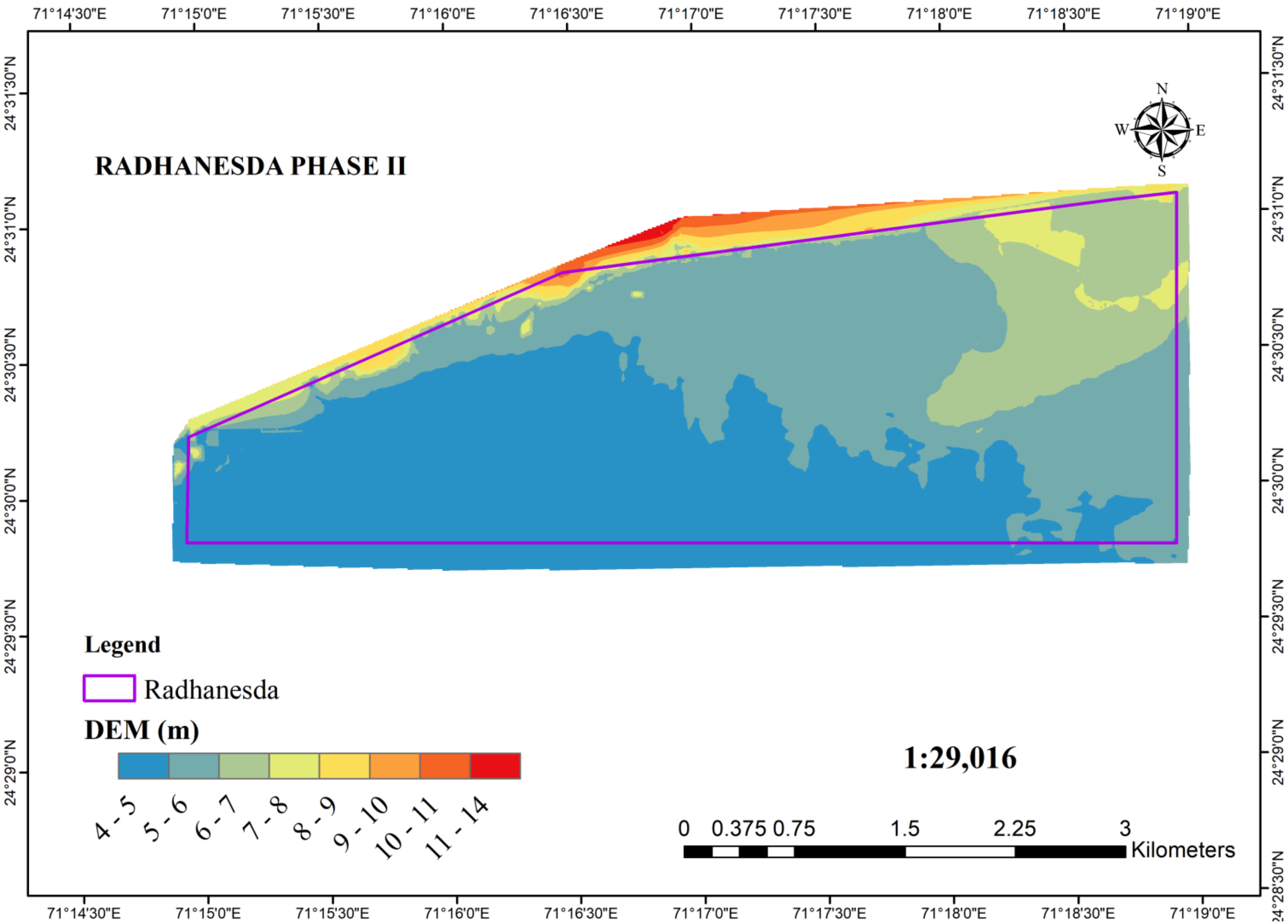

Figure 3.1 DEM - contour zonation map of the study

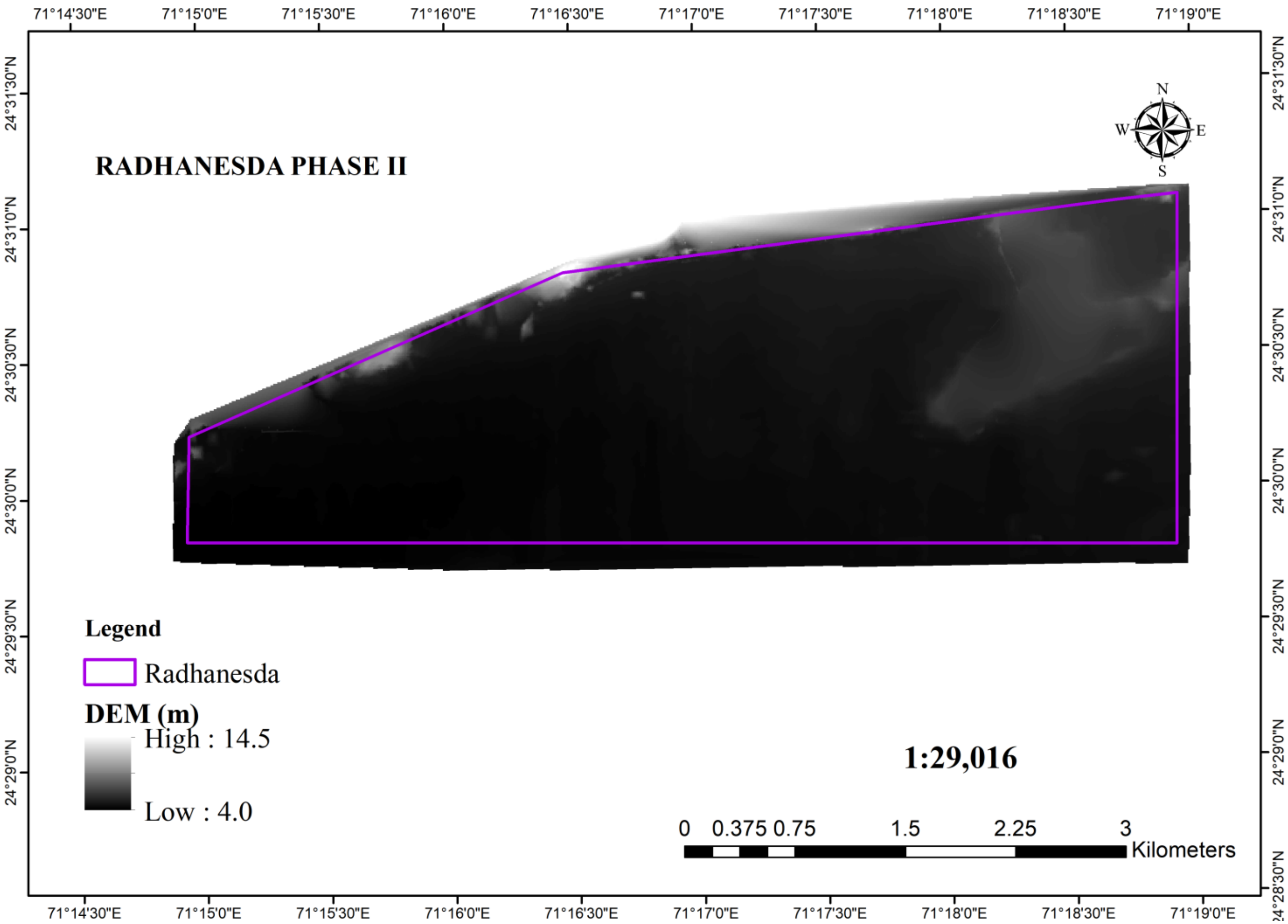

Figure 3.2 DEM - terrain color intensity map of the study

3.3 GENERATION OF STREAM NETWORK

The Spatial analyst tools of ARC-GIS software have been used in the present study for further processing in stream generation.

DEM has been smoothened to eliminate uneven irregularities using the *Fill* tool to remove the sinks. Corrected DEM has been used to generate a pattern of *flow directions* and to identify *flow accumulation* through each pixel of a given elevation. Generated information on flow patterns and flow accumulation considers the Eight-Point Pour model for computing flow directions for use in basin delineation with DEM directions. With the flow directions assigned for each DEM point, the flow accumulation at each DEM point has been computed. The flow accumulation at a given DEM point is the number of earlier DEM points whose flow paths eventually pass through that point.

Streams are identified by large flow accumulation values since the flow paths of many points pass through the stream points. An outlet of a watershed has the highest flow accumulation value of any of the DEM points since the flow paths of all points in the watershed will eventually pass through the outlet point. Streams have been identified by displaying all DEM points with a flow accumulation value of more than 300. Figure 3.3 shows the generated stream network in the study.

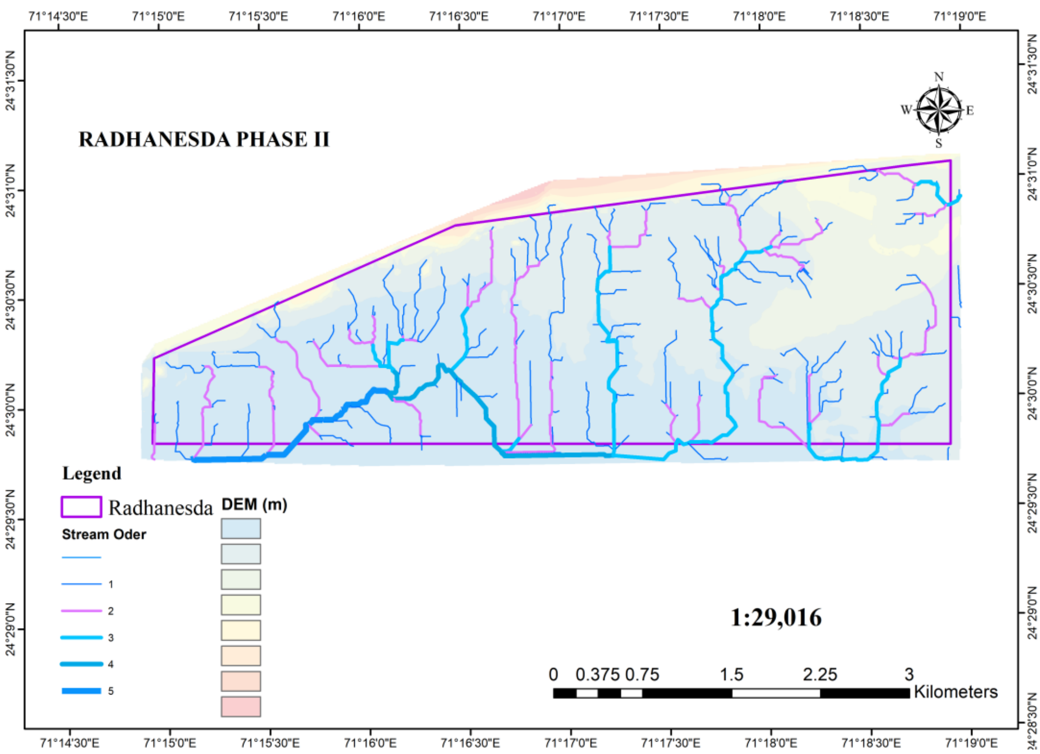

Figure 3.3 Drainage network derived from DEM

3.4 DISTRIBUTION OF STUDY AREA IN DIFFERENT ELEVATION

The Digital Elevation Model prepared in ARC-GIS has been used to compute the natural drainage area (within plant boundaries) at different elevations. The DEM computes the number of pixels at each elevation. Table 3.1 shows the distribution of 1440 ha area from 4 m to 14 m (above m.s.l.) elevation.

Table 3.1 Areal distribution with elevation in the study area as per DEM

Elevation	No. of pixels	Area	Area	Area	Cumulative Area	Cumulative Area
m		m^2	ha	%	%	ha
4	10069615	10069615	1006.9615	69.9194	69.9194	1006.9615
5	3336757	3336757	333.6757	23.1691	93.0885	1340.6372
6	455292	455292	45.5292	3.1614	96.2499	1386.1664
7	254852	254852	25.4852	1.7696	98.0195	1411.6516
8	146319	146319	14.6319	1.0160	99.0355	1426.2835
9	85298	85298	8.5298	0.5923	99.6277	1434.8133
10	29224	29224	2.9224	0.2029	99.8307	1437.7357
11	12405	12405	1.2405	0.0861	99.9168	1438.9762
12	7504	7504	0.7504	0.0521	99.9689	1439.7266
13	3898	3898	0.3898	0.0271	99.9960	1440.1164
14	582	582	0.0582	0.0040	100.0000	1440.1746
	14401746	14401746	1440	100		

Figure 3.4 is a graphical depiction of the cumulative area distribution up to different elevations in the plant area. Most of the plant area (approx. 70%) has plain topography (4 m a.m.s.l). Also, approximately 30% of the area falls between 5 m to 14 m elevation.

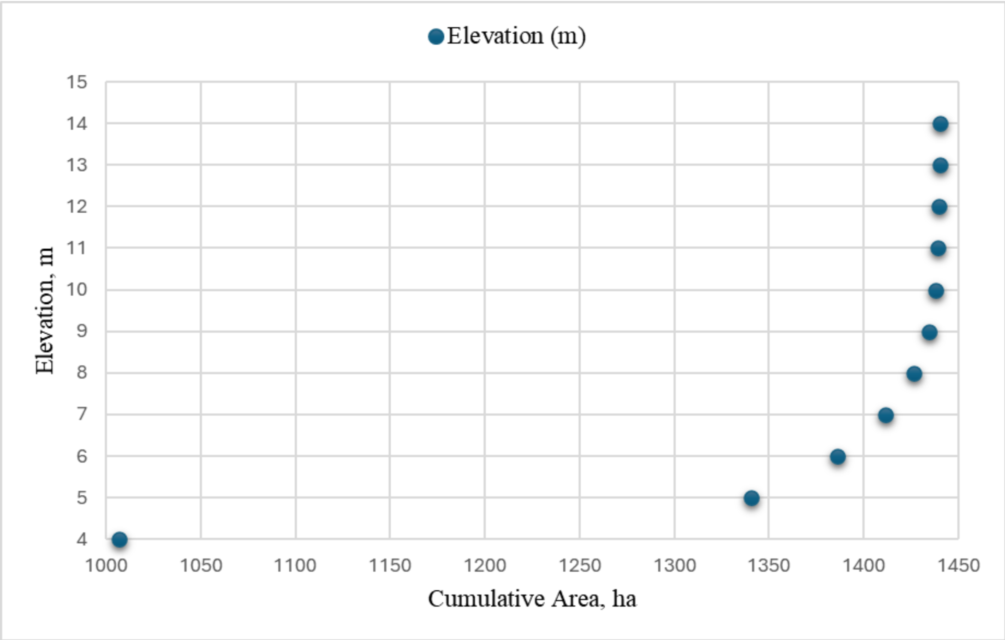

Figure 3.4 Cumulative areal distributions with elevation in the plant area

3.5 STREAM NETWORK IN THE VICINITY OF PHASE II PLANT AREA

The topographic survey of the Radhanesda Phase II plant area was provided by the GPCL, and DEM was prepared. The detailed analysis is already provided in Art 3.2. Furthermore, SRTM data was used to generate the drainage network to determine the drainage characteristics beyond the plant boundary of Phase II. The stream network in the proposed plant area and the vicinity of the Phase II plant area are presented in Figures 3.5 and 3.6.

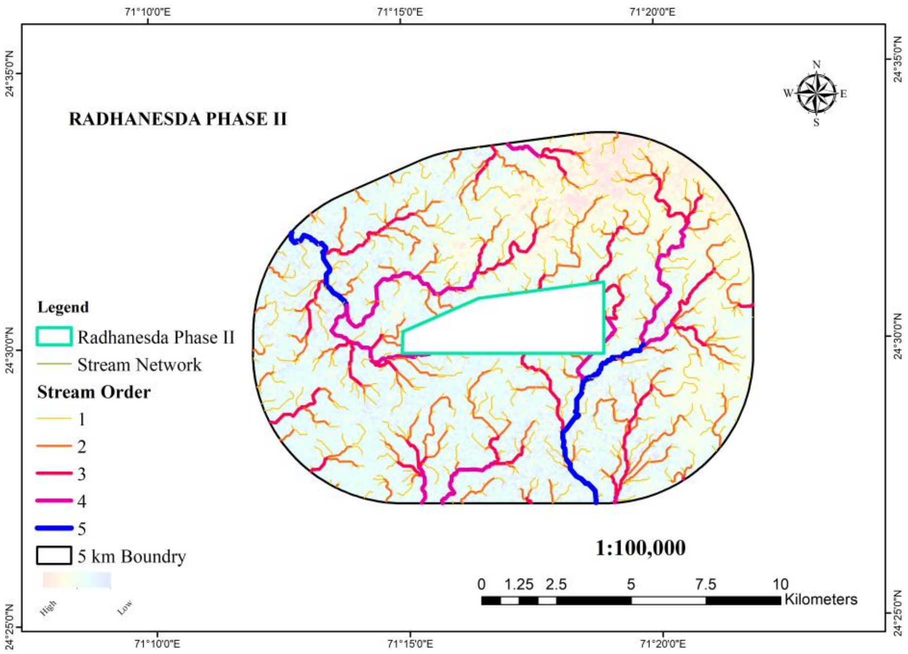

Figure 3.5 Stream network in the vicinity of Radhanesda Phase II plant area

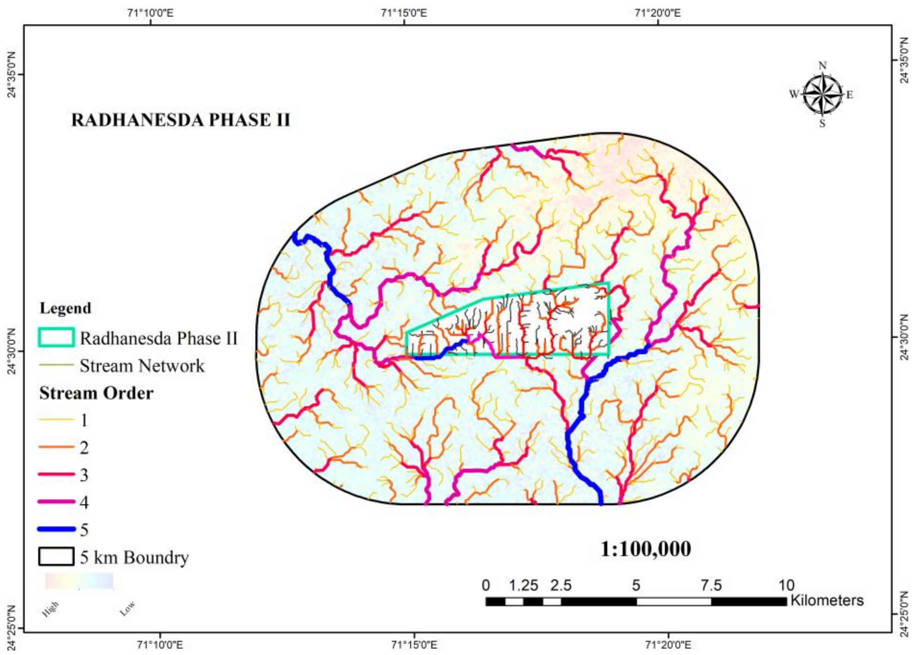

Figure 3.6 Stream network in the proposed plant area and in the vicinity of Phase II plant area

3.6 DEM STUDY OF THE PHASE I AND PHASE II PLANT AREA

A comparison of the DEM study of Phase I and Phase II plant areas was carried out to understand the flow pattern of the stormwater is given in Figure 3.7. Spot levels of the Phase II plant area and contour maps are presented in Figures 3.8 and 3.9.

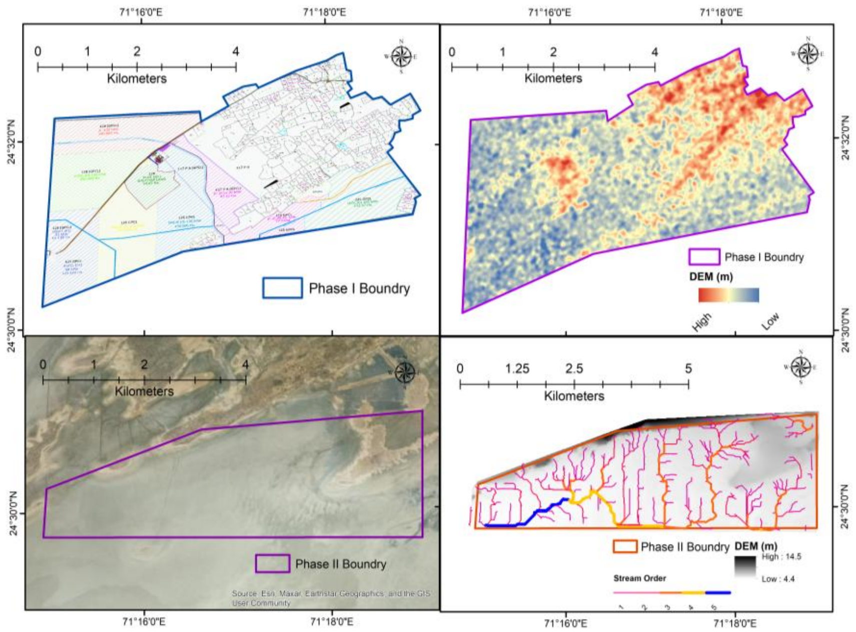

Figure 3.7. Comparison of the drainage of the Phase I and Phase II plant area

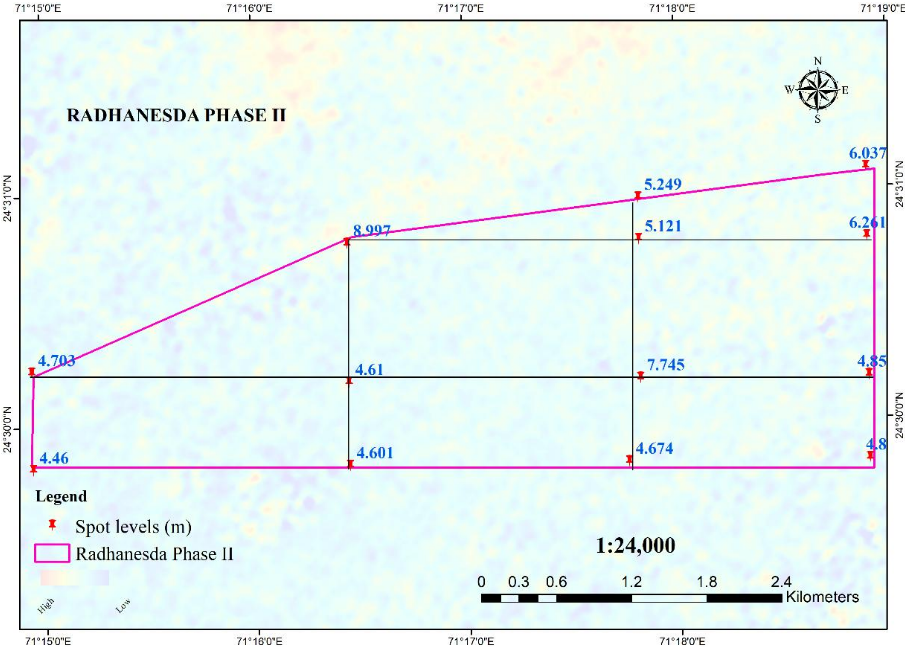

Figure 3.8. Spot levels of the Phase II plant area

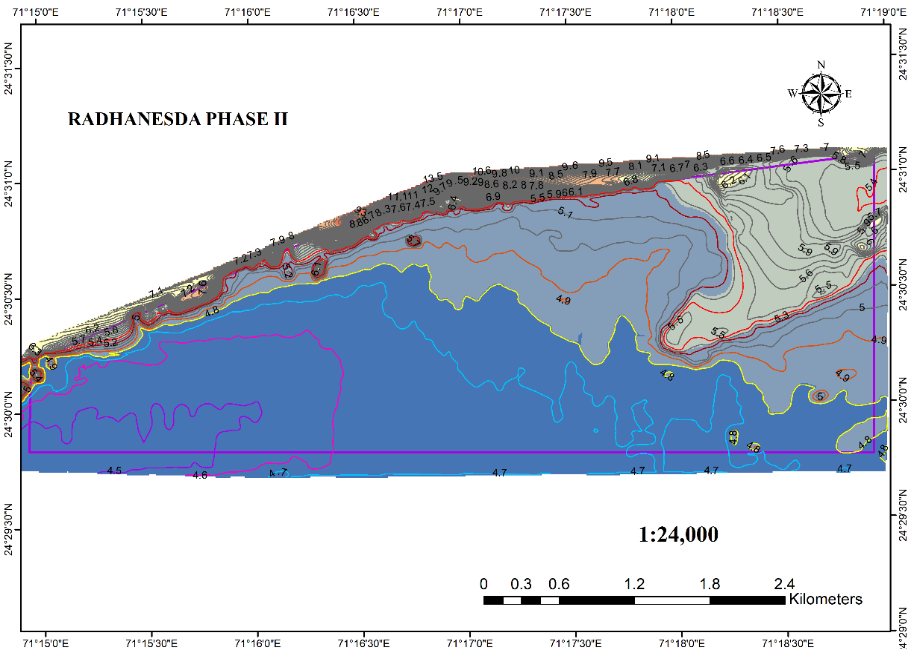

Figure 3.9a. Contour map of the Phase II plant area

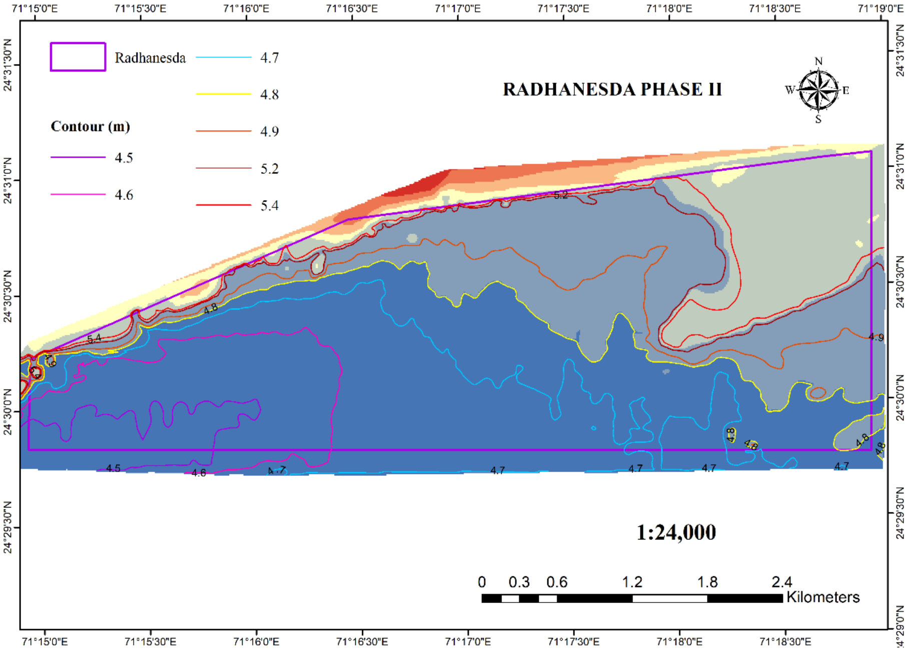

Figure 3.9b. Contour map of the Phase II plant area

CHAPTER 4

RAINFALL ANALYSIS AND DEPTH OF FLOODING

4.1 INTRODUCTION

Most of the Radhanesda Park (RSP) area has ground elevations higher than 4.0 m, except in the southwest, where ground levels are below 4m (up to about 3.7 m). The RSP area is part of the vast Rann of Kachh, has plain topography, and gets waterlogged in the rainy season. In the rainy season, water keeps standing for several days up to a depth of one to two feet at different locations.

