# A STUDY ON LAND AREA DRAINAGE IN COASTAL AREA

**A DISSERTATION**

**Submitted in partial fulfillment of the**

**requirements for the award of the degree of**

**MASTER OF TECHNOLOGY**

**in**

**WATER RESOURCES DEVELOPMENT AND MANAGEMENT (CIVIL)**

**By**


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**MAY, 2016**

# CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation entitled **"A STUDY ON LAND DRAINAGE IN COASTAL AREA"** in partial fulfillment of the requirement for the award of the degree of **Master of Technology** in **Water Resources Development (Civil)** in the Department of Water Resources Development and Management of Indian Institute of Technology Roorkee, is an authentic record of my own work carried out during the period from July 2015 to May 2016 under the supervision and guidance of Dr. U. C. Chaube, Emeritus Fellow and Dr. S. K. Mishra, Professor Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Dated:

Place: Roorkee (SIDDARAJ H. P)

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# CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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(SIDDARAJ H. P)

# ABSTRACT

The drainage systems in the coastal region is predominantly different as compared to urban drainage systems. The coastal region is vulnerable to natural disasters such as storm surges, sea level rise, tidal variations, tsunami and cyclones.

The characteristics of the coastal region which includes climate, rainfall, soil, vegetation and terrain/topography varies from place to place. The major factor considered while designing coastal drainage system for any industrial or urban area is topography, availability of natural slope, constraints in land use and land cover and mean sea level. If the elevation of terrain/topography of coastal region is above compare to mean sea level, the industrial or urban area has to be protected with efficient drainage system which can flow with gravity to dispose the run-off generated within the short duration to avoid flooding in that region. Meanwhile, it has to be checked for constraints in pipeline systems and rectify for efficient dispose the runoff generated.

The elevation of terrain/topography is below/ equal/ slightly above as compare to mean sea-level, the coastal area will be more vulnerable to external flooding caused by tidal variation, cyclones, rise in sea level, storm surges, tsunami etc., these natural disasters may finally result in inundating the low lying areas, loss of valuable properties, loss of lives and waterlogging and it may also lead to accumulation of silts in agricultural land. To protect the area from external flooding, the measures that can be considered are flood plain zoning, planned urbanization, increasing the elevation of roads, providing adequate drainage system, adjustment in life style, cropping pattern and flood warning / preparedness system.

In the present study, the above problems were considered with the help of two case studies at two different coastal regions located at Pudimadaka village, Visakhapatnam, Andra Pradesh and Mithakhari, Port Blair, Andaman and Nicobar Island coastal. For the analysis, modern techniques such as Arc-GIS model, Auto-CAD model and SWMM model were applied and the results showed that, the effect of the flood can be minimized efficiently by making use of these modern techniques. It was observed that, the coastal area is more vulnerable to external flooding caused due to natural disaster. This study helps the planner to monitor the coastal environment due to natural hazards and it may also provide platform for the planning of drainage system.

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# INTRODUCTION

## 1.1 BACKGROUND

Designers of coastal drainage systems have to take into consideration the unique characteristics of coastal flooding, particularly the impacts of tides, low elevations, and high groundwater tables. The rate at which gravity can drain an area depends in part on the difference in elevation between the area being drained and the place to which the water flows. The greater the difference in elevation, the greater the slope of the "hydraulic head" and the faster the water can drain. Coastal areas generally are low-lying and thus vulnerable to flooding. High tides can decrease the elevation difference and further slow gravity drainage. Moreover, storm surges in coastal areas frequently occur during rainstorms, and can completely stop natural drainage. High water tables in coastal areas also limit natural drainage. With water tables just below the land surface, a rainstorm can rapidly saturate the soil (raise the water table to the surface). The saturated soil increases runoff by decreasing the ability of water to percolate into the ground. Coastal flooding can also be exacerbated by problems frequently not considered in designing the drainage system. Storm waves may overtop a seawall; and sediment and debris may block inlets, outlets, and storm sewer pipes and canals. During the worst storm surges, coastal areas may be completely inundated by the sea, leaving the drainage system ineffective until water levels have receded (James, 1987). Increasing concentrations of carbon dioxide and other gases are expected to warm the earth several degrees in the next century, which would raise sea level a few feet and alter precipitation patterns. Both of these changes would have major impacts on the operation of coastal drainage systems. The design of a coastal drainage system depends on the amount of runoff expected during a major storm and the elevation of the area being drained. Although the amount of rainfall and the severity of the worst storm vary from year to year, it has been reasonable to assume that historical weather records provide a reliable guide to future precipitation and runoff over the design life of the project. Recent developments in climatology, however, suggest that design conditions that have been fixed in the past may change substantially in the future. Further summarized from previous studies estimating sea level rise and climate change resulting from the greenhouse effect and examines the impacts on coastal drainage systems and possible responses (James, 1987). Storm surges associated with severe tropical cyclones constitute the world's worst coastal marine hazard. Storm surge disasters cause heavy loss of life and property, damage to the coastal structures and the losses of agriculture, which lead to annual economic losses in affected countries. Death and destruction arise directly from the intense winds characteristics of tropical cyclones blowing over a large surface of water, which is bounded by a shallow basin. As a result of these winds the massive piling of the seawater occurs at the coast leading to the sudden inundation and flooding of coastal regions (Dube, 2008). The National Academy of Sciences (NAS) and atmospheric scientists from around the world have concluded that increasing concentrations of carbon dioxide, methane, and other gases will raise the earth's average temperature a few degrees (C) in the next century. Such a warming would alter precipitation patterns and raise sea level. The former impact would change the load on coastal drainage systems, while the latter would reduce their efficiency (James, 1987).

The main factors contributing to disastrous storm surges in east coast may be summarized as (Dube, 2009) (Dube et al. 2010).

(a) Shallow coastal water,

(b) Convergence of the bay,

(c) High astronomical tides,

(d) Thickly populated low-lying islands,

(e) Favorable cyclone track, and

(f) Innumerable number of inlets in delta such as in the world's largest river system (Ganga-Brahmaputra-Meghna).

Frequency of tropical cyclones in east coast is not so high even then coastal regions of India suffers most in terms of loss of life and property caused by the surges. The reason is inadequate accurate prediction, and the low lands all along coasts are considerably low-lying huge deltas, such as, Gangetic delta and Irrawaddy delta (Dube, 2008). TABLE 1.1 lists the number of deaths associated with several deadly cyclone disasters where death tolls were in excess of 5000 lives. These major surges usually occurred unexpectedly (Dube, 2008)

TABLE 1.1: List of number of deaths associated with cyclone disaster.

| Year | Countries | Death |
|---|---|---|
| 1970 | Bangladesh | 3,00,000 |
| 1737 | India | 3,00,000 |
| 1886 | China | 3,00,000 |
| 1923 | Japan | 2,50,000 |
| 1876 | Bangladesh | 2,00,000 |
| 1897 | Bangladesh | 1,75,000 |
| 1991 | Bangladesh | 1,40,000 |
| 1833 | India | 50,000 |
| 1864 | India | 50,000 |
| 1822 | Bangladesh | 40,000 |
| 1780 | Antilles (W. Indies) | 22,000 |
| 1965 | Bangladesh | 19,279 |
| 1999 | India | 15,000 |
| 1963 | Bangladesh | 11,520 |
| 1961 | Bangladesh | 11,466 |
| 1985 | Bangladesh | 11,069 |
| 1971 | India | 10,000 |
| 1977 | India | 10,000 |
| 1963 | Cuba | 7,196 |
| 1900 | USA | 6,000 |
| 1960 | Bangladesh | 5,149 |
| 1960 | Japan | 5,000 |
| 1973 | India | 5,000 |

(Source: Dube, 2008)

## 1.2 OBJECTIVE AND SCOPE OF STUDY

### Objective

- To plan internal drainage of an industrial area located in coastal area.
- To analyze external flooding of a coastal area and suggest protection measures.

**Scope of study**

- Design flood estimation in ungauged coastal catchments.
- Study of constraints on availability of natural slope.
- External flooding due to man-made changes in land use/land cover, drainage pattern.
- External Flooding due to combination of tides and cyclones.

### 1.3 APPLICATION OF SWMM MODEL, AUTOCAD MODEL AND ARCGIS MODEL IN ANALYSIS OF FLOODING AND DRAINAGE.

The SWMM model is widely used for analyzing the flood and helps for decision making. applications of SWMM is used for various application such as Green infrastructure model, 2D modelling Integrated modelling, Dynamic minor/major system analysis, Mitigation, Water quality, Drainage design, Sanitary system design, Detention storage, Real time control, Wet weather sanitary sewer analysis, Flood mapping/risk analysis. For the present study, SWMM model is used for the design of Internal drainage for industrial area located in coastal area.

AUTOCAD software is used for creating blue prints for buildings, computer chips, bridge, drainage system, etc., this software is initially used for designing the internal drainage of Pudimadaka thermal power plant. It is also, used to get the measurements of pipe length, area, Layout plan of the drainage system, it is also used to know the topography by the means of contour map. Contour map is very reliable for the analysis and for DEM study using Arc-GIS than readily available SRTM, CARTOSAT, and ASTER data. Hence, In the present study, the AutoCAD model is used as 2D tool for drawing the 2D drawings for making the analysis simple and easier.

The basic applications of Arc-GIS are analyzing mapped information, helps creating and using of maps, sharing and discovering geographic information, compiling geographic data also manages the geographic information in a database. In the present study, Arc-GIS is used to view the spatial data, create layered maps, and perform basic spatial analysis which includes manipulation of shapefiles, geodatabases, editing and analysis.

## 1.4 ORGANIZATION OF THE REPORT

Literature review on the topics such as flooding in coastal regions, models for storm prediction, data input for surge prediction models, remedial measures, etc. are discussed in chapter 2.

Analysis tools, methodology, and applications such as, SWMM model, AUTOCAD model and ARCGIS model are discussed in chapter 3.

The study area location, characteristics are described in chapter 4.

Chapter 5 describes problem analysis of Pudimadaka thermal power plant and remedial measures to drain out generated runoff in the plant using SWMM, ARCGIS, and AUTOCAD models.

Chapter 6 describes flood control in Mithakhari (Andaman Nicobar), effect of tsunami, tidal analysis, flood problem and options for the flood control.

Conclusions and future scope of the work are discussed in chapter 7.

# CHAPTER-2

# REVIEW OF LITERATURE

## 2.1 INTRODUCTION

The flooding in coastal areas occurs due to various aspects, such as cyclones, tides, tsunami. Flooding takes place from the combined effect of tides and surges from the sea that penetrate into the land. Catastrophe due to storm surge need be seriously considered by the scientific community. About 90% of the damage is due to inundation of land by sea water. The main factors contributing to disastrous surges in east coast are shallow coastal water, convergence of bay, high astronomical tides, thickly populated low lying Islands and favorable cyclone track. Almost all the lives and most of the damage is due to the storm surges, Thus, it is necessary that the problem of the storm surge be seriously addressed by countries of various regions through collective efforts and integrated manner (Dube, 2009). Designers of coastal drainage systems recognize the unique characteristics of coastal flooding, particularly the impacts of tides, low elevations, and high groundwater tables (James, 1987). Coastal areas generally are low-lying and thus vulnerable to flooding. High tides can decrease the elevation difference and further slow gravity drainage. Moreover, storm surges in coastal areas frequently occur during rainstorms, and can completely stop natural drainage. High water tables in coastal areas also limit natural drainage. With water tables just below the land surface, a rainstorm can rapidly saturate the soil (raise the water table to the surface). The saturated soil increases runoff by decreasing the ability of water to percolate into the ground. Coastal flooding can also be exacerbated by problems frequently not considered in designing the drainage system. Storm waves may overtop a seawall; and sediment and debris may block inlets, outlets, and storm sewer pipes and canals. During the worst storm surges, coastal areas may be completely inundated by the sea, leaving the drainage system ineffective until water levels have receded (James, 1987).

The purpose of this literature review is to understand recent developments in predicting the storm surges in Bay of Bengal and Arabian Sea. Dube et al., (1994, 1997, 2000, 2004, 2005, 2006), Chittibabu et al., (2004), Agnihotri et al., (2006), Jain et al., (2010), Sutapa et al., (2014), Mahendra et al., (2011), Saxena et al., (2012), Sindhu et al., (2012)., Paul et al., (2014), Mehra et al., (2015), have developed storm prediction models which have been successfully applied in the Bay of Bengal and the Arabian sea.

## 2.2 FLOODING DUE TO CYCLONES

A cyclone refers to the combination of very high speed wind, heavy rainfall, and/or high surge hitting coastal region. The occurrences of cyclones often cause huge loss to life and property particularly in coastal areas. The most devastating flood producing rains are generally associated with tropical cyclones. Besides, low-lying coastal areas suffer from most destructive floods. Floods created by tropical cyclones can reach catastrophic proportions when aggravated by wind induced surges along the coast line and can be felt a long distance inland due to back-up of rivers at high flow and subsequent flooding (Rao, 1997).

In general, all cyclones are dangerous. Some are more furious and cause havoc. To differentiate the destructive power of the cyclones based on the order of magnitude of the combined effect of wind velocity, surge height, rain amount, and other factors, National Oceanic and Atmospheric Administration (NOAA) classified the cyclone's-disaster-potential-scale into five categories widely known as the Saffir - Simpson hurricane scale, as show in TABLE 2.1.

TABLE 2.1: The Saffir - Simpson cyclone scale chart (NOAA, 1994)

| Classification | Wind Speed (Kmph) | Pressure (mb) | Storm Surge (m) | Damage |
|---|---|---|---|---|
| Tropical Depression | < 61 | | | |
| Tropical Storm | 62 to 118 | | 0.3 to 1.0 | |
| Category – ONE Cyclone | 119 to 153 | >980 | 1.1 to 1.7 | Minimal |
| Category – TWO Cyclone | 154 to 177 | 979-965 | 1.8 to 2.6 | Moderate |
| Category –THREE Cyclone | 178 to 209 | 964-945 | 2.7 to 3.8 | Extensive |
| Category – FOUR Cyclone | 210 to 249 | 944-920 | 3.9 to 5.5 | Extreme |
| Category – FIVE Cyclone | > 249 | <920 | >5.5 | Catastrophic |

### 2.2.1 History of Cyclones

The coastal region of Andhra Pradesh is extremely vulnerable to cyclones, storm surges, and floods. The State risks are battered by cyclones of moderate to severe intensities every two to three years. Cyclones on the east coast originate in the Bay of Bengal, Andaman Sea or the

South China Sea, and usually reach the coastline of Andhra Pradesh, Odisha, Tamil Nadu, and West Bengal. The cyclones develop in the pre-monsoon (April to May) and post-monsoon seasons (October to December), but most of them tend to form in the month of November. History indicates that most of the tropical cyclones have occurred in late October, and November had been very severe. Since 1975, the State has faced more than 60 cyclones. Some of them were moderate, and a few of them very severe. Table 2 provides a brief description of very severe cyclones hitting Andhra coast. As seen, during the last 40 years, there was not a single year in which the State did not experience either a severe storm or a cyclone or heavy rain and flood. According to the State Disaster Management Department, about 44 per cent of the State is vulnerable to tropical storms and related disasters.

Vulnerability to storm surges is not uniform along the coast of Andhra. The stretch between Nizampatnam in Guntur district and Machilipatnam in Krishna district is most affected by storm surges. East and West Godavari districts, with vast stretches of paddy fields and irrigation, drainage canals always bear the brunt of cyclones accompanied by strong winds and pounding rains. In the aftermath of cyclones, these areas get flooded, leading to huge crop losses besides other damage.

The deadliest cyclone in the past 40 years (1975-2014) was the one that struck Andhra's coast in November 1977, killing about 10,000 people. About 2, 50,000 cattle heads perished, one million houses were damaged, and crops on 1.35 million hectares (ha) were destroyed.

Also, the pre-monsoon cyclone is not rare in the State. A severe cyclonic storm hit the Andhra coast in May 1990, in which the death toll was 817 and the State’s revenue loss was assessed at Rs.2, 137 cr. In the cyclone of May 1979, more than 700 people lost lives. In 2010, seven people were killed in the coastal districts of Andhra when Cyclone Laila arrived. It made a landfall near Baptala in Guntur district on May 20 before monsoon. Harvested paddy in Krishna, Guntur and West and East Godavari districts was damaged badly, leaving farmers distraught. Historically, the occurrence of more than one cyclone in a season is not unusual in Andhra Pradesh. In 1996, the State experienced a severe cyclonic storm in November, which left 1,077 people dead. The state had suffered a loss of Rs.6, 129.25 cr. Again in December 1996, one more severe cyclone hit the State with the death toll of 27.

TABLE 2.2: LIST OF SEVERE TROPICAL CYCLONES OCCURRED IN THE COAST OF ANDHRA PRADESH

| Sl. no. | Date and Name of cyclone | Category & Technical description | Description of Devastation & Impacts |
|---|---|---|---|
| 1 | 28th Oct. - 1st Nov. 1977 | Severe cyclonic storm | The most devastating in the past 40 years. Eight coastal districts affected. About 10,000 people killed. About 250,000 cattle heads perished; 1 million houses damaged and crops on 1.35 million hectares were damaged. Estimated loss: Rs. 172 cr. |
| | 15-16th Nov. 1977 | Severe Cyclonic storm with core of hurricane winds | |
| 2 | 15-13th May 1979 | Cyclonic storm with core of hurricane winds | Heavy rains and floods. As many as 748,000 lakh houses damaged. Estimated loss: Rs. 242 cr. |
| 3 | 15-16th Oct. 1987 | Cyclonic Storm | There were three cyclonic storms. First one in October, which was a severe storm but with no casualty. The second one, on 2-3 November was very severe. 10 districts affected. 119 people died; more than 100,000 houses and 960,000 ha of crops damaged; estimated loss: Rs.126.48 cr. |
| | 2nd - 3rd Nov. 1987 | Severe Cyclonic Storm | |
| 6 | July 1989 | Severe Cyclone storm | Cyclone followed by heavy rains and floods. 22 districts affected. Death toll: 232; crops on about 600,000 ha lost; estimated loss: Rs.913.5 cr. It was followed by a cyclonic storm with no casualty. |
| 7 | 5-10 May 1990 | Severe cyclonic storm with core of hurricane winds. | 14 districts affected. Death toll: 817; houses damaged: 1.4 million; crop loss: more than 500,000 ha; loss Rs. 2,137.27 cr. It was followed by heavy rainfall in August in which 50 people died and the loss was assessed at Rs.179 cr. |
| 8 | November 1996 | Severe cyclonic storm with core | Four districts affected. Death toll: 1,077; houses damaged: 600,000; crop loss: 500,000 ha; loss Rs. |

| | | | |
|---|---|---|---|
| | | of hurricane winds. | 6,129.25 cr. One more severe cyclone in December claimed 27 lives. |
| 9 | 17-21st May 2010 | Severe Cyclone 'named as Laila". Wind speed 100-120 Km/hr. | 14 districts affected. Death toll: 22; houses damaged: 14,298; crop loss: 260,000 ha; loss Rs.1, 603 cr. Cyclone Laila battered Ongole town in Andhra Pradesh; it received heavy rain of 320 mm on May 20 and 142 mm on May 21, and has made rivulets like Gundlakamma, Addavagu and swollen. Addanki received the highest rainfall of 522 mm, followed by Maddipadu with 510 mm and Kothapatnam 258 mm in 24 hours on May 21. The cyclone caused heavy destruction in Prakasam, Krishna and Guntur districts and preliminary reports prepared by the State government put the loss at over Rs.500 cr. |
| 10 | 28 Oct. to 1 November 2012 | Severe cyclone 'Nilam' Wind speed up to 100 Km /hr. | Death toll: 30; crop loss: over 700,000 ha; loss: Rs.1, 710 cr. Andhra Pradesh government conducted their review on the storm, it was revealed that the state suffered huge economic losses of □200 cr. |
| 11 | 19-28th November 2013 | Very Severe Cyclonic Storm equivalent to a category 1 hurricane. Named as 'Lehar' Wind speed up to 140 Km /hr. | Lehar was the second most intense tropical cyclone of the 2013 season, as well as one of the two relatively strong cyclones that affected Southern India in November 2013, the other being Cyclone Helen. |
| | 19-23 Nov. 2013 | Very severe cyclone Named as 'Helen' Wind speed 100-130 Km/hr. | Helen brought extensive damage to Machilipatnam in Krishna district, with uprooted trees and electric lines. The districts of Krishna, East Godavari and Srikakulam, and Guntur suffered heavy rainfall. Heavy damage to harvest crops was also reported, with the West Godavari district being worst |

| | | | |
|---|---|---|---|
| | | | affected. Paddy, coconut and banana crops have suffered damage. The total loss incurred by Krishna and West and East Godavari districts in the state of Andhra Pradesh due to the cyclone Helen was estimated to be Rs.1,628.73 cr. |
| 12 | 7-14 October 2014 | Very Severe Cyclonic storm Equivalent to category-4. Named as Hudhud<br><br>Wind speed 185-215 Km/hr. | Cyclone Hudhud pounded the coastal districts of Andhra Pradesh and Odisha with heavy rain and winds of almost 200 kmph killing four people and left a trail of destruction with Vishakhapatnam where the very severe storm made landfall the worst hit. According to Andhra Pradesh’s Revenue (Disaster Management) Department a total of 2, 48,004 people were "affected" by Hudhud, which also damaged 70 houses and left 34 animals dead. Hudhud caused extensive damage to the city of Visakhapatnam and the neighboring districts of Vizianagaram and Srikakulam of Andhra Pradesh. Damages were estimated to be □21908 cr. by the Andhra state government. At least 124 deaths could be confirmed, and a majority of them were from Andhra Pradesh |

## 2.3 TSUNAMI

Tsunami (Soo-NAH-mee) is a Japanese word meaning harbor wave. A tsunami is a series of waves with a long wavelength and period (time between crests). Time between crests of waves can vary from a few minutes to over an hour. Tsunamis are often incorrectly called tidal waves; they have no relation to the daily ocean tides. Tsunamis can occur at any time of day or night.

### 2.3.1 Cause of Tsunami

Tsunamis are generated by any large, impulsive displacement of the sea bed. Earthquakes generate tsunamis by vertical movement of the sea floor. However, if the sea floor movement is horizontal, a tsunami is not generated. Generally, earthquakes of $M > 6.5$ cause Tsunami.

Tsunamis are also triggered by landslides into or under the water surface, and can be generated by volcanic activity and meteorite impacts.

### 2.3.2 Speed of Tsunami

Tsunami velocity is dependent on the depth of water through which it travels. The velocity is governed by the following equation

$V = g\ h$

Where,

- V is the velocity of Tsunami in m/sec.
- g is the gravitational force in $m/sec^2$
- h is the depth of water in m.

Tsunamis travel approximately at a velocity of 700 kmph in 4000 m depth of sea water, but in 10 m of water depth the velocity drops to about 36 kmph. For example, the tsunami from Sumatra coastal earthquake travelled to Tamil Nadu coast in about two hours. Even on shore, Tsunami's speed could be 35 – 40 km/h, much faster than a person can run.

### 2.3.3 Size of Tsunami

Tsunamis range in size from centimeters to over 30 m height. Most tsunamis are less than 3 m in height. A large tsunami can flood land up to 1.5 km from the coast. In deep water (greater than 200 m), tsunamis are rarely over 1m high and will not be noticed by ships due to their long period (time between crests). As tsunamis propagate into shallow water, the wave height can increase by over 10 times. Tsunami heights can vary greatly along a coast. The waves are amplified by certain shoreline and bathymetric (sea floor) features. The force of some tsunamis is enormous. Large rocks weighing several tones along with boats and other debris can be moved hundreds of feet inland by tsunami wave activity. Homes and other buildings are destroyed. All this material and water move with great force and can kill or injure people.