The natural topography of the solar park phase I has changed due to land development work (land leveling and construction of roads, buildings, etc.) that has been carried out by various solar plant developers in the solar park. Phase II area has natural topography at present as no development work has been carried out.

In this chapter, historical rainfall has been analyzed to estimate the depth of one-day and two-day rainfall of various return periods.

4.2 FREQUENCY ANALYSIS OF 1-DAY MAXIMUM ANNUAL RAINFALL

The daily rainfall records for Banaskantha were available for 54 years, from 1971 to 2024. Using these data, 1-Day annual maximum rainfall series was constructed for Banaskantha for 54 years (1971-2024), and EV Type I probability distribution was applied. The return period of 1-day annual maximum rainfall series is estimated in Table 4.1. The results obtained are given in Table 4.2. Figure 4.1 is a graphical representation of the 1-day maximum rainfall frequency distribution at Banaskantha. 1-day rainfall has been converted to 24-hour rainfall using a factor of 1.15 as per guidelines of Central Water Commission (Flood Estimation Report for Luni Sub Zone-1a by Hydrology Directorate (Small Catchments) of Central Water Commission, New Delhi (November 1993).

Table 4.1 Frequency Analysis of 24-hr Annual Maximum Rainfall at Banaskantha

Rank, m	**Max. 24-hr rainfall in descending order(mm)**	**Plotting position, P**	**Return period, T**	**Rank, m**	**Max. 24-hr rainfall in descending order(mm)**	**Plotting position, P**	**Return period, T**
	1-day max. rainfall × 1.15	P = [m/(N+1)] using Weibull's Formula	T = 1/P		1-day max. rainfall × 1.15	P = [m/(N+1)] using Weibull's Formula	T = 1/P
1	288.79	0.018181818	55.00	28	71.4	0.509090909	1.96
2	249.23	0.036363636	27.50	29	70.1	0.527272727	1.90
3	183.59	0.054545455	18.33	30	69.4	0.545454545	1.83
4	161.1	0.072727273	13.75	31	65.2	0.563636364	1.77
5	145.1	0.090909091	11.00	32	62.2	0.581818182	1.72
6	141.9	0.109090909	9.17	33	58.94	0.6	1.67
7	134.1	0.127272727	7.86	34	58.8	0.618181818	1.62
8	124.5	0.145454545	6.88	35	57.8	0.636363636	1.57
9	123.7	0.163636364	6.11	36	56.44 (2023)	0.654545455	1.53
10	116.7	0.181818182	5.50	37	48.11	0.672727273	1.49
11	116	0.2	5.00	38	47.7	0.690909091	1.45
12	110.76	0.218181818	4.58	39	47.6	0.709090909	1.41
13	101.1	0.236363636	4.23	40	46.6	0.727272727	1.38
14	97.16	0.254545455	3.93	41	45.7	0.745454545	1.34
15	96.3	0.272727273	3.67	42	43.1	0.763636364	1.31
16	92.9	0.290909091	3.44	43	40.8	0.781818182	1.28
17	92.7	0.309090909	3.24	44	40.53 (2024)	0.8	1.25
18	89.32	0.327272727	3.06	45	38.39	0.818181818	1.22
19	86.7	0.345454545	2.89	46	37.7	0.836363636	1.20
20	85.7	0.363636364	2.75	47	35.79	0.854545455	1.17
21	81.5	0.381818182	2.62	48	34.5	0.872727273	1.15
22	80.9	0.4	2.50	49	33.4	0.890909091	1.12
23	79.1	0.418181818	2.39	50	32.9	0.909090909	1.10
24	78.9	0.436363636	2.29	51	29	0.927272727	1.08
25	77	0.454545455	2.20	52	27.4	0.945454545	1.06
26	72.5	0.472727273	2.12	53	22.2	0.963636364	1.04
27	72.1	0.490909091	2.04	54	19.8	0.981818182	1.02

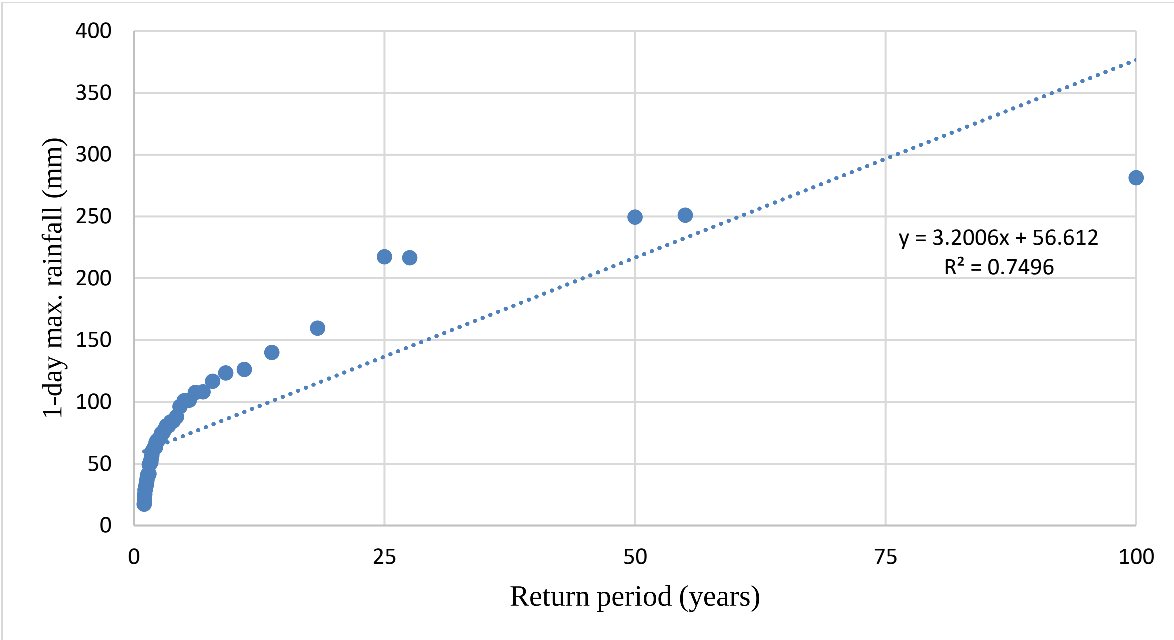

Figure 4.1: Weibull's distribution of 1-day max. rainfall at Banaskantha

Table 4.2 1-Day Rainfall (mm) of Various Return Periods at Banskantha

Return period (years)	**25**	**50**	**100**
1-day rainfall (mm)	217.34	249.48	281.38
24-hr rainfall (mm)	249.94	286.90	323.59

The study area lies in Luni Sub Zone 1a defined by CWC (1993). India Meteorological Department (IMD) has conducted a detailed rainfall study for the Sub Zone 1a (CWC 1993) utilizing the data of 142 ordinary raingauge stations maintained by IMD/States and 40 self-recording rain gauges of IMD/Indian Railways.

The annual maximum series of 1-day rainfall was formed for each of 142 ordinary rain gauge stations using records of 50 to 70 years. This annual extreme series was subjected to frequency analysis using Gumbel extreme value probability distribution, and 1-day rainfall estimates corresponding to 25, 50, and 100-year return periods were computed. The daily values of 25, 50, and 100-year rainfall estimates were converted to 24 hr rainfall estimates using a factor of 1.15. For each return period, these 24-hour rainfall estimates for all the stations in the sub-zone were plotted on the base map, and an isopluvial map was drawn. Thus, isopluvial maps of 25-year, 50-year, and 100-year return periods were prepared.

Isopluvial maps for subzone 1a of the Luni subzone are available for 24-hour rainfall of 25-year, 50-year, and 100-year return periods. Using these isopluvial maps, the 24-hr rainfall of various return periods at Banaskantha is shown in Table 4.3. The 24-hr rainfall values of 25 years, 50 years, and 100 years return periods (as per isopluvial map) and those derived from the frequency analysis of 1-day annual maximum rainfall data of 54 years at Banaskantha are compared in Table 4.3.

Table 4.3 24-hr Rainfall (mm) Values for Different Return Periods

Return Period (Year)	Based on 54 years of recent data at Banaskantha	Based on CWC maps
25	249.94	270
50	286.90	310
100	323.59	360

The area surrounding the solar park is a vast expense of flat land. The depth of flooding outside the solar park may be based on 286.90 mm (24-hr rainfall corresponding to a 50-year return period as obtained by frequency analysis of 54 years of recent data). Only 24-hour rainfall is considered to estimate the design depth of flooding outside the solar park area as there is unobstructed movement of stormwater in the vast expense of flat land beyond the flood embankment.

4.3 ANALYSIS OF 2-DAY MAXIMUM ANNUAL RAINFALL

4.3.1 Rainfall Gridded Data

Although the station (sample point) data are the primary source for the rainfall data, these observations are often biased and distributed non-homogeneously in space and time. Therefore, it is necessary to convert the station data to a regular space-time grid and correct or remove the erroneous values before such observations can be used for further studies. A common approach for converting station rainfall data into grid point data is spatial interpolation, which assumes that spatially distributed station rainfall values are spatially correlated or that the close stations tend to have similar rainfall characteristics.

India Meteorological Department (IMD) has developed a new daily gridded rainfall data set all over India at a spatial resolution of 0.25° × 0.25° (approximate 25 km × 25 km) for 124 years (1901-2024). IMD has used all the available quality rain gauge data to prepare a high-resolution daily rainfall data set for various applications such as climate variability and climate change studies, validation of model rainfall at multiple scales, hydrological modeling, drought monitoring, etc. Various standard quality-checking tests were applied to the data before interpolating the station rainfall data onto fixed spatial grid points.

4.3.2 Analysis of 2-day Annual Maximum Grid Data for Radhanesda and Banaskantha

Twelve years of daily rainfall data (2012 to 2023) for the grid in which the Radhanesda Solar Park area lies has been obtained from the IMD website. This data has been used to prepare an annual 2-day max. rainfall series. For the same period (2012 to 2023), frequency analysis of 2-day annual maximum rainfall data at Banaskantha has also been carried out, as shown in Table 4.4.

Table 4.4 Frequency analysis of 2-day annual maximum rainfall series at Radhanesda and Banaskantha

Rank	**2-DAY Max rainfall (mm) in descending order**		**Plotting position, P**	**Return period, T**
m	(Banaskantha)	(Radhanesda)	P = [m/(N+1)] using Weibull's Formula	T = 1/P
1	458.96	468.95	0.076923077	13.00
2	432.1	320	0.153846154	6.50
3	191.04	191.08	0.230769231	4.33
4	184.72	174.59	0.307692308	3.25
5	148.7	141.71(2023)	0.384615385	2.60
6	119.43 (2023)	138.01	0.461538462	2.17
7	119.24	117.41	0.538461538	1.86
8	86.68	74.51	0.615384615	1.63
9	84.49	69.71	0.692307692	1.44
10	76.56	62.75	0.769230769	1.30
11	59.68	55.48	0.846153846	1.18
12	53.76	23.69	0.923076923	1.08

Estimates of a 2-day annual max. rainfall of 10 years, 25-year, and 50-year return periods for the Radhanesda grid and at Banaskantha station are found to be consistent (Table 4.5). Figure 4.2 is a graphical representation of the 2-day maximum rainfall frequency distribution at Banaskantha and Radhanesda.

Table 4.5 10, 25, and 50-year return periods 2-day max. rainfall at Radhanesda and Banaskantha

Return Period	**2-Day Max. Rainfall in mm**	
(Years)	(Banaskantha)	(Radhanesda)
10	407.61	375.82
25	537.7	496.68
50	634.21	586.34

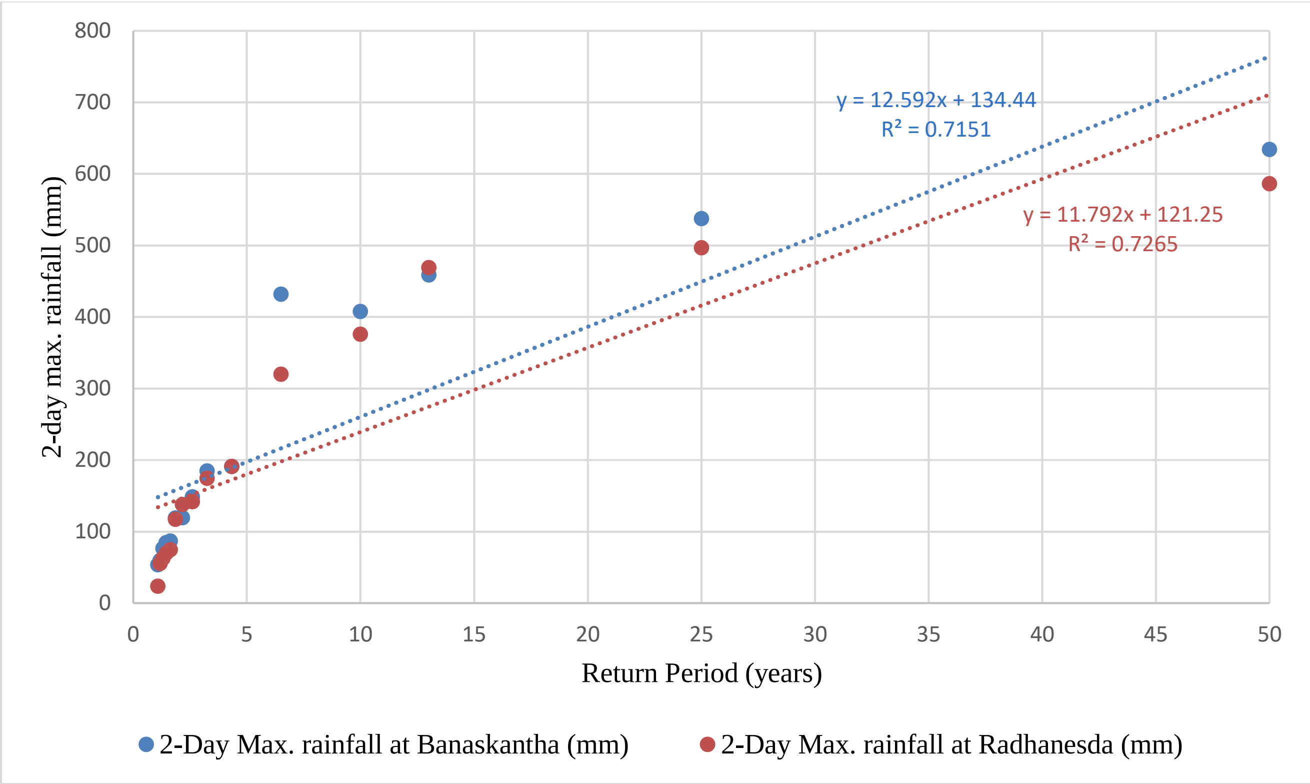

Figure 4.2: Weibull's distribution of 2-day max. rainfall

4.4 DESIGN DEPTH OF FLOODING IN SOLAR PARK

Considering future land development in phase II of the solar park, adopting a 2-day rainfall of 586.34 mm is recommended as the design depth of flooding inside the solar park. Solar panels, roads, electric cables, etc, should be around 0.6 m above the finished grade level.

4.5 DESIGN STORM SCENARIOS FOR FLOOD ESTIMATION

4.5.1 Conversion of 24-hr Rainfall to Short-Duration Rainfall

The average ratios of rainfall of short duration t (1 hr, 3 hr, 6 hr, 9 hr, 12 hr, 15 hr, 18 hr and 24 hr (CWC 1993) with respect to 24-hr rainfall are given in Table 4.6.

Table 4.6 Average Ratio (t-hr Rainfall/24-hr Point Rainfall) for Various Durations

Storm duration (hrs)	1	3	6	9	12	15	18	24
Ratio	0.36	0.58	0.72	0.79	0.85	0.89	0.94	1.00

4.5.2 Conversion of Point to Areal Rainfall

The hourly rainfall data of 18 SRRG stations were used to find the ratios for different durations of storms and different-sized catchments. Detailed procedure is given in CWC (1993). The area reduction factors (ARF) for different catchment areas and different duration storms (viz., 1 hr, 3 hr, 6 hr, 12 hr, and 24 hr) are given in Table 4.7.

Table 4.7 Point to Areal Rainfall Ratios (%)

Area Reduction Factor (%)					
Area (Sq. km)	**1 hour**	**3 hour**	**6 hour**	**12 hour**	**24 hour**
50	81.5	86.0	90.5	91.5	93.5
100	74.25	79.5	84.0	87.5	90.5
150	69.0	75.25	80.0	85.0	88.0
200	65.25	72.0	77.0	83.0	86.5
250	62.0	69.0	74.75	81.5	85.0

CHAPTER 5

ESTIMATION OF FLOOD IN SOLAR PLANT AREAS OF PHASE I AND SUBCATCHMENTS OF PHASE II

The solar plants GSECL(F2), ENGIE SJVNL, and TPREL have box culverts through which the stormwater will be let out on the south side. This runoff needs to be carried safely to the low-lying area in the southwest corner side so that the phase II area is protected from the phase I runoff entering into phase II. Similarly, storm runoff from the tributary sub-catchments of the Phase II area needs to be safely carried to low-lying areas beyond the west side of Phase II. Therefore, it is necessary to estimate the design flood in solar plant areas (at the location of box culverts) of Phase I and in the sub-catchments of Phase II. Floods corresponding to a 50-year return period and storm rainfall are taken as the designed flood. The modified Rational method is used to estimate flood

Basis for estimation of design floods. Flood corresponding to a 25-year return period storm rainfall is taken as a designed flood. The modified Rational method is used to estimate flood. Design flood in the catchment of a nala lying in the upland beyond northeast side of phase I has been estimated in a previous study (IITR 2023). This flood has been used to work out specific discharge (flood discharge per unit area). The specific discharge value is then used to calculate flood discharge in bunded plant areas of GSECL(F2), ENGIE, SJVNL, TPREL of phase I and in sub-catchments of phase II on contributing area basis

5.1 FLOOD ESTIMATION IN A NALA OF UPLAND AREA

5.1.1 The Nala Catchment and Its Parameters

There is a large upland area (about 7 km^2) to the northeast side of the Radhanesda Solar Park Phase I. The upland nala draining towards the SJVNL plot has been considered for the estimation of peak discharge (Figure 5.1). The boundary of the catchment has been marked, and DEM was used to delineate the streams. Nala properties (area, length of nala, slope, elevation at the farthest point from the outlet, and elevation at the outlet) have been calculated while delineating watersheds using ARC-GIS software (Figure 5.3).

Catchment area (A)= 2.5708 km^2; Length of nala (L)= 3240.63 m; Max elevation=13 m

Min elevation=7 m; Slope= (13-7)/3240.63=0.0018 i.e. 0.18%

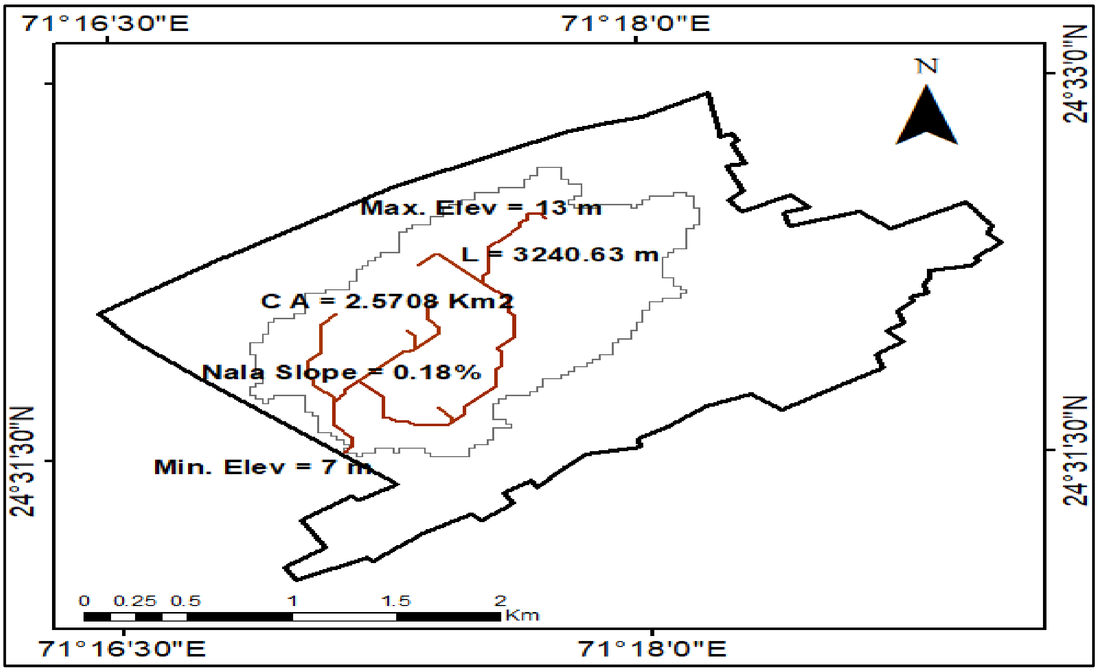

Figure 5.1 The Upland Nala catchment and physiographic parameters.

5.1.2 Design Storm Scenario

Frequency analysis of 1-day annual maximum rainfall at Banaskantha and 2-day Annual maximum Grid Data for Radhanesda has been discussed in Chapter 4. For flood estimation, 24-hour rainfall of a 25-year return period, i.e., 250 mm, is considered.

5.1.3 Rational Method for Small Catchments

For catchments of an area less than 25 km^2, the Rational Method given in the following document is recommended by the Central Water Commission (CWC 1994).

Report No RBF-16 'Flood Estimation Methods for Catchments Less Than 25 km^2 in Area' prepared by Research, Design &Standards Organization (RDSO) of Indian Railway, Government of India

The Rational Equation in metric units is given below.

Q = 0.278CIA

Where, Q = Peak discharge, cubic meter per second; C = Rational method runoff coefficient; I = Rainfall intensity(mm/hour) during the time of concentration; A = Drainage area(km^2)

Time of concentration (t_c) is the time required for the most distant part of the catchment to contribute to the outflow. The time of concentration has been taken from the Bransby-Williams formula as suggested in RBF-16.

$t_c = 0.615L/(A^{0.1}S^{0.2})$

where, t_c = time of concentration (hrs); L=main stream length(km); S = mean slope of mainstream (%); A = catchment area(km^2)

<u>The Runoff coefficient (C):</u> It is a function of the soil type, drainage basin slope, and land cover and may be taken from the formula given in Table 5.1.

Table 5.1 Formula to obtain Runoff coefficient C

Sl. No.	**Description of catchment**	**Formula for C**
1	Sandy soil/sandy loam/arid areas	$C=0.249(R.F)^{0.2}$
2	Alluvium/silty loam/coastal areas	$C=0.332(R.F)^{0.2}$
3	Red soil/clayey loam/grey or brown alluvium/cultivated plains/tall crops/ wooden areas	$C=0.415(R.F)^{0.2}$
4	Black cotton/clayey soil/lightly covered, lightly wooded/plain and barren/ sub montane and plateau	$C=0.456(R.F)^{0.2}$
5	Hilly soils/plateau and barren	$C=0.498(R.F)^{0.2}$

The upland catchment characteristic is sandy soil/sandy loam with bunded fields for cultivation and several village bunds. C for such catchment may be taken as

$C=0.2 (R.F)^{0.2}$

where R =T year 24-hour point rainfall(cm) and F=area reduction factor depending upon catchment area and duration of rainfall.24-hour Rainfall of 25 year return period is 250 mm as a conservative estimate (see Chapter 4).

Upland has a steeper slope (0.15%) compared to the slope in the flat land of the phase II area(0.018%). Further land levelling in phase I plant areas has been carried out. Therefore, it is reasonable to assume a slope of 0.018%

Table 5.2 Rational Method for Flood Estimation

Return period	**25 year**
Catchment area (km^2)	2.5708
24 hr rainfall (R) in cm(table 4.3in ch4)	25
Length (km)	3.241
Slope (S) (%) in upland area	0.18
Area reduction factor for rainfall(F)	0.935
Runoff Coefficient $C=0.2(R.F)^{0.2}$	0.376
Design duration (hours)=time of concentration $t_c=0.615L/(A^{0.1}S^{0.2})$ $=0.615\times3.241/(2.5708^{0.1}\times0.18^{0.2})$=2.6 say 3 hours	3
Storm rainfall (cm)during design duration= Average ratio (t hr rainfall/24 hr point rainfall) × area reduction factorx24 hr rainfall ==0.58×0.935×25 hr rainfall	13.56
Rainfall Intensity(I) during 1 hr duration of rainfall in mm/hr 135.6/4=33.9mm/hr	33.9
Flood Estimate using Rational Formula Q=0.278CIA (m^3/sec)=0.278×0.376×33.9×2.57	9.107

Therefore, 25year flood generated in 2.57 km^2 area with flat slope of 0.18% is 9.107 m^3/sec

5.2 SPECIFIC FLOOD DISCHARGE

Specific discharge is defined as flood discharge per unit area.

=9.107/2.5708 i.e. 3.54 m^3/sec/ km^2 = 0.0354 m^3/sec/ha

5.3 DESIGN FLOOD IN BUNDED SOLAR PLANTS OF PHASE I

Figure 5.2 shows the box culvert locations of the TPREL, SJVNL, ENGIE, and GSECL(F2) plots through which flood water would go to the drain aligned in the east-west direction. The estimation of flood in the solar plant areas is shown in Table 5.3 below.