### 2.3.4 Frequency of Occurrence

On the average, there are two tsunamis per year in the Pacific Ocean which cause damage. Approximately every 15 years a destructive tsunami occurs in Pacific

The details of Tsunami in India are given below (National Disaster Management Division, Ministry of Home Affairs, Government of India, and January, 2006)

TABLE 2.3: Details of tsunami (Source: Disaster prevention and management, volume 15, 2006).

| | |
|---|---|
| April 12, 1762 | Earth Quake in the Bay of Bengal generated tsunami wave of 1.8 m in coastal Bangladesh |
| August 19, 1868 | Earthquake Magnitude 7.5 in the Bay of Bengal. Tsunami wave run-up level at Port Blair, Andaman Island 4.0 m. |
| December 31, 1881 | Earthquake of magnitude Ms 7.9 in the Bay of Bengal, reported tsunami run-up level of .76m at Car Nicobar, 0.3m at Dublat, 0.3 m at Nagapattinam and 1.22 m at Port Blair in Andaman Island |
| 1883 | Karakatau, volcanic explosion in Indonesia. 1.5m tsunami at Chennai, 0.6m at Nagapattinam |
| 1884 | Earthquake in the western part of the Bay of Bengal. Tsunamis at Port Blair & mouth of Hoogly River |
| 26-Jun-1941 | Earthquake of magnitude MW 8.1 in the Andaman Sea at 12.90 N,92.5o E. Tsunamis on the east coast of India with Amplitudes from 0.75 to 1.25 m. Some damage from East Coast was reported. |
| 27-Nov-1945 | Mekran Earthquake (Magnitude Ms. 8.3). 12 to 15 M wave height in Ormara, 13 m at Pasni, and 1.37 m at Karachi (Pakistan). In Gulf off Cambay of Gujarat wave heights of 11.0 m was estimated, and 2 m at Mumbai, where boats were taken away from their moorings |
| 26-Dec-2004 | An earthquake of rear Magnitude (MW 9.3) generated giant tsunami waves in North Indian Ocean. Tsunami made extensive damage to many coastal areas of Indonesia, India, Malaysia, Maldives, Sri Lanka and Thailand. A trans-oceanic tsunami, observed over areas beyond the Ocean limit of origin. More than 2,00,000 people lost their lives in above countries which is a record. |

## 2.4 TIDES

Tides are generated in the Bay of Bengal by the forces of attraction of mainly the sun and the moon upon the rotating earth. The effect of tide is manifested in a regular alteration of rise and fall of the water level of the sea and the estuarine channels and creeks. With the advent of rising tide, the water level of sea starts rising gradually and steadily till a highest level known as the “High Water Level” (H.W.L) is attained. This rising phase of the tide is called the “Flood tide” or the “Flow tide”. After the attainment of H.W.L the tide water level starts falling gradually and steadily till a Lowest Water Level (L.W.L) is reached. This falling phase of the tide is called “Fbb tide”. There upon the tide water starts rising once again till the occurrence of the next L.W.L is termed the “Period of Tidal Circle” which is on average is 12 hours 24 minutes. The tidal cycles are represented graphically by tidal curve.

With the advent of flow tide, the velocity of current which is in the inland direction starts increasing, reaches a maximum at about the middle of the flow tide and begins to decrease there after being zero at the H.W.L which is known as “High water slack”. The reupon, the ebb tide commences and the current velocity which is in the seaward direction starts increasing once again and after attaining a maximum value begins to diminish gradually becoming zero at L.W.L which is known as the “low Water Slack”. Two tides called “Semi-diurnal tides are also found to differ from each other. Another interesting feature of tides lies in the fact that the tidal range at any location fluctuates steadily and gradually from day to day in accordance with the lunar phase. The tidal range at the full and new moon is found to be the maximum. This phase is called the “Spring Tide”. After the occurrence of the Neap Tide at the middle of moon cycle when the tidal range is the minimum.

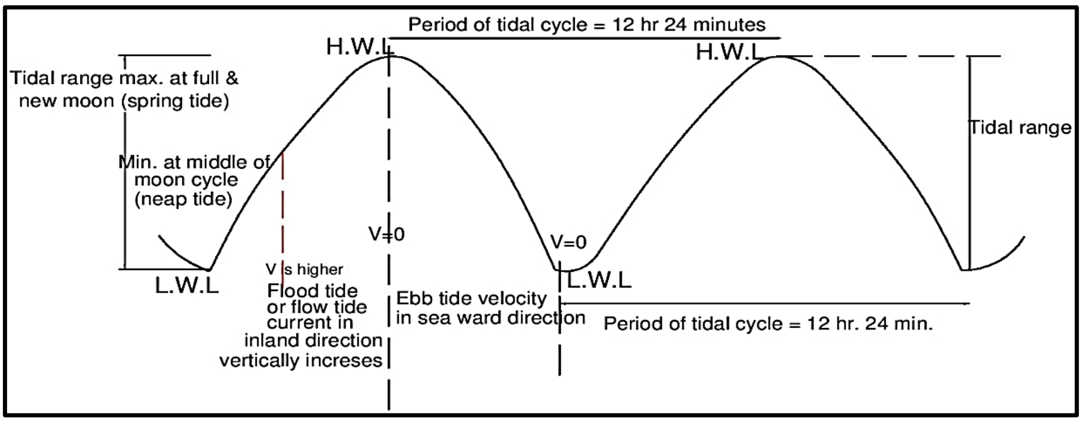



Figure 2.1: Graphically represented tidal cycles by tidal curve

## 2.5 MODELS TO PREDICT STORM SURGES IN COASTAL REGIONS

Chittibabu et al., (2004) addressed Mitigation of flooding and cyclone hazard in Orissa, India (Coastal districts of Orissa Gangam, Puri, Jagatsinpur, and kendrapara) considering two cyclone database has been used one from cyclone database from IMD (1877-2000) and second cyclone in Orissa (1804-1875) provided by British east India company, surge data from IMD, & Maximum sustained wind speed. IIT-D numerical surge model was used to compute storm surges along the Orissa coast. The model is a semi explicit finite difference model with the following characteristics, vertically integrated shallow water coastal zone numerical model, curvilinear representation of coastal boundaries, variable grid representation, Validation type boundary condition, & uses a dynamic storm model to simulate storm winds. The model was applied to estimate surge in coastal region of Orissa and found that the lowest value of surge was 3.0m and highest was 8.0m, and from the study it is suggested to construct a dykes and embankment at the areas of land that exists between major tributaries in the coastal area. The study concluded that no evidence of increase of storm surge amplitudes due to global warming.

Agnihotri et al. (2006) addressed A Bay-River coupled model for storm surge prediction along Andra coast of India (East coast of India) considering bathymetry data for the three cyclones events that struck east coast i.e. November 1977, may 1990 and November 1996 developed a two dimensional bay-river coupled numerical model for storm surges in east of India considering the effects of Krishna and Godavari river along with tropical cyclone, A rectangular cross section and uniform width was developed and coupled with two-dimensional surge model in order to notice the effect of Krishna and Godavari rivers on the surge storm. Simulation showed that the discharge of fresh water carried by the river may modify the surge height in the bay significantly. The surge height was also computed with and without the inclusion of rivers, the maximum predicted surge values computed from two models were about 4.8m, and maximum sea surface elevation computed from two models were same expect where river Krishna and Godavari joins. the bay and conclude that the model may be used for operational prediction of storm surges.

Shahapure et al. (2010) advocated Coastal Urban Flood Simulation Using FEM, GIS and Remote Sensing in coastal urban watershed in Navy Mumbai, in Maharashtra state, in this model parameters considered for simulating the overland flow are bed slope and manning's roughness coefficient, and it was estimated using the DEM and satellite imaginary of the area depending upon land use land cover map. The developed rainfall runoff model also considered the effects of tidal variations using Finite Element Method. Galerkin's FEM was used for the approximation for the governing equations. Overland flow was modeled using the mass balance equation considering the impervious character of the urban watershed. Storm water flow through the channel was modeled using the diffusion wave form using Saint Venant's equations and considering the tidal variations. In this model 5 rainfall events were simulated & different tidal boundary conditions are developed for each event based on the tide table and the basic tidal equation, these tidal models are incorporated in coupled model as a boundary condition. Analysis concluded coupled model could predict the flooding satisfactorily. Further, Sensitivity analysis of the model was also, carried out altering some parameters, namely Manning's roughness coefficient for overland flow and channel flow, the grid element size and time step, observed results showed the values of computed peak discharge are more sensitive to manning's roughness coefficient for overland and channel flow. And finally, concluded developed model is quite useful for the flood simulation for coastal urban watersheds.

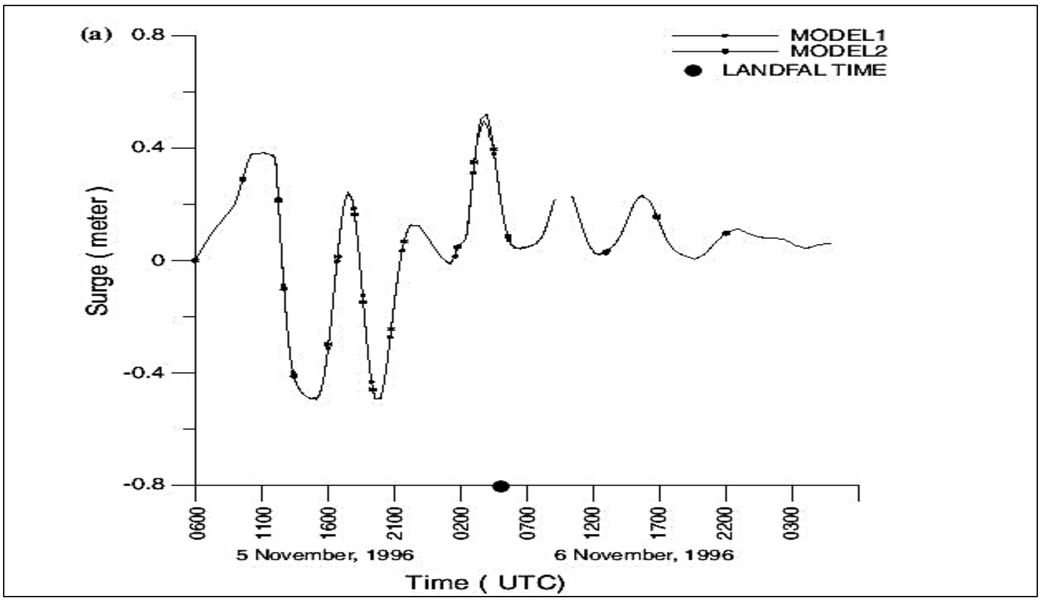



Fig 2.2: Temporal variation of surge height for Kakinada cyclone in Krishna river

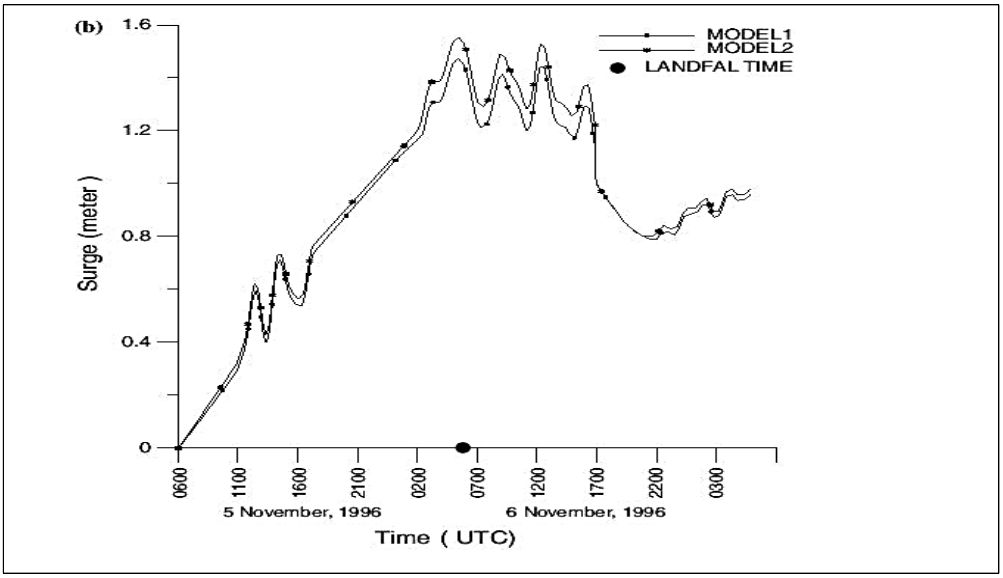
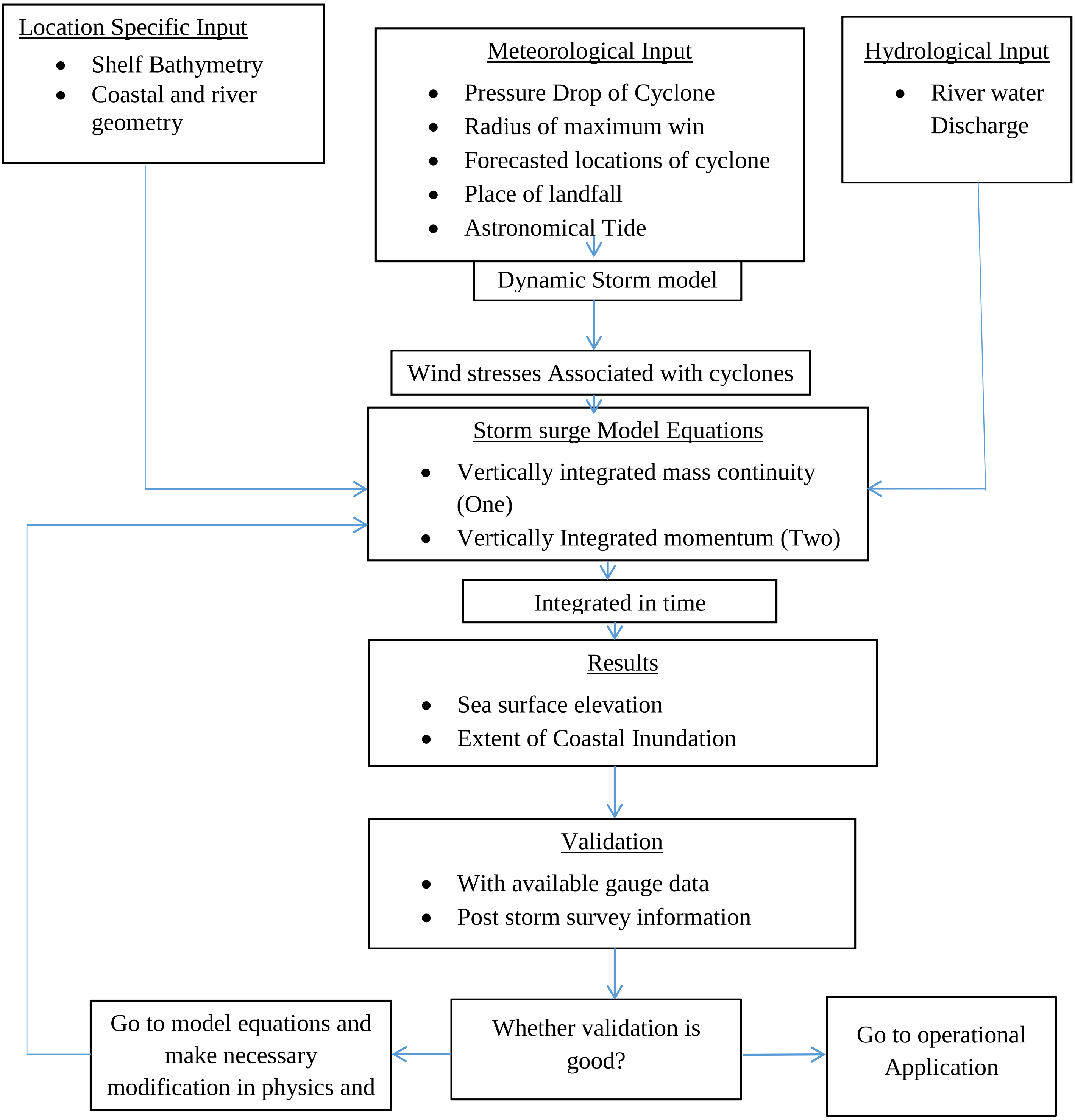



Fig 2.3: Temporal variation of surge height for Kakinada cyclone in Godavari river

Jain et al. (2010) studied the Computation of Expected Total Levels along the East Coast of India (Western sector of Bay of Bengal) considering 117 years' data for the major Historical storm surge (1891-2007), cyclonic tracks, and tide gauge data. The IITD (Indian institute of Technology, Delhi) storm surge model was used to compute the maximum probable surge amplitudes with the help of developed numerical models. A maximum probable surge at coast was simulated and TWL (Total water level) was computed by linearly adding the local tide and wave setup for the simulated surge along the coast. The model represented a balance between pressure gradient, centrifugal, Coriolis, and surface frictional forces for a stationary storm. The feasibility study was then carried out using the parameters of the cyclone based on a 50 yr. return period applied to synthesized tracks as an input to the numerical surge model, which may provide extreme water levels that could occur along the coast, and analysis showed that the lowest and highest values of the surge are about 4.3m and 10m, and finally the analysis from the model concluded that it may help coastal authorities to develop a long term and short term disaster management and vulnerability reduction action with respect to cyclones.

## IIT DELHI STORM SURGE MODEL



Mahendra et al. (2011) have discussed Assessment and Management of coastal multi-hazard vulnerability along the Cuddalore Villupuram, east coast of India using geospatial techniques in Tamilnadu state covering the districts of Cuddalore, Villupuram, and Pondicherry considering parameters of sea level rate change, shoreline change rate, elevation contours and historical storm surge. Sea level rate change was found by plotting linear best fit line using least squares method by using recorded monthly mean values of tide gauge data. ArcGIS and ERDAS model were used to calculate shoreline change and to obtain elevation contours, and storm surges were calculated using Probability of non-exceedance by assigning the rank series by Gringorten method. MHVM of the study area was prepared by overlaying the multi – hazard areas on the base maps. Sea level change indicated a value of 0.085mm/y. The shoreline projected for the next 100 years for the open coast indicated that an area of 3.77 $km^2$ is going to be eroded. Study showed total area of 360 $km^2$ has been delineated hazard zone with 314 $km^2$ under Cuddalore, Villupuram and Pondicherry respectively, and finally Concluded that MHVM can help in planning for aftermath of an event, rehabilitation, civil disturbances, restoration of the utilities, health problems etc.,

Saxena et al., (2012) have discussed Coastal hazard mapping Cuddalore region, south India (Cuddalore, State of Tamilnadu, south India) using data source for Analysis of shoreline change, LANDSAT-1, LANDSAT-TM, IRS, LISS III, EO-I, CARTOSAT-II, and past 20 years' gauge data from Chennai port. Hazard mapping involves identification of shoreline vulnerable to impact of storm surge; arise in sea level and erosion. The model proposed in this study are erosion mapping by (LRR, DSAS model), coastal flood hazard mapping by (statistical distribution or Gumbel's distribution), land use/land cover (ERDAS model, LISS III, ArcGIS model) and socio economic impacts. The result showed that volume of annual net sediment transport is estimated to be 0.40x106 $m^3$. Extreme flood level calculated using Gumbel's distribution (for 100yr return period) 2.98 m MSL, and annual MSL Chennai was 0.041 m, and maximum limit of inundation towards landward was found to be 2050 m .The study concluded that the coastal stretches of Cuddalore district are in the high risk zones for multi hazard, and the results from the study would assist local state govt. in the preparing for the impacts of erosion, inundation risk & future sea level rise along the Indian ocean.

Sindhu et al., (2012) studied Return period estimates of extreme sea level along east coast of India from numerical simulations (East coast of India) considering Visakhapatnam Chennai storm surge events associated with meteorological events, cyclonic tracks occurred during 1989-2000 ETOPO-5 data sets, Radius of maximum wind, core pressure, and position of core of cyclone (Holland model) 2D vertically integrated model was used to simulate storm surge due to 136 low-pressure that occurred during past 27 years (1974-2000) in the bay of Bengal, model includes Atmospheric forcing and storm surge and Holland model. In this present study model is selected in such a way that it is taken care of both tidal force and storm surge simultaneously to calculate the total sea level and further it is subtracted from tidal elevation in order to obtain storm surge. The 5-50nyear return period levels of total sea level along the east coast of India showed considerable increase from south to north. High Return period surges were 0.84m & 0.57m respectively. The model simulation showed considerably good result as compared with the observed surge levels due to cyclone events (Details provided at table 3), from the it is analyzed that 5-50 year return period of surge component considerably high at shallow & wide self-regions such as gudur, karaali, surya lanka, Machilipatnam. The study illustrates that storm surge simulation results can be used to derive return estimates of extreme events at location where long-period observations of sea level don’t exist. The estimated return levels can be used as preliminary estimates for the design of marine structures for the coastal areas.

TABLE 2.4: Cyclone event in east coast

| Cyclone event | Observed surge | simulated surge | mean error model-observed | RMS error |
|---|---|---|---|---|
| Para dip | | | | |
| Aug-81 | 0.12 | 0.08 | -0.0001 | 0.08 |
| Jun-82 | 0.17 | 0.07 | 0.0001 | 0.15 |
| Aug-84 | 0.15 | 0.06 | 0.0001 | 0.12 |
| Visakhapatnam | | | | |
| Nov-76 | 0.04 | 0.04 | 0.02 | 0.06 |
| Aug-86 | 0.15 | 0.05 | 0.02 | 0.12 |
| Chennai | | | | |
| Nov-78 | 0.06 | 0.07 | 0.04 | 0.05 |

Matt Lewis et al., (2013) have discussed a storm surge inundation model of the northern Bay of Bengal using publicly available data developed computationally inexpensive inundation model from freely available data sources for the northern Bay of Bengal region to estimate flood risk from storm surges. Shuttle Radar Topography Mission (SRTM) terrain data has been used in a dynamic coastal inundation model. A sub-grid routine allowed estuary channels with widths less than this resolution to be simulated efficiently, and allowed six major river flows to be represented. The inundation model was forced with an IIT-D model hind cast of the 2007 cyclone Sidr flood event, using parameters from two cyclone databases (IBTrACs and UNISYS). Validation showed inundation prediction accuracy with a root mean squared error (RMSE) on predicted water level of ∼ 2 m, which was of the same order of magnitude as the forcing water-level uncertainties. Concluded that SRTM and other publicly available data can be useful for coastal flood risk management in data-poor regions. SRTM processing techniques may also improve inundation model performance.

Sutapa et al.(2014) addressed Predictability of landfall location and surge height of tropical cyclones over North Indian Ocean (NIO) In this study models were developed to predict storm surge heights and to know exact landfall location of tropical cyclones over NIO basin, for this Artificial neural network (ANN) model with multilayer perceptron (MLP) is developed to forecast exact location of landfall (lat. and long.) and neuro fuzzy coupled (NFC) is developed for precise forecast of surge heights. The result revealed that the prediction error with NFC model in forecasting the surge height is 2.448% with 6-h lead time, whereas the error is observed to increase with increase in lead time, for forecasting the surge height with 18-h lead time, the accuracy is observed to be 11.4%. The study concluded that the lat. & long. Position of landfall can be predicted with acceptable accuracy with ANN model. Further, the study revealed that neuro-fuzzy coupled model is found to be suitable model for forecasting the surge height over NIO with more than 88%accuracy when the lead time is 18-h.

Paul et al., (2014) have reviewed and discussed Implementation of method of lines to predict water levels due to storm along the coastal region of Bangladesh considering April 1991 cyclone as base data to validate the simulated result in comparison with observation, and the track of storm & other meteorological data was collected from BMD. The model was developed based on MOL (method of line), in addition to the classical fourth order Runge-Kutta method, to solve vertically shallow equations for the prediction of water levels due to a storm along the coast of Bangladesh. The developed model was applied to estimate water levels along the coast of Bangladesh due to interaction of tide & surge associated with the storm. Table 2.5 shows computed water levels with respect to MSL associated with 1991 storm along the coast of Bangladesh. The study concluded that the MOL could provide an effective algorithm for solving shallow water equation in comparison with a standard finite difference solution.