Table 5.3 Estimation of flood in the solar plant areas of Phase I

Solar plant	Plot area(ha)	Specific flood m^3/sec/ha	Flood m^3/sec	Cumulative flood
TPREL	192.57	0.0354	6.817	6.817
SJVNL	176.2	0.0354	6.237	13.054
ENGIE	380.0	0.0354	13.452	26.506
GSECL(F2)	129.6	0.0354	4.588	31.094
Phase I End channel to outfall				31.094

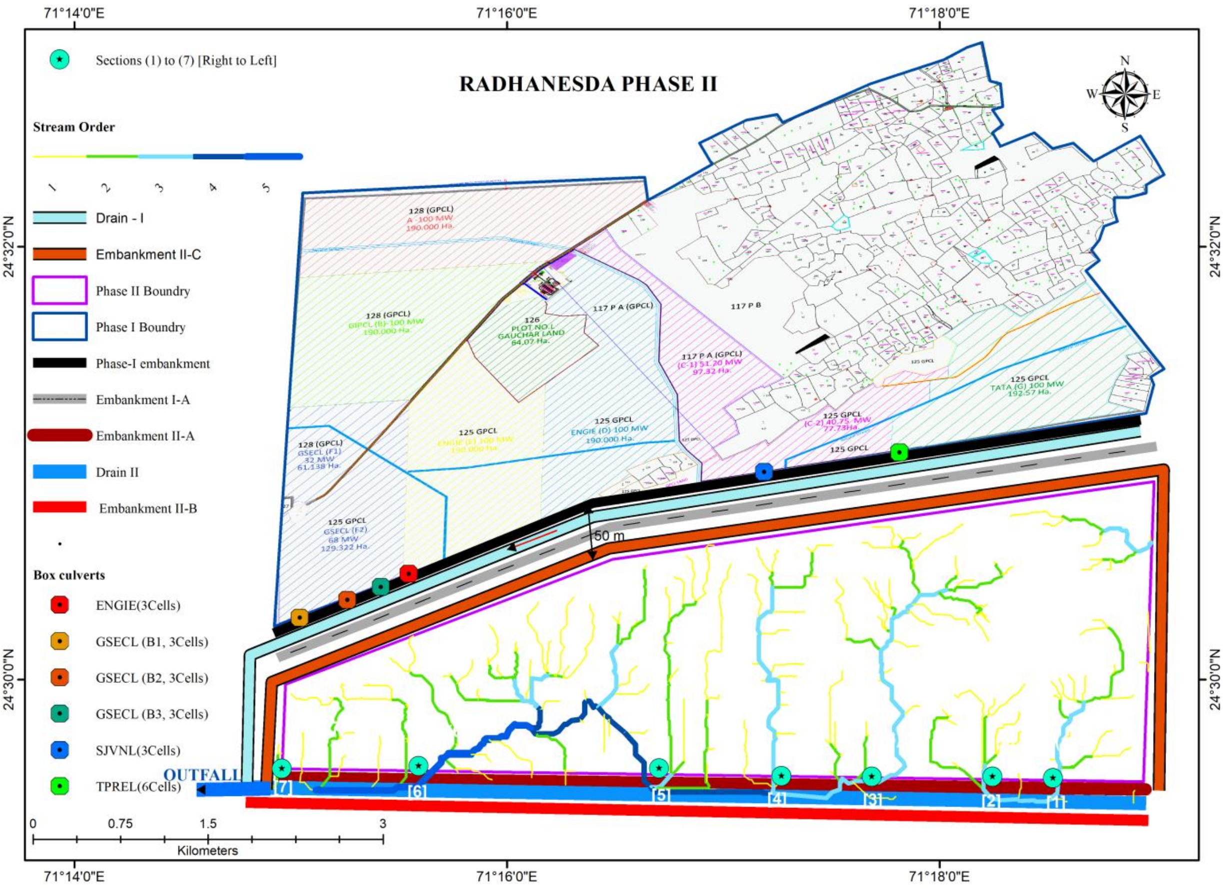

Figure 5.2 Location of box culverts in the TPREL, SJVNL, ENGIE, and GSECL(F2) plots in Phase I and seven outfall locations of nalas in Phase II

5.4 DESIGN FLOOD IN SUB-CATCHMENTS OF PHASE II

At present, plot boundaries within the Phase II area are not demarcated. Therefore, flood discharge at the outlets of sub-catchments has been estimated as shown in the table below. Sub-catchments in the phase II area are shown in Figure 5.3.

Table 5.4 Design flood discharge at the outlets of sub-catchments

Sub-catchment	Area(ha)of sub-catchment	Specific flood $m^3/sec/ha$	Flood m^3/sec	Cumulative flood
1	129.2	0.0354	4.574	4.574
2	161.55	0.0354	5.719	10.293
3	192.46	0.0354	6.813	17.106
4	186.31	0.0354	6.595	23.701
5	115.38	0.0354	4.084	27.785
6	302.15	0.0354	10.696	38.481
7	88.2	0.0354	3.122	41.603
Phase II End channel to outfall	1175.24			41.603

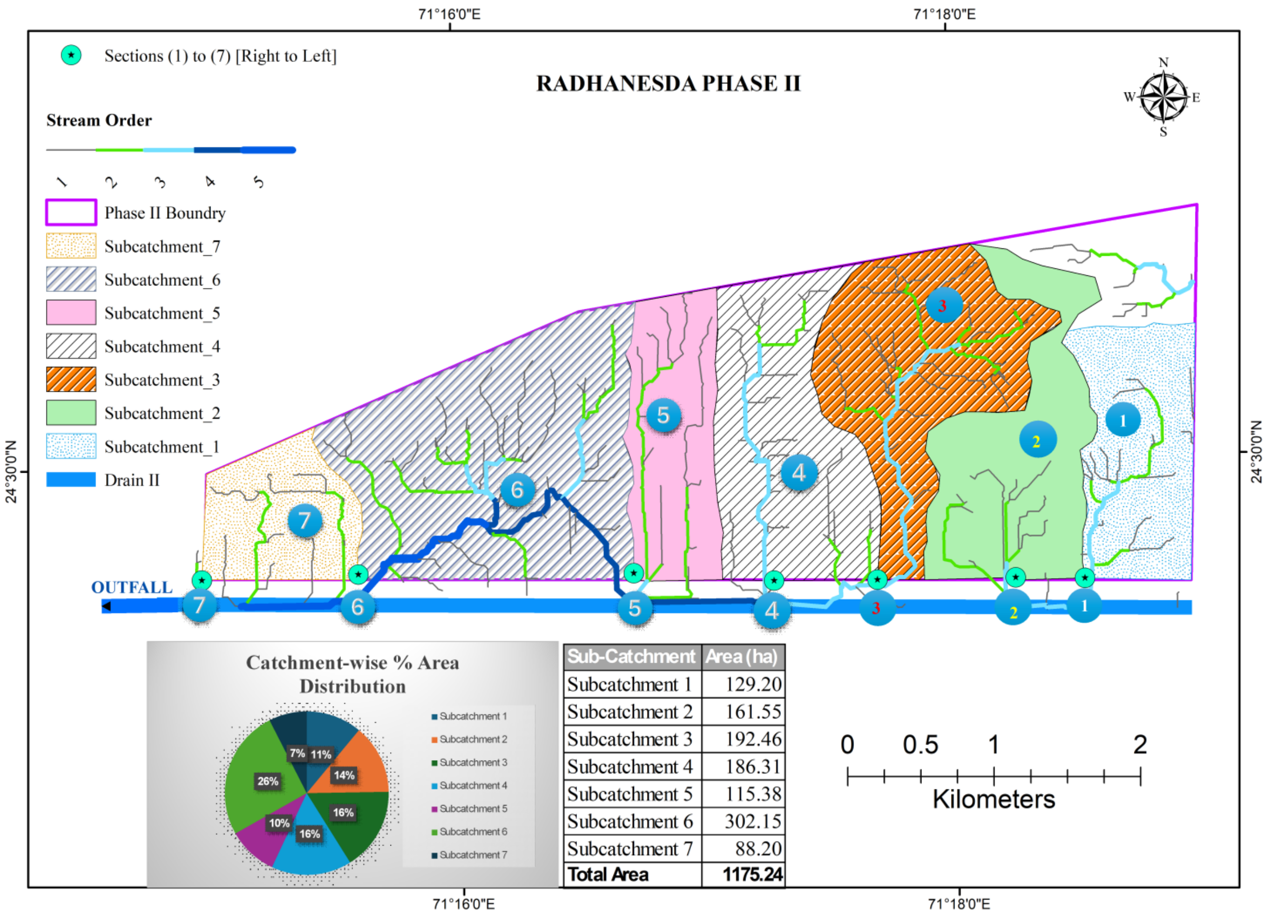

Figure 5.3 Boundaries and area of seven sub-catchments in phase II area

CHAPTER 6

CONTROL OF FLOODING AND HYDRAULIC DESIGN OF MAIN DRAINS

In this chapter, control of flooding and hydraulic design of the main drains in Phase I and II are discussed. **It is important to note that only technical possibilities have been explored in this chapter.**

6.1 FLOOD CONTROL AND MAIN DRAIN ON SOUTH SIDE OF PHASE I

In the area drainage study of phase I (IIT Roorkee 2022), a peripheral embankment around the boundary of the solar park phase I was discussed. The solar plants GSECL(F2), ENGIE SJVNL, and TPREL have box culverts through which the stormwater will be let out on the south side. This flood water needs to be carried safely to the low-lying area in the southwest corner side so that the phase II area is protected from the phase I runoff entering into phase II. For this purpose, the peripheral embankment on the south boundary of phase I is being widened and strengthened, and six box culverts are being provided in this embankment (Figure 6.1). Through these six culverts, the flood water will be received by a drain aligned in an east-west direction along the embankment. Figure 6.2 shows a plan view of the phase I box culvert location, widened embankment, retaining walls, main drain, buffer zone, and north side embankment of phase II.

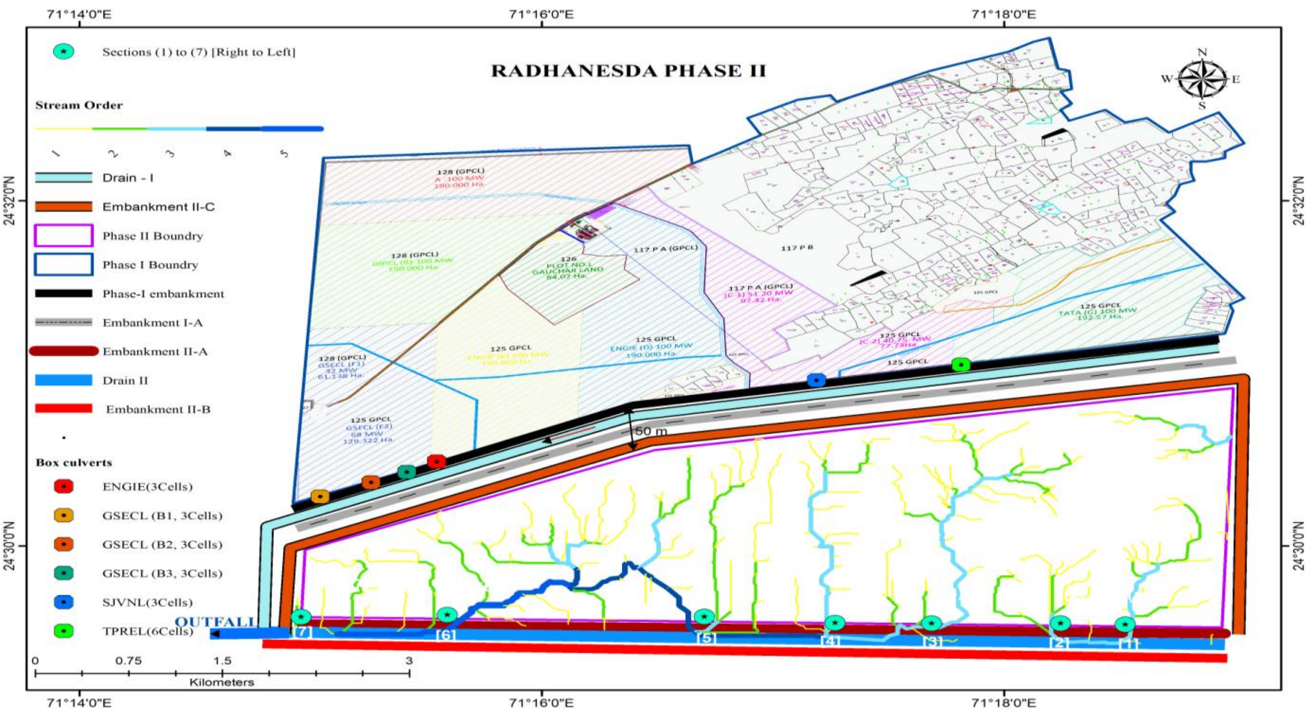

Figure 6.1 Location of box culverts, embankment, and main drain (drain-I) in phase I and location of seven outfall locations of nalas in embankment II-A and main Drain-II of phase II

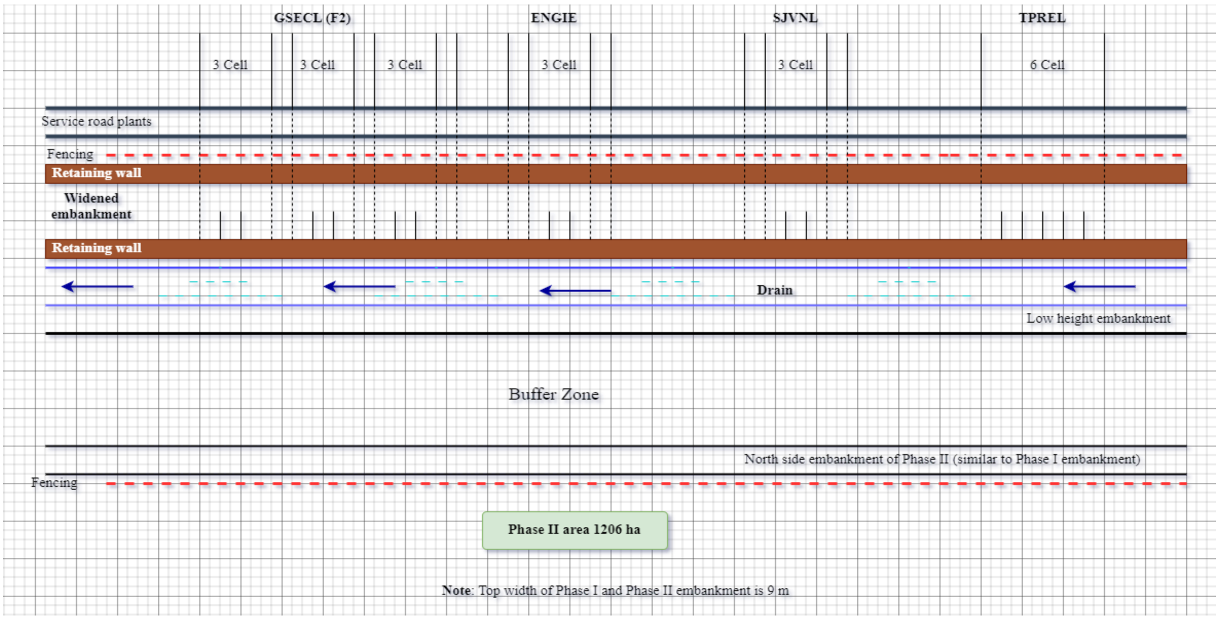

Figure 6.2 Plan view of phase I box culverts, embankment, retaining walls, drain and buffer zone

6.2 FLLOD CONTROL AND MAIN DRAIN ON SOUTH SIDE OF PHASE II:

Phase II area has natural topography at present as no development work has been carried out. It is proposed to provide a peripheral embankment along the phase II boundary to protect it from external flooding (figure 6.1). Further, a drain along southern boundary (similar to that in phase area (figure 6.3) is proposed to carry storm water from phase II area to low lying area in south west side so as to control flooding of solar plant coming up in south of phase II area.

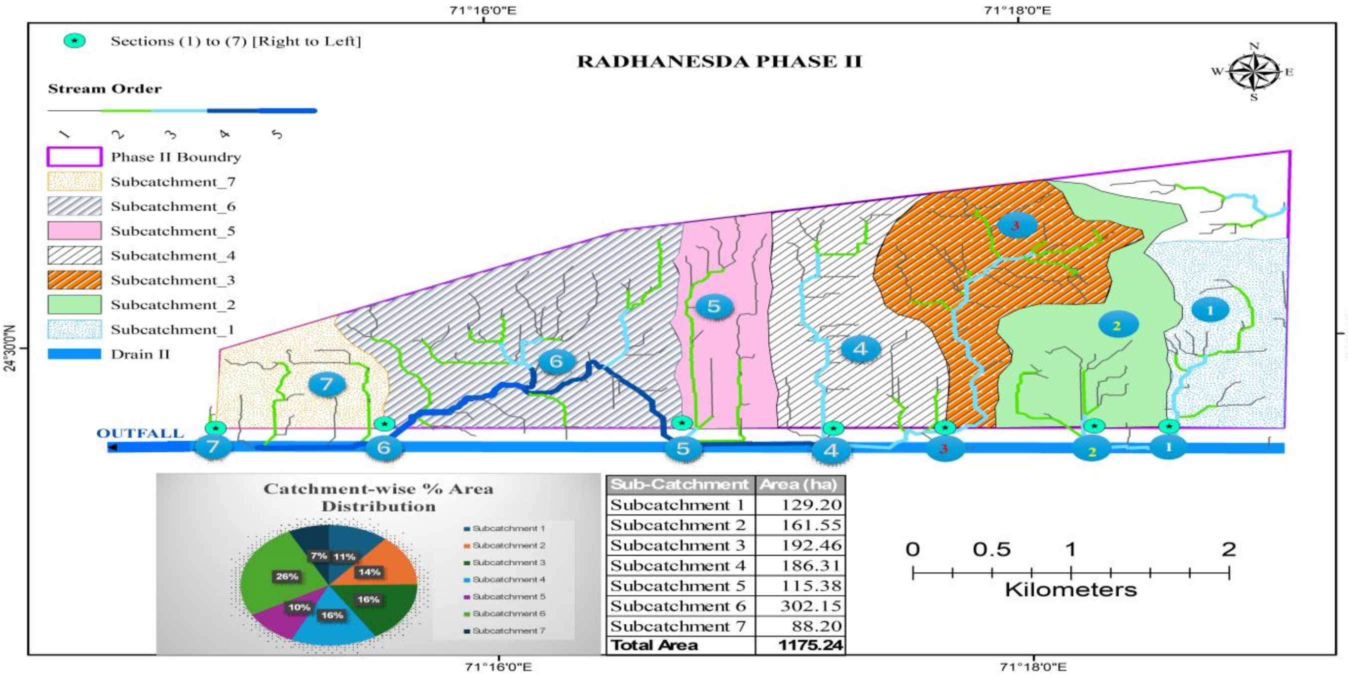

Figure 6.3 Seven subcatchments and outfalls on main drain in phase II area

6.3 RAISING THE FORMATION GRADE LEVEL (FGL) TO ACHIEVE ADEQUATE SLOPE OF LAND

Phase I Area: Land development works in the Phase I area have already been carried out; hence, there is no scope for raising the formation grade level of plots. The solar plants GSECL(F2), ENGIE SJVNL, and TPREL have box culverts through which the flood water will be let out on the south side. As discussed in section 6.1, six box culverts are now being provided in the peripheral embankment (Figure 6.1) through which flood water from already developed plants GSECL(F2), ENGIE SJVNL, and TPREL will go into a drain aligned in an east-west direction along the embankment.

Phase II Area: The Phase II area is flatter than the Phase I area. Land development works in the Phase II area are yet to be carried out. **Technically, it is possible to achieve an adequate slope of land in an east-to-west** direction by earth filling so that the main drain could receive flood water as **gravity flow from phase II blocks** (to be developed). It is suggested to provide a formation grade level of 5.5m in the west, southwest parts, and gradually increase up to 6.0 m in the central part and higher than 6.0 m in the eastern part of the phase II area. However, for this purpose, soil from outside the phase II area may have to be borrowed for filling. The topography of the Phase II area is explained in Chapter 3.

It is important to note that only the technical possibility of earth filling has been considered here for control of flooding, drainage by gravity flow, and the hydraulic design discussed below. Other possibilities are briefly stated in section 6.7.

6.4 DRAIN DESIGN CONSIDERATIONS

6.4.1 Site Constraints

The depth of flow in the drain cannot be increased beyond a certain limit (say 0.9m flow depth of cell in box culvert). The man drains receive storm water (as gravity flow) from the flat land of phase I and phase II at nearly the same level as that of the drain bed level.

The soil is fine-grained clayey sand. Side slopes of the trapezoidal section have to be kept gentle. It is proposed to keep the side slope as 1v:1.25h.

Retaining walls at the toe of embankments would provide stability of embankment slopes and also would protect slopes (particularly the inner side) from erosion due to water flow in main drains

6.4.2 Design Considerations

(i) Return period of 25 years has been considered in drainage design.

ii) Specific discharge (flood discharge per unit area of catchment) is taken as 0.0354 m^3/sec/ha for 50 50-year return period (see sections 5.1 and 5.2 of chapter 5)

(iii) Concrete-lined main drains of trapezoidal shape are proposed. Manning's roughness coefficient for the concrete-lined drain is taken as 0.016.

(iv) In order to check the inflow of silt-laden stormwater into the drain from land on the south side, a low-height embankment or dowell wall shall have to be provided

(v) The Channel section is worked out such that the capacity utilization of the drain (ratio of discharge contributed by connecting sub-catchments to the channel carrying capacity) is near 1.0. However, in a few channel segments, this requirement may have to be compromised based on hydraulic and drainage layout considerations.

6.4.3 Design Discharge in pre- and post-project Condition

The topography of Phase I and Phase II land is plain. The land use in the project area will be modified during post-project conditions. However, the net effect of changes in land use, land cover, and topography in post-project conditions shall be negligible. Part of the area covered by roads, buildings, solar panels, etc., will cause more storm runoff. On the other hand, the flat land (clayey sand) and obstruction of flow by roads would increase the opportunity time for infiltration, and hence, storm runoff shall be reduced. The flood generated by storm rainfall is expected to be the same as that generated by pre-project conditions.

6.5 HYDRAULIC DESIGN OF CHANNEL SECTIONS

Trapezoidal section is proposed for the main drains. The side slope is taken as 1v:1.25h

Manning's roughness coefficient(n) is taken as 0.016 for the concrete-lined channel.

Bed slope: A bed slope of 0.00026 (1:3850) has been considered for the main drain considering flat topography.

Depth of flow in a channel section: a resistance formula proposed by Robert Manning for uniform flow in an open channel is used.

Velocity (V) has been estimated by Manning's equation

$$V(m/s) = \frac{1}{n} \times R^{2/3} \times S^{1/2}$$

$$Q(m^3/s) = A \times V$$

Q: discharge (m^3/s)

n: Manning roughness coefficient. It is assumed to be 0.016 for a concrete-lined channel

R: hydraulic mean depth (=A/P)

A (m^2): Cross-sectional area

P (m): perimeter

S (m/m): surface water slope assumed to be the same as the river bed slope

Longitudinal slope of drain: 1:3850

The drain is assumed to have a lined trapezoidal section.

The side slope of the trapezoidal section is taken as 1V:1.25H

Bed with and depth are found such that

$$\frac{(B+1.25D)^{5/3}}{(B+3.2016\,D)^{2/3}} * D^{\wedge}5/3$$

is nearly the same as the Section factor $Q.n/(S)^{0.5}$.

The width and depth of flow are computed as shown in Tables 6.1 and 6.2 below

Table 6.1. Phase I Main drain design

(Longitudinal slope s=0.00026, Manning coeff=0.016; side slope 1V:1.25H)

Sl. No.	Location box culvert	Carrying Capacity(Q), m^3/sec	Section factor $(Qn/(S)^{1/2)}$	Bed Width (m)	Depth (m)	Section factor achieved
1	TPREL	6.817	6.764	5.50	1.10	6.723
2	SJVNL	13.054	12.953	8.50	1.40	12.318
3	ENGIE	26.506	26.301	12.00	1.75	25.713
4	GSECL(F2)-1	27.653	27.439	12.00	1.82	27.285
5	GSECL(F2)-2	28.800	28.578	12.20	1.85	28.507
6	GSECI(F2)-3	31.094	30.854	12.50	1.90	30.524

Table 6.2. Phase II main drain design

(Longitudinal slope s=0.00026, Manning coeff=0.016; side slope 1V:1.25H)

Sl. No.	Sub-catchment	Carrying Capacity(Q) m^3/sec	Section factor $(Qn/(S)^{1/2})$	Bed Width (m)	Depth (m)	Section factor achieved
1	Subcatchment-1	4.574	4.539	5.60	1.00	4.568
2	Subcatchment-2	10.293	10.214	7.20	1.40	10.134
3	Subcatchment-3	17.106	16.974	8.50	1.70	16.447
4	Subcatchment-4	23.701	23.518	10.45	1.85	23.804
5	Subcatchment-5	27.785	27.570	11.00	1.95	27.348
6	Subcatchment-6	38.481	38.184	12.50	2.20	38.045
7	Subcatchment-7	41.603	41.282	13.40	2.20	41.25

6.6 PHASE II-SECTION OF EMBANKMENT AND DRAIN AT LOCATION 7

Figure 6.4 shows a section of the embanked drain at location 7. Location 7 corresponds to the final outlet of stormwater from the Phase II area. The inner side embankment would also have a 9m wide service road. Its design is similar to the widened embankment of Phase I. This embankment would have box culverts at seven locations corresponding to the outlets of the seven sub-catchments. It is recommended to have a minimum formation grade level of 5.5m in the west and southwest parts and higher than 5.5 m in the central and eastern parts of the phase II area (see section 6.3.1). The topography of the Phase II area is explained in Chapter 3. It may be necessary to borrow soil from outside the Phase II area for filling.

The outer side embankment need not be as high as the inner side embankment. The main purpose of the outside embankment is to protect the drain and phase II area from flooding. The depth of stormwater on the south side beyond the outer embankment is not likely to be more than 2 to 3 ft due to the vast expense of open land.

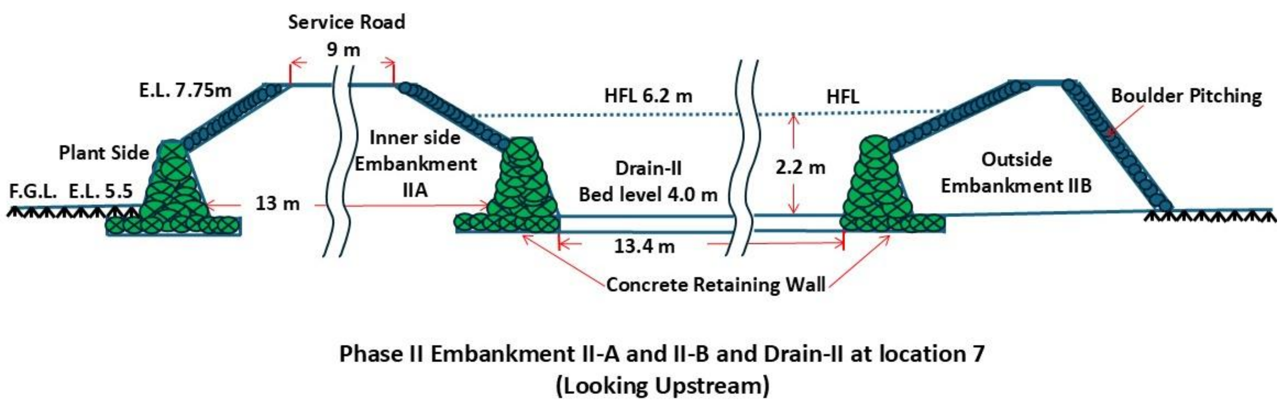

Figure 6.4 Section of an embanked drain at location 7 in Phase II

6.7 ALTERNATIVE TO EARTH FILLING IN PHASE II AREA

There are two other possibilities if earth filling is to be avoided.