TABLE 2.5: The computed water levels with respect to MSL associated with 1991 storm along the coast of Bangladesh

| Coastal location | Simulated max. surge level in this study (m) | Simulated overall peak water level by this study (m) |
|---|---|---|
| Hiron point | 3.92 | 4.01 |
| Tiger point | 4.21 | 4.57 |
| Kuakata | 3.52 | 3.86 |
| Rangabali | 4.1 | 4.5 |
| Char madras | 5.5 | 5.81 |
| Char Jabbar | 6.19 | 6.35 |
| Char chenga | 5.11 | 5.81 |
| Companiganj | 6.7 | 7.28 |
| Sandwip | 5.24 | 5.63 |
| Sitakunda | 4.83 | 5.78 |
| Chittagang | 5.17 | 6.26 |

Mehra et al., (2015) have given overview on Coastal sea response to the tropical cyclone forcing in the Northen Indian Ocean in areas such as Rathnagiri, Verem, karwar, Tuticorin, mandapam, Gopalpur, gangavaram, Kakinada, and port Blair, considering Cyclonic parameters during E1& E2, Wind speed, Sea level pressure, and Storm forward translation speed Multi-linear regression Analysis model is used to examine the characteristics of the sea level oscillation at different topographic locations in AS & BOB due to metrological events.

i.e., $\eta = B0+B1\tau u+B2\tau v+B3Ap+\varepsilon$,

$\tau u = PA*CD*U\sqrt{u^2+v^2}$

Where,

$\eta$=sea level rise residual,

B0, B1, B2, &B3 = co-efficient of regression,

$\varepsilon$=Difference b/w measured SLR & estimated SLR.

PA=density of air,

CD= drag co-efficient

The present study indicated that surge peak lagged up to Verem, at Ratnagiri & Karachi surge peak leads the E1 with constant amplitude. (Ref.table.2.6)

TABLE 2.6: Peak and Propagation speed of the areas near North Indian Ocean

| Location | Peak (cm) | Propagation speed $ms^{-1}$ |
|---|---|---|
| Columbo | 31.6 | 7.9 |
| Mandapam | 24.3 | 1.8 |
| Turticorin | 21.4 | 13.1 |
| kochi(Peak1) | 12.9 | |
| kochi(Peak2) | 14.14 | |
| Karwar | 36.9 | 7.6 |
| Verem | 35.5 | 5 |

The study concluded that multi-linear regression using local daily mean winds (cross and along shore) in association with the atmospheric pressure is able to account for up to 69% of daily mean sea level residual (SLR) at Ratnagiri, Verem and Karwar during E1. However, in BOB up to 57% of daily mean SLR is accounted for at Gopalpur, Gangavaram and Kakinada.

## 2.6 DATA INPUT FOR STORM PREDICTION MODELS (Dube, 2008).

To obtain confidence in surge prediction the good knowledge regarding input parameters for the model plays a vital role. These parameters include oceanographic parameters, hydrological inputs, basin characteristics, coastal geometry, astronomical tides, and meteorological parameters (Dube, 2008). It is evident that these input parameters strongly influence surge development. The brief details of this parameters are discussed below**.**

1. Meteorological data

The main characteristics required are i) The pressure drop (difference between ambient pressure surrounding the storm and the central pressure), maximum sustained winds and radius of maximum wind these parameters are estimated by satellite imageries (Dube, 2008). ii) Point of rainfall, duration of the storm, and vector motion of storm are obtained from IMD (Indian meteorological department).

2. Oceanographic data

Data on oceanographic are concerned with the following i) bathymetry ii) astronomical tides and iii) inshore currents in closed regions (Dube, 2008).

3. Basic characteristics and coastal geometry

The location of the highest surge depends upon the coastal geometry of the basin.

4. Hydrological input

The main hydrological information needed is a) river discharge in the sea and b) rainfall distribution (Dube, 2008).

## 2.7 REMEDIAL MEASURES (Dube, 1997)

Risk Assessment:

Evaluation of risks of tropical cyclones should be undertaken and illustrated in a hazard map indicating analysis of climatological records to determine how often cyclones have struck and their intensity. Map should incorporate information of past history of winds speeds, frequencies of flooding, possible height & location of storm surges etc. A master plan for flood plain management should be developed to protect critical assets from flash, riverine, and coastal flooding.

Land Use Control:

It refers to controlling land use so that the least critical facilities of the proposed plant are placed in most vulnerable areas. Policies regarding future development may regulate land use and enforce building codes for areas vulnerable to the effects of tropical cyclones. For example, in coastal areas, regulation can stipulate maximum building heights, types of land and staff residences. Another option includes the development of vulnerable areas for use of parks, sports facilities and open tree planting/ grazing land.

Reducing Vulnerability of Structures and Infrastructures

- New buildings should be designed as wind and water resistant. Design standards are usually contained in building codes;
- Communication and utility lines should be located away from coastal area or installed underground;
- Improvement of building sites by raising the ground level to protect against flood and storm surges;

- Protective river embankments, levees and coastal dikes should be regularly inspected for breaches due to erosion and opportunities taken to plant mangroves to reduce breaking wave energy;
- Improved vegetation covers to reduce soil erosion and landslides and facilitate the absorption of rainfall to reduce flooding.
- Disaster preparedness
- Educating the community in the risk hazard areas.
- Practical training how to reduce damage in the event of disaster.
- Promoting ingenious way for coping with the consequences.

# CHAPTER-3

# ANALYSIS TOOLS

## 3.1 INTRODUCTION

The Analysis tools used in the present study follow the standard sequence of drainage, landforms, cover and the integration of their results for geological and hydrogeological assessment. In this study, ARCGIS model and SWMM model are used i) to simulate and understand the topography, land use and land cover ii) to obtain economic design to drain generated storm water in plant location of study area, and iii) to level undulated topography by identifying areas requiring cutting and filling.

## 3.2 ARC-GIS MODEL (DEM STUDY)

### 3.2.1 Geo-referencing of topography map

The actual survey contour maps prepared in AutoCAD format was converted to raster files (tiff format). In order to Geo-reference these data the projections used in this project is WGS – 1984 zone 44N by listing the four corners coordinates (x and y, in meters) in the map. The coordinates are also used to create a GIS layer representing the topographic maps index of the topographic coverage. This layer was created with the GIS software, with a command that generates regular grids, represented by lines and polygons, according to a specified distance on the x and y axes. The distance was given by the difference between the coordinates of map corners. The topographic maps index GIS layer has been then converted in shape file format in order to be integrated in ArcView with the other layers of the database.

The geo-referencing procedure was carried out using Ground Control Point (GCP) method. For each map file, the four corner co-ordinates have been entered as GCPs and a first order polynomial transformation was used to re-calculate the coordinates of each pixel in the raster layer. The Root Mean Square error (RMS) resulted less than the pixel value. Carrying the correct UTM -WGS 44 coordinates. An evaluation of the quality of geo-referencing was carried out by loading in Arc map both the topographic maps and geo-referenced maps are checked for mismatching. Slight differences found can be auto adjusted.

### 3.2.2 Generation of DEM

Digital elevation model (DEM) is the digital representation (digital map) of the ground elevation data in meters. ARC-GIS software is used for preparation of the DEM. Given file format of the contour map (DWG) of study area has been converted into shape file (SHP) which is the working format in GIS environment. Each contour was assigned its value. The contours in shape file are interpolated to obtain digital elevations of the equally sized gridded cells. Variation in elevation is depicted through different colors. The DEM can be used to identify areas requiring cutting and filling and to estimate the volume of earthwork required to level the undulating topography of the study area.

### 3.2.3 Generation of Stream Network and Basin Delineation

The derived digital elevation model has been used for further processing in the context of stream generation and basin delineation. DEM has been smoothened out for eliminating uneven irregularities (such as pits) using filter size. Corrected DEM has been used as input data to generate pattern of flow directions and for identification of flow accumulation through each pixel of given elevation. Generated information on flow pattern and flow accumulation considers Eight-Point Pour model for the purpose of computing flow directions for use in basin delineation with DEMs 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 defined as the number of earlier DEM points whose flow paths eventually pass through that point. Streams are identified by large values of flow accumulation since the flow paths of many points pass through the stream points. Outlet of a watershed has the highest value of flow accumulation 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.

### 3.2.4 Distribution of Land Area in Different Elevation Ranges

The Digital Elevation Model has been used to compute the natural drainage area (within plant boundaries) between different elevation ranges. The DEM computes number of pixels in each interval. The graphical depiction of the cumulative area distribution shows different elevation in the plant area. This information will be derived from DEM study can be used to arrive at cost effective levels at which different plant components should be finally located.

## 3.3 DESIGN STORM SCENARIOS OF VARIOUS RETURN PERIODS

Design storm scenarios are required for

(i) estimation of design flood and planning of internal drainage in the plant area and

(ii) for assessing possible submergence in the plant area from external flooding.

The areal distribution and time distribution of the rainfall of a given duration are two main meteorological factors deciding the flood peak and the shape of the flood hydrograph. This input has to be converted into excess rainfall and convoluted with synthetic unit hydrograph to obtain a flood hydrograph after addition of base flow.

### 3.3.1 Estimation of Storm Rainfall of 25 Year, 50 Year and 100 Year Return Periods

The following procedure has been adopted for estimation of critical distribution of storm rainfall to cause the maximum flood due to rainfall of a specified duration:

1. The duration of the storm rainfall which causes the maximum discharge in a drainage basin is called the design storm duration ($T_D$). Central Water Commission (CWC 1994) has recommended that $T_D$ may be estimated as:

   $t_p(\text{hrs.}) = 1.1808\ (LLc/\sqrt{S})^{0.285}$

$t_p$ is basin lag (hours), L is longest length of main river from farthest point on watershed boundary to outlet and S is equivalent stream slope. Lc is length of Main River from a point near the centroid of catchment to the outlet of catchment.

2. Locate catchment area under study on the T-yr., 24-hour isopluvial map and obtain the T-yr, 24-hour point rainfall value in cm. For catchment covering more than one isohyets, compute the average point storm rainfall.
3. Use the conversion ratio for $T_D$ hours and multiply the T-yr 24 –hr rainfall in step-2 by the ratio to obtain T year $T_D$-hr point rainfall.
4. Convert the T-yr $T_D$-hr point rainfall to T-yr $T_D$-hr areal rainfall by multiplying with the area reduction factor (ARF) corresponding to catchment area and for $T_D$-hr duration.
5. Apply the time distribution coefficients corresponding to design storm duration $T_D$ to obtain the cumulative rainfall depths at 1-hr interval since the unit duration of synthetic U.G. is 1-hour.

6. Obtain the 1-hourly rainfall increments from subtraction of successive 1-hour cumulative value of rainfall in step-5

Apply appropriate design loss rate to obtain effective rainfall in each hour.

### 3.3.2 Extrapolation of Storm Rainfall for Other Return Periods

A plot of 24 hr storm rainfall of 25 yr, 50 yr and 100 year return periods (isopluvial map) on extreme value probability paper has been used for extrapolation of 24-hour storm rainfall of various return periods.

## 3.4 STORM WATER MANAGEMENT MODEL

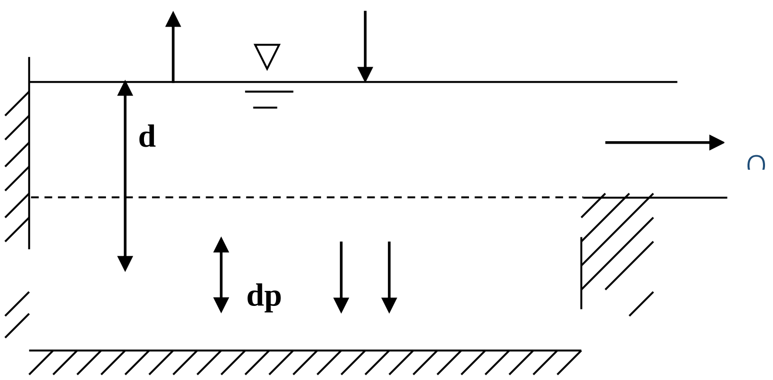
### 3.4.1 Plant Area Drainage Planning

The Storm Water Management Model (SWMM) is a dynamic rainfall – runoff simulation model which has been used in the present study for design of drainage system. The runoff component of SWMM operates on a collection of sub-catchment areas that receive rainfall and generate runoff. The kinematics wave flow routing portion of SWMM transports this runoff through a system of open channels to specified outfall locations. SWMM tracks the quantity of runoff generated within each sub-catchment and the flow rate and flow depth in each channel during a simulation period comprised of multiple time steps (source: SWMM manual 5.1). In the present study SWMM 5 software running on Windows has been used for the analysis.

### 3.4.2 Overview of Computational Methods

SWMM is a physically based discrete – time simulation model. The conceptual view of surface runoff used by SWMM is shown below [31].

EVAPORATION RAINFALL




INFILTRATION

Each sub-catchment surface is treated as non-linear reservoir. Inflow comes from rainfall and any designed upstream catchments. There are several outflows, including infiltration, evaporation and surface runoff. The capacity of this reservoir is the maximum depression storage, which is the maximum surface storage provided by ponding, surface welling and interception. Surface runoff per unit area Q occurs only when the depth of water in the reservoir exceeds the maximum depression storage $d_p$ in which case the outflow is given by Manning's equation. Depth of water over the sub-catchment (d) is continuously updated with time (t in seconds) by solving numerically a water balance equation over the sub-catchment.

**Infiltration:** Green-Ampt method has been used in this study for modeling infiltration. This method assumes that sharp wetting front exist in the soil column, separating soil with some initial moisture content below from saturated soil above. The input parameters required are the moisture deficit of the soil, the soil's hydraulic conductivity and the suction head at the wetting front.

**Flow routing:** flow routing within a conduit link in SWMM is governed by the conservation of mass and momentum equations for gradually varied, unsteady flow (i.e. Saint Venant's flow equation). Kinematic wave routing method has been used for flow routing in channels. This routing method solves the continuity equation along with a simplified from of the momentum equation in each channel. The latter requires that the slope of the water surface equal the slope of the channel.

The maximum flow that can be conveyed through conduit is the full flow Manning equation value. Any flow in excess of this entering the inlet node is either lost from the system or can pond atop the inlet node and be introduced into the conduit as capacity becomes available.

**Surface ponding:** normally in flow routing when the flow into junction exceeds the capacity of the system to transport it further downstream, the excess volume overflows the system and is lost. An option exists to have instead the excess volume be stored atop the junction in a ponded fashion and be reintroduced into the system as capacity permits. Under kinematic flow routing the ponded water is stored simply as an excess volume. Alternately the ponded water may have separate surface overflow system.

## 3.5 AUTOCAD MODEL

The AUTOCAD software was developed and marketed by Autodesk, which is a multinational software corporation and it was released in December 1982. AUTOCAD software is an application program used for 2D and 3D computer aided design (CAD) and technical drawing. CAD is used to create precision drawings by drafters, artists, engineers, architects.

AUTOCAD software is used for designing mechanical components, analyzing piping systems and solving design issues. AUTOCAD can be used in MS windows, Mac OS X, and iOS Android. This software is initially used for designing the internal drainage of Pudimadaka thermal power plant. It is used to get the measurements of pipe length, area. The AUTOCAD drawing of the pudimadaka thermal power plant is shown in the Fig 3.1 and it is further divided into two parts as shown in Fig 3.2 & 3.3. The commands used for drawing are in the Table 3.1

Table 3.1: AUTOCAD commands.

| **COMMANDS** | **DESCRIPTION** |
|---|---|
| ARC | Creates an arc. |
| BLOCK | Creates a block definition from selected object. |
| BREAK | Breaks the selected object between two points. |
| CLOSE | Closes the current drawing. |
| CLOSEALL | Closes all currently open drawings. |
| CIRCLE | Create a circle. |
| COPY | Create a copy of an object. |
| DIST | Measures the distance and angle between two points. |
| DIVIDE | Creates evenly spaced point objects. |
| ERASE | Delete an object. |
| EXTEND | Extends the object to meet the edges of other objects. |
| EXPLODE | Breaks an object into component object. |
| EXTERNALREFERENCE | Opens the External References pallet. |
| FILLET | Rounds and fillets the edges of the objects. |
| HATCH | Fills an enclosed area. |
| LAYER | Manages layers and layer properties. |
| LINE | Creates straight line segments. |
| LIST | Displays property data for selected objects |
| MATCH PROP | Applies the properties of selected objects to other objects. |

| | |
|---|---|
| MIRROR | Create a mirror copy of other object. |
| MODEL | Switches from layout tab to model tab. |
| MSPACE | In a layout, switches from paper space to model space in viewport. |
| MTEXT | Creates a multiline text object. |
| OPTIONS | Customizes the program settings. |
| ORTHO | Constraints cursor movement to horizontal or vertical direction |
| OSNAP | Sets running object snap model |
| PROPERTIES | Controls properties of existing objects. |
| PRINT | Prints the 2D drawing. |
| PAN | Moves view planner to the screen |
| PLINE | Creates a 2D polyline. |
| POLYLINE EDIT | Edits the polyline. |
| PURGE | Removes unused items |
| REGEN | Regenerates the entire drawing from the current viewport. |
| RECTANG | Creates the rectangular polyline |
| ROTATE | Rotates the selected object. |
| SCALE | Enlarges or reduces selected object. |
| SELECT | Places selected objects in the previous selection set. |
| TEXT | Creates a single- line text objects. |
| STRETCH | Stretches objects crossed by a selection window. |
| TRIM | Trim object to meet the edges of other objects. |
| TEXTSCR | Opens the text window. |
| UNITS | Controls coordinates and angle display format and precision. |
| ZOOM | Increases or decreases the magnification of the view in the viewport. |

Figure 3.1: Plan of Pudimadaka Thermal Power Plant

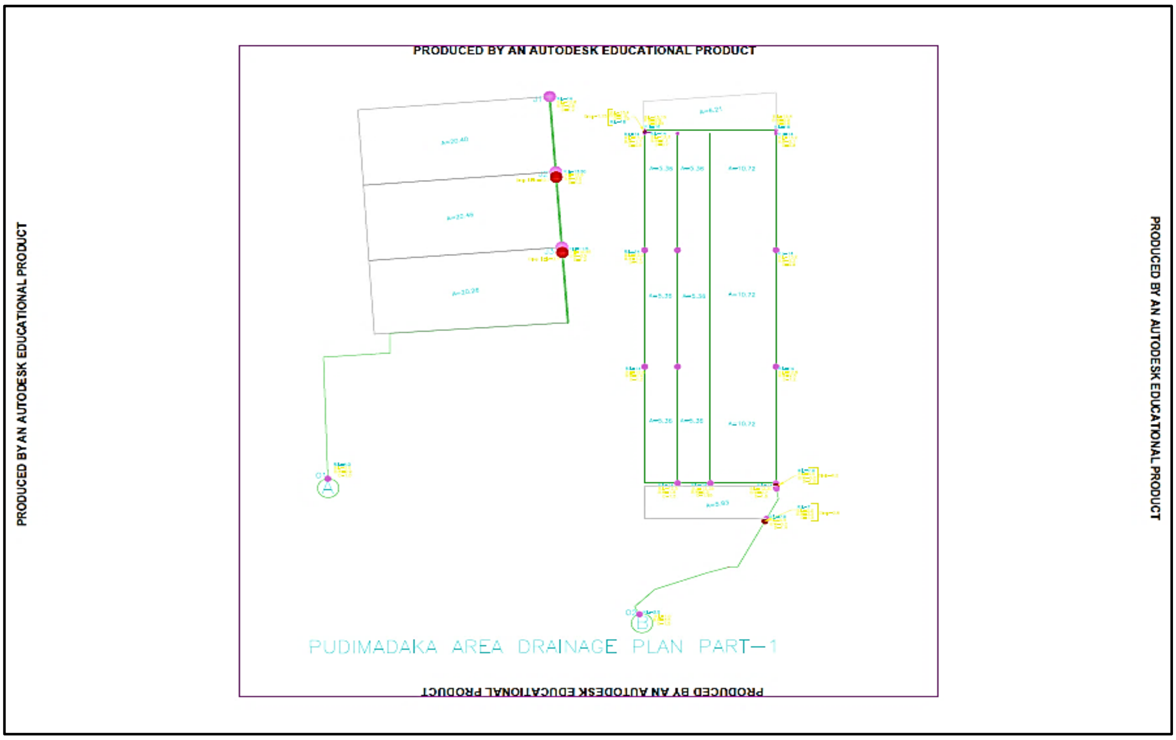



Figure 3.2: Plan showing Pudimadaka Thermal Power Plant Part 1

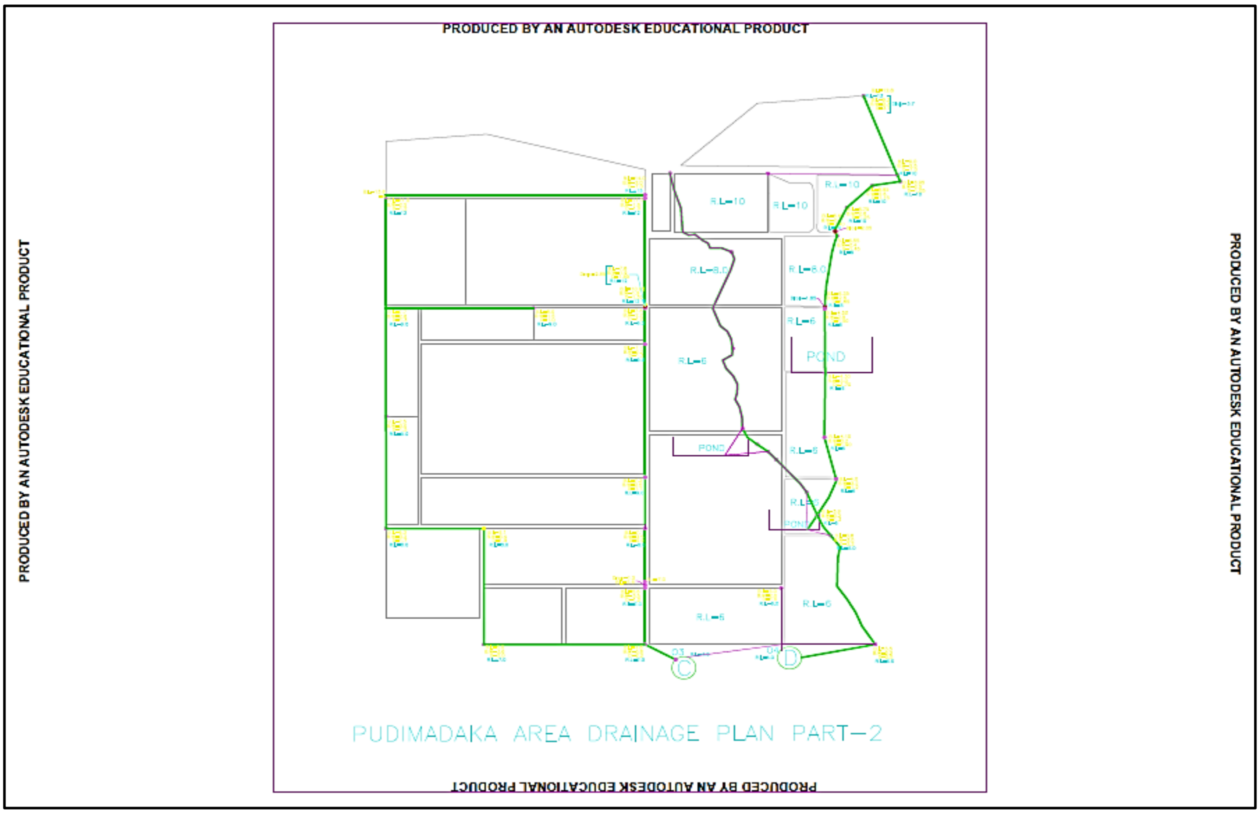



Figure 3.3: Plan showing Pudimadaka Thermal Power Plant Part 2

# CHAPTER - 4

# STUDY AREA

## 4.1 CHARACTERISTICS OF STUDY AREA-I

### 4.1.1 Location

The site is located at Andra Pradesh state, Vishakhapatnam district, near Pudimadaka village, Achutapuram & Rambilli Mandals and is approximately 40 km from district headquarters Visakhapatnam. The site is well connected through Pudimadaka road to NH-16 at a distance of 12.2 km and by SH-97 at a distance of 3.5 km. Gangavaram port is about 35 km NE of the site and Vizag port is at a distance of 47 km from the site. Figure 4.1 shows the Index map of Pudimadaka Power Plant.