First Possibility:

A peripheral embankment is provided around the phase II area (as stated in section 6.2) to protect it from external flooding. No outlets are provided in the peripheral embankment. The top level of internal roads shall be 0.6 m above natural ground level.

In the rainy season, the soil is completely saturated; therefore, whatever rain falls over the area would cause internal flooding and waterlogging. Design depth of flooding in the solar park is 586.34 mm (or 0.58634 m) as explained in section 4.4 of chapter 4. The Phase II area is 1206 ha. Therefore, the volume of stormwater that would accumulate inside the area is:

$$1206 \text{ ha} \times 0.58634\text{m} = 707.126\text{-hectare meter} = 7.0713 \text{million cubic meters}$$

The design (probable maximum) storm water volume of 7.0713 MCM inside the phase II area shall have to be pumped out by installing a large number of high horsepower pumps. It is not necessary that every year the quantity of storm water volume to be pumped would be 7.0713 MCM. Rainfall and hence volume of storm water are random variables over the years.

Second Possibility:

A peripheral embankment is provided around the phase II area (as stated in section 6.2) to protect it from external flooding. Outlets (pipe and/or box culverts) on the south side embankment are provided. Location and size of these outlets would depend on the layout of the blocks and the layout of internal roads. The top level of the road shall be 0.6 m above natural ground level.

The invert level of the outlets shall be the same as the natural ground level at these locations. These outlets would be able to drain storm water only when the depth of water in the vast flat land in the vicinity of Phase II is lower than the storm water level inside the blocks. The rainwater in the vast flat land is likely to recede slowly, and hence it may take several days to drain out the floodwater from the phase II area.

ANNEXURE-I

BRIEF REVIEW OF FIRST STUDY (2016) OF PHASE I

Following the success of Charanka Solar Park, the Government of Gujarat appointed GPCL as the nodal agency for the development of a 700 MW Ultra Mega Solar Power Project phase I at Radhnesada, Taluk Vav, Dist. Banaskantha. M/s GPCL issued an LOA to IIT Roorkee vide letter no GPCL/700MW/Roorkee/43238 dated 15/06/2016 for " Area Drainage, Flood Control, Water Harvesting, and Water Availability study for proposed Solar Power Plant at Radhanesda." The scope of work and the terms and conditions of LOA are given in the Annexure of the report of the above-mentioned study.

LAND AREA CHARACTERISTICS

Location: GPCL identified a government wasteland area of 1460 ha (3607.74 acres) at Radha Nesda village of Vav Taluka in Banaskantha district for setting up of Ultra Mega Solar Power Project (UMSPP) of 700 MW capacity. The perimeter of the site has been estimated to be 27.414 km. The Proposed site is located about 271 km from Ahmedabad in the west direction.

Geology and Seismic Zones: Geologically, the area is covered with a saline tract of brownish-grey silt, clay, sand, and murram at depth. The site falls in Seismic Zone IV, which indicates a High Damage Risk Zone.

Drainage: There is no channelized drainage available in and around the site. Rainwater remains standing for several days around the Radhanesda village at lower elevations during monsoon season.

Groundwater: Soil is heavily saline in nature, and the groundwater level is as low as 1.0 – 1.2 m from the ground level. This is a perched water table formed due to water logging in the monsoon season. The total dissolved salts of groundwater range around 500 ppm during monsoon; however, during the summer season, the level rises to about 3,000 ppm.

Analysis of Non Rainy Days: Daily rainfall data for 41 years (from 1971 to 2011) was analysed. On average, there are 343 non-rainy days in a year (ranging from 325 days to 361 days per year over a period of 41 years). Frequency analysis of non-r rainy days on an annual basis has also been carried out. There are 332 non-rainy days having 90% dependability and 336 days having 75% dependability.

DEM-BASED TOPOGRAPHICAL STUDY OF THE AREA

The digital elevation model (DEM) is the digital representation (digital map) of the ground elevation data in meters. The following data have been used for the DEM study:

i) Shuttle Radar Topography Mission Digital elevation model (SRTM DEM) of the plant area with 30 m spatial resolution.

ii) Topographical survey (grid size of 100m × 100m) of the Radhanesda Solar Park Area (RSP), which was carried out by M/s M. K. Soil Testing Laboratory, Ahmedabad, in November 2009.

iii) Geographic referencing points: These have been extracted from the features common in the Google map and geo-referencing points provided by M/S GPCL Gandhinagar.

ARC-GIS software was used to prepare the DEM. Based on the spot-level data, contours at 0.2 m intervals have been drawn. The ground level in the RSD area and its vicinity vary from 0.167 to 18 m. Within the RSP area, levels vary from 3.7 m to 18 m. Except for a small part in south west, ground elevations in the RSP area are more than 4.0 m. There are a few hillocks, including a major hillock in the central part with elevation ranging from 5.0 m to more than 18 m. The remaining area is flat with a very mild slope towards the west, south, and north.

The lowest elevation in the vicinity of the RSP boundary is 0.167 m (on the southwest side). This point can be considered as the indicator of the size of the water lake that is seen in the Google map of the region.

DESIGN STORM SCENARIO

Design storm and flood scenarios are required for (i) planning of drainage in the plant area and the area in the vicinity and (ii) for assessing possible submergence in the plant area from internal and external flooding.

Frequency Analysis of 1-Day Annual Maximum Rainfall: The daily rainfall records for Banskantha were available for 41 years from 1971 to 2011. Using these data, 1-Day annual maximum rainfall series was constructed for Bankantha for 41 years (1971-2011) and EV Type I probability distribution was applied. Graphical frequency analysis of 1-day annual maximum rainfall at Banskantha was carried out, and 1-day rainfall of various return periods were computed. 1-day rainfall has been converted to 24 hr rainfall using a factor of 1.15 as per guidelines of Central Water Commission (Flood Estimation Report for Luni Sub Zone-1a by Hydrology Directorate (Small Catchments) of Central Water Commission, New Delhi (November 1993).

Isopluvial Maps:. India Meteorological Department (IMD) has conducted a detailed rainfall study for the Luni Sub Zone 1a (CWC 1993). Isopluvial maps for the subzone are available in the CWC Report (CWC November 1993) for 24-hour rainfall of 25-year, 50-year, and 100-year return periods. Using these isopluvial maps, the 24-hour rainfall of various return periods at Radhanesda is estimated. The 24-hr rainfall values of 25 years, 50 years, and 100 years return periods (as per isopluvial map) and those derived from the frequency analysis of I day annual maximum rainfall data of 41 years at Banaskantha are compared in the table below.

Table 24-hr Rainfall (mm) Values for Different Return Periods

Return Period (Year)	Based on frequency analysis of 41 years recent data	Based on CWC maps
25	183	270
50	214	310
100	230	360

24-hour storm rainfall for 50 50-year return period obtained from frequency analysis of 41 years of rainfall data has been used for the estimation of flood peak. However, as a conservative estimate, the depth of flooding in the vicinity of the plant has been based on 310 mm (24 hr rainfall corresponding to 50-year return period as obtained by isopluvial maps).

RAISING FGL FOR CONTROL OF FLOODING

Partitioning of Park Area into Blocks: The Radhanesda Solar Park (RSP) area has been partitioned into six blocks which are proposed to be allotted to various developers for accommodating solar plants of 125 MW capacity in each of these blocks. Earth filling and ground leveling is required in each block. In order to economize the cost of earth transport, earth fill and earth cut requirements have been worked out separately for each block.

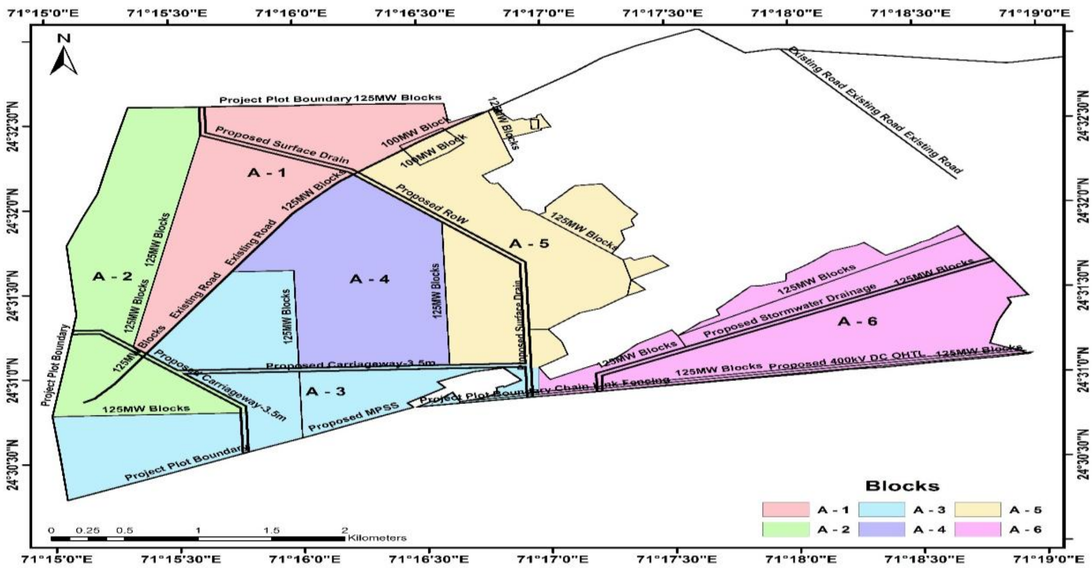

Figure: Partitioning of phase I area into six blocks(A-1 to A-6)

Depth of Flooding and Need for Earth Filling

Most of the Radha Nesda Park (RSP) area has ground elevations higher than 4.0 m. There are a few hillocks, including a major hillock in the central part with elevation ranging from 5.0 m to more than 18 m. The remaining area is flat with a very mild slope towards the west, south, and north.

During rain, water just stands above the ground due to the absence of natural drainage channels and also due to the existence of several bunds in the vicinity of Rdhanesda village and Kundalia village. During the site visit, local people informed that in the rainy season, water keeps standing for several days up to a depth of one to two feet at different locations.

Under the condition when soil is fully saturated due to preceding storm, the depth of flooding could be same as the depth of storm rainfall because there will be almost zero infiltration into ground and storm water would be stagnating due to absence of natural drainage. Thus as a conservative design estimate, depth of flooding could be 310 mm(nearly one feet) for a 50 year return period storm rainfall of 24 hour duration.

Based on above considerations it is evident that earth filling in part of the RSP area is necessary so as to raise the ground level and thus protect the area from flooding. Raising the ground level by earth filling is also required to lay internal drainage channels with adequate slopes for conveying storm water safely to the outlets on the boundary of the RSP area.

Proposed FGL and Required Earth Work

In order to estimate the amount of earthwork in cutting and filling, area and volume at different elevations in the RSP area have been worked out. Using the DEM and GIS software, elevation-area-volume tables were prepared for six partitioned blocks and the entire RSP area. Annexure 5A provides computation details of earth fill volumes and earth cut volumes for each block and for the entire RSP area.

Depth of flooding is estimated to be 310 mm (nearly one foot) for a 50-year return period storm rainfall of 24-hour duration (see table above). Therefore, the invert level of outfall for stormwater drainage from each block should have FGL higher than 4.8 m. Considering the depth of flow in stormwater drains as 80 cm (0.8 m), FGL should be higher than 5.6 m. Table 5.3 in Chapter 5 shows the proposed FGL and required earthwork in cutting and filling in each block. Each block has a different FGL. As an exercise, cut fill balance level for the entire RSP area has also been worked out. In case the entire area is to be leveled at 6.15 m, then 1253 ham volume shall be cut and filled over the entire area.

Proposed FGL and Required Earthwork in Block A1: Ground level varies from 3.72 m to 10.45 m. At 5.75 m elevation cut and fill volume are equal (160 ham). It is safe level, so FGL is kept at 5.75 m.

Proposed FGL and Required Earthwork in Block A2: Ground level varies from 4.16 m to 13.15 m. At 5.3 m elevation cut and fill volume are equal (100 ham). It is not a safe level, so FGL is kept at 5.75 m, for which the required fill volume is 190 ham and the available cut volume in the block area is only 80 ham. So 110 ham earth can be taken from block A4, which has a large cut volume.

Proposed FGL and Required Earthwork in Block A3: Ground level varies from 3.73 m to 12.75 m. At 5.5 m elevation, cut and fill volumes are equal (200 ham). FGL is kept at 5.75 m, for which the required fill volume is 280 ham, and the available cut volume in the block area is only 190 ham. So 90 ham can be taken from block A4 which has large cut volume.

Proposed FGL and Required Earthwork in Block A4: Ground level varies from 4.32 m to 18.29 m. At an elevation of 8.5 m, the cut and fill volume is equal (300 ham). FGL is kept at 7.0 m, for which the required fill volume is 134.4 ham, and the available cut volume in the block area is 441.7 ham. So 307.3 ham soil is available for use elsewhere. Part of it shall be used in earth filling in A2 block (110 ham) and in A3 block (90 ham).

Proposed FGL and Required Earthwork in Block A5: Ground level varies from 4.31 m to 11.35 m. Safe level is 6.95 m. Cut and fill volumes are equal (230 ham). FGL is kept at 6.95 m.

Proposed FGL and Required Earthwork in Block A6: Ground level varies from 3.97 m to 9.93 m. At 5.85 m FGL, elevation cut and fill volume are equal (200 ham). It is safe level.

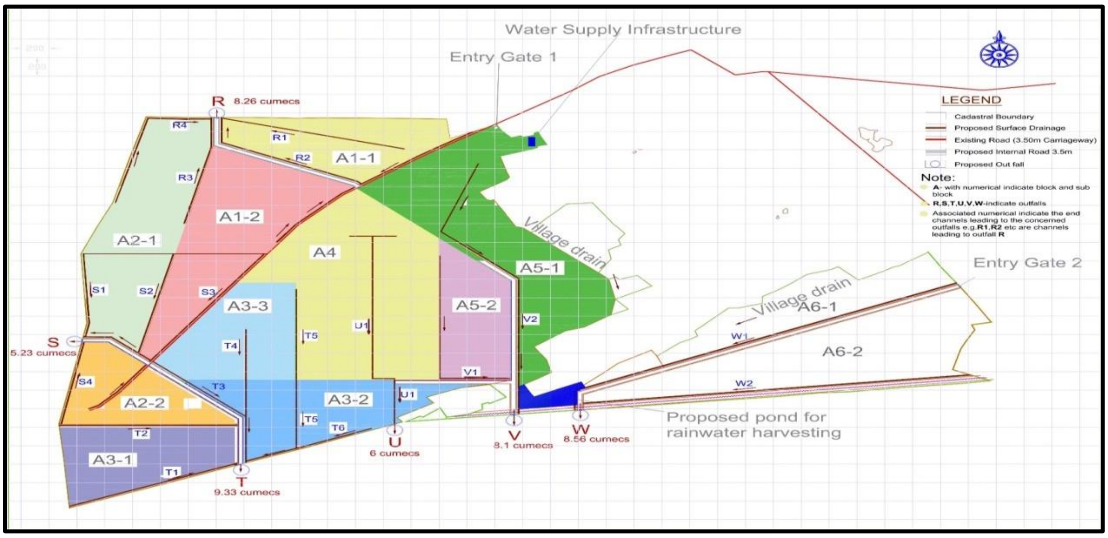

Figure: Internal drains and outfalls

AREA DRAINAGE

Design Considerations: The drainage layout is based on the following considerations:

(i) Drainage channels should safely carry storm runoff caused by design storm of 50 year return period. High flood level in the vicinity of RSP is based on storm water depth corresponding to 50 year return period. The Rational equation, which is the simplest and most common method used for sizing sewer systems, has been used in the estimation of peak floods.

(ii) The Radhanesda Solar Park (RSP) area consists of six blocks, which are proposed to be allotted to various developers to accommodate solar plants with 125 MW capacity in each of these blocks. An attempt has been made to provide separate outfall for each block. Six outfalls are proposed at suitable locations to follow the natural topography and to manage slope lengths.

(iii) The bed slope of drainage channels has been kept such that flow is carried with sufficient velocity so that silting does not occur in channels and channel invert levels are not in deep cutting. The difference in FGL and invert level at outfall is 0.5 m in blocks A1, A2, and A3. The length of the flow path from the farthest point has been adjusted to provide a slope of 1:4000. In block A4 difference in FGL and invert level at the outfall is 1.75m, and the slope is 1:2285. In block A5 difference in FGL and invert level at outfall is 1.7 m and slope is 1:2350. In block A6 difference in FGL and invert level at outfall is 1.6 m and slope is 1:2500. With these slopes, flow with sufficient velocity is possible.

(iv) Concrete-lined rectangular sections are provided throughout.

(v) Channel slope, length, bed width are determined such that the capacity utilization in each of the channel segments (ratio of discharge contributed by connecting sub-catchments to the channel carrying capacity) is near 1.0.

(vi) The bed level of the channel just upstream of each outfall has been kept at +5.25 m, which is higher than flood levels in the vicinity corresponding to the 50-yearyear return period. Marginal flooding in the end channel in case of extreme rainfall (say storm of return period higher than the design return period of 50 years is permitted at outfall R,S and T. Such marginal flooding (a rare occurrence) should be accepted. As a further safety measure, earthen embankments can be provided in the end channel of out fall R, S and T to prevent flooding of plant area near outfall. There is no possibility of flooding in end channels at outfall U, V and W.

(vii) Major drains in each block are considered in this study. Attempt has been made to locate drains along the boundary of blocks and sub blocks for the purpose of proper maintenance. Layout of small size feeder drains within a block can be prepared after layout of roads and solar panels within the blocks is finalized by the developers.

Referring to the report (2016) Concrete lined rectangular channels are proposed to route the sub-catchment runoff to the outfalls. Manning's Roughness coefficient for concrete-lined channels is taken as 0.016 . Table 6.2 shows peak flood discharge at the outfalls. Table 6.3 shows the capacity of major drains near outfalls and the end channel of the outfall. Table no. 6.4 shows the section of major drains in the six blocks. Table 6.5 shows the sections of the outfall channels in the solar park area.

WATER DEMAND AND SUPPLY

Water Demand During Construction Period: For construction of civil works the daily water requirement is estimated to be 30K litre per day (or 30 m^3 per day). So construction period (one year) requirement is 10950 m^3 (or 1.095 ha.m.).

Water Demand During Operation Stage: During operation stage, fresh water shall be required for cleaning of solar panels and for meeting the domestic requirement of the staff. Table 7.2 in chapter 7 shows computation of water requirement during operation stage. The estimated water demand includes all water usage such as industrial, residential etc. Water will be required mainly for cleaning and maintaining the solar panels. Therefore, the probability of waste water generation will be insignificant from the solar farm area. In addition buffer stock is also needed to meet emergency requirement during canal closure.

Total water demand during operation stage

Total Water Requirement (without buffer stock)	1.3	MLD
Unforeseen wastage of water assumed as 15%	0.195	MLD
Total including unforeseen wastage	1.5	MLD
Underground buffer storage to meet emergency requirement during canal closure	4.0	MLD
Overhead buffer storage to meet emergency requirement during canal closure	2.0	MLD
Total including buffer storage	7.5	MLD

SOURCE OF WATER

There are four possible sources of water; (a) Shallow flood water lake (b) Ground water(c) Surface water from Narmada Canal and (d) Surface water by Rain Water Harvesting

Shallow flood Water Lake: Google map of the region shows a large size shallow flood water lake on the west side of plant area. This lake is created in monsoon season. The water is highly saline and it gets evaporated during the non-monsoon season. The lake was seen to be completely dry during the site visit. It is not techno-economically feasible to use this water

Ground Water: The salt content in the ground water is very high. Report of the Central Ground Water Board, Government of India “Groundwater Brochure Banaskantha District Gujarat” (CGWB-2011) provides detailed information on ground water availability and ground water quality in Vav block where the solar plant site is located. Entire Vav block is covered by saline soil. These are typically deep grey calcareous sandy clay loams of low permeability. The hydrogeological map shows that the area is not suitable for ground water development. There are only 121 drinking water wells over the block area of 1700 km^2 giving a density of 1 drinking water well per 14 km^2 of the area. Quality of ground water is saline because of marshy land salt/mud flats devoid of vegetation (Rann). The villages are dependent on regional water supply scheme as the quality of ground water is saline.

Surface water from Gadsisar Branch Canal: SSNNL main Canal is one of the major sources of water in the region. Techno economic feasibility study of the supply from Gadsisar branch canal of SSNNL canal has been carried out by M/s Mott MacDonald (2016).

Rain Water harvesting: As per standard maintenance practice, SSNNL canal shall have to be closed for a period of about fifteen days for normal maintenance and repair work. During this period water supply to the plant shall be made from the stored canal water (underground and overhead). Rain water can also be harvested and stored in a water harvesting pond for use during canal closure.

Under the existing condition, the harvested water may not be of suitable quality due to runoff contamination. Since the area is part of Holocene sedimentation, the soil is salty in nature which in turn affects the quality of runoff.

However, during operation stage, it may be possible to harvest the rain water because of proposed land leveling and earth filling to raise ground level. Further, most of the ground shall be covered by solar panels and this will allow good catch of rain water which could be channelized for storage in a surface pond.

Storm runoff from some of blocks (such as A1, A2, A3) may not be of suitable quality because FGL is 5.75 m and sufficient depth of storage by gravity flow in the connected pond may not be possible. It is desirable to locate harvesting pond at higher level to avoid ingress of poor quality ground water, and to store good quality of runoff from the catchment at higher level (such as block A4, A5 and A6). Therefore harvesting pond(s) may be located in vicinity of outfalls U, V and W which are adjacent to each other.

Runoff contributing area is A4 (202.15 ha) +A5 (273.18 ha) + A6 (288.06 ha) =763.39. The solar panels may cover approximately 50% of the site area i.e. 0.5×763.39=381.69 ha.

Harvested water=381.69×0.3×0.579=66.3 ha-m say 63 ha-m.

In case runoff from blocks A1, A2 and A3 is also to be harvested then a demineralization plant may be installed to enhance the quality of harvested water depending upon end use.

CANAL WATER SUPPLY SCHEME

It has been decided that the primary source of water for the proposed park is Sardar Sarovar Narmada Nigam Limited (SSNNL). The water is proposed to off-take from the zero chainage of Gadsisar Branch Canal and drawn to the project site through pipeline running within the Right of Usage (RoU) land of SSNNL with due permission or can be drawn along the road network leading to project site.

Civil structures such as canal off-take structure, underground sump, pump house and elevated service reservoir (ESR) at Gadsisar Branch Canal zero chainage, water transmission pipeline to the project site, underground sump, pump house, ESR and internal water distribution network are proposed for water supply.

SAMPLING AND ANALYSIS OF EXISTING WATER QUALITY

During the site visit, three samples were collected from the Location=S1 (Bore hole near BSF watch tower); Location: S2 (Pumping Well in Kundaliya Village), S3 (Pond Near by Temple near Kundaliya village).

The water samples of groundwater (S1) and pond water (S2) had yellowish color with rotten egg smell and the pumped water was colorless before they were analyzed in the laboratory. Results obtained during the analysis have been compared with values of WHO (2006), ISI-IS: 2296 –1992, and BIS 10500:1991 Drinking water standards.

All results of the study area show higher values than the WHO and BIS standard limits and therefore the water is unacceptable for drinking purpose.

ANNEXURE-II

REVIEW OF SECOND STUDY OF PHASE I (2023)

Radhanesda Solar Park (RASP) Phase I area is spread over 1407 hectares area. It largely falls under the eastern part of Rann of Kutch. The solar park has been affected by flooding during the monsoon season and continued water logging during the non-monsoon season. Patches of water-logged areas and salt crystal layers could be observed at several locations inside and outside the solar park area, even during March.

M/s GPCL approached IIT Roorkee to conduct a hydrological study of the existing Radhanesda Solar Park (termed phase I). The scope of work assigned to IIT Roorkee is in two parts as follows:
Part A: Control of Flooding and Waterlogging in the GPCL-700 MW Radhanesda Ultra Mega Solar Power Park

Part B: Management of Flood Disaster (Mitigating Measures in the Event of Flood Disaster)

Five developers have been allocated 1319.8 hectares land in the solar park as shown in figure below

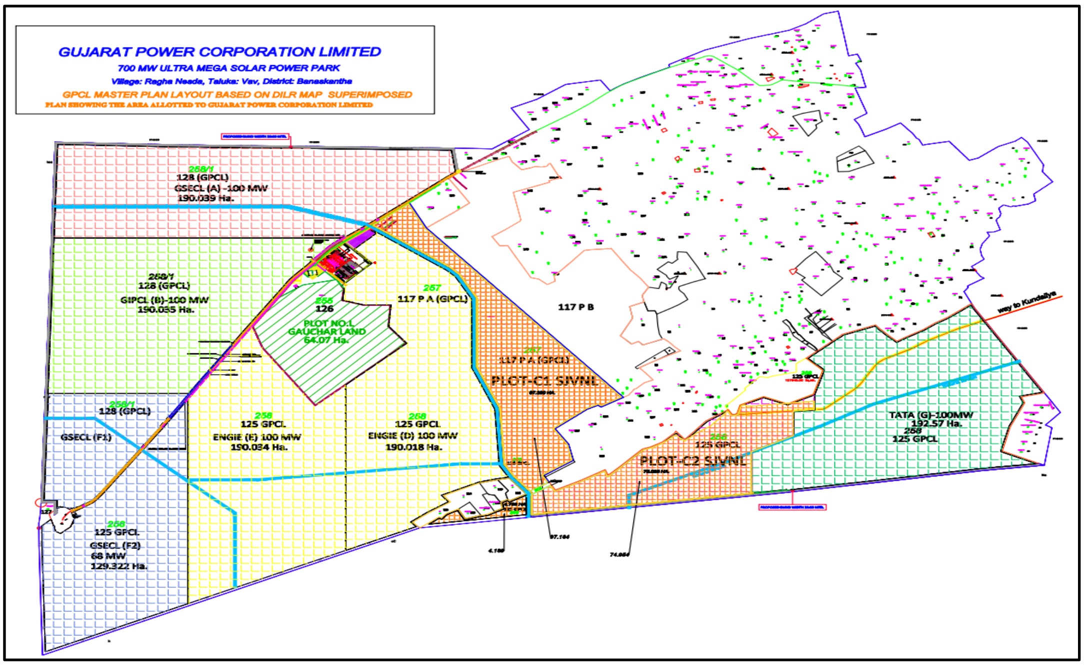

Figure 1: Layout plan of solar plants and upland area in the northeast of Radhanesda Solar Park phase I

PART A

CONTROL OF FLOODING AND WATERLOGGING IN THE RADHANESDA SOLAR POWER PARK

FLOOD EMBANKMENT AND FLOODING: An earthen embankment along the boundary of the solar park has been constructed over the length of 16.394 km.