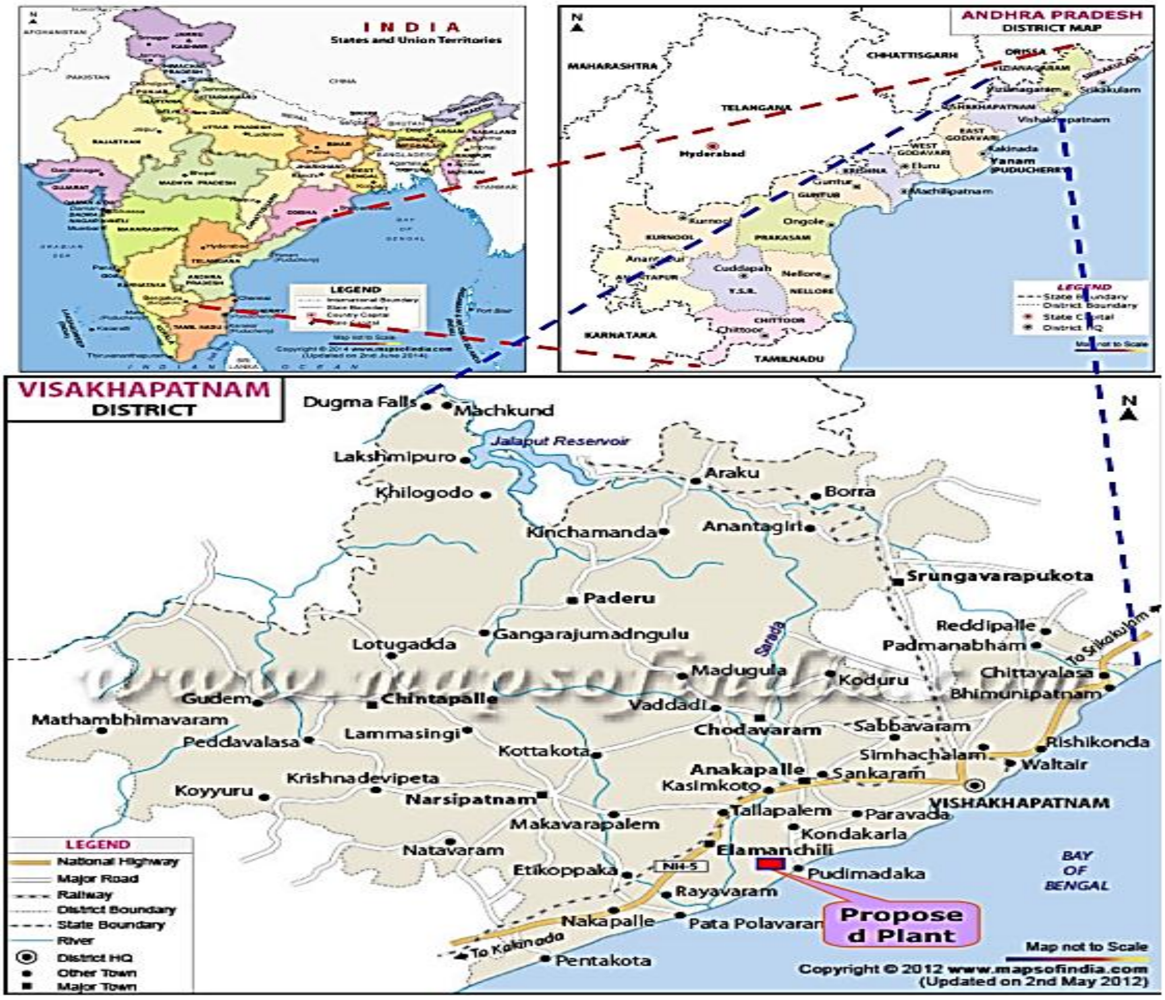



Figure 4.1: Index Map of Pudimadaka Power Plant

### 4.1.2 Topography

The study area is predominantly plain with few hillocks observed adjacent to the project site. Maximum difference in levels would be about 36 – 40m.

### 4.1.3 Rainfall & Climate

Climatologically the district experiences tropical sub-humid type of climate with moderate summer and good seasonal rainfall. The southwest monsoon sets in the second week of June and lasts till September end. October and November receive rainfall from northeast monsoon. Winter season with cool and fine weather prevails from December to February followed by summer season up to early June. The average annual rainfall of the district is 1116 mm. and monthly rainfall ranges from nil rainfall in January to 207.5 mm in October. October is the wettest month of the year. The mean seasonal rainfall distribution is 673.5 mm. in southwest monsoon (June September), 271.8 mm. in northeast monsoon (October-December), 10.9 mm. rainfall in winter (Jan-Feb) and 159.6 mm in summer (March–May). The percentage distribution of rainfall, season-wise, is 60.36% in southwest monsoon, 24.36 % in northeast monsoon, 0.97 percentage in winter and 14.3 % in summer.

### 4.1.4 Soils

The different soils in the district are red loams, sandy loams, sandy soils and black cotton soils. Red loamy soils are predominating and occupy about 70% in the district. Sandy loamy soils are largely confined to the coastal areas and to certain stretches in the interior mandals of Chodavaram, Narsipatnam, K. Kotapadu and Madugula. Black cotton soils occur in parts of K. Kotapadu, Devarapalli, Chedikada, Paderu and Hukumpeta mandals.

### 4.1.5 Drainage

The most important rivers drained in the district are Machikund, Tandava, Varaha, Sarada and Gostani. Most of the rivers are ephemeral in nature. However, some of the tributaries of Machikund are perennial with indications of substantial ground water discharge. Almost all the rivers and streams experience flash floods during rainy season. A good number of springs exist in Paderu and Araku areas. The district is characterized by sub-dendritic to dendritic nature of drainage pattern and is of coarse texture. In general, the density is in the range of 0.6 to 1/Km2. Many of the hill streams in Paderu valley disappear on entering the plains due to high permeability of the pediment gravels. The disappearance of streams in and along the hill slopes is contributing to the ground water, which is again discharged through the silty soils at lower elevations.

### 4.1.6 Land cover and land use

The plant area lies mostly in the agricultural fields with coconut and cashew plantation area. The area is selected excluding the existing villages Kothakudur, Vasattipalem, Laxmipuram and Nalapalem. There are some scattered huts in the agricultural fields inside the plant area. The village Pudimadaka is about 300m from the proposed plant area. Overall the area is plain with gentle slope the total level difference in the site is about 30m. There is no water logging area in the plant site. There are some salt beds on the south of the plant area. Small village ponds are seen inside the plant area and adjacent to the plants area as well.

### 4.1.7 Data Used for The Study of Study Area -I:

- Daily rainfall records for Vishakhapatnam for 2000 to 2011 and daily rainfall data for Kakinada for 1996 to 2014 were obtained from National Institute of Hydrology, Roorkee.
- Natural drainage within plant area and vicinity based on reconnaissance survey of the area.
- Plant layout map and contour map for the plant area and the nearby area based on recent topographic survey.

## 4.2 CHARACTERISTICS OF STUDY AREA-II

### 4.2.1 Location

The second study area is located in Andaman and Nicobar islands. There are 572 islands in the territory having an area of 8,249 km$^2$ (3,185 sq. mi). Of these, only 38 are permanently inhabited. The islands extend from 6 ° to 14 ° North latitudes and from 92 ° to 94 ° East longitudes. The Andaman's are separated from the Nicobar group by a channel (The Ten Degree Channel) some 150 km (93 mi) wide. The highest point is located in North Andaman Island (Saddle Peak at 732 m (2,402 ft.)). The Andaman group has 325 islands which cover an area of 6,408 km$^2$ (2,474 sq. mi) while the Nicobar group has only 24 islands with an area of 1,841 km$^2$ (711 sq. mi).

The capital of the union territory, Port Blair, is located 1,255 km (780 mi) from Kolkata, 1,200 km (750 mi) from Visakhapatnam and 1,190 km (740 mi) from Chennai. The northernmost point of the Andaman and Nicobars group is 901 km (560 mi) away from the mouth of the Hooghly River and 190 km (120 mi) from Burma. Indira Point at 6° 45' 10''N and 93° 49' 36''E at the southern tip of the southernmost island, Great Nicobar, is the southernmost point of India and lies only 150 km (93 mi) from Sumatra in Indonesia.

The proposed site is located near Mithakhari village, and is approximately 30km from Port Blair. The Index map is shown in Figure 4.2(a). Figure 4.2(b) is the site vicinity map.

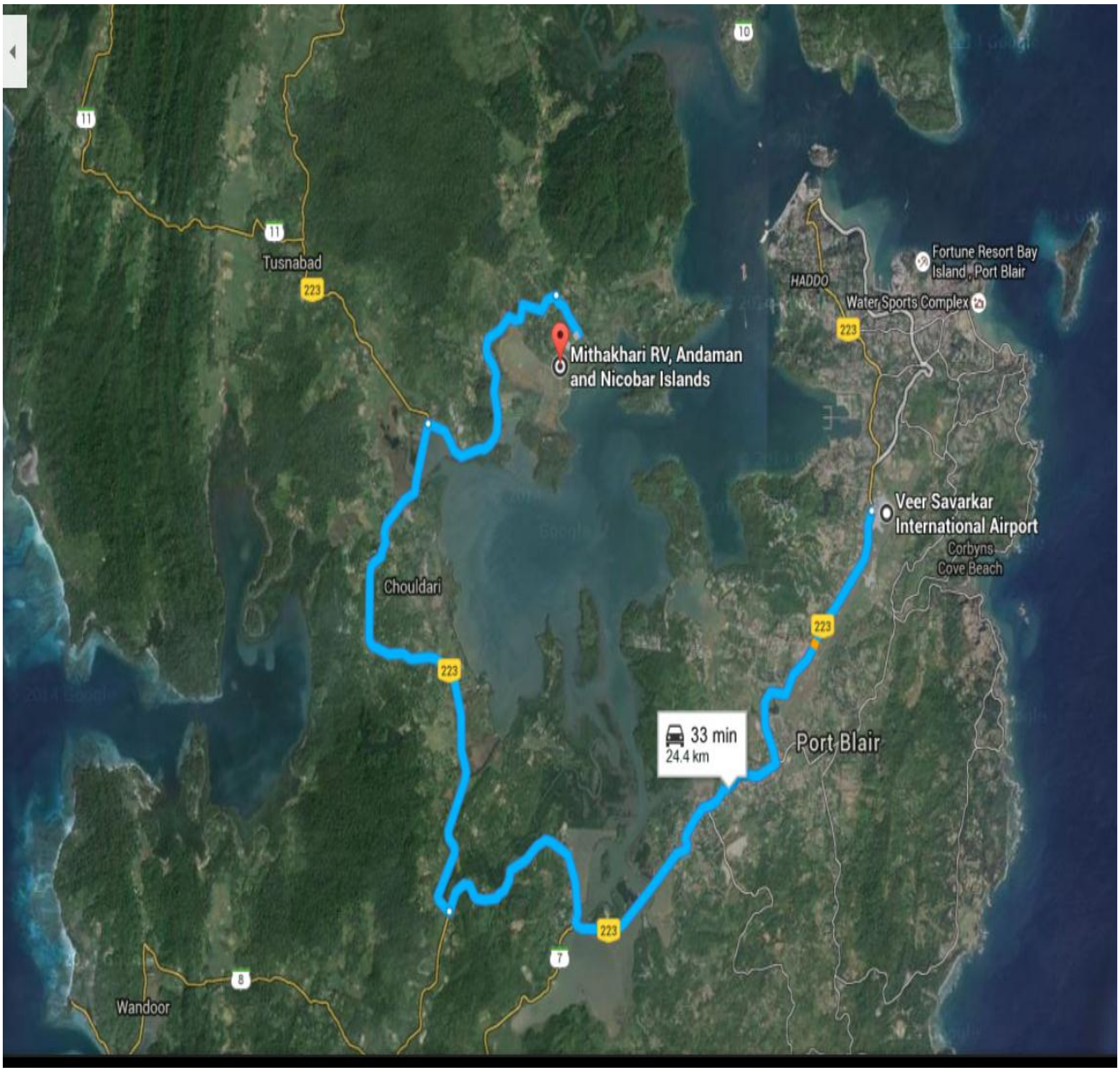



Figure 4.2(a) Index map of Mithakhari solar plant site


Figure 4.2(b) Mithakhari solar plant site vicinity map

### 4.2.2 Soil and Vegetation

Andaman and Nicobar Islands soil and vegetation are favorable for tropical evergreen forest and semi-evergreen forests; in some regions, the soil and vegetation of Andaman and Nicobar Islands also supports tropical monsoon.

Andaman and Nicobar Islands experiences a tropical climate, without any extremes except for the rains and thunder storms. Rainfall is common in the Islands, and is generally divided into two phases: May to mid-September and November to mid-December. Thus, the climate of Andaman and Nicobar Islands is highly favorable for the evergreen forest.

The soil and vegetation at Andaman and Nicobar Islands supports the growth of epiphytic vegetation (plants that grow on other plants). In fact, the vegetation of Andaman and Nicobar Islands mostly comprise of ferns and orchids.

The vegetation of Middle Andaman mostly includes moist deciduous forests. The monsoon rains largely supports the deciduous type of vegetation in the Andaman and Nicobar Islands. Further, the vegetation of North Andaman is characterized by wood climbers: the type of vegetation found here is moist evergreen type. Another aspect of vegetation in Andaman and Nicobar Islands is that throughout the length and breadth of the islands, the coastline is dotted with coconut trees. The entire fringe of the island is outlined with coconut trees.

### 4.2.3 Climate

Like most islands in the Bay of Bengal, Andaman and Nicobar too have a tropical climate with humidity about 80% and temperatures varying from 23 ° C to 31 ° C. The North East Monsoon sets in November whereas the South West Monsoon towards the end of May. Weather remains more or less uniform throughout the year with neither extreme hot summers nor chilly winters.

### 4.2.4 Rainy days and monthly rainfall at port Blair

Fifteen years (from 2000 to 2014) daily rain fall data at Port Blair has been analyzed. Study of rainy days and seasonal rainfall is also relevant as efficiency of solar plant in electricity generation depends on sunshine duration in a period. Months having more amounts of rainfall and more number of rainy days are less effective as far as electricity generation is concerned.

1. Rainy days

Table 4.3 shows number of rainy days in different months. A day is considered to be rainy day if rainfall on that day is more than 6 mm. On an average there are 100 rainy days in a year. May to October is the rainy season sometimes extending in the month of November also. February is the driest month with only one rainy day on an average.

2. Monthly rainfall

Table 4.4 shows monthly rainfall in year’s 2000 to 2014.Average annual rainfall is 3114 mm. 2796 mm rainfall (89.8%) is received during May to November. September is the rainiest month with an average rainfall of 500 mm followed by May month with average rainfall of 491 mm. February is the driest month with average rainfall of 23 mm.

Table 4.3 Number of Rainy Days (Considering Rainfall More Than 6 mm) at Port Blair

| Yr. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 2 | 3 | 4 | 6 | 15 | 14 | 11 | 17 | 12 | 10 | 5 | 3 | 102 |
| 2001 | 4 | 0 | 5 | 1 | 23 | 11 | 12 | 14 | 12 | 10 | 6 | 4 | 102 |
| 2002 | 0 | 0 | 0 | 3 | 12 | 9 | 14 | 9 | 14 | 4 | 9 | 4 | 78 |
| 2003 | 1 | 0 | 4 | 1 | 11 | 9 | 22 | 15 | 14 | 9 | 3 | 4 | 93 |
| 2004 | 1 | 3 | 0 | 1 | 17 | 18 | 11 | 13 | 12 | 15 | 5 | 0 | 96 |
| 2005 | 0 | 0 | 0 | 3 | 8 | 15 | 17 | 15 | 15 | 10 | 12 | 8 | 103 |
| 2006 | 1 | 0 | 0 | 7 | 14 | 18 | 8 | 14 | 23 | 11 | 4 | 1 | 101 |
| 2007 | 0 | 0 | 0 | 3 | 15 | 14 | 10 | 15 | 16 | 11 | 9 | 1 | 94 |
| 2008 | 1 | 3 | 4 | 9 | 16 | 14 | 18 | 14 | 12 | 9 | 11 | 0 | 111 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2009 | 0 | 0 | 1 | 7 | 11 | 16 | 9 | 10 | 12 | 10 | 6 | 2 | 84 |
| 2010 | 2 | 0 | 0 | 0 | 10 | 14 | 18 | 16 | 13 | 18 | 11 | 11 | 113 |
| 2011 | 6 | 3 | 11 | 2 | 11 | 12 | 19 | 17 | 20 | 11 | 3 | 4 | 119 |
| 2012 | 1 | 1 | 0 | 4 | 16 | 9 | 12 | 13 | 19 | 11 | 11 | 5 | 102 |
| 2013 | 2 | 0 | 0 | 2 | 14 | 19 | 18 | 14 | 22 | 7 | 12 | 3 | 113 |
| 2014 | 0 | 0 | 0 | 0 | 11 | 13 | 17 | 10 | 13 | 14 | 7 | 0 | 85 |
| Avg. | 1.4 | 0.867 | 1.933 | 3.267 | 13.6 | 13.667 | 14.4 | 13.73 | 15.27 | 10.67 | 7.6 | 3.333 | 99.73 |

Table 4.4 Monthly Rainfall (mm) at Port Blair

| Yr. | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2000 | 32.5 | 85.5 | 200 | 210.6 | 468.3 | 383.6 | 230.9 | 572.5 | 258.3 | 300.7 | 141.1 | 79.6 | 2963.6 |
| 2001 | 122.3 | 5.1 | 121.5 | 16.4 | 942.5 | 228.6 | 305.1 | 454.2 | 431.6 | 290.4 | 117.7 | 79.2 | 3114.6 |
| 2002 | 0 | 0 | 0 | 84.4 | 386.1 | 354.6 | 441.1 | 294.2 | 421.8 | 78.3 | 313.5 | 122 | 2496 |
| 2003 | 21.4 | 0.1 | 127.3 | 13.3 | 316.2 | 225.2 | 535 | 352.6 | 420.2 | 290.1 | 56.8 | 69.9 | 2428.1 |
| 2004 | 104.2 | 25.9 | 1 | 33.7 | 662.8 | 601.3 | 401.4 | 362.9 | 431 | 270.3 | 143.9 | 0.9 | 3039.3 |
| 2005 | 0 | 0 | 3.4 | 51.7 | 312.3 | 912.4 | 546.4 | 463.7 | 609.7 | 207.5 | 366.7 | 285.4 | 3759.2 |
| 2006 | 6.7 | 1.9 | 0.9 | 149.8 | 403.8 | 481.2 | 177.3 | 314.1 | 791.7 | 561.4 | 79 | 34.4 | 3002.2 |
| 2007 | 0 | 0 | 0 | 40.7 | 274.2 | 402.5 | 251.6 | 489.1 | 473.2 | 320.9 | 263.8 | 9.6 | 2525.6 |
| 2008 | 10.5 | 43 | 80.6 | 287.9 | 976 | 374.4 | 632.8 | 527.5 | 479.8 | 274.1 | 443 | 0.8 | 4130.4 |
| 2009 | 0 | 0 | 27.2 | 157.4 | 405.1 | 566.1 | 178.8 | 418.5 | 411.2 | 237.6 | 86.9 | 62.6 | 2551.4 |
| 2010 | 88.9 | 0 | 0 | 7 | 320.1 | 390.7 | 594.2 | 423 | 314.5 | 420.7 | 222.3 | 328.8 | 3110.2 |
| 2011 | 132.1 | 77.4 | 456.2 | 54.2 | 409.3 | 450.1 | 607.6 | 535.2 | 643.6 | 150.7 | 70.6 | 240.6 | 3827.6 |
| 2012 | 36.1 | 109.4 | 8.5 | 63.2 | 597 | 395.2 | 298 | 406.3 | 904.8 | 252.4 | 249.1 | 155.1 | 3475.1 |
| 2013 | 28.9 | 0.1 | 5.7 | 21.3 | 659.1 | 616.8 | 597.1 | 235.2 | 493.2 | 267.1 | 352.7 | 129.4 | 3406.6 |
| 2014 | 0.4 | 0 | 0 | 0 | 229.9 | 501.7 | 696.6 | 283.5 | 409.4 | 564.9 | 174.6 | 16 | 2877 |
| Avg. | 38.93 | 23.23 | 68.82 | 79.44 | 490.85 | 458.96 | 432.93 | 408.83 | 499.6 | 299.14 | 205.45 | 107.62 | 3113.79 |

### 4.2.5 Data Used for The Study of Study Area -II:

Daily rainfall data for IMD station at Port Blair

- WAPCOS Report on Flood Control Works in Mithakhari
- Data tidal observations at Port Blair
- Layout details of existing 5 MW solar plant at Port Blair
- Natural drainage within proposed plant area and vicinity based on reconnaissance survey of the area.

# CHAPTER 5

# INTERNAL DRAINAGE PLANNING OF STUDY AREA-I

Storm water management model can be used for the planning of drainage scheme in a proposed industrial area. A variety of options can be tried to arrive at appropriate plan satisfying various physical and technical constraints such as topography, plant layout etc.,

This chapter illustrates potential use of AUTOCAD, SWMM and Arc-GIS model in coastal drainage planning through case study of proposed Pudimadaka thermal power plant (study area-I). Fig 5.1 shows the plant area details with their components.

The Auto-CAD model and Arc-GIS model combined is used for the DEM study the brief procedure followed has been explained as below.

## 5.1 Procedure for Digital Elevation Model (DEM)

The contour map prepared using AutoCAD software was converted to raster format. The converted contour map was geo-referenced providing X and Y co-ordinates i.e. (Latitude and Longitude) in ARC-GIS by selecting four or more points in clockwise direction. The geo-referenced values were verified using Link table. Further, for the minor changes in the co-ordinates during the selection are adjusted by selecting Auto adjusts in Link table and geo-referenced raster file is rectified.

The geo-referenced rectified file saved in image format i.e. (.img). The same file is opened from catalog of Arc-GIS. Using Arc toolbar, from Data Management Tool, Projection and Transformation select Define projection, provide input parameter as Universal Transverse Mercator (UTM) projected coordinate system and Zone 44 N WGS 1984 for geo-referencing and click ok the file is Geo-referenced.

Open the contour map (.dwg file) using AutoCAD software, switch off all the layers except contour layer and save the file. From ArcGIS software open the same file, the opened file can be viewed at Table of contents, Right click on it and open attribute table and view the contour elevations. After that, again right click, go to Data and Export data to create a Shape file.

Using, spatial adjustment and editor tool, start editing by selecting four points on the map to set adjustment data and select save edit and stop editing. Also, if necessary using editor tool bar start editing by deleting unnecessary things and join the missing contours.

For creating DEM in ArcGIS from the contours exported from AutoCAD, first identify whether the contour lines are belonging to respective contour elevations or else assign elevation values for each of the contour lines in ArcGIS. Further, after assigning the values create TIN file using 3D analyst tool, Data Management, TIN, create TIN, for input class give contour and at Height field select Elevation.

Convert TIN to raster in order to get DEM for that go to 3D Analyst tool, Conversion, TIN to raster, create TIN, and give input file name as (.img) click ok. Further, Extract the boundary file by Extract by mass using Spatial Analyst Tool, Extraction, Extract by mask and provide input parameter as (dem.img) that was created in previous step and output parameter as Boundary shape file. Now, only plant area is ready for further analysis.

Further, reclassify in-order to obtain Area-Elevation-capacity calculations using, Arc toolbar, Spatial Analyst tool, Reclass, Reclassify, provide extracted file as input raster and enter the value up to which elevation point is maximum and provide breakages manually.

ARC-GIS software has been used for preparation of the DEM. The contours in shape file have been interpolated to obtain digital elevations of the equally sized gird cells. Size of a grid cell is 0.5 m × 0.5 m in this study. The DEM of the plant area is shown as contour zoning map in Fig 5.4 and variation in elevation from 0 m to 20.5 m is depicted through different colors. The DEM of the study area is also shown as single color intensity map in Fig 5.4(a).

Fig 5.4 shows, the existing ground levels varying from 0.0 m to 20.5 m in the project area. The north-west part of the area has elevations in the range of 1.6 m to 20.5 m. The south-west part and eastern part of the project area have lower elevations in the range of 0 m to 6.0 m. The plant area can be leveled in order to economize cost of earthwork in excavation and filling and plant components can be kept at different levels as per the requirement.