The solar park experienced flooding in the July and August months of 2022. Considering the inadequacy of pumps in rapid dewatering and the resulting rise in water level inside plant areas, the embankment had to be cut by developers at two locations on 18 August 2022 and at 5 locations on 23rd August 2022. Again, due to heavy waterlogging caused by the Biporjoy cyclone, from 14-June to 17-June, 2023, the embankment was cut at 7 locations.

FIELD VISITS: The first field visit to the Radhanesda Solar Park site was conducted from 2 March to 5 March 2023 to survey the park infrastructure and to collect data. Second field visit to Radhanesda Solar Park was conducted from 24 June to 27th June 2023, soon after the Biporjoy cyclone. Visual observations on the impact of the cyclone were recorded in the form of photographs with explanatory notes.

RAINFALL ANALYSIS: The daily rainfall records for Banskantha were available for 52 years, from 1971 to 2022. Using these data, 1-Day annual maximum rainfall series was constructed and EV Type I probability distribution was applied.In addition, eleven years of daily rainfall data (2012 to 2022) for the grid in which the Radhanesda solar park area lies has also been analysed for preparing annual two max rainfall series and conducting frequency analysis of 2-day annual maximum rainfall data.

DESIGN DEPTH OF FLOODING IN SOLAR PARK: Considering land development within the solar park, it is recommended to adopt 2-day rainfall of 563 mm as the design depth of flooding inside the solar park. Solar panels, roads, electric cables, etc., should be around 0.6 m above the finished grade level.

FGL AND SAFE LEVELS IN DEVELOPERS' PLOTS: In the previous study (2016) by IIT Roorkee, earth cutting and filling in various parts of the solar park were analysed, and finished grade levels (FGL) were recommended. The block boundaries of developers' plots are now somewhat different from those that were considered in the earlier study. Further, land development work and other infrastructure have already been constructed. Therefore, FGLs recommended in the earlier study(2016) have been used only as a guide to approximate the safe levels in developers' plots to avoid infrastructure flooding (roads, solar panels, cables, etc.)

Table: Finished Grade Levels and Safe Levels for infrastructure

	Plot	FGL(m) (Assumed)	Design depth of flooding(m) for safe clearance above FGL	Safe level(m)
1	TPREL	5.85	0.6	6.45
2	SJVNL	6.95	0.6	7.55
3	ENGIE	5.75 to 7.0	0.6	6.35 to 7.6
4	GIPCL	5.75	0.6	6.35
5	GSECL(A)	5.75	0.6	6.35
6	GSECL(F1)	5.75	0.6	6.35
7	GSECL(F2)	5.25	0.6	5.85

If existing FGLs are higher than those given in the table, then those may be considered. Further, with adequate drainage, the design depth of flooding could be decreased.

UPLAND CATCHMENT RUNOFF AND DIVERSION DRAIN

There is a large upland area (about 7 km^2) to north east side of the Radhanesda Solar Park, as shown in Figure 1. Elevations in the area range from 6 m to 27 m, significantly higher than the finished grade levels in the solar plant area. Storm runoff from this upland area drains towards the solar park area, causing waterlogging (Figure 2.)

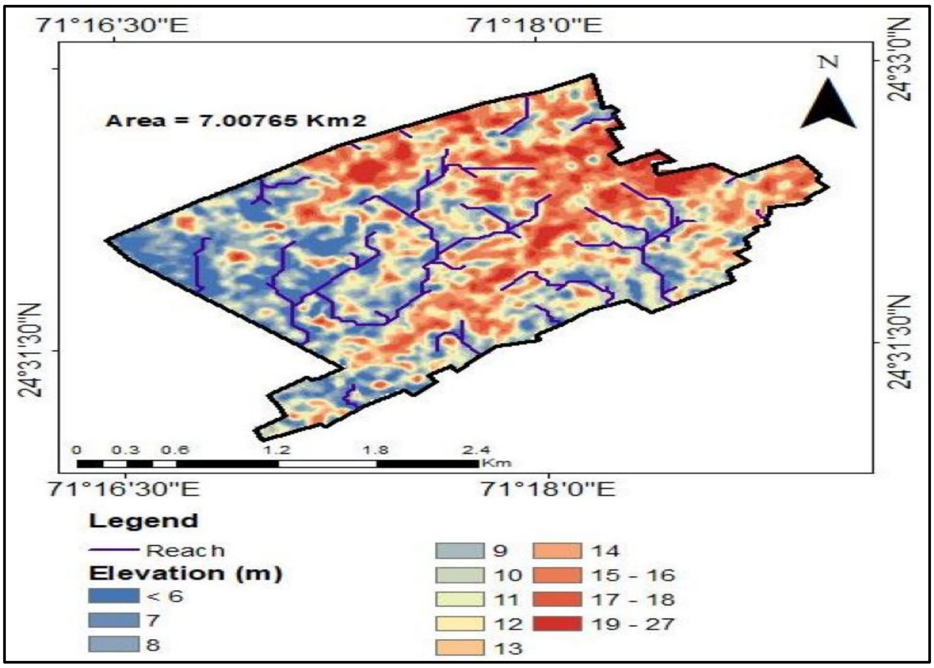

Figure 2.Upland topography on east side of the Radhanesda solar park

Flood discharge of 50-year return period has been estimated (17.67 m^3/sec), and a diversion drain has been designed to carry this discharge. To economize the cost, the proposed drain consists of two parts with different bed widths and depths of flow. The rectangular cc-lined channel is along the SJVNL boundary (bed width of 1.5 m and depth of 1.25m) from the north point upto Nala junction on the boundary and then 2.8m bed width and depth of 2.75m onward upto outfall (on south side boundary).

MEASURES TO CONTROL FLOODING IN GSECL(A) PLOT: The following measures are suggested.

i) Raise the level of the peripheral road of the plot on the west side (i.e., along the embankment) upto 2m, as has been done in the GIPCL plot. Provide two pipe outlets on the peripheral road. Replace the pipe outlets in the embankment with box culverts (with stop log arrangement) having an invert level near about base level of the embankment so that waterlogging does not occur near the embankment.

ii) M/s GPCL has been advised to construct a 2m high cross bund in the west side channel to plug (block) the entry of stormwater from the GIPCL plot into the GSECL (A) plot(see section 6.2.3 of phase I report)

iii) Construct pipe culverts on the approach roads within the plant area to allow the free flow of stormwater towards outfall locations.

iv) <u>Provision of nala:</u> Develop the nala passing through the GSCEL(A) plot to carry storm runoff not only from the GSECL(A) plot but also from the north part of ENGIE and SJVNL plots as shown in Figure 6.2. Carry out land grading(sloping towards nala) of the plot on either side of Nala so that the depth and duration of waterlogging in the GSCEL(A) plot are minimized.

v) <u>Alternate option for nala alignment:</u> Longitudinal section of the embankment on the north side of the GSCEL(A) plot shows that the ground level on the Luni basin side is significantly lower than the ground level of the Luni basin on the west side embankment. A sufficient gradient in the Nala would be available if the Nala is realigned with an outfall on the north side (instead of on the west side). The outfall could be located between chainage 280m to 530m or between chainage 710m to 800m. However, this would require shifting of some of the solar panels. **However, it needs to be verified through a recent topographic survey whether the ground level on the Luni basin side (adjacent to the embankment) is localized (due to the excavation of soil for making earthen embankment)or whether the land continues to be low lying area further beyond also.**

vi) Examine the possibility of raising the level of the footing of the solar panels located in the vicinity of the Nala

vii) Even if the Nala is not realigned as discussed above, the provision of two box culverts in the north side embankment (between chainage 280m to 530m and between chainage 710m to 800m) (see Chapter 9)and provision of a drain (along SJVL boundary to carry runoff from east side upland (see chapter 5) should greatly reduce waterlogging in GSCEL(A) plot.

MEASURES TO CONTROL FLOODING IN GIPCL PLOT

i). Block the entry of stormwater (through the west side channel) from the GIPCL plot into the GSECL (A) plot and the GSECL (F1) plot by constructing 2m high cross bunds between the flood embankment and the plot boundary at the upper and lower end as shown in figure 6.4.

ii). Construction of two box culverts in the flood embankment ;

a) One culvert (with four boxes) in the embankment at the location opposite to the location of the B1 culvert on the plant boundary on the northwest side

b) One culvert (with four boxes) in the embankment at the location opposite to B5 culvert on the plant boundary in the southwest corner.

iii). Provide gates (manually operated stop logs) in the proposed culverts in the embankment, considering functional efficiency.

iv). There is a pond of stormwater in south southeast corner of the plot. Construct a drain along the east-west peripheral road to take the water to B5 culvert in the southwest corner.

v). There are four internal roads laid in the east-west direction. It is suggested to provide pipe culverts at suitable locations on these internal roads laid in east-west direction to allow free flow of the stormwater.

v). Grooves have been provided in the box culverts on the boundary road. Stop logs may be placed in these groves to control external flooding (entry of flood water into the plot from the embankment side area.

MEASURES TO CONTROL FLOODING IN GSECL(F1) PLOT

The following measures are suggested.

i) Plug the entry of stormwater from the GIPCL plot into the GSECL(F1) plot by constructing 2m high cross bunds; a) in the channel between the flood embankment and the plot boundary road in the west corner and b) at the junction of BSF road with GIPCL southern boundary road in the east corner.

ii) Examine the possibility of relocating the solar panels at higher ground levels within the plot (along BSF road)

iii) Construct pipe culverts (wherever possible) on the approach roads inside the plot to allow the free flow of stormwater.

iv) Pipe outlets should have a low invert level. Reconstruct if necessary.

MEASURES TO CONTROL FLOODING IN GSECL(F2) PLOT

Ideally earth filling should have been carried out in the low-lying area to raise the level of solar panels. Following measures are suggested.

i) The low-lying area (NGL 4m and below) on the south side of the plot is most prone to flooding. Low lying area may be filled with soil from outside to achieve finished ground level of at least 4.75m in the entire plot area. This may require the dismantling of some of the solar panels. Alternately examine the possibility of raising the height of solar panel footings (say up to 5 m elevation).

ii) Construct 2 m high approach roads within the plant area and periphery road adjacent to ENGIE plot.

iii) Provide drains on both sides of the approach roads and along the periphery road.

iv) Provide box culverts with stop log gates at three locations where embankment has been cut.

v) Examine the possibility of relocating the solar panels at higher ground levels within the plot(along BSF road)

vi) Construct pipe culverts (wherever possible) on the approach roads inside the plot to allow the free flow of stormwater.

vii) Storm runoff coming out of the box culverts in the embankment shall have to be channelized towards low lying area(in south west corner of the solar park).Stone pitching shall be provided on the inner and outer slopes of the embankment so that water flowing along the embankment does not erode the slopes.

MEASURES TO CONTROL FLOODING IN ENGIE PLOT

i) The low-lying area (NGL 4m and below) in south west part is most prone to flooding. Examine the possibility of earth filling in the low lying area (upto 4.75m) with soil excavated from the hillock in the central part of the plot. Thus more area shall be available for putting solar panels.

ii) Concrete-lined drains have already been constructed. Protect these concrete-lined drains from silting. Construct 30 cm high dowel along the drains on its bank. Alternately bank side along the drain may be covered with thick hedge of climatically suitable grass. However, this measure would last for only two to four years as soil eroded from upper side would ultimately get deposited along the dowel or grass hedge, and silt would again start coming into drains. Grass cover of the land would provide a permanent soil erosion control measure.

iii) Earth fill the natural depressions to avoid waterlogging.

iv) Provide two box culverts with stop log gates in the flood embankment.

v) Allow storm runoff from northern part of the plot to drain through the BSF road culvert into the rejuvenated nala in the GSECL(A) plot.

vi) Storm runoff coming out of the box culverts in the embankment shall have to be channelized towards low lying area(in south west corner of the solar park).Stone pitching shall be provided on the inner and outer slopes of the embankment so that water flowing along the embankment does not erode the slopes.

MEASURES TO CONTROL FLOODING IN TPREL PLOT

i) Raise the height of the boundary road that is near the embankment and is adjacent to the SJVNL plot. Provide a cross bund to connect with the embankment at the southwest corner of the TPREL plot so that stormwater from the SJVNL area does not enter the TPREL plot and vice-versa.

ii) Provide guide bunds to guide the flow from the TPREL box culvert towards the proposed box culvert in the embankment so that flow coming out of TPREL box culvert does not get waterlogged in the area between TPREL boundary and the embankment. The area between the southern TPREL boundary and the embankment should be made sloping such that storm runoff in this area flows towards the proposed box culvert in the embankment. This would reduce waterlogging in the area.

iii) Grooves have been provided in the box culverts by TPREL. When required,stop logs(wooden planks) can be placed in the grooves **so that water from outside(when water level outside is higher than inside) does not enter into plot**. On other box culverts(inside plot area), it may not be necessary to place stop logs(wooden planks) in the grooves. Flow of stormwater inside the plot to lower ground levels should not be obstructed.

iv) Earth fill the natural depression in the southeast part to the extent possible considering existing operationalization of the plant so as to reduce waterlogging in the area.

v) It was stated by TPREL that the upland nala entering the TPREL plot has been diverted toward a low-lying area in the east in the vicinity of the plot. Regular maintenance (desilting, weed control etc)of the diversion arrangement is necessary to maintain its carrying capacity.

vi) Storm runoff coming out of the box culvert in the embankment shall have to be channelized towards low lying area(in south west corner of the solar park).Stone pitching shall be provided on the inner and outer slopes of the embankment so that water flowing along the embankment does not erode the slopes.

MEASURES TO CONTROL FLOODING IN SJVNL PLOT

i) SJVNL plot receives storm runoff from the upland. It is suggested to provide a bund and a drainage channel along the bund so that storm runoff from the upland does not enter the SJVNL plot. Delineation of stream network and watershed boundaries in upland area is based on Digital Elevation Model(DEM) study of elevation data downloaded from internet in absence of topographic field survey data of the uplnd area.

ii) The elevation profile and topography of the upland show that only a small part of the upland land is sloping in a north and northwest directions. Major part of upland slopes in south-east and south direction. Topography suggests carrying this storm runoff through a drainage channel to a low-lying area in the south.

iii) SJVNL shared the layout plan of the plant. 1 m clearing has been planned between the solar panel and the finished grade level to avoid submergence during flooding. This is considered to be adequate.

iv) Raise the ground level of SJVNL plot (C1 and C2) near embankment upto 5m .Particularly fill the low-lying area with soil in the southeast corner of the C2 plot to avoid waterlogging. Internal roads may be kept at 2m above developed formation level of ground. It should be feasible to implement this work(to the extent possible) as the land is at present under development .

v)Instead of a pipe culvert, provide a box culvert in the embankment (at the location where the embankment was cut) to drain the runoff from the C2 and C1 area. The box culvert is similar in design to box culvert provided in TPREL plot. If necessary, one more culvert in embankment C2 plot may be provided to drain the runoff from C1 and C2 area.

vi) Provide a pipe outlet in the C3 boundary and in the embankment to drain the runoff from the C3 area.

vii) Storm runoff coming out of the pipe outlet and box culverts in the embankment shall have to be channelized towards low lying area(in south west corner of the solar park).Stone pitching shall be provided on the inner and outer slopes of the embankment so that water flowing along the embankment does not erode the slopes.

MODIFICATIONS IN THE FLOOD EMBANKMENT

The table below shows existing and proposed outlets in various reaches of the embankment.

Table: Location of existing and proposed outlets in various reaches of the embankment

Solar plant	Boundary	Chainage (m)of embankment		Existing outlets on plant boundary	Existing outlets in embankment	Outlets suggested in embankment @	Remark
		from	to				
GECL (A)	East side	0.0	200	-	-	-	
	North side	200	2880	-	-	2 box culverts	Low NGL on outside
	West side	2880	3750	3 road cuts	3	Replace pipe outlets with box culverts	Provide cross bund at ch 3750
GIPCL	West side	3750	5040	5 box culverts	-	2 box culverts	Provide cross bund at ch 5040
GSECL (F1)	West side	5040	6610	3 pipe outlets	3	Pipe outlets should have low invert level	Provide flap gates if possible
GSEC	West	6610	7500	-	-		

L	side						
(F2)	South side	7500	8510	6 pipe outlets	-	3 box culverts	Land filling
ENGIE	South side	8510	10250	-		2 box culverts	Land filling
SJVNL	South side	10250	12500	-	-	1 or 2 box for C1& C2, and 1 pipeoutlet for C3	Land filling
TPREL	South side	12500	13220	1 box culvert		1 box culvert	Provide cross bund at ch 12500
	East side	15520	16395	1 box culvert		1 box culvert	

Note: @:All box culverts in the embankment should have a stop log arrangement to stop the entry of flood water from outside the embankment and should have an invert level lower that of outlets in adjacent boundary road of solar plants.

i. Recommendations given below are complimentary to those given in the table above.
ii. The location of pipe outlets with flap gate proposed earlier are no more relevant as some of the locations are not suitable, and existing outlets on the plant boundary and in the embankment have been constructed by plant developers without considering the proposed locations.
iii. In those reaches where the height of the embankment is not adequate to construct outlets or where the difference in ground level inside and outside the embankment is not adequate, adopt syphoning/pumping the flood water from inside the embankment to outside the embankment.
iv. Provide culverts in the embankment at suitable locations considering the already constructed culverts on peripheral roads by the developers.
v. The SJVNL plot and TPREL plot receive storm runoff from upland. It is suggested to provide a drainage channel along the eastern boundary of the solar park (SJVNL plot) so that storm runoff from the upland is carried to the outfall on the southern boundary and the stormwater does not enter the SJVNL plot.
vi. Stone pitching needs to be provided on the inner slope of the embankment. At present, stone pitching has been done only on the outside slope of the embankment. Severe erosion and cuts on the inner slope have been observed at several locations. At some of the locations, situation is critical and may cause the failure of the embankment.
vii. Storm runoff coming out of the pipe outlet and box culverts in the embankment along the **SOUTHERN boundary** of the solar park shall have to be channelized towards low lying area(in south west corner of the solar park).Stone pitching shall be provided on the inner and outer slopes of the embankment so that water flowing along the embankment does not erode the slopes. Alignment of this channel(drain) shall be based on recent topographic survey of vicinity area to identify the low lying area where storm water could ultimately be disposed off in absence of natural drainage in the vicinity area.
viii. Storm runoff coming out of the pipe outlet and box culverts in the embankment along the **WESTERN boundary** of the solar park shall have to be channelized towards low lying area(

in west side of the solar park). Alignment of the channels(drains) shall be based on recent topographic survey of vicinity area to identify the low lying area where storm water could ultimately be disposed off in absence of natural drainage in the vicinity area. Figure 9.3 below shows the spot levels on west side and north side of the solar park. However the topography should be verified with recent survey .

ix. Regular maintenance and emergency repair procedures for the Radhanesda Solar Park have been discussed in Part-B of this report. These procedures should be invariably followed for proper upkeep of the flood embankment.

Figure 9.3 The spot levels on west side and north side of the Phase I of solar park.

PART B

<u>MANAGEMENT OF FLOOD DISASTER (MITIGATING MEASURES IN THE EVENT OF FLOOD DISASTER)</u>

Part B of the report deals with flood disaster management in the Radhanesda solar park.
Flood disaster management practices relevant to Radhanesda solar park have been prepared within the constraints of the data availability.
Part B consists of the following four chapters on flood disaster management.Some important recommendations are given below

<u>Chapter 1 Cyclone preparedness and case study of Biporjoy cyclone :</u> A checklist for disaster preparedness during the operation stage of the solar power project is given. Disaster preparedness in Radhanesda solar park during Biporjoy cyclone is illustrated through a case study of the GIPCL plot.

<u>Chapter 2 Government responsibility at the state, district, and taluk level:</u> Solar plant developers in the Radhanesda solar park need to understand the role and responsibilities of the disaster management agencies at the Gujarat state level, Banaskantha district level, and Vav taluk level. A checklist in the form of a questionnaire is provided that would help in understanding the government responsibility at various levels.

Chapter 3 Warning of storms, lightning, and action plan : The role of the India Meteorological Department in the forecast and issue of alerts/warnings is discussed. 'Now Casting' type of forecast has a lead time/validity of 3 to 6 hours, whereas short to medium-term forecast has a lead time/validity of 1 to 5 days. Weather bulletin of IMD provides information on i) intensity of rainfall, ii) spatial distribution of weather phenomenon, iii) emergency situation, and iv) evacuation. A list of weather websites is also included.

Weekly rainfall at Radhanesda (grid rainfall) from 1st July to 30 September in each year from 2012 to 2022 has been compared. It is seen that relatively higher rainfall is received from 15th July to the end of August each year. Even though floods may occur at any time during monsoon, the period from 15th July to the end of August may be considered more vulnerable to flooding. The solar plant developers and disaster management team need to keep a close watch for severe storms during this period.

Chapter 4 Safety of Flood embankment and Buildings: Responsibility for the maintenance of flood embankments should not be left to individual developers. There should be a single common establishment (GPCL) for proper upkeep and maintenance of the flood embankment.
The requirement of the material for regular and emergency maintenance is given. Emergency measures for the flood embankment (Seepage/leakage, scouring, sliding, settlement, breach) are explained with the help of sketches and diagrams.

An inundation intensity scale for damage to houses on a broad basis is proposed.Structural changes for the buildings in Radhanesda Park are suggested.

Chapter 5 IMD bulletin on Biporjoy cyclone: IMD is responsible for issuing a national bulletin. For illustration, following bulletin illustrates the procedure of cyclone warning at the national level.

BULLETIN NO. 76 (ARBA/01/2023) issued by India Meteorological Department (Ministry of Earth Sciences, Govt. of India) at 2030 hours IST on 15.06.2023

PART B

CHAPTER 1

EXTREME RAINFALL AND WIND-RELATED RISKS AND ADAPTATION MEASURES FOR SOLAR PLANTS

1.1 NEED FOR FLOOD DISASTER MANAGEMENT PLANS FOR SOLAR PARKS

Electrical systems of any sort and water do not mix, and solar power plants are no different. Safety becomes the greatest concern when any part of the solar plant (switchboard, solar inverter, solar battery, accessories such as isolators, solar panels gets submerged during the flooding. It is well recognized worldwide that saving human lives is the priority in case of any flooding incidence, and proper implementation of flood warning and emergency action procedures is a must for that purpose. Whereas flood disaster management plans have been developed for dams and embankments in the country, not much attention has been given to the preparation of flood disaster management plans for solar parks in the country. It is a necessity that has been neglected, partly due to the non-availability of tools, techniques, and data and partly due to the non-availability of proper guidance on this specific topic. An attempt has been made here to prepare the flood disaster management practices relevant to Radhanesda Solar Park within the constraints of the data availability for the solar park. These practices are based on the review of available literature and the professional experience of IIT Roorkee consultants.

1.2 SOLAR PLANTS' INFLUENCE ON FLOOD RISK

The common setup of solar plants means sites are usually considered 95% permeable, with the other 5% being impermeable for associated infrastructure. However, without the incorporation of basic drainage, the development may lead to increases in flood risk elsewhere.

Rainfall drains freely off the panels onto the ground beneath the panels, where the surface is usually permeable. Thus, the total surface area of the solar panels is not considered to be an impermeable area, and the impact is assumed to be nil, except for the provision of required infrastructure such as substations, access roads, etc.

However, the nature of the underlying ground cover and antecedent conditions can have a demonstrable influence on the surface water run-off characteristics of a site. In the case of Radhanesda Solar Park, even though the surface is permeable, due to flat topography and sluggish natural drainage, the soil remains waterlogged for a considerable time.

1.3. EXTREME RAINFALL AND WIND-RELATED RISKS TO SOLAR PLANTS

A. Solar photovoltaic power generation plant. The likely impacts on solar PV systems are due to increased cloud cover and extreme rainfall events in the plant area. The specific climate risks to the PV plants are:

i. Solar PV panels have an operating lifetime of over 20 years. PV systems are vulnerable to hailstorms, strong winds, and extreme temperatures. Solar cell output is generally rated at an ambient temperature of 25ºC with outputs decreasing by about 0.25% (for amorphous cells) to 0.5% (for most crystalline cells) for every 1ºC of temperature rise.

ii. Inverters that convert direct current power output from the PV panels into alternating current (DC to AC) account for up to 69% of the unscheduled maintenance costs. Inverters are generally kept indoors under controlled temperatures to avoid exposure to the weather, and hence, they are not especially vulnerable to climate risks such as extreme rainfall events.

iii. Solar PV technology converts the photons from the sunlight falling into the PV panels into electricity. During cloud covers, PV panel output can decrease by 40%–80% within a few seconds, increasing just as dramatically when the sky clears. For large solar PV arrays in MW range power plants, this rapid fluctuation can cause localized voltage and power quality concerns because shading in one panel affects the entire array connected to a single inverter.

iv. High wind speeds can increase dust particle deposits on the solar PV arrays, causing a decrease in PV cell outputs. However, strong winds can also cool down the PV modules, increasing efficiency and output, and subsequent rainfalls can wash the dust. In arid regions, higher wind speeds can risk damage to the PV panels from increased abrasion.

B. Distribution grid upgradation. Increasingly variable weather events and potentially stronger storms may interrupt the power distribution and cause failure in the distribution system and its equipment in the following ways:

i. Strong winds (over 100 km/hour) may damage distribution infrastructure, including electric wires, through the falling of tree branches and the uprooting of old and aging distribution towers. On the other hand, stronger winds also cool overhead lines by increasing heat convection. Cool lines can carry higher electric load while staying within the temperature limits, which is usually 80°C at the conductor surface.

ii. Distribution infrastructure, especially the ground-mounted equipment in substations, is susceptible to damage from increased risks of flooding, landslides, and other natural hazards.

Lightening events can affect the reliability of the distribution transformers

1.4 ADAPTATION MEASURES

a. Solar PV generation plant

(i) Equip the PV panels on robust mounting structures to withstand higher winds and gusts from the strongest cyclones of the past 50 years to limit the probability of generation unavailability as well as to reduce potential hazards of panels being lifted and blown onto adjacent properties.

(ii) The technical design should consider improved passive airflow beneath PV mounting structures, reducing panel temperature and retaining the rated power output within the design limit.

(iii) The solar plant project should consider distributed power exports (rather than feeding power into a single point of the grid), for grid stability. Mobile repair teams will be setup to repair damage from extreme weather events.

(iv) The solar PV plants should be constructed in locations where the expected changes in cloud cover are relatively low.