The DEM can be used to identify areas requiring cutting and filling and to estimate the volume of earthwork required to level the undulating topography of the study area.

Figure 5.1: Showing the plant area details with their components

### 5.1.1 Distribution of land area in different elevation ranges

The Digital Elevation Model prepared in Geographic Information System (GIS) has been used to compute the natural drainage area (within plant boundaries) between different elevation ranges. The DEM computes the number of pixels in each interval. Table 5.1 shows distribution of area from 0 m to 20.5 m elevation. The DEM pixel size used in this study is 0.5m × 0.5 m.

### 5.1.2 Distribution of land area in Pudimadaka project area

Table 5.1 show that, in the pudimadaka project area 486.09 ha (65.39%) of land area lies below 9 m elevation (317.85ha) and the project area having elevation higher than 9 m elevation is 168.24 ha (34.61%).

Table 5.1 Cumulative areal distributions with elevation in the Pudimadaka project area.

| Elevation | No. of pixels | Area (sq.m) | Area (Ha) | Cum. Area (Ha) | Area (%) | Cum. Area (%) |
|---|---|---|---|---|---|---|
| 1 | 31 | 16998 | 1.7 | 1.70 | 0.35 | 0.35 |
| 2 | 465 | 254973 | 25.5 | 27.20 | 5.25 | 5.60 |
| 3 | 623 | 341610 | 34.2 | 61.36 | 7.03 | 12.62 |
| 4 | 642 | 352028 | 35.2 | 96.56 | 7.24 | 19.86 |
| 5 | 823 | 451275 | 45.1 | 141.69 | 9.28 | 29.15 |
| 6 | 1106 | 606453 | 60.6 | 202.33 | 12.48 | 41.62 |
| 7 | 848 | 464984 | 46.5 | 248.83 | 9.57 | 51.19 |
| 8 | 672 | 368478 | 36.8 | 285.68 | 7.58 | 58.77 |
| 9 | 587 | 321870 | 32.2 | 317.87 | 6.62 | 65.39 |
| 10 | 473 | 259360 | 25.9 | 343.80 | 5.34 | 70.73 |
| 11 | 387 | 212204 | 21.2 | 365.02 | 4.37 | 75.09 |
| 12 | 328 | 179852 | 18.0 | 383.01 | 3.70 | 78.79 |
| 13 | 285 | 156274 | 15.6 | 398.64 | 3.21 | 82.01 |
| 14 | 335 | 183691 | 18.4 | 417.00 | 3.78 | 85.79 |
| 15 | 268 | 146952 | 14.7 | 431.70 | 3.02 | 88.81 |
| 16 | 234 | 128309 | 12.8 | 444.53 | 2.64 | 91.45 |
| 17 | 206 | 112956 | 11.3 | 455.83 | 2.32 | 93.77 |
| 18 | 208 | 114053 | 11.4 | 467.23 | 2.35 | 96.12 |
| 19 | 257 | 140921 | 14.1 | 481.32 | 2.90 | 99.02 |
| 20 | 87 | 47705 | 4.8 | 486.09 | 0.98 | 100.00 |
| Total Plant Area = 486.0944 | | | | | 100.00 | |

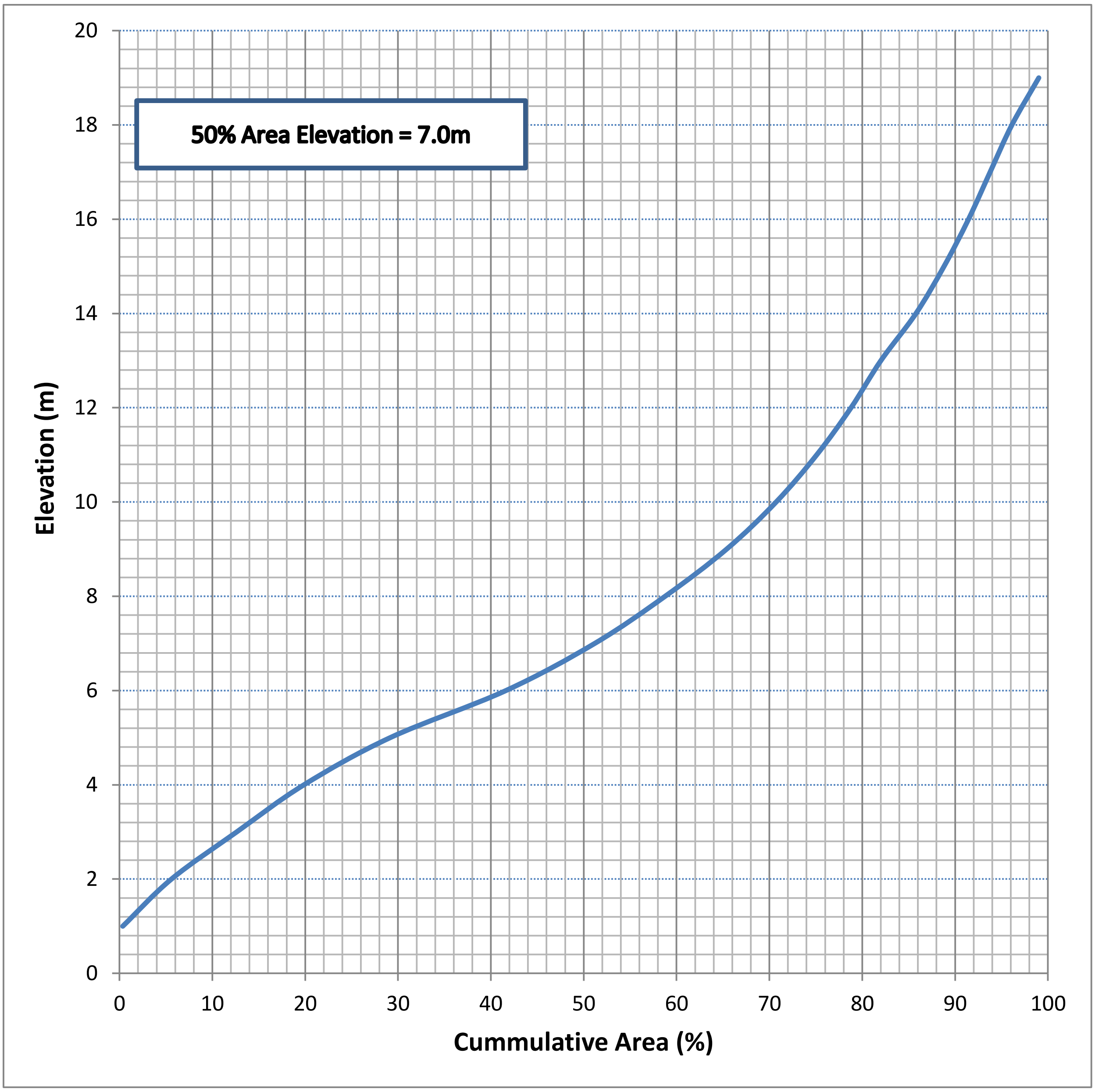



Figure 5.2: Cumulative areal distributions with elevation in the Pudimadaka Project area.

Fig 5.2 is graphical depiction of the cumulative area distribution up to different elevation. The information derived from the DEM study can be used to arrive at cost effective levels at which different plant components should can be finally located.

Table 5.2: Elevation-Area- volume Computation for entire Project area

| Elv | No. of pixels | Area (sq.m) | Area (Ha) | Area (%) | Cum. Area (Ha) | Cum Area (%) | H-h (m) | Avg. Area (ha) | Vol. (ha-m) | Vol. (%) | Cum. Vol. | Cum. (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 31 | 16998.2 | 1.70 | 0.35 | 1.70 | 0.35 | 1 | 1.70 | 1.70 | 0.35 | 1.70 | 0.35 |
| 2 | 465 | 254973.4 | 25.50 | 5.25 | 27.20 | 5.60 | 1 | 13.60 | 13.60 | 2.81 | 15.30 | 3.16 |
| 3 | 623 | 341609.5 | 34.16 | 7.03 | 61.36 | 12.62 | 1 | 29.83 | 29.83 | 6.16 | 45.13 | 9.31 |
| 4 | 642 | 352027.8 | 35.20 | 7.24 | 96.56 | 19.86 | 1 | 34.68 | 34.68 | 7.16 | 79.81 | 16.47 |
| 5 | 823 | 451275.5 | 45.13 | 9.28 | 141.69 | 29.15 | 1 | 40.17 | 40.17 | 8.29 | 119.97 | 24.76 |
| 6 | 1106 | 606452.9 | 60.65 | 12.48 | 202.33 | 41.62 | 1 | 52.89 | 52.89 | 10.91 | 172.86 | 35.67 |
| 7 | 848 | 464983.7 | 46.50 | 9.57 | 248.83 | 51.19 | 1 | 53.57 | 53.57 | 11.06 | 226.43 | 46.73 |
| 8 | 672 | 368477.7 | 36.85 | 7.58 | 285.68 | 58.77 | 1 | 41.67 | 41.67 | 8.60 | 268.11 | 55.33 |
| 9 | 587 | 321869.6 | 32.19 | 6.62 | 317.87 | 65.39 | 1 | 34.52 | 34.52 | 7.12 | 302.62 | 62.45 |
| 10 | 473 | 259360.0 | 25.94 | 5.34 | 343.80 | 70.73 | 1 | 29.06 | 29.06 | 6.00 | 331.68 | 68.45 |
| 11 | 387 | 212203.7 | 21.22 | 4.37 | 365.02 | 75.09 | 1 | 23.58 | 23.58 | 4.87 | 355.26 | 73.32 |
| 12 | 328 | 179852.2 | 17.99 | 3.70 | 383.01 | 78.79 | 1 | 19.60 | 19.60 | 4.05 | 374.87 | 77.36 |
| 13 | 285 | 156274.0 | 15.63 | 3.21 | 398.64 | 82.01 | 1 | 16.81 | 16.81 | 3.47 | 391.67 | 80.83 |
| 14 | 335 | 183690.5 | 18.37 | 3.78 | 417.00 | 85.79 | 1 | 17.00 | 17.00 | 3.51 | 408.67 | 84.34 |
| 15 | 268 | 146952.4 | 14.70 | 3.02 | 431.70 | 88.81 | 1 | 16.53 | 16.53 | 3.41 | 425.20 | 87.75 |
| 16 | 234 | 128309.2 | 12.83 | 2.64 | 444.53 | 91.45 | 1 | 13.76 | 13.76 | 2.84 | 438.97 | 90.59 |
| 17 | 206 | 112956.0 | 11.30 | 2.32 | 455.83 | 93.77 | 1 | 12.06 | 12.06 | 2.49 | 451.03 | 93.08 |
| 18 | 208 | 114052.6 | 11.41 | 2.35 | 467.23 | 96.12 | 1 | 11.35 | 11.35 | 2.34 | 462.38 | 95.42 |
| 19 | 257 | 140920.8 | 14.09 | 2.90 | 481.32 | 99.02 | 1 | 12.75 | 12.75 | 2.63 | 475.13 | 98.05 |
| 20 | 87 | 47704.7 | 4.77 | 0.98 | 486.09 | 100 | 1 | 9.43 | 9.43 | 1.95 | 484.56 | 100.00 |
| | | | 486.09 | 100.0 | | | | 484.56 | 484.56 | 100.0 | | |

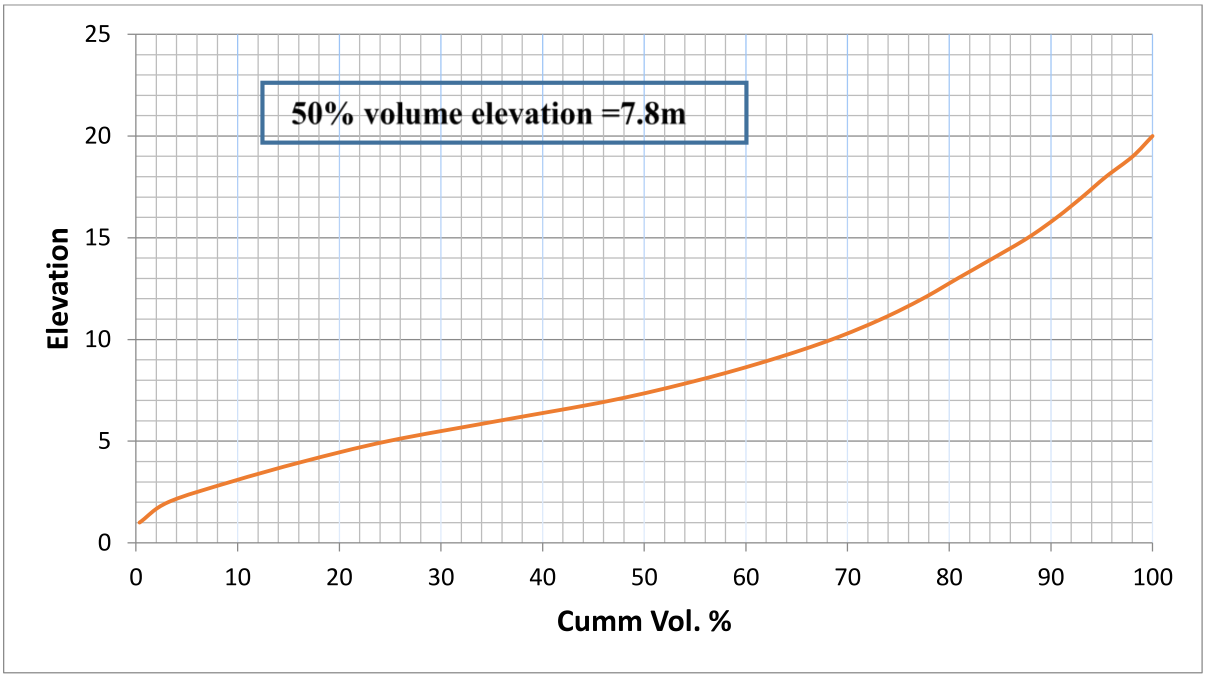



Figure 5.3 Cumulative volume distributions with elevation in the Pudimadaka Project area

Fig 5.3 is graphical depiction of the cumulative volume distribution up to different elevation. The information derived from the DEM study can be used to arrive at cost effective levels at which different plant components should can be finally located.

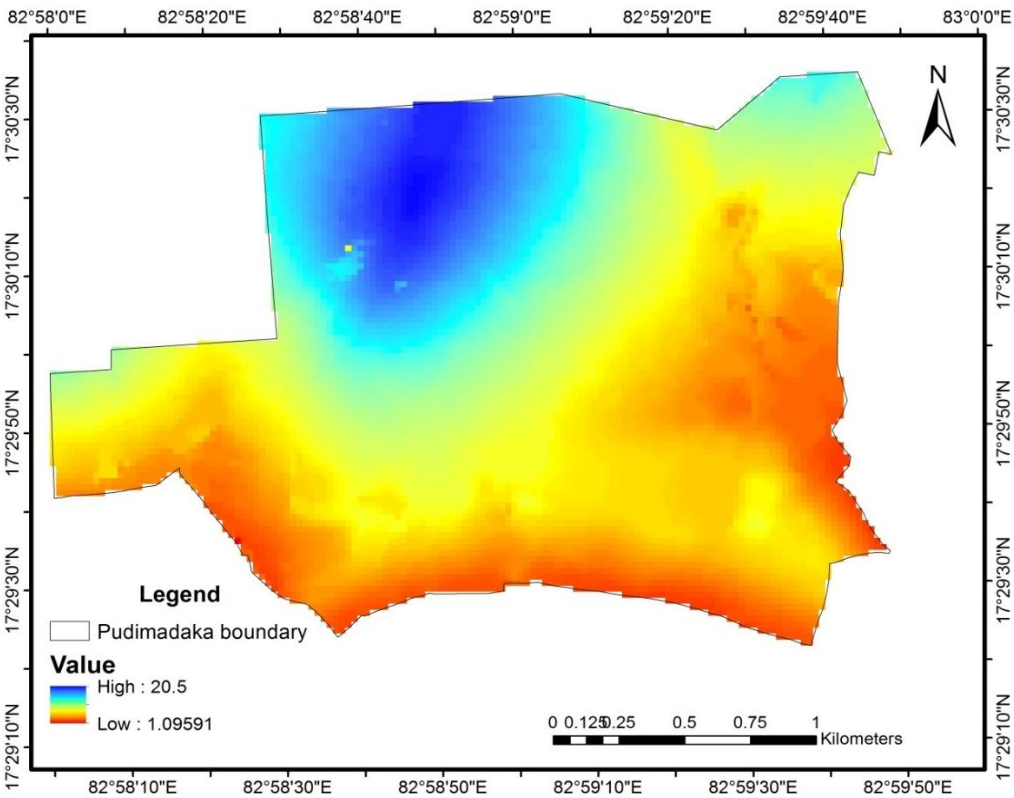



Figure 5.4: DEM of the plant area.

### 5.1.3 Generation of stream network

The Spatial analyst tools of ARC-GIS software has been used in the present study for further processing in the context of stream generation. DEM has been smoothened out for eliminating uneven irregularities using Fill tool to remove the sinks. Corrected DEM has been used to generate pattern of flow directions and for identification of flow accumulation through each pixel of given elevation. Generated information on flow pattern and flow accumulation considers Eight-Point Pour model for the purpose of computing flow directions for use in basin delineation with DEMs 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 defined as the number of earlier DEM points whose flow paths eventually pass through that point. Streams are identified by large values of flow accumulation since the flow paths of many points pass through the stream points. Outlet of a watershed has the highest value of flow accumulation 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. Fig 5.5 shows the generated stream network in the study area.

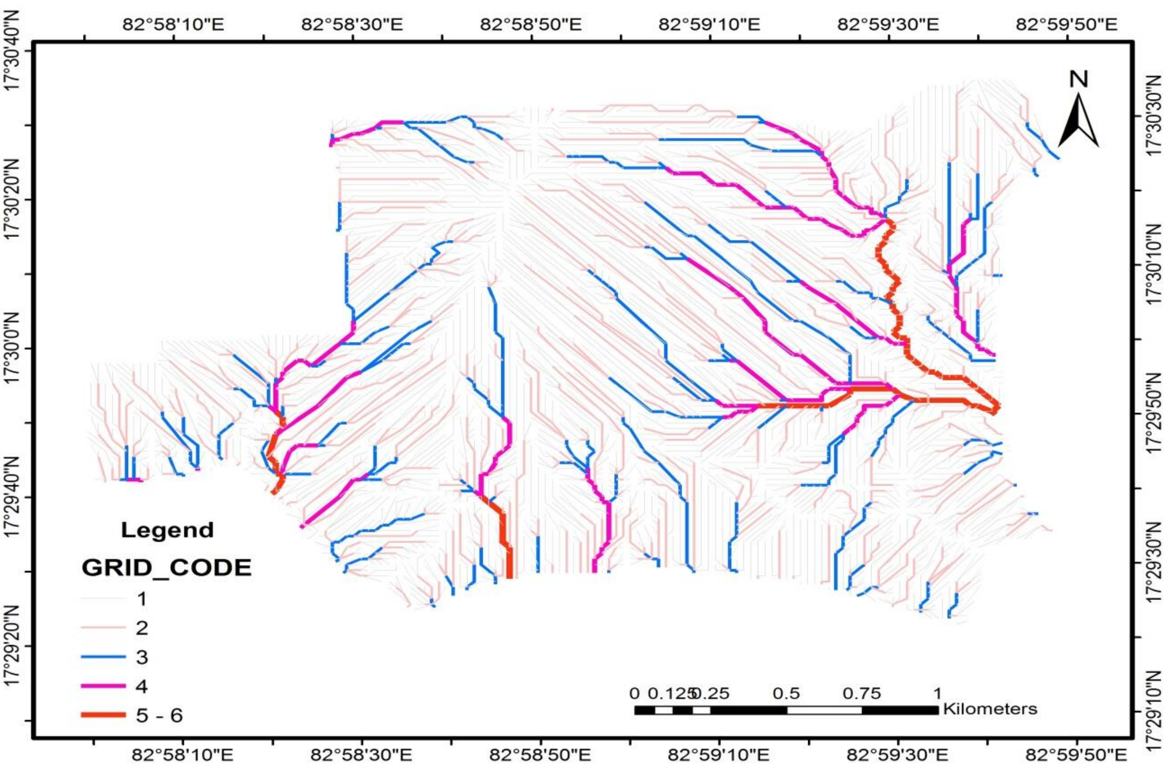



Figure 5.5: DEM stream network of the plant area.

### 5.1.4 Summary Results of DEM Study

From the DEM study it is evident that the plant natural ground varies from 0 to 20.5m, the F.G.L in the plant area ranges from 7 to 15m. The average elevation corresponding to balancing the cut and fill volume of earthwork is 7.8m. It means earth may have to be brought from outside for filling. (Based on the Table 5.2 for which area/volume above a certain elevation is of the order of 50%).

## 5.2 INTERNAL DRAINAGE FOR THERMAL POWER PLANT

Storm water management model can be used for planning and drainage scheme in a proposed industrial area. A variety of options can be tried to arrive appropriate plan satisfying various technical and physical constraints such as plant layout, topography, soil characteristics etc.

The potential use of SWMM software in planning for internal drainage through case study of proposed thermal power plant in Vishakhapatnam, Andra Pradesh.

### 5.2.1 Plant Area Characteristics

STPP area is about 358 ha (= 885 acres) consisting of different land uses. The plant area having undulating topography exhibits large difference in its ground levels. DEM study using recent topographic data has been presented previously. Based on this study, the existing ground levels vary from 1m to 20.5 m in the project area. The north-west part of the area has elevations in the range of 1.6m to 20.5 m. The south-west part and eastern part of the project area have lower elevations in the range of 1 m to 6.0 m. The plant area to be levelled. In order to economize cost of earthwork in excavation and filling.

TABLE 5.3: Plant components at different levels

| Elevation (m) | Space for various components | Area (ha) |
|---|---|---|
| 14 | Crushed coal stock pile unit | 60.65 |
| 16 | Space for transmission line (in north of coal yard) | 5.26 |
| 15 | Space for transmission line (in north of switch yard) | 11.33 |
| 12 | Switch yard (16.99 ha), space for preassembly north of Boiler unit (8.09ha) | 25.08 |
| 10 | Residential and Office complex area | 17.75 |
| 9 | Main plant (Boiler Unit) | 44.1 |
| 8 | CW pump house, Desalination plant | 17.08 |

| | | |
|---|---|---|
| 8 | Space for lay down and pre assembly and green belt (to east of switch yard) | 11.28 |
| 7 | Desalination unit and water storage area | 7.68 |
| 7 | Desilting basin to the south of coal stock pile unit area | 5.26 |
| 6 | Space for lay down and pre assembly and green belt (to east of main plant) | 52.19 |
| Total plant area | | 257.66 |

### 5.2.2 Location of Streams around Plant Boundary

There are five natural drains in vicinity of plant. These are Krishnapalem nala, upper Rambilli nala, lower Rambilli nala (Upper Rambilli nala is termed as lower Rambilli nala after confluence with Krishnapalem nala), Doraipalem nala (passing through plant area on east side) and Pudimadaka nala. Doraipalem nala joins Pudimadaka nala near south east boundary of plant area. The plant site is located on high ground between the drains on west and east sides. In general, all the drains flow in north to south directions following the slope of terrain the Green Ampt Method has been used for estimating infiltration. according to various land use/cover and soil conditions, Green Ampt parameters are shown in Table 5.6.

### 5.2.3 Bankful Discharge Calculations and Computation of Streams

In order to assess the flooding, bankful discharge capacity of natural drains have been estimated using slope area method. For estimation of cross section parameters, approximate ground levels on the left and right banks have been worked out with the help of recent contour map of the plant area. Eleven locations have been selected to assess the bankful discharge capacity. There are five natural drains in vicinity of plant. These are Krishnapalem Nala, upper Rambilli nala, lower Rambilli nala (after confluence of Krishnapalem nala), Doraipalem nala (passing through plant area on east side) and Pudimadaka nala. Doraipalem nala joins Pudimadaka nala near south east boundary of plant area. The plant site is located on high ground between the drains on west and east sides. In general, all the drains flow in north to south directions following the slope of terrain. To compute bankful capacity of these nala the cross sections has being taken near to the adjoining nala's and also section taken at the point where two nala's coincides each other. Using the below Empirical formulae the bankful discharge capacity is calculated:

Velocity (v) has been estimated by Manning's equation $V(m/s) = \frac{1}{n} \times R^{2/3} \times S^{1/2}$

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

- n: Manning roughness coefficient assumed to be 0.0375 for small streams in plains with small boulders.
- R: hydraulic mean depth (=A/P)
- A ($m^2$): Cross section area
- P (m): perimeter
- S (m/m): surface water slope assumed to be same as river bed slope (0.00391)
- Q: discharge ($m^3$/s).

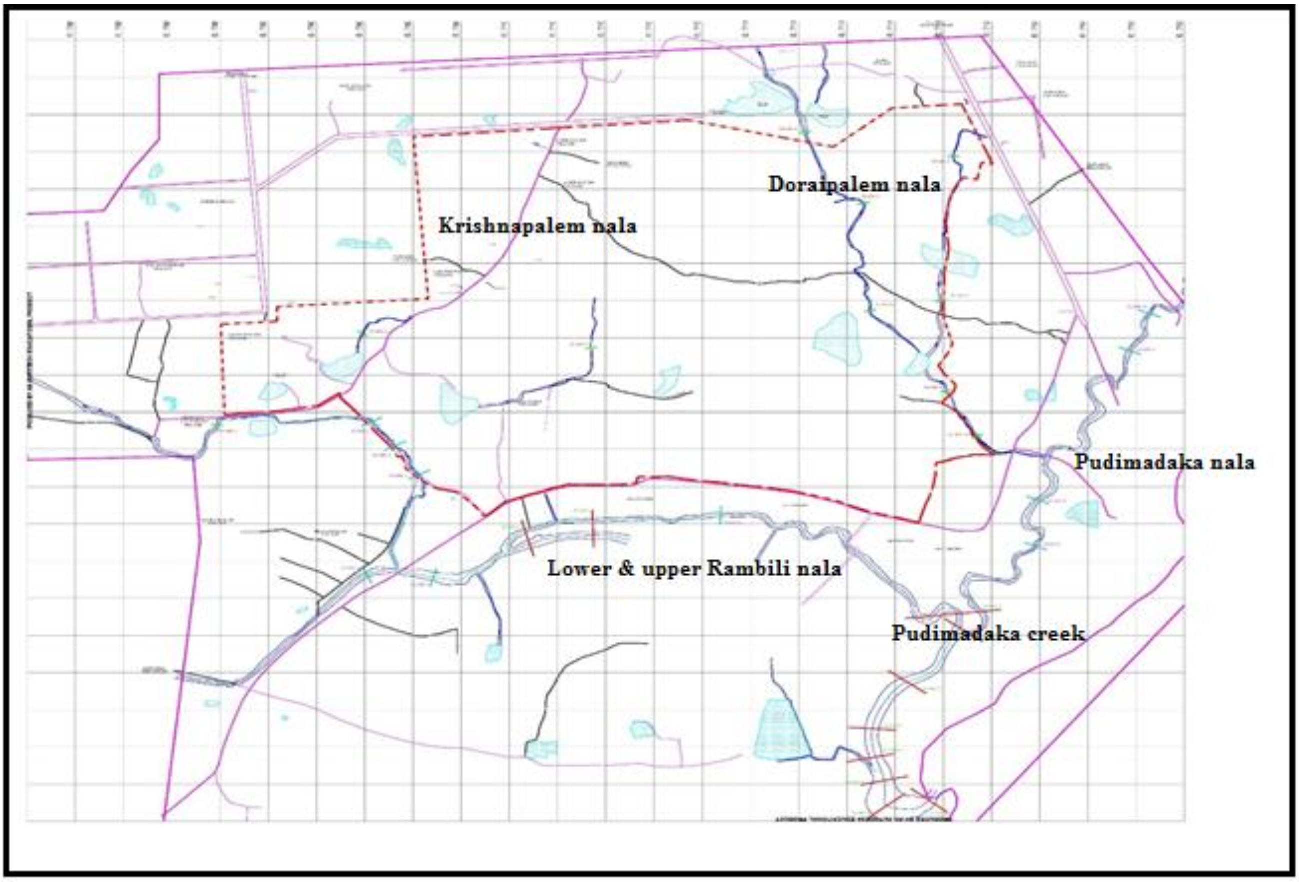



Fig 5.6: Nala sections at the plant boundary.

TABLE 5.4: Velocity and discharge of nala's in the plant area

| Sl.no. | Nala | Velocity (m/s) | | Discharge ($m^3$/sec) | |
|---|---|---|---|---|---|
| | | Maximum | Minimum | Maximum | Minimum |
| 1 | Krishnapalem | 2.31 | 1.71 | 127.86 | 44.59 |
| 2 | Doraipalem | 1.82 | 1.78 | 50.59 | 45.20 |
| 3 | Lower & Upper Rambilli | 3.31 | 2.09 | 1005.15 | 152.97 |
| 4 | Pudimadaka | 3.21 | 3.00 | 520.37 | 363.23 |
| 5 | Pudimadaka creek | 3.94 | 2.82 | 1841.73 | 386.52 |

## 5.3 FREQUENCY ANALYSIS OF 1-DAY ANNUAL MAXIMUM RAINFALL

Daily rainfall data for Vishakhapatnam from 2000-2011 in which data for 2003 and 2004 are missing and for Kakinada station from 1996-2014 (18 years) have been utilized for estimation of design storm. The maximum rainfall of Vishakhapatnam for missing data years of 2003 and 2004 has been taken the same as of Kakinada station, i.e. 120 mm on 15 July 2003 and 119.6 mm on 3 Aug. 2004, respectively. Thus, the 1-Day annual maximum rainfall series was constructed for Vishakhapatnam for 12 years (2000-2011) and EV Type I probability distribution was applied. Return period of 1-day annual maximum rainfall series at Vishakhapatnam is estimated in Table 5.5. Fig 5.7 shows graphical frequency analysis of 1-day annual maximum rainfall at Vishakhapatnam.

### 5.3.1 Regional Depth Duration Frequency Studies

The study area lies in Eastern Coastal Region Sub Zone 4a defined by CWC (1987). India Meteorological Department (IMD) has conducted detailed rainfall study for the Sub Zone 4(a, b, c) (CWC 1987) utilizing the data of 24 self-recording rain gauge stations and 376 ordinary rain gauge stations maintained by IMD/States and 43 self-recording rainguages of Indian Railways maintained in 10 bridge catchments in these subzones.

TABLE 5.5: Frequency analysis of 24-hr Annual Maximum Rainfall at Vishakhapatnam

| Sl. No. | Year | Date | Annual Max 1-day Rainfall | Rainfall in Descending Order | Rank (m) | m/(n+1) | Return Period (Years) |
|---|---|---|---|---|---|---|---|
| 1 | 2000 | 25-Aug-00 | 86 | 183 | 1 | 0.08 | 13.00 |
| 2 | 2001 | 30-Sep-01 | 114 | 153.2 | 2 | 0.15 | 6.50 |
| 3 | 2002 | 10-Jun-02 | 74 | 132 | 3 | 0.23 | 4.33 |
| 4 | 2003 | 15-Jul-03 | 120 | 129.4 | 4 | 0.31 | 3.25 |
| 5 | 2004 | 3-Aug-04 | 119.6 | 124.3 | 5 | 0.38 | 2.60 |
| 6 | 2005 | 20-Sep-05 | 153.2 | 120 | 6 | 0.46 | 2.17 |
| 7 | 2006 | 4-Aug-06 | 124.3 | 119.6 | 7 | 0.54 | 1.86 |
| 8 | 2007 | 5-Oct-07 | 115.1 | 115.1 | 8 | 0.62 | 1.63 |
| 9 | 2008 | 10-Feb-08 | 129.4 | 114 | 9 | 0.69 | 1.44 |
| 10 | 2009 | 30-Sep-09 | 84 | 86 | 10 | 0.77 | 1.30 |
| 11 | 2010 | 1-Nov-10 | 183 | 84 | 11 | 0.85 | 1.18 |
| 12 | 2011 | 7-Jul-11 | 132 | 74 | 12 | 0.92 | 1.08 |

TABLE 5.5(a): 1-day rainfall (mm) of various return periods

| Station | Return period (Years) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 |
| 1-day rainfall at Vishakhapatnam(mm) | 115 | 150 | 170 | 190 | 200 | 238 | 260 | 285 |
| 24-hr rainfall (mm) | 132.25 | 172.5 | 195.5 | 218.5 | 230 | 273.7 | 299 | 327.75 |

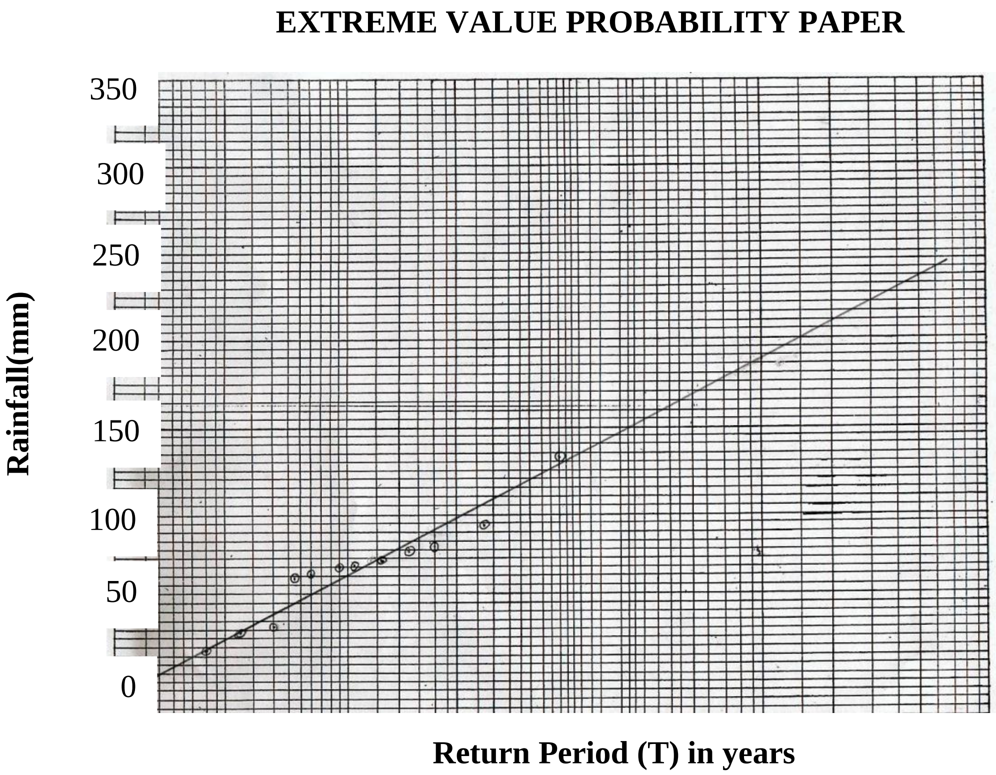



Figure 5.7: EV Type-I Probability distribution of annual maximum 1-day rainfall at Vishakhapatnam

### 5.3.3 Design Storm

In the absence of site specific hydro-meteorological data, regional approach has been adopted to arrive at the design storms of return periods corresponding to 25 years, 50 years and 100 years, the drainage network for this plant is designed for 25 year return period flood. Design storm duration is adopted as 6 hours considering the geomorphological characteristics of the area. The hourly distributions of rainfall for 25 year return period storm is given in Table 5.6.

TABLE 5.6: Time distribution of Cumulative and Incremental Rainfall of different Return Periods

| Return Period (Year) | Rainfall (mm) | Hour | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1st | 2nd | 3rd | 4th | 5th | 6th |
| 25 | Cumulative | 77.76 | 106.56 | 123.84 | 132.48 | 141.12 | 144 |
| | Incremental | 77.76 | 28.8 | 17.28 | 8.64 | 8.64 | 2.88 |

## 5.4 DESIGN CONSIDERATIONS

The drainage layout has been planned based on the following considerations:

- Drainage channels should safely carry storm runoff caused by design storm of 25 year return period.
- Bed slope of drainage channels is to be 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.
- Concrete lined rectangular sections are provided throughout.
- Vertical drops are necessary to negotiate level differences in plant components as proposed.
- Based on engineering as well as economic considerations, several outfalls are proposed at suitable locations to follow the natural topography.
- Channel slope, length, bed width is 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. However, in few channel segments this requirement has to be compromised based on hydraulic and drainage layout considerations.
- Green Ampt method has been used for modelling infiltration.
- Kinematic wave routing has been used for flow routing in channels.

## 5.5 DRAINAGE PLAN

Fig 5.8 and 5.9 shows the adopted drainage plan in the main plant area. Plant area, is having undulated topography and there is a significant difference in ground level. For the efficient and economic disposal of generated runoff, the plant area is divided into forty number of subcatchments with four different drain network, namely A, B, C and D with individual outlets O1, O2, O3, O4. For the analysis the plant area is divided into two parts as shown in the Fig 5.8 and 5.9.

Natural drainage indicates that; the existing ground levels vary from 1m to 20.5 m in the project area. The north-west part of the area has elevations in the range of 1.6m to 20.5 m. The south-west part and eastern part of the project area have lower elevations in the range of 1 m to 6.0 m. Fig 5.8 and 5.9 shows the proposed layout of drainage channels (rectangular section) and runoff contributing subcatchments. Four lateral drains will collect the storm runoff in the main plant area. Water from the drains are collected in the outfall. The outfalls are in different elevation. Water from these outfalls shall be disposed of to the sea. In drainage plan D, three storage units are provided (T3, T4, T5) in order to retain the existing ponds in the plant area.

TABLE 5.7: Green Ampt parameters used in storm rainfall – runoff study

| Soil | Saturated hydraulic conductivity (mm/hr.) | Soil suction head (mm/hr.) | porosity |
|---|---|---|---|
| Silty Clay | 1.0 | 292.2 | 0.092 |

Source: SWMM model manual 5.1

### 5.5.1 Shape and Size of the Channel Section

SWMM simulates runoff from subcatchments and flow through channels. Shape, size of channels sections and slope of channels (invert levels at upstream and downstream end of each channels) are to be specified for simulation study.

Peak discharge resulting from the subcatchments are computed by rational formula (Q=CIA), Runoff coefficient (C) is obtained from the SWMM module. Invert levels are decided such that excessive excavation is avoided and the same time and discharge capacities are adequate to carry storm runoff in channels without causing excessive surface flooding. It is proposed to provide concrete lined rectangular channel. The manning's roughness co-efficient is taken as n=0.016.

### 5.5.2 Preparation of Input Data File

Fig 5.8 and 5.9 shows sub-catchments, junction, conduits, outfalls along with user assigned identification names. The input data/parameters used in this SWMM study are given below.

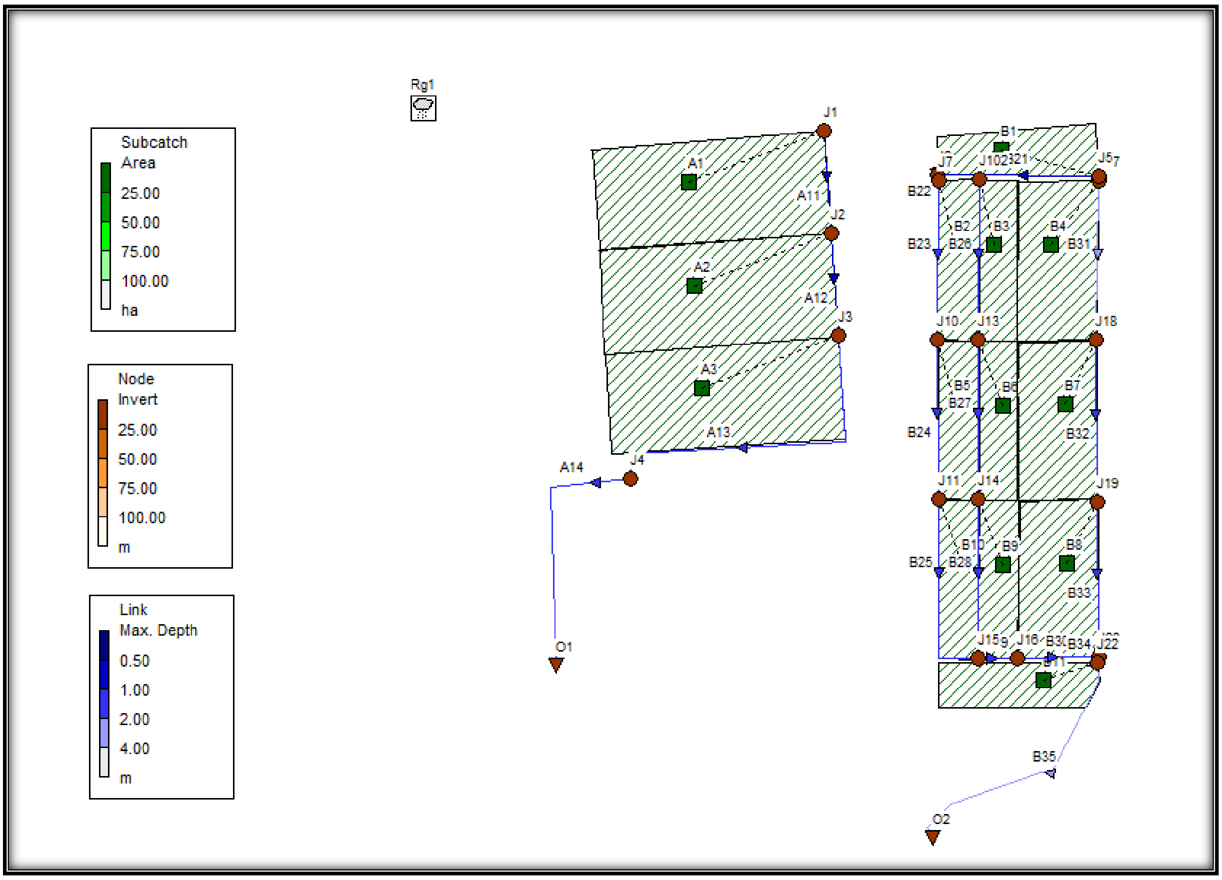



Figure 5.8: Pudimadaka internal drainage layout part 1

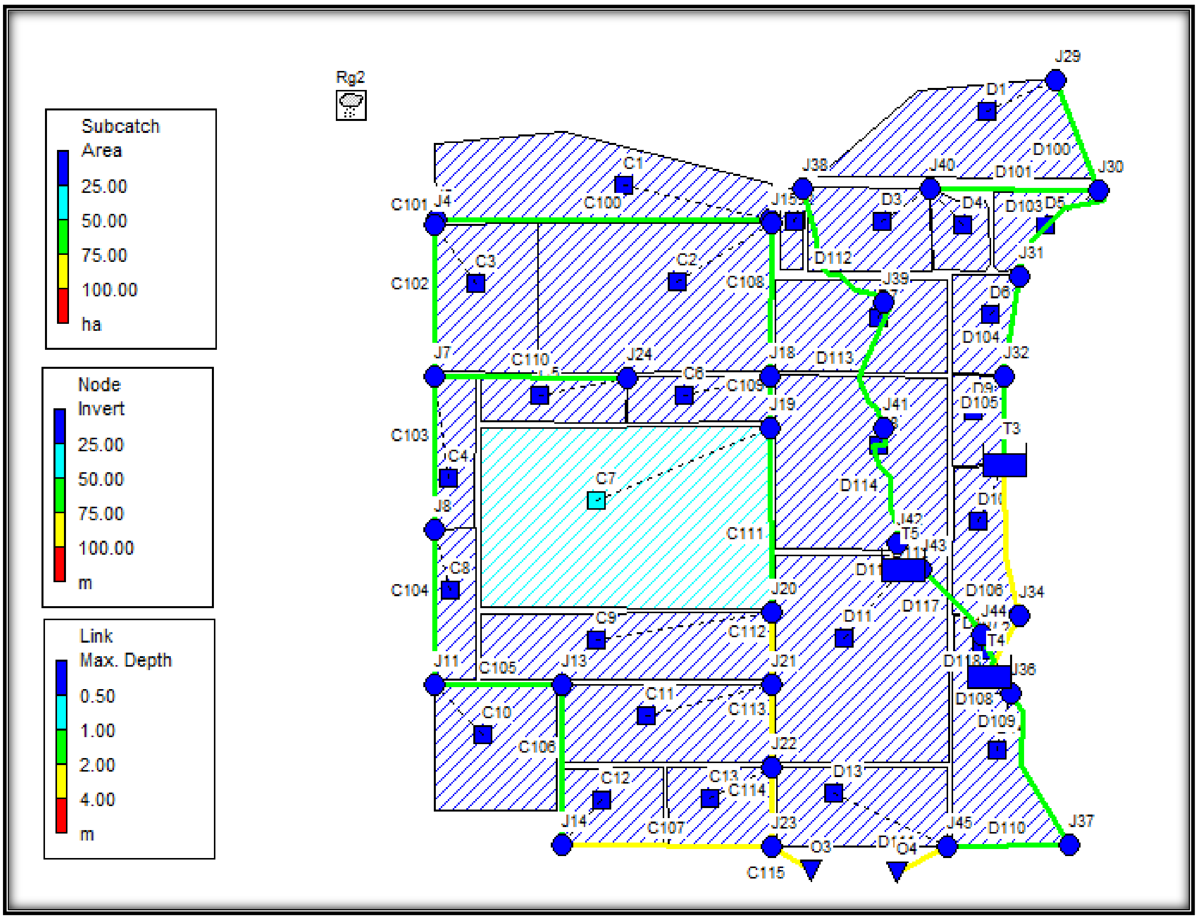



Figure 5.9: Pudimadaka internal drainage layout part 2

1. Raingauge- A raingauge provides rainfall data for one or more sub-catchments in the study area. In this study, drainage network is designed for 25 year of return period employing a distribution factor, this design storm is then distributed at 1-hour interval for the first six-hour duration, as follows.

| Time (hour) | 1st | 2nd | 3rd | 4th | 5th | 6th |
|---|---|---|---|---|---|---|
| Incremental Rainfall (mm) | 77.78 | 28.8 | 17.28 | 8.64 | 8.64 | 2.88 |

2. Subcatchment- Subcatchments are hydrologic units of land whose topography and drainage system elements direct surface runoff to a single discharge point. The whole study area is divided into 40 sub-catchments. These sub-catchments differ in their topography, land use, soil and finally discharge their runoff into single outlet point as shown in fig 5.8 and 5.9. Discharge outlet points can be either nodes of the drainage system or other subcatchments.

TABLE 5.8: Sub-catchment properties

| | |
|---|---|
| Name | User-assigned sub-catchment |
| Rain gauge | Name of the rain gauge associated with the sub-catchment. |
| Outlet | Name of one single outlet of sub-catchment that receives runoff from it. |
| Area | Area of sub-catchment in hectares |
| Width | Characteristic width of overland flow path for sheet flow runoff in meters. Characteristic width is given by the subcatchment area divided by the average maximum overland flow length. The maximum overland flow is the length of the flow path from the inlet to the furthest drainage point of the subcatchment. |
| % slope | Average percent slope of the sub-catchment is assumed to be 1in 1000 for all subcatchments |
| % Imperv | Percent of land area which is impervious. It ranges from 5% to 100% |
| N- Imperv | Manning's n for overland flow over the impervious portion of sub-catchment. It is taken as 0.012 |
| N- Perv | Manning's n for overland flow over the previous portion of sub-catchment. It is taken as 0.05. |
| D-store Imperv | Depth of depression storage on the impervious portion of the sub-catchment. It is taken as zero. |
| Dstore Perv | Depth of depression storage on the pervious portion of the sub-catchment. It is taken as 2.54mm. |
| % Zero-Imperv | Percent of the impervious area with no depression storage. Assumed to be 100% |
| Subarea routing | Outlet: runoff from both area flows directly to outlet. |
| Infiltration | The option controls how infiltration of rainfall into the upper zone of subcatchment is modeled. Green Ampt parameters such as suction head(mm), hydraulic conductivity (mm/hr), initial moisture deficient (equal to difference of porosity and field capacity) corresponding to sandy loam with relatively higher/lower percent of sand and silty loam soils found in different sub-catchments have been taken. |

3. Junction – In a drainage network, junctions are the nodes which join links. A Junction also shows an outlet of any sub-catchment which receives runoff from that sub-catchment. Fig 5.7 and 5.8 shows how a node is attached with each sub-catchment and it joins the links up to outfall of the area to route the runoff.