(v) The module mounting structures should be optimally tilted for the best catchment of available sunshine round the year, as well as for allowing auto-cleaning of the dust and deposits caused by strong winds.

b. Battery and energy storage systems (BESS)

(i) Battery containers shall be placed on suitably raised platforms (1 m above the floor level) to avoid damage due to flooding for longer periods.

(ii) Measures should be taken to ensure flood risks are not increased to areas surrounding the BESS. This

includes using single drainage around the site. The project should validate if the sizing of these drainage systems is sufficient to cope with the projected increase in precipitation extremes by around 10% by 2050

c.Distribution grid upgradation

The project considers higher design standards for distribution poles and towers. It will change routes of overhead lines along roads away from trees, rigorously prune trees, and use covered and/or insulated conductors and underground cables, especially in wooded areas if any.

(i) The project embedded lightning protection (earth wires, spark gaps) in the distribution network. The distribution network design will allow increased rerouting during times of disruption. Forbid construction of power lines near dikes and ban “permanent” trees such as eucalyptus and melaleuca next to existing dikes.

(ii) Improve flood protection measures for ground mounted equipment in substations. Where stronger winds are expected, strengthen distribution poles with guy wires. Increased pressure on the grid, whether it is climate-induced, will also be reduced through distributed, decentralized energy generation.

(iii) Protect masts, antennae, switch boxes, aerials, overhead wires, and cables from precipitation (water ingress), wind, unstable ground conditions (flooding, subsidence), and changes in humidity.

(iv) Modern transformer designs should be used to reduce losses by up to 80% and handle a wider range of ambient conditions. Globally, network losses range from 4%–27%, of which a third typically occur in transformers and 70% in the distribution system.

d.AC and DC Power Risk And Adaptation Measure

There are two sides to power to consider: AC, coming from the grid, and DC, coming from a solar PV array.

AC Power: The AC power coming from the grid, has inbuilt protection in the switchboard, and if moisture is present, power will trip.

If the switchboard is fully submerged, then an electrician can restore power. The power provider should seek advice on the next steps.

DC Power: The DC side, coming from the solar PV array to the site office is where the greater danger lies. This is because as soon as the array is back in the sun, the modules/panels will be operational and generate power. If isolators have been submerged, then there is a real potential for fire.

- If it is safe to do so, switch off the AC and DC isolators connected to your PV system.
- If there is a possibility that solar panels are submerged, then the DC isolator will also need to be switched off and assessed by a qualified electrician to make the array safe.

If there is power and the system looks dry and operational, still it is not recommended to turn the system back on until it has been assessed for damage by a qualified Engineer

1.5 CHECKLIST FOR DISASTER PREPAREDNESS DURING THE OPERATION STAGE OF THE SOLAR POWER PROJECT

a. Solar projectsite- normal operations

- Follow the generic technical requirements for most issues, as responsibility has beenallocated.
- For solar farms, check, particular attention is given to debris and surrounding vegetation.
- Clear the site of any debris, loose material, or equipment no longer in use (if possible);otherwise, tie down.
- Remove delicate instrumentation such as externally mounted pyranometers.
- Maintenance of roads, drains, and electrical systems should be scheduled with consideration of pending cyclone seasons.

b.Modules, fasteners, racking, support structures, and active tracking - normal operations

- Routine maintenance includes tightening bolts, cleaning panels, and checking panel integrity. Verify that the operations and maintenance plan includes all activities necessary to keep the system as designed. Determine if additional activities or a specific schedule of activities are planned to accommodate the cyclone season and verify that these changes are being followed.
- Ensure that the additional operational and maintenance requirements of active versus passive systems, where applicable, have been addressed.
- Check the module for damage, including the front sheet, back sheet, edge seal, and junction box for exposure; replace if possible or ensure the module/string remains unpowered during a storm event.
- Document and take images (visual, infrared, electroluminescence) to capture the state of the array before the event. Check for any missing or corroded fasteners and replace them if necessary.
- Check the torque of fasteners and tighten them according to manufacturer specifications.
- Check all hardware for corrosion, missing or damaged parts, and replace, if necessary.
- Check the torque of the racking hardware and tighten it according to manufacturer specifications, if necessary.

c. Electrical systems (connectors,wiring, and supports) —normal operations

- Before conducting any electrical adjustments or modifications, ensure all system AC/DC disconnects, fuses, switches, and circuit breakers are in the open position.
- Check J-box is securely attached to the module and is intact.
- Check that PV cable connections are securely connected and free of corrosion, and replace, if necessary, avoid cross-mating when possible.
- Check system DC wiring for kinks, damage, or exposed conductors, replace if needed.
- Inspect any other cable connections for secure contact and corrosion, replace or repair, if necessary, and avoid cross-mating when possible.

- Check cable ties, clips, and/or clamps are in place, holding cable securely to the module frames and racking. The cable should not be dangling or loose but should not be pulled taut against metal surfaces that might wear out the sheathing in high winds or damage the connectors. Replace damaged or worn materials with UV-resistant ties and wire clips/clamps (preferably metal and not plastic) on modules and rails, if possible.
- If conduit is used, check conduit to ensure it is not damaged and continuous; replace or repair if necessary.
- If conduit is used, check conduit supports and ensure conduit is secured, replace if necessary.
- Check enclosures for structural integrity, corrosion, and water tightness (including combiner boxes, inverter boxes, and battery storage enclosures); replace or repair if necessary.
- Check structural mounting of enclosures, tighten to specifications, or replace if necessary.
- Check electrical connections in enclosures (including corrosion, and damaged connectors, and check the torque on all bolted power connectors); replace, repair, or tighten if necessary.
- Check the grounding system for tightness of connections and electrical continuity of the system
- Check gaskets, conduit fittings, and seals on penetrations in electrical enclosures to prevent wind-driven rain, tighten, and/or apply outdoor rated sealant if necessary.
- Ensure access panels to enclosures are closed and latched, when possible.
- Install a weep hole in the bottom of the electrical enclosure for moisture to escape

d.Solar projects operational ERP

- The shut-down procedure for a solar farm is likely to be automated where SCADA (supervisory control and data acquisition) is inplace.
- Check SCADA installation, and ability to report storm damages. Check manual systemswhere SCADA is not in place.
- A check system is in place to put the plant in stowage, and emergency backup

systemsparticularly for power supplies is in place.

- Shutdown may also include physical intervention, including placing equipment coverings.
- Determine if failure of auxiliary power systems due to water ingress, lack of insulation, and high humidity will trigger an alarm and if a remote reset is possible or a prolonged loss of earnings, partial or total, will be indicated. Likewise, failure of the main networkwill result in a loss of exportability even if the site is operational.
- Check that the re-start procedure includes:
  - **Accessing the site** — In addition to the generic safe site access considerations, check specifically for solar farms that consideration is given to further falling debris, including panel parts.
  - **Error clearing and restarting** — Manually or remotely, including full inspection (looking for cracking, delamination, structural deformation, and evident damage)and testing regime. Stowage angles should be checked for evidence of forced movements. The extent of testing will depend upon the extent of the storm, plusthe time the site has been disconnected, and whether backup power has been made available or the site has been fully shut down. A phased restart may be used for safety and to maximize production.
  - **Reconnection** — This may be undertaken when technical compliance has been demonstrated to the System Operator and may also be undertaken as a phased exercise.

e.Flooding andDrainage

- Conduct ongoing inspection and cleaning of drainage systems as specified in the O&Mplan and modified appropriately to accommodate cyclone seasons.
- For a cyclone, the ERP should include pre- and post-storm clearance and post-stormdamage assessment.
- Drainage may be required after a storm, including pumps that require backup pumps (orcontracts for them) with electricity. If the flooding affects the electrical infrastructure, competent personnel are required to test and restore or write off.

f. Grid contracted obligations

Notification to grid operators is a crucial contracted requirement in the event of curtailment.

Communications

- Create a **central war room**, where the overall monitoring and control of activities like grid supply status, damage to infrastructure, response, and restoration coordination will be undertaken. This should also coordinate and seek regular updates from the IMD and the state disaster management authority on the status of the cyclone.
- Formation of core teams across Generation, Transmission, and Distribution utilities in the state, each exclusively looking into the following:
    - Material procurement and management
    - Manpower arrangement and deployment
    - Logistics/Transportation, lodging and boarding, food, etc.
    - Collection of field Information and MIS preparation/ reporting,

Coordination with field offices through messengers.

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CHAPTER 2
WARNING OF STORMS, LIGHTNING, AND ACTION PLAN

The discussion in this chapter is based on a review of available literature, mainly "Guidelines for Thunderstorm & Lightning (2021)", prepared by Gujarat State Disaster Management Authority (GSDMA), Gandhinagar.

2.1 DEFINITIONS

2.1.1 Thunderstorms: A thunderstorm is said to have occurred if thunder is heard or lightning is seen. Usually, the thunder can be heard up to a distance of 40 km from the source of origin. Considering their intensity, the thunderstorms in India are categorised as follows:

- **Moderate thunderstorm**: Loud peals of thunder with associated lightning flashes, moderate to heavy rain spells, and a maximum wind speed of 29 to 74 kmph.
- **Severe thunderstorm**: Continuous thunder and occasional hailstorm, and maximum wind speed exceeding 74 kmph.

Thunderstorms occur around the year in different parts of the country. However, their frequency and intensity are maximum during the summer months (March to June) as the most important factor for the occurrence of thunderstorms is the intense heating up of the atmosphereat the surface level.

2.1.2 Squall: A squall is defined as a sudden increase of wind speed of at least 29 kmph (16 knots) with speed rising to 40 kmph (22k nots) or more and lasting for at least one minute. It is of two types:

- **Moderate squall**: If the surface wind speed (in gusts) is up to 74 kmph.
- **Severe squall**: If the surface wind speed (in gusts) is greater than 74 kmph.

The climatology of the spatial distribution of the occurrence of a squall is almost the same asthat of thunderstorms.

2.1.3 Hailstorm: India, with about 29 hail days of moderate to severe intensity per year, is among those countries in the world that experience a very high frequency of hail.

Hailstorms are mainly observed during the winter and pre-monsoon seasons, with virtually no events after the onset ofthe southwest monsoon.

It appears to be associated with a particular cell of convective cloud rather than a storm as a whole. Hail occurs in the mature stage if at all it occurs. Cells in which hails occur have updrafts of greater than average intensity, exceeding 15 meters per second. It is of three types:

- **Slight Hailstorm**: If it is sparsely distributed, usually small in size and often mixed withrain.
- **Moderate Hailstorm**: If it is abundant enough to whiten the ground.
- **Strong Hailstorm**: If it includes at least a proportion of large stones.

2.1.4 Dust storm: Northwest India experiences convective dust storms, locally called *"aandhi",* during the pre-monsoon season with maximum frequency and intensity in May. The frequency of dust storms is maximum over Rajasthan, followed by Haryana, Punjab, and West Uttar Pradesh. It is of three types:

- **Slight dust storm:** If the wind speed is up to 41 kmph and visibility is less than 1,000 metres but more than 500 meters.
- **Moderate dust storm:** If the wind speed is between 42-74 kmph and visibility is between 200 and 500 metres.
- **Severe dust storm:** If the surface wind speed (in gusts) exceeds 74 kmph and visibility is less than 200 metres.

2.1.5 Lightning: Lightning is a high-energy luminous electrical discharge accompanied by thunder. It is of three types:

- Thundercloud or Intra-cloud lightning (IC)
- Cloud-to-cloud or Inter-cloud lightning (CC)
- Cloud-to-ground lightning (CG)

The third type of lightning takes a toll on lives and property and, therefore, is of more concern to us. However, inter-cloud and intra-cloud lightning are also dangerous as they may hit aircrafts. These are also the precursor to cloud-to-ground lightning.

2.2 FORECAST AND ISSUANCE OF ALERTS/WARNING

India Meteorological Department (IMD), Ministry of Earth Sciences, is the nodalagency for providing current weather information and forecast, including warnings for all weather-related hazards. There are two types of forecasts; short to medium-range weather forecasts and "Now casting" forecast

Forecasts (Based on Specific Range, Time Duration, and Area)

Now casting:
(Lead time/validity of 3 to 6 hours)

Short to Medium range forecast:
(Lead time/validity of 1 to 5 days)

While short to medium-range forecasts provide the potential areas with a probability of occurrence, Now Casting provides more specific information about the place/time of occurrence.

On the day of the occurrence of a severe weather incident/thunderstorm, State-level offices of the IMD start ‘now casting.’ As ‘now casting’ is valid for the next two to three hours, it gives only a limited lead time. This nowcast, which is at the district level, is provided to Relief Commissioners, State Control Rooms, District Collectors, Disaster Management units, etc. This alert is specific and issued for a district with the time of occurrence and associated wind speed.

2.3 IMD STATIONS NEAR RADHANESDA SOLAR PARK

IMD station at Banaskantha is an important Weather forecast station.

Weather monitoring systems such as automatic weather stations (AWS) of IMD provide some basic parameters such as wind speed, wind direction, relative humidity, temperature, pressure, etc., but do not predict lightning.

2.4 WEATHER BULLETIN AND WEATHER WEBSITES

2.4. 1 Weather Bulletin

A weather bulletin should provide information on i) the intensity of rainfall, ii) the spatial distribution of weather phenomena, iii) emergency situations, and iv) evacuation. General terminology used by IMD in weather bulletins is given below in Table 2.1

Table 2.1 Terminology used in weather bulletins

(A)	**Intensity of Rainfall**		**Terminology used.**
1.	0.1.mm to 2.4 mm	(24 hrs)	Very light rain
2.	2.5 mm to 7.5 mm	”	Light rain.
3.	7.6 mm to 34.9 mm	”	Light to Moderate rain
4.	35.0 mm to 64.9 mm	”	Moderate rain
5.	65.0 mm to 124.9mm	”	Heavy rain
6.	Exceeding 125 mm.	”	Very Heavy rain.
(B)	**Spatial distribution of weather phenomenon.**		
	Percentage Area Covered		**Terminology Used**
1.	1 to 25		Isolated
2.	26 to 50		Few Places
3.	51 to 75		Many Places
4.	76 to 100		At Most Places
(C)	**Emergency Situation**		

1.	When the water level rises above the danger of H.F.L	
2.	When the intensity of rainfall is above 65 mm /hr	
3.	When breaches are anticipated, they may cause disaster.	
4.	When water levels are rising abruptly it may cause disaster.	
(D)	**Evacuation**	
1	White Signal -	Alert condition
2	Blue Signal -	Ready for Evacuation
3	Red Signal -	Immediate Evacuation

2.4.2 Weather Websites

Information regarding weather in a particular area can also be obtained from the following websites

Satellite websites for storm prediction
http://en.allmetsat.com/images/asia.php
http://en.allmetsat.com/images/met5_cimss_irc.php
https://mausam.imd.gov.in
http://manati.orbit.nesdis.noaa.gov/dataimages21/cur/zooms/WMBas49.png
http://cimss.ssec.wisc.edu/tropic/real-time/indian/images/xxirmet5n.GIF
http://cimss.ssec.wisc.edu/tropic/real-time/indian/images/xxwvmet5.GIF
https://www.mosdac.gov.in
http://www.sat.dundee.ac.uk/abin/geobrowse/IODC/2007/8/7/600
http://imkhp2.physik.uni-karlsruhe.de/~muehr/satbilder1.html#Asien

A thunderstorm is a small-scale phenomenon and has a life cycle of about three hours. It has a dimension of 2 km to 20 km, and therefore, its detection is difficult.

Geostationary Weather Satellite captures images from a height of 36,000 km above the earth. It takes about half an hour to capture the image and another half an hour to process the data. So, by the time someone sees the satellite imagery on IMD's website,it is already one hour late. Due to the short life cycle of thunderstorms, a satellite cannot capture its initiation unless it is a large-scale thunderstorm activity.

The Doppler Weather Radar, which takes an observation every 10 minutes, can detect the occurrence of thunderstorms. Therefore, for better monitoring, there is a needfor a wider network of Doppler Weather Radars in the country.

In the last decade, there has been a significant improvement in the monitoringand forecasting of thunderstorms. This can be attributed to a good network of Doppler Weather Radars, a dense AWS network, half-hourly satellite observations from INSAT 3D & 3DR satellites, better analysis tools, and advanced computational and communication capabilities. With these, IMD has started all India now cast services for localized, high-impact weather incidents such as thunderstorms, squalls, and hailstorms with a lead time of up to 3 hours since 2013.

Doppler Weather Radars (DWR) based observation is the main source of information for *nowcast* of thunderstorms and associated weather incidents.

2.5 ACTION PLAN FOR LIGHTNING INCIDENTS

Lightning has a total path length of a few kilometres. Its peak power and total energy are very high, with the peak power discharge in the order of a 100 million watts per meter of the channel and the peak channel temperature approaching 30,000 °C. Peak currents in a lightning discharge range up to hundreds of kilo amperes (kA) with its typical value being 40 kA. Predicting the precise time and location of lightning is very difficult. However, a season or a period of lightning occurrence is known for many regions. **Fortunately, Banaskantha district is relatively less prone to lightning incidents compared to other parts of Gujarat.**

Lightning incidents can be detected by the ground-based Lightning Detection Network in real time. There is a need to create a high-density network in regions vulnerable to lightning strikes.
Before the preparation of the Action Plan for lightning, it is imperative that thefollowing actions are taken:

1. Mapping of lightning-affected zones on the basis of:
   (a) Available data of deaths and injuries (both humans and animals) at differentplaces, complete with latitude and longitude points,
   (b) Data on lightning incidents available with Radar/lightning detection system,
   (c) Data available from the National Crime Record Bureau.
2. Systemic study of past lightning occurrences by any expert agency or group (to be taken up with State-level knowledge institutions).
3. Sharing of data between different agencies for preparation of mitigation plan.
4. Installation of lightning and thunderstorm detection devices.
5. Generation of a database for future planning.

2.6 DISSEMINATION STRATEGY OF WARNING MESSAGES

The dissemination strategy should aim at reaching the last person as soon as possible. The following points should be kept in mind:

a. The warning messages from agencies such as IMD should contain safety directions to be followed; e.g.; the *now casting* messages for severe thunderstorms/dust stormsmay ask the public to take a safe shelter or move indoors in the wake of an inevitabledisaster;

b. The message should be short, clear, in simple(local) language and action-oriented;

c. The following activities may be considered to ensure that everyone in the affected area is warned in time –

i. Flash messages/tickers / 'breaking news' to be displayed on the local TV news channels;

ii. Radio announcements through public and private broadcasters;

iii. Flash messages / SMSs to the users by the mobile operators in the affected areas;

iv. In the case of rural areas and small towns, an early warning may be issued by the local authorities using loudspeakers, sirens, etc.; and

v. Social Media, including group messaging services, should be extensively used.

2.7 REVIEW & EVALUATION OF THE EARLY WARNING SYSTEM (EWS)

The reliability of EWS and its forecasting performance for natural hazards – in terms of hits, missed incidents, and false alarms for different thresholds – has to be evaluated periodically. In addition,it is also necessary to evaluate the efficiency of the technical reliability of the system components.

2.8 PROBABLE PERIOD OF HIGH RAINFALL

Weekly rainfall at Radhanesda (grid rainfall) from 1st July to 30 September in each year from 2012 to 2022 has been compared. As shown in Figure 2.2 relatively higher rainfall is received from 15th July to the end of August each year. Even though cyclones may occur any time during monsoon, but the **period from 15th July to the end of August may be considered more vulnerable. BUT CYCLONE BIPORJOY OCCURRED IN JUNE 2023.** The solar plant developers and disaster management team need to keep a close watch for severe storms.

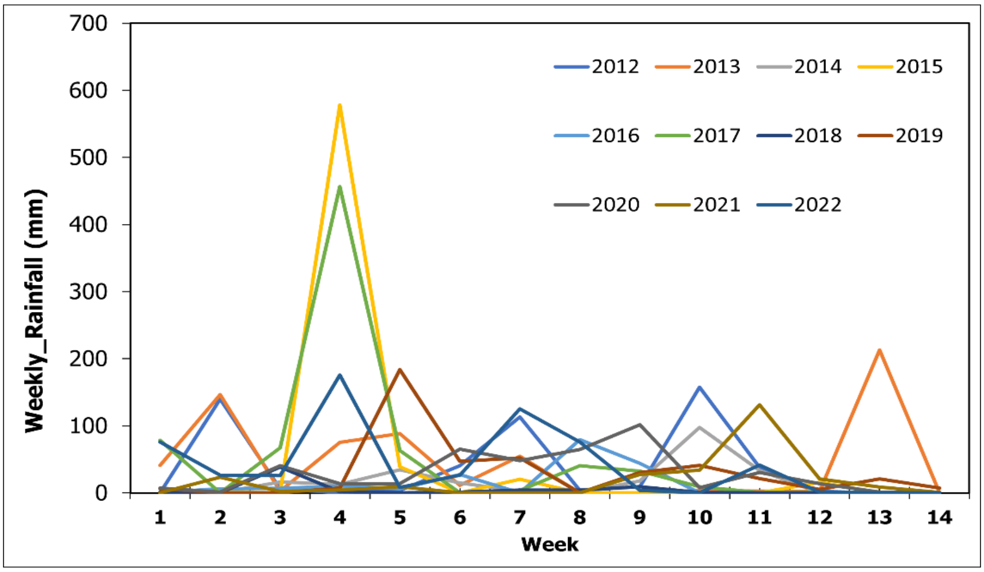


Figure 2.1 Weekly rainfall from July to September each year (2012 to 2022)

2.9 STRUCTURAL MITIGATION MEASURES

a) Protection Against Strong Winds

During cyclonic conditions, strong winds are able to reach velocities of more than 200km/hr. These high-velocity winds can cause severe damage to light structural and non-structural systems such as claddings. People will be safe against the most harmful effects of the high wind velocity provided they are inside cyclone shelters or other well-constructed buildings.

Typical wind speeds during thunderstorms are in the range of 50-80km/hr. During severe thunderstorms, the wind speeds may reach around 100 km/hr. The wind velocity is highest in storms that are associated with extensive lightning activities.

Structures do not require any special protection against storms with wind speeds up to 100km/hr if they are designed and constructed asper approved standards.

Buildings that are made using non-engineered materials may not be able to resist the wind forces. In general, components that provide large areas for the application of wind forces are the first to be damaged.

Protection against the lightweight panels under such wind speeds can be provided by properly securing them with their supporting frames. The connection has to ensure that shearing or punching is avoided. Also, it has to be ensured that the panels themselves have the requisite strength to withstand the wind force. The supporting frames also need to have adequate strengthto safely transfer the forces imposed on them.

(b) Protection Against Lightning

Installation of lightning arrestors and sound earthing for each building is essential. Lightning shields are the most commonly employed structural protection measure for buildings and other structures. A lightning shield consists of the installation of a lightning conductor at a suitably high location at the top of the structure. The conductor is grounded using a metal strip of suitable conductance. The grounding of the conductor is also specially designed to ensure rapid dissipation of the electrical charge of a lightning strike into the ground.

(c) Action–Before, During and After Thunderstorms and Lightning

i) <u>Before Thunderstorms and Lightning</u>: To prepare for a thunderstorm, you should do the following:

a. Do remember that vivid and frequent lightning indicates the probability of a strong thunderstorm.

b. Build an emergency kit and make a communication plan.

c. Remove dead or rotting trees and branches that could fall and cause injury or damage during a severe thunderstorm.

d. Postpone outdoor activities.

e. Remember the 30/30 Lightning Safety Rule: Go indoors if, after seeing lightning, you cannot count to 30 before hearing thunder. Stay indoors for 30 minutes after hearing the last clap of thunder.

f. Secure outdoor objects that could blow away or cause damage.

g. Get inside a home, building, or hard-top automobile (not a convertible). Although you may be injured if lightning strikes your car, **you are much safer inside a vehicle than outside.**

h. Remember, rubber-soled shoes and rubber tires provide NO protection from lightning.

i. However, the steel frame of a hard-topped vehicle provides increased protection if you are not touching metal.

j. Unplug appliances and other electrical items such as computers and turn off air conditioners. Power surges from lightning can cause serious damage.

k. Shutter windows and secure outside doors. If shutters are not available, close window blinds, shades or curtains.

l. Unplug any electronic equipment well before the storm arrives.

<u>ii) During Thunderstorms and Lightning;</u> If thunderstorms and lightning are occurring in your

area, you should:

a. Use your battery-operated radio/TV for updates from local officials.
b. Avoid contact with corded phones and devices including those plugged for recharging. Cordless and wireless phones not connected to wall outlets are OK to use.
c. Avoid contact with electrical equipment or cords.
d. Avoid contact with plumbing or pipes. Do not wash your hands, do not take a shower, do not wash dishes, and do not do laundry. Plumbing and bathroom fixtures can conduct electricity.
e. Stay away from windows and doors, and stay off porches.
f. Do not lie on concrete floors and do not lean against concrete walls.
g. Avoid natural lightning rods such as a tall, isolated tree in an open area.
h. Avoid hilltops, open fields, the beach, or a boat on the water.
i. Take shelter in a sturdy building. Avoid isolated sheds or other small structures in open areas.
j. Avoid contact with anything metal - tractors, farm equipment, motorcycles, golf carts, golf clubs, and bicycles.
k. If you are driving, try to safely exit the roadway and park. Stay in the vehicle and turn on the emergency flashers until the strong rain ends. Avoid touching metal or other surfaces that conduct electricity in and outside the vehicle.

iii) After lightning strikes a human being: If lightning strikes you or someone you know, call for medical assistance as soon as possible. You should check the following when you attempt to give aid to a victim of lightning:

a. **Breathing**–If breathing has stopped, begin mouth-to-mouth resuscitation.
b. **Heartbeat**–If the heart has stopped, administer Cardiopulmonary Resuscitation (CPR).
c. **Pulse**–If the victim has a pulse and is breathing, look for other possible injuries. Check for burns where the lightning entered and left the body. Also be alert for nervous system damage, broken bones and loss of hearing and eyesight.

CHAPTER 3

THE BIPARJOY CYCLONE, ITS IMPACT ON RAGHANESDA SOLAR PARK AND LESSONS LEARNT

3.1 THE BIPARJOY CYCLONE

3.1.1 Forecast Track and Intensity

Very Severe Cyclonic Storm “Biparjoy” (pronounced as “Biporjoy”) occurred in June,2023 over Northeast Arabian Sea: Cyclone Warning for Saurashtra & Kutch Coasts . The Biparjoy cyclone is illustrated through IMD bulletin number 76 issued on 15th June,2023 at 2030 hrs IST. The Very Severe Cyclonic Storm “Biparjoy” (pronounced as “Biporjoy”) over Northeast Arabian Sea moved nearly eastward with a speed of 12 kmph during the past 6-hoursand lay centered at 1730 hours IST of the 15th June 2023 near latitude 22.9°N and longitude 68.0°E, about 70 km west-southwest of Jakhau Port (Gujarat), 130 km west-northwest of Devbhumi Dwarka, 100 km west-southwest of Naliya and 240 km south-southeast of Karachi (Pakistan).