TABLE 5.9: Junction properties

| | |
|---|---|
| Name | User assigned junction name |
| Inflows | Assign time series, dry weather to the junction. Assumed to be zero. |
| Invert El. | Invert elevation of the junction in meters. |
| Max. Depth | Max. Depth of junction (i.e. from ground surface to invert) in meters. |
| Initial depth | Depth of water at the junction at the start of the simulation in meters. Assumed to be zero. |
| Surcharge Depth | Additional depth of water beyond Max. Depth that is allowed before the junction floods in meters. This parameter can be used to simulate bolted manhole covers. Assumed to be zero as no flooding is allowed. |
| Ponded Area | Area occupied by ponded water atop the junction after flooding occurs in sq. Meters. It is taken as zero. |

4. Conduit- Conduits are pipes or channels that move water from one node to another in the conveyance system. Conduits are used to convey the water to the outfall, it can be an open channel or closed conduit. Conduits are joined with nodes to divert the water and it is provided with an adequate slope so that the water flows by gravity.

TABLE 5.10: Conduit Properties

| | |
|---|---|
| Name | User assigned conduit name |
| Inlet Node | Name of the node on the inlet end of the conduit. (which is normally the end at higher elevation) |
| Outlet node | Name of the node on the outlet end of the conduit. (which is normally the end at lower elevation) |

| | |
|---|---|
| Shape | Geometric properties of the conduit's. An open channel is provided for this study.<br>The geometric properties of the conduit's cross-section. Rectangular channel section is taken. |
| Length | Length of conduit in meters. |
| Roughness | Manning's Roughness coefficients. It is taken as 0.016 for concrete lined open channel. |
| Inlet offset | Height of the conduit invert above the node invert at the upstream end of the conduit in meters. |
| Outlet offset | Height of the conduit invert above the node invert at the downstream end of the conduit in meters. |
| Initial Flow | Initial flow in conduit. It is zero. |
| Maximum Flow | Maximum flow allowed in the conduit under dynamic wave routing. Use zero if not applicable. |

5. Outfall- Outlets are flow control devices that are typically used to control outflows from storage units. Outfall is the final output obtained in any catchment area. Further, it is a combination for all sub-catchments which in turn contribute to total runoff in the whole catchment area. Conveyance system routes the runoff and discharges into the river or any storage unit

TABLE 5.11: Outfall Node Properties.

| | |
|---|---|
| Name | User-assigned outfall name |
| Inflows | Assign time series, dry weather to the outfall |
| Invert El. | Invert elevation of the outfall in meters. |
| Tide Gate | NO- no tide gate is provided. |
| Type | Type of outfall boundary condition: Free: outfall stage determined by minimum or critical flow depth and normal flow depth in the connecting conduit. |

6. Storage Units-Storage Units are drainage system nodes that provide storage volume.

TABLE 5.12: Storage unit properties

| | |
|---|---|
| Name | User-assigned storage unit name. |
| Tag | Optional label used to categorize or classify the storage unit. |
| Inflows | Click the ellipsis button (or press Enter) to assign external direct, dry weather, or RDII inflows to the storage unit. |
| Invert El. | Elevation of the bottom of the storage unit (feet or meters). |
| Max. Depth | Maximum depth of the storage unit (feet or meters). |
| Initial Depth | Initial depth of water in the storage unit at the start of the simulation (feet or meters). |
| Storage Curve | Method of describing how the surface area of the storage unit varies with water depth:<br>FUNCTIONAL uses the function:<br>Area = $A \times (\text{Depth})^B + C$<br>to describe how surface area varies with depth;<br>TABULAR uses a tabulated area versus depth curve.<br>In either case, depth is measured in feet (or meters) above the bottom and surface area in sq. feet (or sq. meters). |
| TABULAR | The tabulated data is given for T3, T4, T5. |
| Curve Name | Name of the Storage Curve containing the relationship between surface area and storage depth (double-click to edit the curve). The curve will be extrapolated outwards to meet the unit's Max. Depth if need be. |

## 5.6 RESULTS OF SWMM STUDY

ANNEXURE 1 and ANNEXURE 2 provides summary information on analysis options, runoff quantity continuity, flow routing continuity and routing time step summary. Total storm rainfall in 6-hour duration is 144 mm (25 year return period) using Green Ampt model. The summary of Runoff quantity and Flow routing results are shown is the Table 5.13 & 5.14.

TABLE 5.13: Runoff Quantity Continuity Summary

| Runoff Quantity Continuity | Part 1 | Part 2 | Total Volume (hectare-m) |
|---|---|---|---|
| Total Precipitation | 19.812 | 31.788 | 51.6 |
| Evaporation Loss | 0.000 | 0.000 | 0.000 |
| Infiltration Loss | 4.597 | 6.840 | 11.437 |
| Surface Runoff | 14.396 | 24.474 | 38.87 |
| Final Storage | 0.824 | 0.506 | 1.33 |
| Continuity Error (%) | -0.031 | -0.102 | -0.133 |

TABLE 5.14: Flow Routing Continuity Summary

| Flow Routing Continuity | Part 1 | Part 2 | Volume (ha-m) |
|---|---|---|---|
| Dry Weather Inflow | 0.000 | 0.000 | 0.000 |
| Groundwater Inflow | 0.000 | 0.000 | 0.000 |
| External Inflow | 0.000 | 0.000 | 0.000 |
| Final Stored Volume | 0.102 | 0.085 | 0.187 |
| Wet Weather Inflow | 14.394 | 24.473 | 38.867 |
| RDII Inflow | 0.000 | 0.000 | 0.000 |

## 5.7 CONCLUSION

The proposed plant layout of different components is at different F.G.L, this will be more economical than levelling the entire plant area. From SWMM study it is evident that the channels are hydraulically efficient to drain out the generated storm (Annexure part 1 and Annexure part 2 shows the entire results of SWMM). Shape and size of the channels can be further reduced depending upon the sub catchment runoff.

# CHAPTER – 6

# FLOOD CONTROL IN COASTAL AREA

## 6.1 INRODUCTION

This chapter, focuses on external flooding and its vulnerability in coastal regions that occurs due to the natural disaster such as tsunami, tides, storm surges due to heavy rainfall. Due to which sea water penetrates the coast with high speed causing excessive inundation which is called run-up. Fig.6.1 shows the different aspects of inundation. Run-up is used for determine extent of vulnerability, human settlement in coastal area it is useful in coastal land use planning. The run-up level data available for the study area i.e., (Andaman and Nicobar Islands) indicates 4 m in Port Blair (1868), 0.76 m in Car Nicobar (1881) and 1.22 m in Port Blair (1881) (Zhao, 2006). Due to developmental activities human encroachment takes place in coastal area for settlement or for agriculture purpose in the flood plain, is the place where all flood damages occur. This flood plain can be defined as relatively flat area bordering the stream (source: current science, 2005). Flood inundate valuable properties, endanger lives, due to high rate of flow or run-off from the catchment area causing large scale of erosion and results in deposition of sediments, floods also cause damage for drainage channels, bridges, and other structures and also results in loss of lives, economic losses etc.,

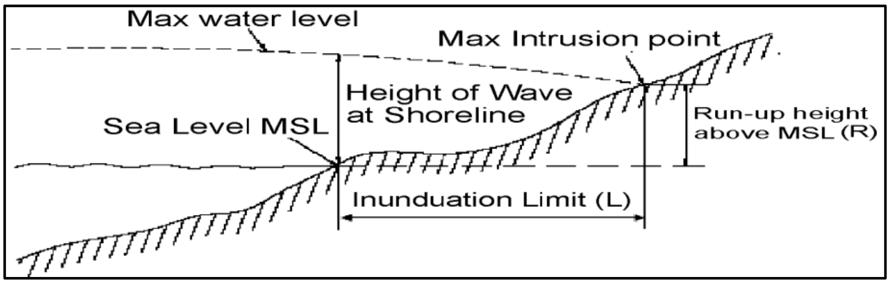



Figure 6.1: - Schematic diagram showing measurement of run-up height.

Flood control i.e., measures taken to reduce the effects of flood. The flood control is primarily aimed for the control of flood damage, there are many programs associated with flood control that determines on the basis of constructing various types of works, and to estimate the amount of damage. Many Literature is available on different methods of flood control. The methods are classified as below (Dube, 2008).

- Construction of detention and storage tanks in the catchment areas for flood moderation.
- Construction of ring bunds around imported towns properties etc., to prevent flooding.
- Construction of bye-pass channels on the rivers and divert the flood water.
- Flood plain zoning.
- Providing suitable drainage arrangement
- Conversion of soils by catchment area treatment plan ad prevent soil erosion
- Flood relief works, construction of embankment during flooding and emergency measures.
- Flood prediction warning system to keep alert in advance.
- Construction of dykes in sea shores to prevent flooding due to tsunami and sea level rise.

## 6.2 EFFECT OF TSUNAMI IN ANDAMAN AND NICOBAR

Tectonics, gas-hydrate destabilization and submarine landslides are possible sources for generation of tsunamis (Narayana, 2010). The description of tsunami is discussed in chapter 2 briefly. The great Sumatra tsunami of 2004 is a significant reminder of understanding seismic and tsunami hazards, the average slip of this earthquake was 12-15 m and the propagation was about 2.5 km/s over a distance of 1200 km, this earthquake produced vertical displacements approaching 5 m above the sundra trench southwest of Nicobar Islands creating a largest tsunami record in Indian Ocean. As per the data available in national Geophysical data centre of U.S. National oceanic and Administration (http://www.ngdc.noaa.gov) 16 tsunami events was recorded in regions of Indian ocean from past 1700- 2016.The details are shown in table 6.1.

TABLE 6.1 showing tsunami events, location and cause from the year 1700 – 2016

| Year | Tsunami cause | | Location | Max.water ht. height |
|---|---|---|---|---|
| | Earthquake magnitude | Volcano | | |
| 1737 | - | - | Calcutta | - |
| 1819 | 7.7 | - | Kutch | - |
| 1845 | 6.3 | - | Rann of Kutch | - |

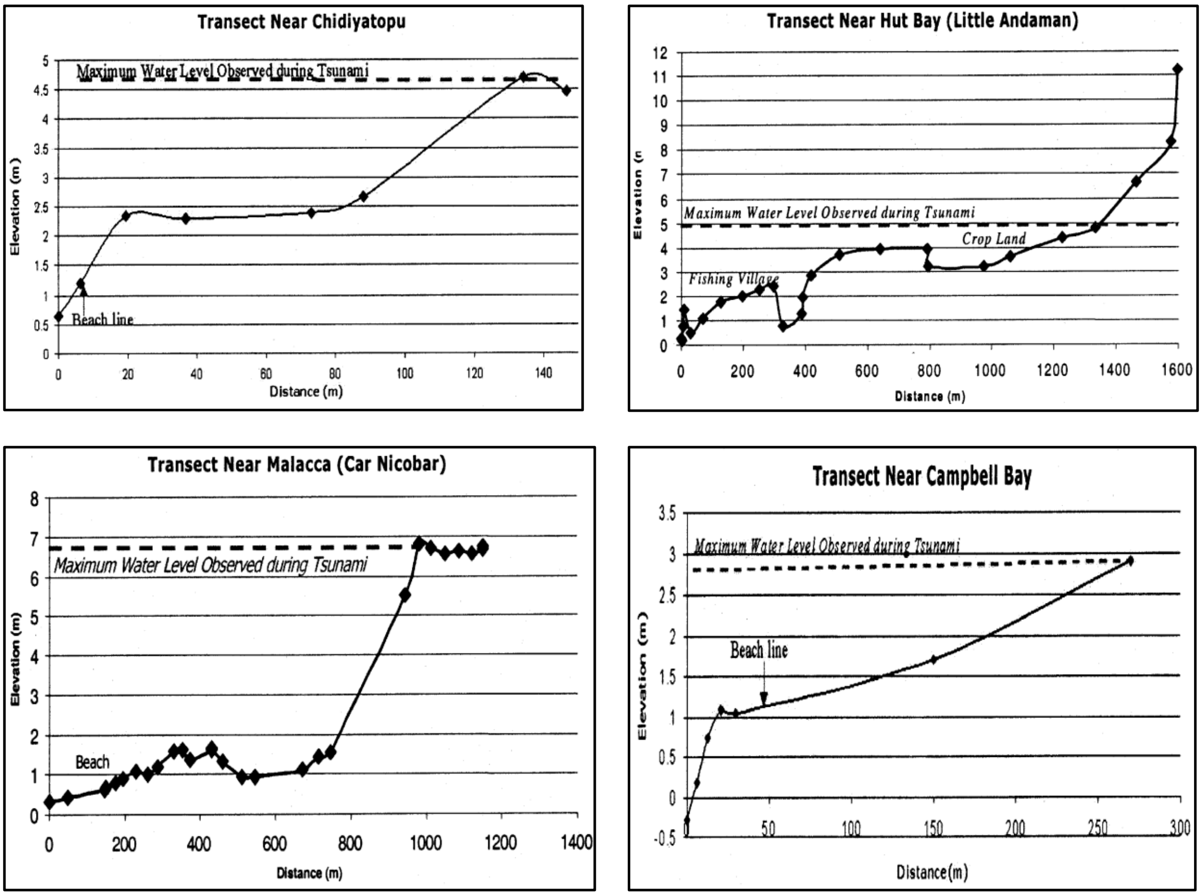
| | | | | |
|---|---|---|---|---|
| 1847 | - | - | Little Nicobar Island | |
| 1868 | - | - | Andaman Island | 4 |
| 1876 | - | - | Bay of Bengal | - |
| 1881 | 7.9 | - | Car Nicobar | 1.22 |
| 1897 | 8.7 | - | Assam | - |
| 1905 | 7.8 | - | Kangra, India | - |
| 1941 | 7.6 | - | Andaman sea, east coast of India | 1.50 |
| 1950 | 8.6 | - | India-China | 0.50 |
| 1955 | 7.3 | - | Little Nicobar Island | - |
| 1978 | - | - | India | - |
| 2002 | 6.5 | - | A&N, India | - |
| 2009 | 7.5 | - | A&N | 0.01 |
| 2010 | 7.5 | - | Little A&N | 0.03 |

(Source: http://www.ngdc.noaa.gov)

The Andaman and Nicobar Islands (A&N) located in the subduction zone of Burma Plate are classified as seismic zone 5, indicating high level of risk due to earthquakes (Zhao, 2006). A tsunami was generated on 26 December 2004 by an earthquake of magnitude M 9.0 that occurred off Sumatra Island of Indonesia with the epicentre located on the shallow depths of seabed, and the Acoustic Tide Gauge (ATG) of the National Institute of Ocean Technology (NIOT), located inside the Port Blair bay (Chattam Island), which was set only for normal tidal variations, could record the sea water level up to 3.5 m on the day of tsunami. This is about 1.5 m more than normal tide level (llayaraja, 2009). Table 6.2 shows the run-up level at different sites of Andaman and Nicobar coast which were taken using Real-time Kinematic Global Positioning System and Fig.6.2 shows coastal land profile during the 2004 tsunami.

TABLE 6.2: The Run-up level of sea water during tsunami in A&N (Murthy et al, 2006).

| Location | Maximum run-up level (m) | Distance of sea water inundation inland (m) |
|---|---|---|
| Andaman and Nicobar Islands, South Andaman (Port Blair) | | |
| JNRM college, Aberdeen | 2.9 | 130 |
| Bamboo Flat | 3.5 | 250 |
| New Wandoor | 3.7 | 215 |
| Wandoor | 3.9 | 215 |
| Chidiyatopu | 4.5 | 130 |
| Sippyghat (Creek) | 2.0 | 2000 |
| North Andaman | | |
| Digilipur | 1.5 | 100 |
| Rangat | 1.5 | 200 |
| Little Andaman | | |
| Hut Bay | 5.0 | 1200 |
| Car Nicobar | | |
| Malacca | 7.0 | 1000 |
| Great Nicobar | | |
| Campbell bay (Central) | 3.0 | 300 |
| Campbell bay (North) | 6.0 | 50 |




(Source: current science, June 2005)

Figure 6.2: shows Coastal land profile at Chidiyatopu (South Andaman), Hut Bay (Little Andaman), Malacca (Car Nicobar) and Campbell Bay (Great Nicobar).

(Source: Current science, may 2005)

Figure 6.3: Inundation of land and waterlogging up to 1.0 m in low-lying areas around Sippyghat near Port Blair.

Further, from the aerial as well as field surveys along the North, Middle and South Andaman Islands exhibits land subsidence and Inundation of land due to rise in water level and water-logging up to 1.0 m were common in the low-lying areas of Port Blair area., the (source: current science., may 2005). Fig 6.3 shows Inundation of land and waterlogging up to 1.0 m in low-lying areas near Port Blair.

## 6.3 STUDY OF TIDAL DATA AT PORT BLAIR

Frequency study of the water level during monsoon at Port Blair using Gumbel's probability method for different return period, of 5 yrs., 10 yrs., 25 yrs., 50 yrs., and 100 yrs. has been made as shown in Annexure-6A

It is apparent from the study that maximum predicted water level of 2.52 m is of the frequency of 100 yrs. return period and the A.H.W.L of 2.48 m. during the month of July to October is of the frequency of 5-yrs return period.

However, to provide a balance between the economy and safety up to a dependable degree of confidence commensurate with requirement under different situation, it is proposed to fix up the high water level at 2.52 m. having a frequency of 100-yrs return period for the design of undersluice at different places of Andaman and Nicobar Islands under Water Shed Development Projects.

### 6.3.1 Analysis of Daily High and Low Tide Table for Period from 2005 to 2015

The daily tide water levels at Port Blair (Andaman Islands) for the year 2005 to 2015 have been downloaded from **website tides.mobilegeographics.com**. Data corresponding to new moon day & full moon day are shown in Annexure 6B. Average of the H.W.L is 2.4m (i.e. in the month of August & October), Similarly, average of L.W.L is 0.1m (in the month of March).

In the Annexure 6B, figure 6B-1 shows graphical depiction of New Moon Tidal events in each month from the year 2005 to 2015 and figure 6B-2 shows graphical depiction of Full Moon Tidal events in each month from the year 2005 to 2015.

Entire daily data were analyzed to find highest and lowest tidal level in each month of the years 2005 to 2015 as shown in table 6.3. The highest and lowest tidal level in each month of the years 2005 to 2015 are graphically depicted in figure 6.4

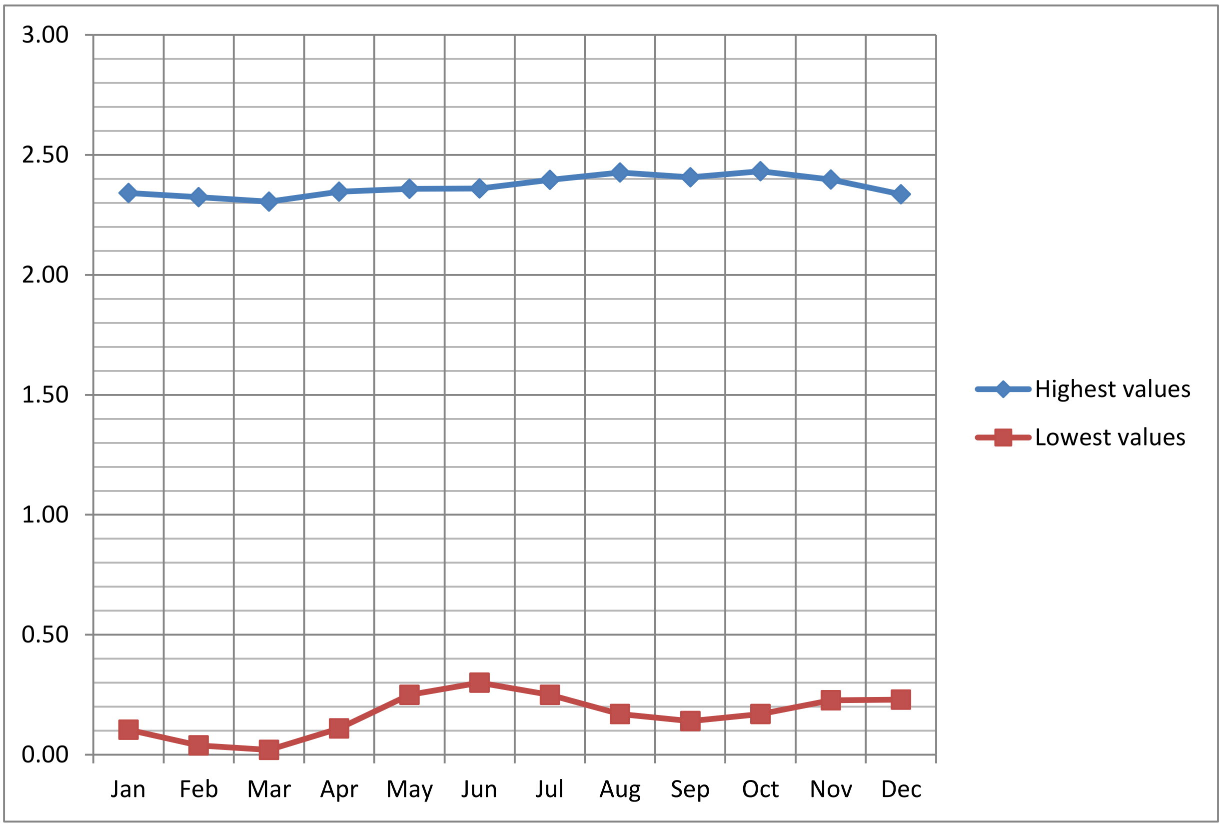



Figure 6.4: Highest and lowest tidal level in each month of the years 2005 to 2015