It is very likely to move northeastwards and cross Saurashtra & Kutch and adjoining Pakistan coasts between Mandvi (Gujarat) and Karachi (Pakistan) near Jakhau Port (Gujarat) during the next few hours as a very severe cyclonic storm with a maximum sustained wind speed of 115-125 kmph gusting to 140 kmph. The landfall process commenced around1830 hours IST of today and would continue till midnight today, the 15th of June 2023.

Forecast track and intensity are given below:

Date/Time (IST)	Position (Lat. ^{0}N/ long. ^{0}E)	Maximum sustained surface wind speed (Kmph)	Category of cyclonic disturbance
15.06.23/1730	22.9/68.0	115-125 Gusting To 140	Very Severe Cyclonic Storm
15.06.23/2330	23.4/68.7	105-115 Gusting To 125	Severe Cyclonic Storm
16.06.23/0530	23.9/69.5	80-90 Gusting To 100	Cyclonic Storm
16.06.23/1130	24.5/70.4	50-60 Gusting To 70	Deep Depression
16.06.23/1730	25.2/71.4	35-45 Gusting To 55	Depression

3.1.2 The IMD bulletin contained detailed information on following

(i) **Heavy Rainfall warning:** Places where heavy to very heavy rainfall, light to moderate rainfall would occur on15th June,2023 on 16th and on 17th June 2023

LEGEND: **Heavy Rainfall**: 64.5 to 115.5mm, **Very Heavy Rainfall**: 115.6 to 204.4mm **Most Places**:more than 76% of total stations, **Isolated Places**: Less than 25% of total

(ii) Wind (gale wind speed) over: Northeast Arabian Sea; East central Arabian Sea; Wind warning along & off Saurashtra & Kutch coasts (Kachchh, Devbhumi Dwarka, Porbandar, Jamnagar, Rajkot, Junagarh, and Morbi districts) including Gulf of Kutch, Wind Warning for South Rajasthan

Sea condition (rough, very rough) along & off Saurashtra& Kutch coasts:

(iii) **Storm Surge Warning:** Storm surge of about 2 -3 m above the astronomical tide is likely to inundate the low lying areas of above districts during the time of landfall.

Damage expected over Kachchh, Devbhumi Dwarka, Porbandar, Jamnagar, Morbi & Junagarh &Rajkot districts of Gujarat on 15th June:

Fishermen Warning & Action Suggested (Kachchh, Devbhumi Dwarka, Porbandar, Jamnagar, Rajkot, Junagarh and Morbi districts) and for Offshore & Onshore Industries:

(iv) Total suspension of fishing operations over the northeast and adjoining east-central Arabian Sea till 15th June.

(v) Those out at sea are advised to return to the coast.

(vi) Judicious regulation of offshore and onshore activities.

(vii) Ports along the west coast of India may take necessary precautions.

(viii) Naval base operations may maintain necessary precautions.

(ix) Movement in motor boats and small ships all & off these coasts to be avoided.

(x) Mobilize evacuation from coastal areas of Saurashtra and Kutch (Kachchh, Devbhumi Dwarka, Porbandar, Jamnagar, Rajkot, Junagarh and Morbi districts).

(xi) Judicious regulation of rail and road traffic.

(xii) People in affected areas to remain indoors.

(xiii) Tourism activities may be restricted over these areas.

(xiv) Preparatory actions before the cyclones.

Post Landfall Outlook for Banaskantha District

Light to moderate rainfall at most places with heavy to extremely heavy rainfall at isolated places very likely over Banaskantha and Patan; on 16th June.

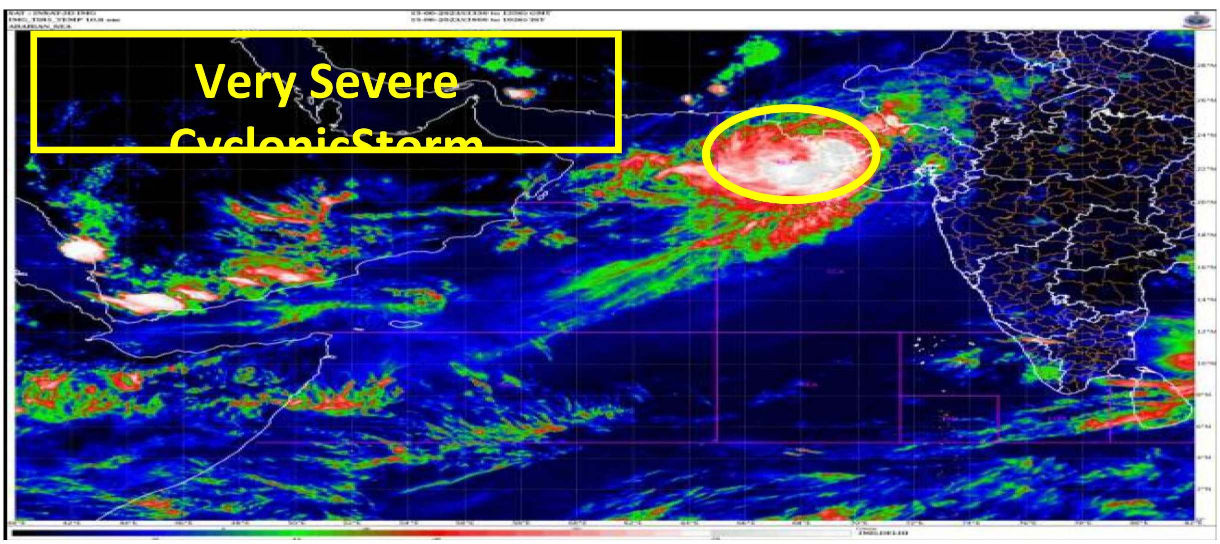
Light to moderate rainfall at most places, with heavy to very heavy rainfall at isolated places, likely over Banaskantha and Sabarkantha on 17th June.

Damage expected over interior districts of Saurashtra and north Gujarat region (Districts apart from those mentioned under warning):

(i) Major damage to Kutcha and minor damage to Pucca roads. (ii) Breaking of tree branches, uprooting of small trees. Damage to orchards. People in affected areas remain indoors.

The system is under continuous surveillance, and the next message will be issued at 2330 hours IST on 15th June 2023.

For State Government Agencies: The list of affected villages with corresponding estimated wind speed, flood level, and surge height can be seen in the Web-DCRA &DSS Application (https://webdcra.ncrmp.gov.in/). The concerned States/UTs can generate and download the list of affected villages through the distinct Tab named '*Affected Villages*' under the MOST AFFECTED DISTRICTS panel at the right bottom provided in Real Time Cyclone Impact Forecasting dashboard of the Web-DCRA & DSS Application.



Very severe cyclone storm

3.2 BIPORJOY CYCLONE PREPAREDNESS IN RADHANESDA SOLAR PARK

3.2.1 The Cyclone Strikes The Solar Park

The "Biparjoy Cyclone", known for its intensity and destructive force, struck the region with unprecedented ferocity. The cyclone brought forth strong winds, torrential rainfall, and turbulent atmospheric conditions. As per, forecasting agencies, its cyclonic eye passed approx. 35 Km away from GIPCL plant location in phase I solar park area.

Cyclonic impact started from evening of the 15/06/2023. Light rain and wind gustblown and weather was cloudy.In the morning 08:00 Hrs. on 16/06/2023, wind speed was around 30 to 35 Km/Hr and light rain was impacting. After 21:00 Hrs on 16/06/2023 wind speed was around 80 to 90 Km/Hr with heavy rain. This condition continued till 09:00 Hrs. on 17/06/2023 (almost for 12 Hrs.) with same intensity. After that wind speed decreased little bit but heavy rain was impacting the site badly. Wind gust decreased to 30 Km/Hr by 18:00 Hrs. on 17/06/20223 and rain stopped at 22:45 Hrs. on 17/06/2023.Cyclone totally moved away from site by 23:45 Hrs. of 17/06/2023. After that there was no rain and wind speed also became normal but some wind gusts were affected.The site was continuously impacted by BIPARJOY CYCLONE for approx.34 Hrs.

There was very heavy rainfall on 16th June (176.2 mm) and on 17th June, 2023 (73.8 mm). Intensity of rainfall was very high from 12:00 AM of 16 June,2023 to 2:00PM of 17th June, 2023. There was 393 mm of rainfall during 6 hours (2AM to 8AM on 17th June) with highest intensity recorded as 89.4mm/hour during 5AM to 6AM on 17th June.

The GIPCL solar plant report sheds light on the pre-cyclonic preparations, actions taken during cyclonic impact at the site, post-cyclonic actions, damages incurred, the subsequent operational disruptions, and the measures undertaken to restore the plant's functionality.

3.2.2 Pre-Cyclonic Preparation

a.) Meeting with TPSSL in-charge (O&M contractor) to discuss their preparedness and finance availability for instant purchase during cyclonic conditions.

b.) Meeting with plant O&M team to explaincyclonic effects and possible damage to man, machine and material.

c.) Prepared schedule of manpower. Necessary skilled and capable technical staff was instructed to remain at the site and the remaining staff to remain on standby. The site in charge also stayed at the site during the occurrence of the cyclones to co-ordinate and mitigate any worst conditions.

d.) Meeting with Taluka Mamlatdar, Deputy mamlatdar and TDO regarding preparedness and shared contacts to get help in emergency.

e.) Meeting with local police station for necessary help and contact sharing to mitigate any emergency situation.

f.) Meeting with security agency to plan minimum availability of manpower which can provide effective security of plant.

g.) Gave safety training to the technical and non-technical staff. Made available paddy shoes, helmet and fresh 11 kV safety gloves to use during maintenance in rainy condition.

h.) Maintained availability of torch, battery cell, candle, match box, rain coat and toolkit set in ready condition to mitigate any adverse situations.

i.) Made availability of food and water for at least five days stay of minimum 6 persons at site.

j.) Three teams were deputed with additional labour to check the module tightness of the blocks which are facing towards desert area and probable impact area of cyclone.

k.) One team with additional labours was searching the material from field which could damage the PV module during high wind condition. These materials were collected at the safest point of the scrap yard.

l.) One team was arranging material in open scrap area to avoid any possible damage to property due to high wind.

m.) Training was given by site incharge Mr Oza to manpower to make them aware about their roles and responsibility during emergency situation.

n.) Spare inverter was covered with waterproof cover.

o.) All Inverter duty transformer's water ingress points were covered with waterproof tape to avoid any false tripping due to water ingress.

p.) GPCL engineer was informed to check the availability of drainage pumps.

q.) Airtouch robot engineer was informed to take necessary actions to take care ofrobots.

r.) All roof structures, which are approachable had been tied by old string cableand weight was put on its upper surface to avoid flying of roof during high wind.

s.) All N2 panels of IDT were also covered and tied.

t.) All marshalling boxes of IDT were covered with water proof cover and lockedproperly.

u.) Maintained the costly and crucial material in the store with propersafety and above ground level.

v.) Isolated module cleaning system properly to avoid any damage to it. Placed the Aegeus make robot in the ICR to avoid any possible damage to it.

x.) Made tool kit set, key set and set of safety PPEs for the individual maintenance team to provide instant access and to avoid mash up during blackout condition if happened.

y.) Checked healthiness of UPS batteries and UPS which may play crucial role during black out condition.

z.) Tied up communication tower with rope to protect it and it was tied in such a way that its landing path should not affect 33 kV main line cables.

aa.) Stopped labour intervention at site by 15/06/2023.

FIG: ROPE SUPPORT TO COMMUNICATION TOWER

3.2.3 Activities During Cyclone

Following were the activities carried out during cyclone.

a.) It is good achievement that on 16/06/2023 till the end of generation Hrs. all 32 inverters were synchronised without any tripping.

b.) After generation Hrs. team took a round of the field to check any abnormalities but all things were found in order.

c.) During night time as the wind speed and rain intensity increased, water startedto ingress in the MCR. GIPCL team was continuously wiping out the water and savedthe MCR.

d.) Water ingress was observed from roof of MCR and maintenance bay shutter was hampered badly due to high wind.

e.) During night time Mr Oza along with his team continuously sat in front of SCADA to observe any abnormal alarms.

f.) Alarm occurred of DC failure in N2 panel of transformers. Team went with fullsafety and took the system on manual to avoid any false tripping. Because a false tripping leads to a major job in transformer and it takes time to restore.

g.) Block# 8 IDT's marshalling box glass broke due to high wind and its tarpaulinwas torn out, so rain water was falling on the controls of transformer. As it is nearer to MCR, team went with full safety to isolate the supply of marshalling boxand retied the new tarpaulin.

h.) In the morning, team has taken in line all protections which were isolated or taken in manual mode, with proper checking of their healthiness.

i.) In the morning, out of 32 only 18 inverters were synchronised. We didn't try to start remaining inverters. It was not safe for the man as well as machine. Whole day of 17/06/2023, 18 inverters were runnning and generated 33 MW. Other solar plants in the solar park could not generate electricity on the day of cyclone.

j.) During rain IDT#2 got tripped due to earth fault and over current. It was kept as it is, because during rain it was not possible to attend.

k.) ICR 1,2 and 4 SCADA communication also got effected. Security guard was deputed nearer to ICR under shed to keep watch and inform if any abnormalities should occur.

l.) 03 Nos. of heavy voltage dip was observed, during that time our MCR UPS and battery charger got tripped. Team had attended the same on the spot.

m.) No attempt was made to start the machine which got tripped during cyclone. Team tried to maintain the healthiness of the equipmentwhich were running / got tripped/ not running.

n.) Arranged and provided food and water to technical staff and security guards.

o.) Maximum precautions were taken for safety of man and machine both.

p.) No major fault occurred during cyclonic condition.

3.2.4 Post Cyclonic Activities

During the last phase of cyclone there was heavy rain and due to that water level in the plant area increased. On the other side, there was a heavy rain in Rajasthan so due to that "Luni river" water spread on the down stream side of the GPCL earthen bund. Water logged inside the plant could not drain out and plant water level kept on increasing.

To avoid any damage to inverter, "Emergency stop" was applied in all 32 invertersto disengage them from grid. Again, all the transformer marshallingbox and N2 panel were checked for sack of safety.

Following were the actions carried out after impact of cyclone.

a.) In the morning, team checked all inverters one by one and also applied hot blower as and where needed and 24 inverters were taken in line.

b.) One team was allocated to restore IDT#2 which was under breakdown. It was taken on load by 13:42 Hrs. of 18/06/2023. One by one its three inverters werealso taken in line after soaking period of transformer.

c.) One team was sent in field to check module and structure damage. They checked healthiness of LA structure.

d.) One team was working on restoration of the SCADA communication. It was restored by evening of 18/06/2023.

e.) One team was sent to inspect all ICR to find any damage. f.) One team was sent to check peripheral property damaged.

g.) Three inverters 1D, 2A and 5A have critical alarm on SCADA. So, Mr Oza contacted OEM service engineer to inspect and take necessary action at the earliest.

h.) Inverter 1D had been attended by team under the remote supervision of the inverter service engineer and it was taken on load by 19/06/2023.

i.) 04 nos. of N2 panel were kept on manual mode as water was still there in its panel. j.) All marshalling box protections were restored.

k.) MCR HT cable trench water was drained out.

l.) Mr Oza had personally checked each and every corner of the site.

m.) Team was isolating the faulty strings from SCB if eeded.

n.) Team has applied hot blower in HT panels to remove moisture and avoid falsetripping.

o.) Team applied hot blower to all IDT marshalling box to remove moisturefrom it.

FIG: TEAM WAS WORKING ON RESTORING IDT#2 AND BLOCK#2 INVERTERS AFTER CYCLONE

Flooding in the solar park

3.2.5 Maintenance Required After Cyclone

As such, our site has not been affected much by the Biparjoy cyclone due to our pre-cyclonic preventive actions, but some minor maintenance is required, and the same iselaborated below.

a.) Due to steps taken, not a single module got affected but they may become loose due to continuous wind pressure. So, retorqueing of all modules is highly recommended.

b.) We have to check the torque of the mechanical structure of the module, and we have to retighten them if needed.

c.) The roof, its structure, and its canopy require maintenance on an urgent basis as the monsoon is just behind, and we have faced water leakage from it.

d.) False ceilings got damaged/destroyed in ICR and MCR, which also needurgent maintenance.

e.) 10 nos. of street light polls are found damaged. We need to reconstruct their foundation as well as to provide strength to the other polls, which are getting weak in this cyclone.

f.) Block#3 and 4 security cabin base required maintenance.

g.) All ICR door locks got damaged, and we could not lock our ICR, so they needreplacement.

h.) The shutters of MCR and ICR are hampered badly by the high wind. So, they needmaintenance.

i.)Inverter 2A and 5A needs more attention and its component replacement afterdetail checking by inverter service engineer.

j.) All N2 panel of IDT are required maintenance as some part got submerged inwater and their protection also got hampered during rain.

k.) Inverter's PDB needs routine maintenance as it was also impacted badly by rain.

l.) Field SCADA panels are also having tripping during rain so, we have carried outits maintenance.

m.) Cleaning of pipe culverts and box culvert is required a it played a crucial role inwater draining.

n.) During high voltage dip spare battery charger got some issue and it is notgetting in boost mode. So, with the help of OEM it is required to fix.

3.2.6 **Recommendations by Site Incharge**

a.) Module and its structure retorquing work.

b.) Due to continuous water retention on module structure, at some place corrosion is noticed. So, we should process anticorrosion treatment to enhance the life of the module structure.

c.) We have to prepare drainage canal in Block#7 for dewatering of water logging.

d.) We may purchase 3 nos. of Solar pump to evacuate water from Block#5, 6 and some location of the plant where gradient is not supportive in water draining.

e.) We have to strengthen all roof structures. There was so much water ingress in MCR and ICR.

f.) There was water ingress in N2 panel of Transformer. If it is possible we may lift the height of its structure. Because in some blocks, water entered and we got protection alarms.

The experience gained from this cyclone event serves as a valuable learning opportunity. It underscores the importance of proactive measures and preparedness to minimize the impact of extreme weather events on renewable energy infrastructure. By integrating resilience strategies and incorporating lessons learned, solar plants can become more resilient and continue to contribute to sustainable energygeneration, even in the face of adverse weather conditions.

3.3 LESSONS FROM BIPARJOY CYCLONE

The Cyclone Biparjoy highlighted the gap areas for improvement. The way forward emphasizes specific considerations to enhance preparedness, response, and recovery efforts related to cyclones.Cyclone Biparjoy offered opportunities to learn for capacity enhancement and improvement in disaster risk reduction and resilience. Some of the key aspects are briefly discussed below.

3.3.1 Preparedness and Early Warning:

Integration of all observed and forecast information into a single platform/ bulletin

During Cyclone Biparjoy, IMD issued forecast about the cyclone and NRSC, Hyderabad, was issuing inundation maps based on IMD’s forecast track. Similarly, Central Water Commission was providing riverine outflow. Additionally, Space Application Centre, ISRO provided scatterometer based imageries. It is suggested that all risk information products from different centres / agencies like ISRO, CWC, IMD etc. should be made available on a common platform/ consortium of such organizations in the country and the region. All these products should be integrated within a single bulletin, website and GIS platform for easy accessibility and better decision making on early warning, preparedness, protection, pre-positioning and response actions.

3.3.2 Augmentation of Observational and Modelling Capabilities

Cyclone Biparjoy changed its path 9 times during its life period of 13 days 3 hours. Enhanced observations, better modelling capabilities like dynamic numerical multi- model ensemble techniques with improved lead time and accuracy, use of advanced technologies like satellite images, UAVs, aircrafts, augmented observational network including doppler weather radars, wind profiler, automatic weather stations etc. helped to get the real-time information about the cyclone including rapid intensification during genesis & growing stage and slow weakening after landfall. The learning from this forecasting has to be institutionalized.

3.3.3 Synergised Standard Operating Procedure (SSOP)

Every organization/agency has its own set of standards of procedures and guidelines for working on forecast and early warning. Thus, they have different standards and parameters for issuing alerts and sharing information in different formats. It becomes difficult for disaster management authorities and communities to make effective decision based on this kind of information. Hence, a consortium of such organizations should establish a minimum standard of practice which may be termed as Synergised Standard Operating Procedure (SSOP) among various stakeholders for effective warning, communication & dissemination. There is a need to enhance interoperability among these various stakeholders.

3.3.4 Regulatory framework for weather forecast by various agencies / experts to avoid rumors and misinformation

During times of disasters, various meteorological agencies/ experts (some of whom may not have adequate qualification and competence as well as lack proper resources an infrastructure) have been sharing weather related information with the public, for awareness among masses with respect to impending hazard on 𝕏 (Twitter), Facebook, news media etc. Sometimes such practices result in misinformation and rumors, thereby misleading the concerned authorities and communities. Therefore, to bring accountability by regulatory framework may be brought in place to restrict issuing of the early warning and alerts on cyclone and other extreme weather events by these agencies/ experts. The nodal agencies for early warning, mitigation and response to specific disasters have been identified in the National Disaster Management Plan (2019).

3.3.5. Mobilisation of Volunteers

A lot of effort has gone into training volunteers, such as Aapda Mitra to be of assistance during such disasters. During Cyclone Biparjoy, Gujarat state has very well utilized the trained and skilled Aapda Mitra in response to the disaster situation. Similarly, Kerala state utilized Aapda Mitra during the floods in 2018 and Odisha during Cyclone Fani in 2019. The Aapda Mitra system has provided a huge pool of human resources, trained and skilled as first responders. However, this resource pool can even be more effectively deployed and monitored if regular update is mandated for states to include this data in IDRN portal.

3.3.6.Periodic Review of DM plans, SoPs and Guidelines

Periodic review of Disaster Management (DM) plans, Standard Operating Procedures (SoPs) and guidelines is essential to ensure their effectiveness and relevance. It helps identify gaps, incorporate new information, address emerging risks, and enhance coordination among stakeholders. The plans should be updated in a holistic manner in consideration with the concurrent hazards and risks.

3.3.7.Codes and Standards for Cyclone Resistant Design and Construction

In coastal regions, strict adherence to the Central Electricity Authority's (Technical Standards for Construction of Electrical Plants and Electric Lines) Regulations, 2022, should be made mandatory. Innovations related to the design codes and standards for the power structures and networks particularly in the coastal regions to withstand the heavy winds should be adopted.

3.3.8.Enhance Drainage Systems

The Cyclones are often accompanied by heavy precipitation leading at times to floods / flood like situations, particularly in the urban areas where drainage systems are not appropriately and adequately designed for such situations Cities, particularly in the coastal states of the country, need to give special focus to storm water drainage system and ensure litter free cities by introducing responsible waste management systems including resource recovery centers so as to reduce drainage congestions. The drainage systems may also be modified and strengthened, including appropriate design, construction, and maintenance of stormwater drains, improved solid waste management practices, and implementing proper urban planning to avoid development in flood-prone areas.

3.3.9.Public-Private Partnerships

It is important to foster partnerships between the public and private sectors for undertaking activities initiatives for disaster risk reduction and resilience. This can involve leveraging private sector expertise and resources to implement innovative solutions, while governments can provide regulatory frameworks, incentives, viability gap funding and support to ensure infrastructure resilience.

3.3.10 Women Leadership and Empowerment

During Cyclone Biparjoy, ASHA workers and other grass-roots women leaders helped in mobilizing the affected community for medical assistance and any post cyclone outbreak of diseases was prevented. Similarly, women self-help groups, particularly in coastal state like Kerala have contributed a lot in response and relief during the flood in the year 2018.

3.4 GOVERNMENT RESPONSIBILITY IN BANASKANTHA DISTRICT

The disaster management branch in the Banaskantha district is responsible for the implementation of the Disaster Risk Management (DRM) Program. Its key functions are:

- Relief compensation of natural disasters i.e. Flood/Earthquake/cyclone/Scarcity
- Relief compensation of communal right cases/Hearing of such cases indentation of communal tension places
- Implementing DRM programs
- Maintain the district disaster management plan, Taluka disaster management plan, city disaster management plan, and village disaster management plan in collaboration with other branches.
- Providing various Training, i.e., EOC Management Training, Search & rescue, first Aid, Early Warning Communication, Special Orientation cum Training for Govt. Official/Volunteers/NGOs.
- School-level mock drills for school safety, Various Industrial Unit's Offsite Mock drills, Various Administrative level Mock drills on checking SPO of level Specific Disaster Management plan
- DM orientation program in schools/collages, Campaigns/rallies at various levels, Mass Awareness Generation Program

Contact details of the disaster management officers in Banaskantha district are given in Table 11.2. It is important to verify the details of disaster management officers regularly (monthly), particularly before the onset of monsoon season.

Table 11.2 Government Officers at the District Level

Mamlatdar (Disaster management)	02742250627	dismgmt-ban@gujarat.gov.in
District Project Officer (Disaster Management)	95375 11458	dpodisasterbk@gmail.com
Disaster Management Control Room	02742-50627	

ANNEXURE III provides a checklist on Government responsibility for disaster management in the Banaskantha District

ANNEXURE III

CHECKLIST ON GOVERNMENT RESPONSIBILITY AT THE DISTRICT AND SUBDIVISIONAL LEVEL

A checklist in the form of a questionnaire is given below. Some of the questions may not be directly relevant to Radhanesda solar park. The main problem in the park is that of waterlogging and drainage. Questions relevant to the Radhanesda solar park are highlighted.

1. *Have you identified the flood-prone blocks, talukas, tehsils, and villages?*
2. *Is there a responsible officer in charge of relief and anti-disaster operations?*
3. *Is there an operation control center?*
4. *Is a log book maintained to keep data about the rise of flood waters at regular intervals of the rivers in the district?*
5. *Is there a coordination committee for relief? Are the District level officers and Block Development Officers of health, Water Resources, Roads & buildings, Telephones and Police, represented on it? Are Voluntary Relief organizations having repute and standing and are the District Branch of the Indian Red Cross associated with the committee?*
6. *How is the flood warning communicated through mobile units and microphones in the flood-prone sub-division and blocks to issue warning?*
7. *Has the Deputy Controller of Civil Defence received any training on Disaster Preparedness?*
8. *Has the Deputy Controller of Civil Defence trained the Civil Defence Wardens in this matter?*
9. *Has the Home Guards been given any training in disaster preparedness for floods, as well as rescue/relief/first aid? How are they kept in readiness for being mobilized at short notice?*
10. *Are the flood-prone blocks connected to the telephones and police?*

(i) Mobile water tankers, canvas water tanks, drums, and Jerry cans for transporting water buckets are kept ready.
(ii) Sandbags for repairs of flood protection embankment are kept ready?
(iii) Basic field Sanitary Engineering equipment are available?

11. *Has the Chief Medical Officer like-wise checked up on the stock of essential medicines, vaccines, disinfectants, and first aid kits at the District/Sub-divisional medical store and kept the primary Health Centers in flood-prone area well supplied with the following?*

(i) Disinfectants such as bleaching powder, chlorine liquid chloroscope, orthotoludine solution, water purifying tablets, and phenyl (for ensuring quantity of free chlorine for supplying safe and potable drinking water).
(ii) Essential medicines for mobile teams and dispensaries in the evacuee camps are available? are such stations provided with wireless sets?
Can wireless sets/telephones be provided at still lower levels of administration?
(iii) Who is responsible for disseminating the flood warning at the village level? Has the village Mukhi and/or the Sarpanch of the Gram Panchayats been given the responsibility? Do they have a transistor?

12. *Has the officer-in-charge of relief inspected the District/Sub-divisional Relief stores after the occurrence of the last floods?*
13. *In particular has he checked the stockpiles of :-*

a. Clothing (including children's garments) durries/mats?
b. Tents, tarpaulin, G.C.I Sheets, and other materials for providing temporary shelters?

*c.	Boats, power-driven and life-jackets?*

*14.	Anti diarroheals, antibiotics, chomother appecuties and anti-malaria drugs, anti-phyrotics, and analgesic and anti allergic drugs cholorosel I.V. fluids pediatric formulations for the treatment of gastro informal and respiratory infections in children have been kept ready?*

First aid kits containing splints (including Thoms splints) tornique, dressing, and as sorted bandages antiseptic cream, scissors, and safety pins, are kept ready?

*15.	Have flood shelters (Schools, Community Centers) been identified? Has the list of such shelters been published in the local news papers and displayed in the blocks, taluka, and tehsil offices?*

*16.	Are the shelters easily accessible? Is it contemplated to use the flood for work progress for constructing link roads?*

*17.	Are the shelters provided with sources of drinking water? If not what action being taken to locate water sources, tube wells, and wells near the shelters on a priority basis?*

*18.	What are the sanitary arrangements for these evacuation camps? Have local officers in charge of these evacuation camps been told to construct the following?*

*(a)	Deep trench latrines*

*(b)	Temporary Urinals with soak pit.*

*(c)	Incinerations for burning dry refuses.*

*19.	Has the District Manager, Food Corporation of India checked up if sufficient stock of food grains are in position in the flood prone areas of the District before the monsoon starts?*

*20.	Has the Officer-in-charge of civil supplies ensured that the dealers keep sufficient stock of essential articles like pulses, edible oil, salt, milk powders, baby food, matches and lanterns before the start of flood season?*

*21.	Have the wholesale consumers co-operative societies, been requested to keep in readiness the stocks of aforesaid articles at the branch level?*

*22.	Have suitable sites for probable hele-pade on raised grounds in the flood-prone area been located? Have these been indicated on the District and Thana Map ?*

*23.	Has a meeting of the Transport Operators been called by the Chairman of the Regional Transport Authority to negotiate with the former the placement of private vehicles at reasonable rates for evacuation of flood victims and movement of relief goods?*

*24.	Has the collector/ Sub-Divisional Officer ascertained the availability of country boats with boatmen at reasonable rates in the event of an emergency. A few country boats may be converted into improvised boat Ambulances by providing them with 1 or 2 stretchers.*

*25.	Have people in low lying area which are inundated in every flood been alerted first about the flood warning? Are you searching for alternative sites which can be allotted to such families ?*

*26.	Has the concerned block been identified and kept in readiness in the shelf of projects of relief works which can be launched when the flood water recedes?*

*27.	Have the villages waterlogged for a long time been identified?*

*28.	Is there a list of people who cannot be provided with gainful work, but many have to be fed, freed at Government cost for some time? Have the Panchayats been associated in preparing the list of such beneficiaries for gratuitous relief?*

*29.	Have the people in flood-prone villages been trained in relief and rescues?*

Have volunteers been grouped for patrolling embankments that are likely to give way?

CHAPTER 4

SAFETY OF THE FLOOD EMBANKMENT AND BUILDINGS

4.1 THE RADHANESDA SOLAR PARK FLOOD EMBANKMENT

An earthen embankment along the boundary of phase I of Radhanesda Solar Park has been constructed over a length of 16.394 km. It is being widened now and box culverts are being provided in this embankment. In the present study, a similar embankment is proposed in phase II of the solar park to control flooding from the outside.

Proper maintenance of embankments is extremely important as breaches in these can be disastrous and can cause even greater damage than flooding in solar parks where no embankments are provided. Very careful maintenance of the embankment is necessary during high waters. Frequent inspections and constant attendance by all concerned are essential, particularly in the case of new embankments or dangerous sections of old embankments.

Responsibility for the maintenance of flood embankments should not be left to individual developers. There should be a single common establishment (GPCL) for proper upkeep and maintenance of the flood embankment.

4.2 MATERIALS REQUIRED TO MEET EMERGENCY SITUATION

Materials required during the monsoon period should be provided in ample quantity as experience shows them to be necessary. Particular care should be taken that there is an adequate quantity of the required materials distributed with careful forethought so as to be readily available everywhere, particularly at dangerous sites, for example, at the cuts recently made in the embankment and the culverts in the embankment. The following scale of materials is a rough indication of the relative quantities of the different kinds of materials usually required during the monsoon period (Table 4.1).

4.2.1 Patrolling

Patrolling should commence as soon as the water comes against an embankment and should continue until the water finally leaves the embankment. During the rainy season, the embankment requires close and constant watching and unremitting supervision both day and night by adequately trained staff. The material requirement is as given in Table 4.1 below

Table 4.1: Material requirement for patrolling

(i)	Lamps Hurricane	1 For every 2 Labours. 1 For every Work Assist/Karkoon. 1 For every A.E/A.A.E./Overseer. and 20% of the Total for Spare.
(ii)	Wicks	9 Nos. per Lamp.
(iii)	Globes	1 No. spare for each Lamp.
(iv)	Burners and Caps	Spare for 1/3 No of Lamp.
(v)	Torches	To each of the patrolling staff
(vi)	Cells	1 Fill and Two Spare sets.
(vii)	Petromax Lamps.	At dangerous places as necessary; each lamp with 2 spare Globes, 2 Nozzles, 2 Washers, 2 Wire Gauzes, 2 Needles and 6Mantles. (3/4 of the members should be 300 C.P. and 1/4th 200 C.P.
(viii)	Fuel for Lighting	Fire To be collected by labour establishment.
(ix)	Kerosene & Oil	1 Tin per hurricane Lanterns (Excluding Spare)and 2 Tins for Petromax lamp per season.
(x)	Match Boxes	One Dozen per Lamp per season.
(xi)	Spirit	1 Bottle per petromax lamp per Season
(xii)	Funnels	½ Dozen per Work Assistant / Karkoon
(xiii)	Oil Extractors/Caps	¼ Dozen per Work Assistant / Karkoon
(xiv)	Spirit Cane	1 per Petromax.

4.2.2 Leaks

Water coming out through the body of the embankment in any form, such as seepage through cracks or piping action, may be termed a leak. Rodents and other borrowing animals make holes, cavities, and tunnels through and under an embankment. These are a source of danger as very often these cause leaks, excessive seepage, and even serious breaches during flood periods. Material requirement for repairing leaks is given in Table 4.2.

Table 4.2: Material requirement for repairing leaks

(i)	Gunny Bags	(a)	Where High Flood Depth is less than 1.80 Mt and the embankment is generally safe then 65 Bags per Kilometer.
		(b)	Where High Flood Depth is greater than 1.80Mt. or the embankment is known to give trouble of leaks then 130 Bags per Kilometer.
(ii)	Stakes	65 to 130 Stakes per Kilometer.	
(iii)	Baskets	1 Basket of Toot/labour or 1 Basket of lai/labour and One Spare.	
(iv)	Sutli	450 gms. Per 100 Bags.	
(v)	Needles	½ Dozen with each Work Assistant.	
(vi)	Sand	Collection of 1.80 to 3.60 Cu.Mt.Per every Kilometer for Dangerous Lengths.	

4.2.3 Breaches

Failure of a section of earth embankment due to over-topping causes a breach of the section. Successive and heavy rains cause very often severe erosion of unprotected slopes and render the section unsafe. This may result in disastrous breaches. In case of such emergencies, the top and sides of particularly weak and dangerous sections of freshly made-up earth should be protected by materials, sandbags, etc., as discussed below in the section on emergency measures.

Provision for materials required should be made for One or More small breach lengths, each 76 Mt. long, depending upon the embankment. Materials for protecting ends of one breach and constructing one 76 m. long are as under (Table 4.3)

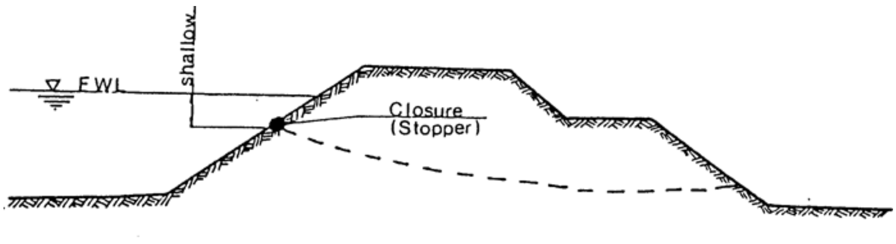
Table 4.3: Material requirement for repairing breaches

(i)	Big stakes or Sal Ballies.	Every 1.50 Mt. apart with 100% spare.
(ii)	Split Sal Ballies or Bamboos.	For Horizontal bracing of Vertical ballies - 3.0 Mt. long each for the entire length.
(iii)	Split Sal Ballies or Bamboos	For Cross bracing of vertical ballies – 3.0 Mt. long One for each verticalballies.
(iv)	Mattresses of split bamboos or “Pilchi” or other locally available material.	For sufficient length.
(v)	Brushwood of local material	For sufficient length.
(vi)	Stakes	0.45 Mt. centre long each row of frame.
(vii)	Munj Rope	Enough quantity
(viii)	Coir Rope	Enough quantity
(ix)	Gunny Bags	Enough quantity
(x)	Sutli	450 gms. Per 100 Nos. Bags.
(xi)	Needles	1 No. per 100 Nos. Bags.
(xii)	Baskets	Enough quantity

4.3 EMERGENCY MEASURES FOR THE FLOOD EMBANKMENT

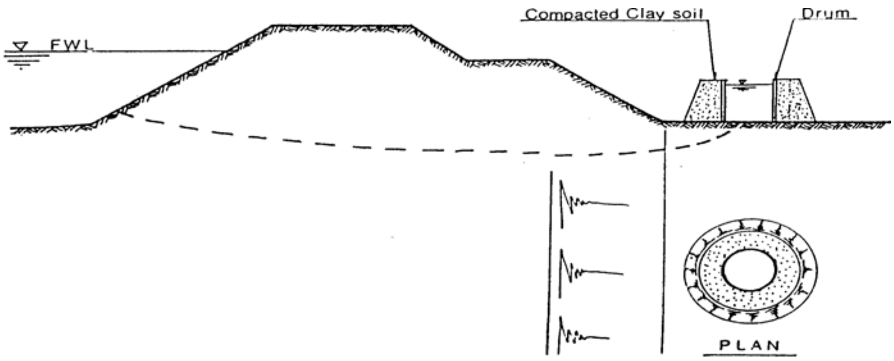
Seepage/Leakage

a). Direct method: If possible, close the hole with a sack closure of old clothes. The hole spot can be identified from the existence of a water vortex (eddy).

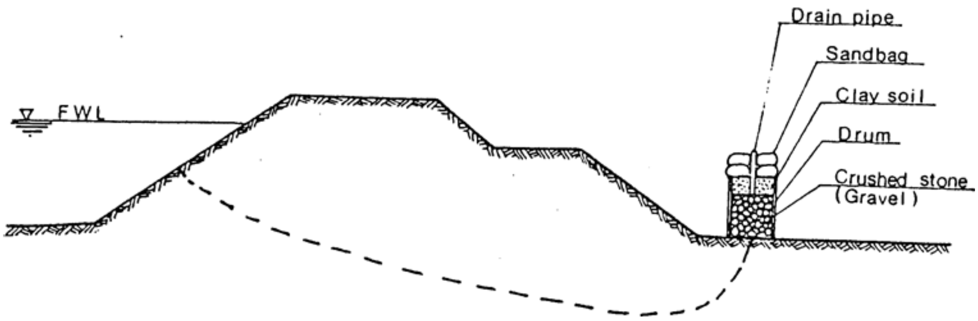


b) Indirect method: If direct closing of the hole is not possible due to the depth of the hole spot, then seepage/leakage shall be prevented behind the embankment.

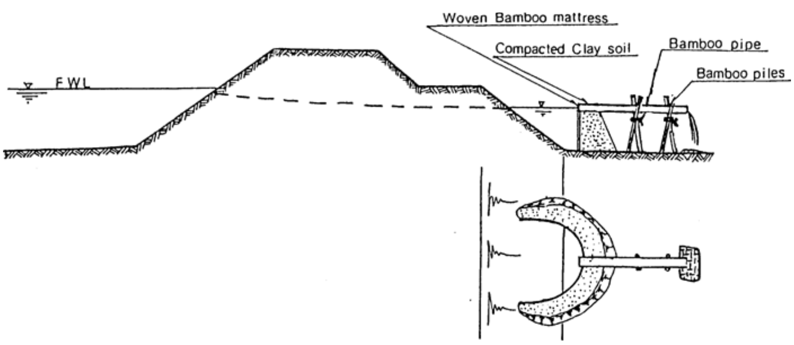
i)If seepage/leakage occurs just locally, then seepage/leakage water shall be collected, placing a drum behind the embankment, which is reinforced by dumping of compacted clay soil surrounding the drum. This helps in lowering of water level difference between the water in front and behind the embankment. So the seepage/leakage waterforce becomes lower and piping can be overcome.



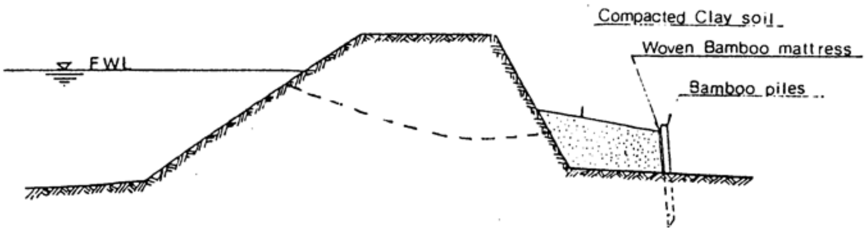
ii) If the aforementioned method is not able to prevent piping, then the drum shall be filled with crushed stone, functioning as a counterweight and filter. Clay soil is placed compacted on the above-crushed stone; then sandbags are placed on it. It is also equipped with a drain pipe to drain the seepage/leakage water.



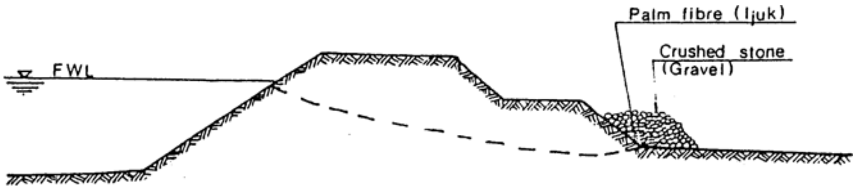
iii) If some leakage/seepage appears along the toe of the embankment, then timber/woven bamboo matter surrounds the leakage/seepage. The mattress is reinforced by driven piles and compacted clay soil.



iv) If the outflow of leakage/seepage water from the steep back side of an embankment will cause sliding of the embankment slope, then that leakage/seepage spot shall be dumped and compacted with clay soil. Besides, it is supported by the woven bamboo mattress fixed at a bamboopile.



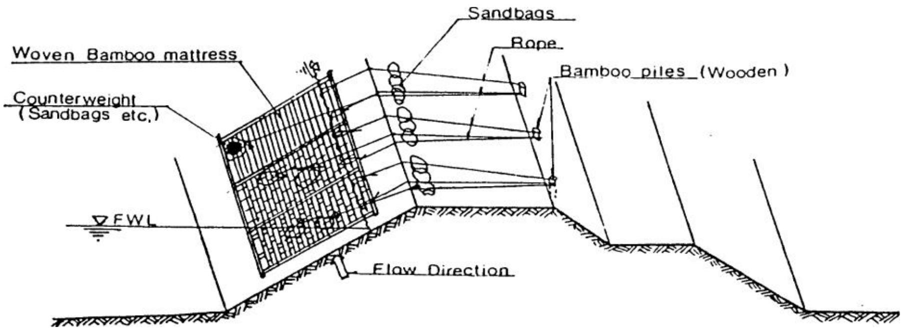
v) The place of the leakage/seepage closed by palm fibre layer functioning as a filter to protect the moving of the foundation material. The palm fibre layer is protected by the dumping of crushed stone.

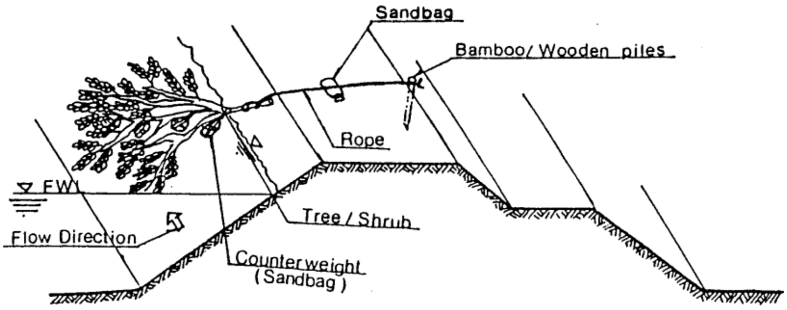


vi) At the place of leakage/seepage, bamboo pipe will be provided to release leakage/seepage water from the toe of the embankment. At the top of the bamboo pipe, palm fiber will be provided, functioning as a filter.

Scouring

a) To prevent scouring caused by turbulent flow, a tree stem, including its branches, shall be provided at the front side slope of the embankment. At the front end, a counterweight shall be provided to prevent washing out by the water, while the tail end of the tree shall be fixed on a pile driven in the embankment body.

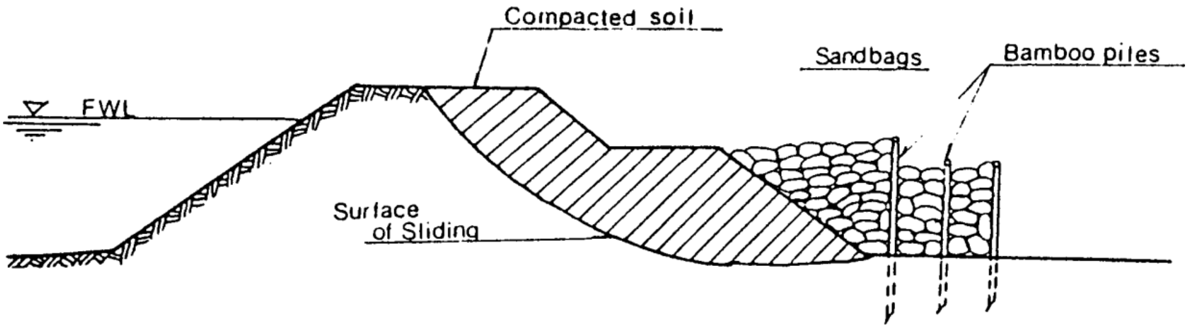




b) Another method is the use of woven bamboo mattress provided with a counterweight at the tail end and fix the front end at a pile driven in the embankment body.

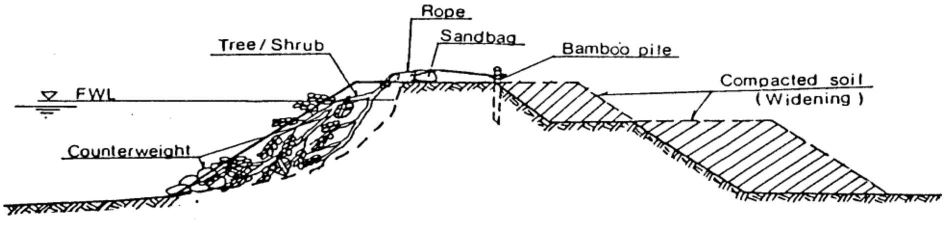
Sliding

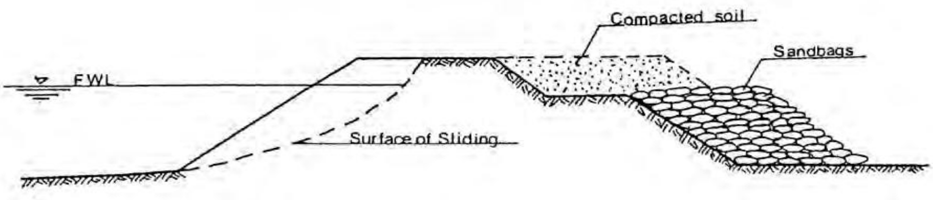
a) If sliding occurs at the backside of the embankment, then after dumping of compacted soil on it that place shall be provided with a counterweight which consists of sandbags with driven piles.



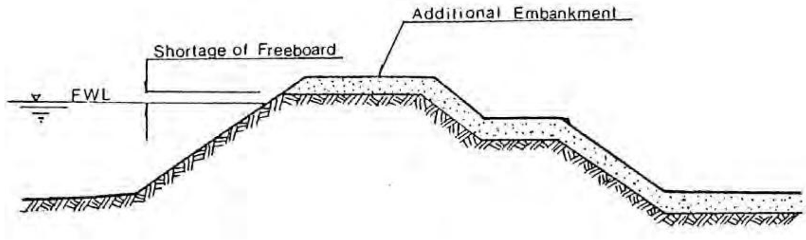
b) If sliding occurs at the front side of the embankment, to avoid a breach, the damaged position shall be provided with a tree stem including its branches. The tail end of the tree fixing on a bamboo pile driven in the embankment body, while the front end of the tree is equipped with a stone counterweight. The back side of the embankment should be strengthened with the widening of the embankment crest by the dumping of compacted soil.

c) Sliding at the front side of the embankment, may also be prevented by construction of the emergency embankment which consist of sandbags, and compacted clay soil, as same as the original height at the backside of thedamaged embankment.

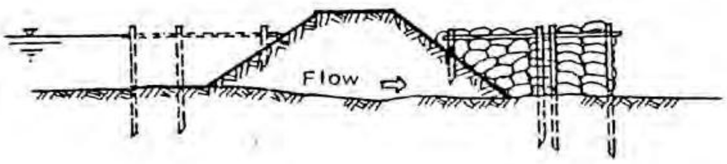


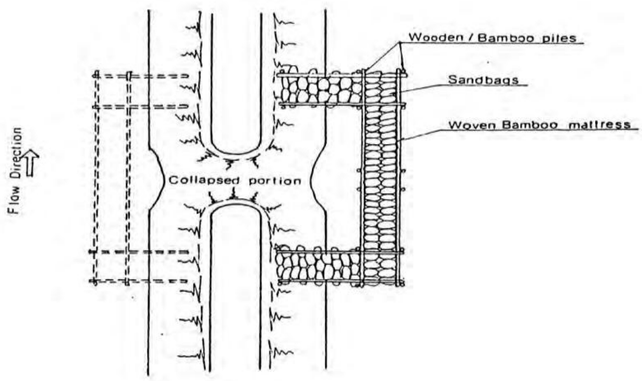


Settlement of Embankment: Place additional embankment(heightening) wherever settlement is noticed.



Breach of Embankment: An emergency embankment is constructed which consisting of staple of sandbags reinforced by driven piles.





4.4 PROTECTION OF BUILDINGS AGAINST INUNDATION EFFECTS

An intensity scale that records the impact on buildings takes into account the depth of inundation (e.g. short-term inundation below plinth level may have a limited impact), time period of inundation (as a period of saturation of materials like earth is critical in determining their wet compressive strength) and rate of inundation (to understand the impact of hydro-dynamic forces). An inundation intensity scale for damage to houses on a broad basis is proposed in Table 4.4

Table 4.4: Inundation Intensity Scale (I V) for Damage to Houses*****

Depth of Inundation	**Inundation Intensity Scale (I to V)**		
above plinth (mm)	**Period of Inundation in hours**		
	24	**> 24 to 72**	**> 72**
< 900	I	**I**	III
900 - 2000	**I**	III	IV
> 2000	III	IV	V

* *Intensity may be assumed to increase linearly between the hours of inundation or depth of inundation stated in the table.*

i. The depth and duration of inundation determine the intensity of the inundation hazard. The lower portions of the walls up to the inundation level plus capillary rise are susceptible to damage except where constructed as *pucca* using burnt bricks/stones with cement-sand- mortar of 1:6 mix – or richer.

ii. The safest way will be to find the critical height, and build this portion along with the foundationin *pucca* masonry (that is, using burned brick or stone built using cement – sand mortar).

iii. Use of *semi-pucca masonry* in the foundation and plinth and that of waterproof mud in the damp proof course, as well as plastering in the critical height of the wall on both faces, should save the house if the inundation was less than 24 hours.

iv. For safety from roof collapse, it will be preferable to use lightweight water proof sheeted roofin flood Inundation intensities of III and more (*see Table 2*).

v.Walls of buildings liable to flood inundation intensity of III and above should be of *pucca* construction to achieve maintenance-free long-term safety.

Specific Protection of Buildings Against Flowing Water

The nature of protection from flowing water would depend on the velocity and depth of flowing water. It can cause erosion of soil around the buildings, scour the foundations, and demolish or overturn the wall, obstructing the flow.

i. Minimum safety requires that all external walls, including foundations, should be of *pucca* construction with cement-sand mortar pointing or plastering.
ii. High plinth all round in pucca construction as the walls in (i) above will be an additional safety feature.
iii. Where flowing water depth is expected to be higher, the wall thickness may be made equal toone-third of the expected water depth.

Structural Changes in Buildings:

Damage susceptibility can be reduced by undertaking structural changes such as the construction of walls of buildings with impervious materials, closure of low-level windows, underpinning of buildings, construction of buildings on stilts, etc. Structural change is appropriate only where (i) the flooding is low, (ii) the duration of flood is short and where the velocity is low, (iii) when the traditional type of flood protection is not feasible, (iv) when individuals want to solve this problem by themselves or collective action is not possible and (v) when a higher degree of protection than that afforded by an existing or proposed flood control project is desired.

Radhanesda and Kundalia villages are located at high grounds above flood levels in the area and the villages are connected to nearby roads. Primary school premises in these villages can be utilized for the temporary evacuation of solar plant equipment

Flood Proofing of Buildings:

Floodproofing is essentially a combination of structural change and emergency action, though it does not involve evacuation. Certain measures that can be put into action as soon as a flood warning is received are; the installation of removable covers such as steel or aluminum bulk heads over doors or windows, permanent closure of low-level windows or other openings, waterproofing of interiors, keeping store counters on wheels, the closing of sewer well, anchoring machinery, covering machines with plastic sheets, seepage control, etc.