**TABLE 6.3 : 2005-2015 MONTHLY HIGHEST AND LOWEST TIDAL VALUE**

| **Months** | **January tide level (m)** | | | | **February tide level (m)** | | | | **March tide level (m)** | | | | **April tide level (m)** | | | | **May tide level (m)** | | | | **June tide level (m)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Years** | Date | High | Date | Low | Date | High | Date | Low | Date | High | Date | Low | Date | High | Date | Low | Date | High | Date | Low | Date | High | Date | Low |
| **2005** | 11 | 2.36 | 12 | 0.14 | 9 | 2.34 | 11 | 0.06 | 10 | 2.28 | 12 | 0.05 | 26 | 2.3 | 9 | 0.14 | 25 | 2.35 | 8 | 0.3 | 23 | 2.38 | 23 | 0.31 |
| **2006** | 31 | 2.36 | 31 | 0.06 | 28 | 2.35 | 1 | 0.05 | 1 | 2.34 | 2 | -0.02 | 29 | 2.34 | 1 | 0.12 | 27 | 2.28 | 14 | 0.34 | 13 | 2.28 | 13 | 0.39 |
| **2007** | 20 | 2.29 | 22 | 0.13 | 18 | 2.33 | 20 | 0.01 | 21 | 2.34 | 20 | -0.01 | 18 | 2.4 | 18 | 0.07 | 17 | 2.38 | 17 | 0.23 | 16 | 2.32 | 16 | 0.37 |
| **2008** | 23 | 2.26 | 24 | 0.18 | 8 | 2.23 | 10 | 0.11 | 10 | 2.26 | 9 | 0.04 | 8 | 2.36 | 7 | 0.07 | 6 | 2.4 | 6 | 0.17 | 5 | 2.39 | 4 | 0.28 |
| **2009** | 12 | 2.36 | 13 | 0.1 | 10 | 2.32 | 11 | 0.05 | 29 | 2.25 | 12 | 0.09 | 26 | 2.33 | 26 | 0.19 | 26 | 2.37 | 25 | 0.27 | 24 | 2.41 | 24 | 0.26 |
| **2010** | 31 | 2.39 | 31 | 0.05 | 1 | 2.34 | 1 | 0.01 | 1 | 2.33 | 2 | -0.01 | 1 | 2.3 | 1 | 0.11 | 15 | 2.27 | 15 | 0.32 | 14 | 2.34 | 14 | 0.3 |
| **2011** | 21 | 2.35 | 22 | 0.06 | 19 | 2.35 | 20 | -0.02 | 21 | 2.35 | 21 | -0.01 | 19 | 2.39 | 19 | 0.1 | 18 | 2.36 | 18 | 0.25 | 17 | 2.3 | 16 | 0.36 |
| **2012** | 11 | 2.24 | 12 | 0.19 | 9 | 2.28 | 10 | 0.06 | 10 | 2.29 | 10 | 0.01 | 8 | 2.39 | 8 | 0.05 | 7 | 2.43 | 7 | 0.15 | 5 | 2.41 | 5 | 0.24 |
| **2013** | 12 | 2.36 | 13 | 0.11 | 10 | 2.28 | 12 | 0.09 | 29 | 2.29 | 29 | 0.09 | 27 | 2.38 | 27 | 0.14 | 26 | 2.43 | 26 | 0.19 | 24 | 2.44 | 25 | 0.21 |
| **2014** | 2 | 2.41 | 3 | 0.08 | 1 | 2.37 | 2 | 0.02 | 1 | 2.31 | 2 | 0.03 | 1 | 2.27 | 1 | 0.11 | 16 | 2.34 | 16 | 0.24 | 14 | 2.4 | 15 | 0.23 |
| **2015** | 21 | 2.38 | 23 | 0.05 | 19 | 2.37 | 21 | -0.02 | 22 | 2.32 | 21 | 0.01 | 20 | 2.36 | 19 | 0.1 | 19 | 2.34 | 18 | 0.25 | 4 | 2.29 | 4 | 0.32 |
| **Avg.** | | **2.34** | | **0.10** | | **2.32** | | **0.04** | | **2.31** | | **0.02** | | **2.35** | | **0.11** | | **2.36** | | **0.25** | | **2.36** | | **0.30** |

| **Months** | **July tide level (m)** | | | | **August tide level (m)** | | | | **September tide level (m)** | | | | **October tide level (m)** | | | | **November tide level (m)** | | | | **December tide level (m)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Years** | Date | High | Date | Low | Date | High | Date | Low | Date | High | Date | Low | Date | High | Date | Low | Date | High | Date | Low | Date | High | Date | Low |
| **2005** | 23 | 2.44 | 23 | 0.23 | 21 | 2.46 | 21 | 0.16 | 18 | 2.38 | 19 | 0.14 | 18 | 2.38 | 17 | 0.19 | 3 | 2.33 | 3 | 0.28 | 2 | 2.31 | 2 | 0.31 |
| **2006** | 13 | 2.37 | 13 | 0.29 | 11 | 2.45 | 11 | 0.17 | 9 | 2.44 | 9 | 0.1 | 8 | 2.47 | 7 | 0.11 | 6 | 2.43 | 5 | 0.18 | 5 | 2.31 | 6 | 0.31 |
| **2007** | 31 | 2.32 | 31 | 0.3 | 30 | 2.4 | 30 | 0.15 | 20 | 2.46 | 28 | 0.11 | 27 | 2.49 | 26 | 0.14 | 25 | 2.42 | 25 | 0.23 | 25 | 2.31 | 25 | 0.25 |
| **2008** | 4 | 2.39 | 4 | 0.3 | 2 | 2.37 | 19 | 0.26 | 17 | 2.36 | 17 | 0.19 | 16 | 2.44 | 15 | 0.18 | 4 | 2.43 | 14 | 0.22 | 13 | 2.38 | 15 | 0.21 |
| **2009** | 23 | 2.45 | 24 | 0.2 | 21 | 2.43 | 21 | 0.17 | 20 | 2.36 | 19 | 0.18 | 19 | 2.34 | 18 | 0.26 | 4 | 2.36 | 3 | 0.28 | 3 | 2.35 | 4 | 0.26 |
| **2010** | 14 | 2.42 | 14 | 0.21 | 11 | 2.47 | 12 | 0.14 | 9 | 2.42 | 9 | 0.11 | 8 | 2.45 | 8 | 0.15 | 6 | 2.39 | 6 | 0.24 | 22 | 2.28 | 24 | 0.23 |
| **2011** | 4 | 2.31 | 31 | 0.28 | 30 | 2.42 | 30 | 0.13 | 29 | 2.47 | 20 | 0.11 | 21 | 2.48 | 27 | 0.15 | 25 | 2.4 | 27 | 0.22 | 25 | 2.31 | 26 | 0.23 |
| **2012** | 5 | 2.38 | 5 | 0.28 | 3 | 2.35 | 19 | 0.23 | 18 | 2.39 | 17 | 0.17 | 16 | 2.46 | 16 | 0.15 | 14 | 2.46 | 15 | 0.17 | 14 | 2.41 | 15 | 0.15 |
| **2013** | 24 | 2.45 | 24 | 0.2 | 22 | 2.4 | 22 | 0.2 | 20 | 2.31 | 20 | 0.23 | 6 | 2.36 | 6 | 0.23 | 4 | 2.41 | 4 | 0.21 | 4 | 2.41 | 5 | 0.17 |
| **2014** | 14 | 2.46 | 14 | 0.18 | 12 | 2.48 | 12 | 0.14 | 10 | 2.42 | 10 | 0.13 | 9 | 2.41 | 9 | 0.17 | 7 | 2.35 | 7 | 0.25 | 23 | 2.35 | 24 | 0.16 |
| **2015** | 4 | 2.37 | 4 | 0.27 | 31 | 2.46 | 31 | 0.12 | 29 | 2.46 | 29 | 0.1 | 28 | 2.47 | 28 | 0.14 | 26 | 2.39 | 27 | 0.21 | 25 | 2.28 | 27 | 0.24 |
| **Avg.** | | **2.40** | | **0.25** | | **2.43** | | **0.17** | | **2.41** | | **0.14** | | **2.43** | | **0.17** | | **2.40** | | **0.23** | | **2.34** | | **0.23** |

## 6.4 STORM RAINFALL & RUNOFF

Design storm and flood scenarios are required for (i) planning of storm water drainage in the plant area and the area in vicinity and (ii) for protecting the plant area from external flooding. This covers estimation of storm rainfall of various return periods for draining of storm water from the solar plant area to avoid flooding.

### 6.4.1 Frequency Analysis of Annual maximum 1-day rainfall at Port Blair

26years (1989 to 2014) data series of annual maximum 1-day rainfall at Port Blair has been analyzed as shown in Table 6.4 and Figure 6.5. Data from the period 1989 to 1999 has been taken from unpublished report. Daily rainfall data for the period from 2000 to 2014 has been procured from IMD. The 1-day rainfall and 1-hr rainfall of various return periods are given in Table 6.5 below.

TABLE 6.4: Frequency Analysis of Annual Maximum 1-Day Rainfall at Port Blair

| Year | Max. 1day rainfall | rank m | series in descending order | Plotting position m/n+1 = m/27 | Return period 27/m |
|---|---|---|---|---|---|
| 1989 | 129.88 | 1 | 237.6 | 0.0370 | 27.00 |
| 1990 | 84.3 | 2 | 212.9 | 0.0741 | 13.50 |
| 1991 | 145.6 | 3 | 206.8 | 0.1111 | 9.00 |
| 1992 | 126.7 | 4 | 204.9 | 0.1481 | 6.75 |
| 1993 | 128.4 | 5 | 197.3 | 0.1852 | 5.40 |
| 1994 | 195.6 | 6 | 195.6 | 0.2222 | 4.50 |
| 1995 | 237.6 | 7 | 192.2 | 0.2593 | 3.86 |
| 1996 | 119 | 8 | 179.1 | 0.2963 | 3.38 |
| 1997 | 192.2 | 9 | 163.5 | 0.3333 | 3.00 |
| 1998 | 107.9 | 10 | 156.5 | 0.3704 | 2.70 |
| 1999 | 66 | 11 | 145.6 | 0.4074 | 2.45 |
| 2000 | 112.5 | 12 | 138.3 | 0.4444 | 2.25 |
| 2001 | 138.3 | 13 | 129.88 | 0.4815 | 2.08 |
| 2002 | 124.4 | 14 | 128.4 | 0.5185 | 1.93 |
| 2003 | 107.8 | 15 | 126.7 | 0.5556 | 1.80 |
| 2004 | 108.2 | 16 | 125.2 | 0.5926 | 1.69 |

| | | | | | |
|---|---|---|---|---|---|
| 2005 | 197.3 | 17 | 124.4 | 0.6296 | 1.59 |
| 2006 | 156.5 | 18 | 119 | 0.6667 | 1.50 |
| 2007 | 114.7 | 19 | 114.7 | 0.7037 | 1.42 |
| 2008 | 206.8 | 20 | 112.5 | 0.7407 | 1.35 |
| 2009 | 125.2 | 21 | 108.2 | 0.7778 | 1.29 |
| 2010 | 95.3 | 22 | 107.9 | 0.8148 | 1.23 |
| 2011 | 163.5 | 23 | 107.8 | 0.8519 | 1.17 |
| 2012 | 179.1 | 24 | 95.3 | 0.8889 | 1.13 |
| 2013 | 212.9 | 25 | 84.3 | 0.9259 | 1.08 |
| 2014 | 204.9 | 26 | 66 | 0.9630 | 1.04 |

TABLE 6.5: ONE-Day Rainfall and 1-hr Rainfall of Various Return Periods

| Return Period (year) | 20 | 25 | 50 | 75 | 100 | 1000 |
|---|---|---|---|---|---|---|
| 1-day rainfall (mm) | 218 | 228 | 247 | 260 | 268 | 335 |
| 1-hr rainfall (mm) | 113.5 | 118.7 | 128.6 | 135.4 | 139.6 | 174.5 |

The largest 1-day storm rainfall value is 335 corresponding to a return period of 1000 years, storm water drains are not designed for unusual occurrences of rare storms on account of high cost of large size drains/pipes as well as non-utilization of their full capacity for most of the years, besides having risk of siltation and clogging of drains/pipes due to non-generation of self-cleansing velocity in partly flowing condition.

It is suggested that 247 mm rainfall of 1-day duration corresponding to 50 year return period as obtained from frequency analysis of 26 years’ annual maximum 1-Day rainfall data series may be adopted for design purposes.

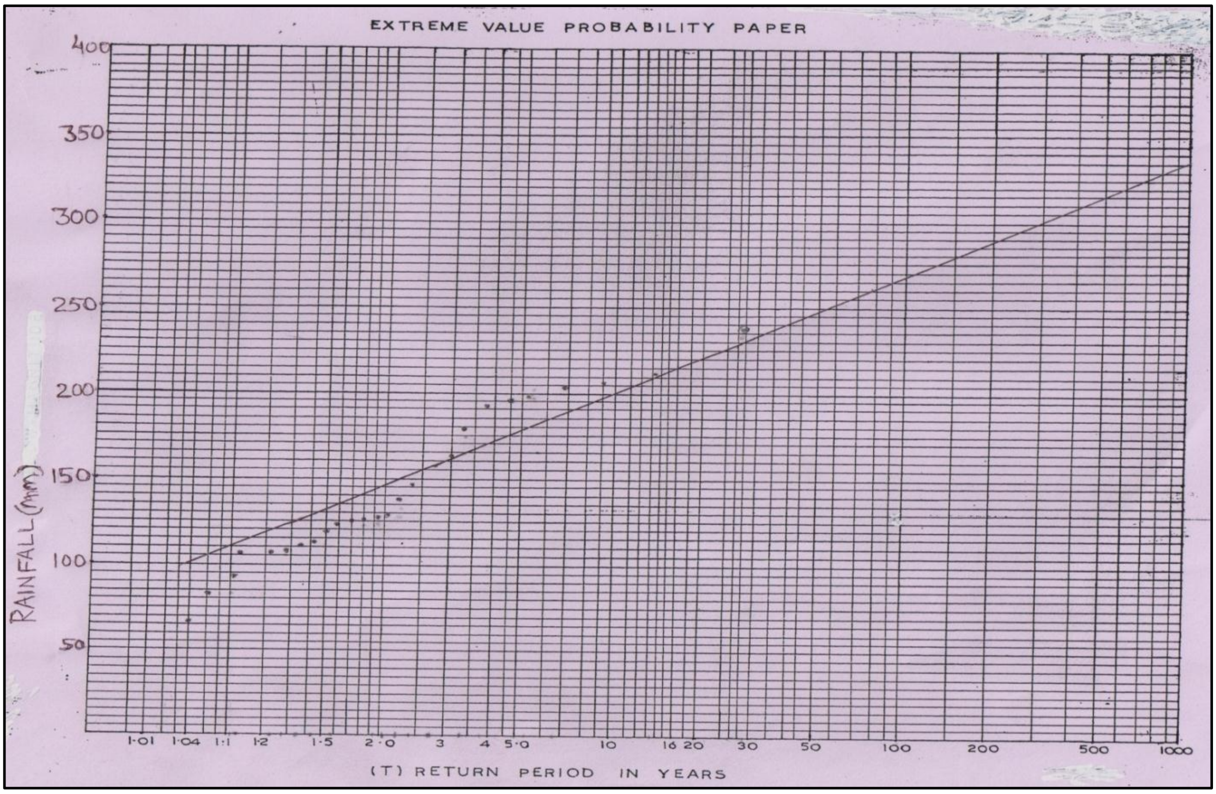



Figure 6.5: Frequency analysis of 1-day annual maximum rainfall at Port Blair.

In the present study, the main aim is to understand the flooding situation in the Port Blair referring to previous literature. In Port Blair it is evident that the major destruction was caused due to the great Sumatra tsunami and earthquake (Mw 9.2) of December 2004 inundating the coast land which includes agriculture land, townships and properties, low-lying coastal zone is more prone to coastal hazards, hence, any projects taken up in low-lying area, one should have proper knowledge regarding coastal hazard behavioral characteristics and possible remedial measures that can be adopted to control the intensity of coastal flooding. An attempt is made in this present study considering a case study in Port Blair to protect the plant area from this flooding and last the project for long-term, and suggest the structural/non-structural measures to divert the excess flooded water safely out of the plant area. The plant characteristics locations have been described in chapter-3 briefly. Fig 6.6 shows the components parts of plant distributed area wise.

The total plant area is about 126.21 ha as mentioned in the Fig.6.6, the solar plant area is about 40.65 ha, and remaining area is about 85.56 ha, the watershed boundary divides the plant area into two parts and the area of divided at watershed location of Mithakhari nala is about 31.57 ha as shown in fig.6.6 and remaining portion is about 94.64 ha. The volume of run-off that can be generated considering 1-day storm runoff. Depth of rainfall is 247 mm corresponding to 50 year return period. It is assumed that all rainfall shall be converted into runoff due to ground level being very near to mean sea level and very shallow water table.

The storm runoff is computed for the worst possible condition as below:

Runoff volume from catchment area of Mithakharinala (considering no loss)

= 247 mm x $10^{-3}$ m rain x 31.57 ha

= 77977.9 $m^3$

Runoff volume from the remaining catchment area (considering no loss)

= $247 x 10^{-3}$ m rain x (126.21 - 31.57 - 40.65) ha

= 133354.8 $m^3$

Runoff volume from the Solar Plant area (considering no loss)

= $247 x 10^{-3}$ m rain x 40.65 ha Solar Plant area x $10^4$ $m^2$

= 100406 $m^3$

Total runoff volume = 77977.9 + 133354.8 + 100406 = 311738.7 $m^3$

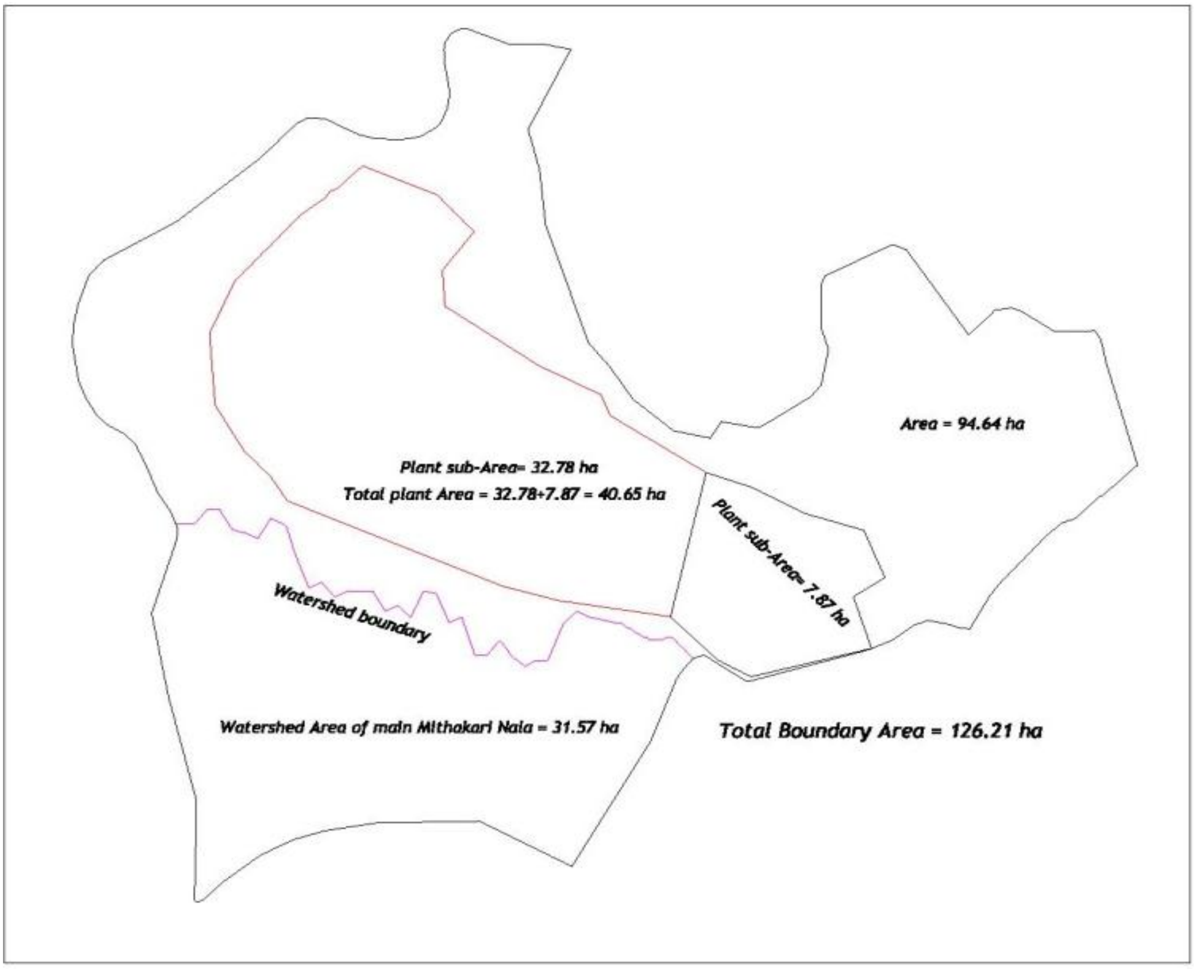



Figure 6.6: Mithakhari solar power plant area details

The solar plant area is entirely flat (referring. Mithakharinala which joins the sea through an undersluice and entire plant area storm water is drained through the undersluice which is already existing in the plant. The details of existing structure taken from unpublished report are as follows.

Crest level of undersluice = (+) 0.30 m

Slope of channel = 0.1 / 1000, Length of channel = 2.1 km (approx.)

Drop in water level = (0.1 / 1000) x 2.1 x 1000 m = 0.21 m

Water level at off-take of canal = (+) 0.30 + 0.21 = (+) 0.51 m

From the topographic survey data area of spread at (+) 0.51 m = 28.59 ha

Thus, the area of 28.59 ha (up to R.L (+) 0.51m) remains under perpetual flooding and it cannot be drained through the existing undersluice, maximum of this area lies at solar plant and also causing waterlogging. The undersluice is operated manually such that the entry of sea water to the proposed plant area is restricted. Its gates are closed when there is a high tide so that the sea water does not enter the plant area and these gates are opened during low tide. Referring to previous literature it is seen, Inundation of land and waterlogging up to 1.0 m in low-lying areas to Sumatra tsunami of 2004 (figure 6.3). Therefore, it can be recommended that the solar plant area may be kept the level of 1.0 m, provided with proper sluice gate in order to divert the excess flood water.

## 6.5 CONCLUSION.

In planning for the flood protection scheme for the solar plant site, the following options can be visualized. These options are not mutually exclusive and an appropriate combination can be considered:

- Raising the level of land at solar plant site by earth filling. Earth filling up to (+) 0.5 m necessary to avoid perpetual waterlogging. Earth filling above (+) 0.5m level would help in reducing depth and duration of temporary flooding in the plant area.
- Peripheral embankment around the plant site coupled with pumping.
- Diversion of Mithakharinala to sea on right side. The diversion can be done at a location just below road culvert or at a location further downstream which will require sluice for control of flooding due to high tide inflow.
- Draining of Mithakhari watershed runoff through the existing undersluice and that of the remaining area (including solar plant) runoff through a separate storm water channel and undersluice to sea.

# CHAPTER-7

# SUMMARY AND CONCLUSION

The main objective of this dissertation work is to illustrate use of modern analytical tools in planning and design of i) internal drainage and ii) measures for controlling external flooding of industrial area located in coastal region.

To take up any industrial project in the coastal region the problem of flooding has put a question mark on sustainability of prestigious project. Depending upon the terrain/topography and type of project taken up requires proper understanding and knowledge about the area and its vulnerability towards flooding in in order to make the project sustainable. For this study, depending upon the terrain/topography two case studies were considered.

i. The first case study pertains to planning and design of internal drainage of a thermal power plant proposed near village Pudimadaka, Vishakhapatnam, Andra Pradesh(study area-I).

   50 year return period total water levels(TWLs) along the coast of Vishakhapatnam district range from 4.5 m to 4.8m. The total water level is projected on to the adjacent coastal area and plant site by using topography to demarcate the horizontal extent of inundation. This conservative approach may slightly overestimate the extension of 105 inundations, but it is desirable for hazard mitigation as well as coastal zone management and is widely used around the world (Jain et al. 2010).

   SRTM data based DEM study of the study area has been carried out, and topographic contours generated., elevations ranges were from 0 m to 173 m. Contours of 5m,10m, 15m, 20m and above elevations on north and west side of the plant indicates that the area is safe considering cyclone surges (4.5m to 4.8m) of 50 year return period. Contours ranging from 1m to 5 m on south side of plant up to sea coast. It is seen that area adjacent to southern boundary and eastern boundary of the plant have elevations lower than 4m (1m to 4m). The cyclone surges may travel up along Pudimadaka creek and inundate the low-lying areas. These low lying areas are susceptible to flooding and inundation for several days when flood water in streams is unable to discharge to sea due to high tides and cyclone surges.

   The finished grade levels (FGL) of various parts in the plant are in the range of 6.0m on east side to 14.0 m in coal yard area. Thus, there is no danger of cyclonic flooding in the plant area. The green belt on east side will have FGL of 6.0 m and hence safe against flooding but it is not so in the green belt on south side. Greenbelt in south east part has natural ground level between 2m to 4m. The ground level outside southern boundary is in the range of 1.5m to 2.5m. Therefore, this part is prone to flooding when sea water level is high and there is heavy rainfall in vicinity of the plant area.

Rambilli nala flows along southern boundary of the plant in east west direction. that flooding occurs mainly because flood water cannot flow towards sea due to high water level in sea. Land remains submerged for several days. Thus, a protection wall can be built along south side boundary to avoid submergence of the green belt.

Based on the 25 year return period flood generated using SWMM model. Various channels/conduits were designed. The maximum velocity attained in each channel is generally below or near to 2 m/s. In this study, trial values of channel dimensions were employed such that no channel/node exhibits surcharge or flooding or overflow, the analysis showed infiltration loss 11.437 ha-m and surface runoff is 38.87 ha-m. Evaporation loss during the flood event is assumed to be negligible.51.6 ha-m is accounted as total precipitation, as per the SWMM results it is found that layout of drainage channels is hydraulically satisfactory.

ii. The second case study pertains to planning and design of measures for controlling external flooding in Mithakhari solar plant, at Port Blair, Andaman and Nicobar.

A number of alternatives/options were explored for safe disposal of storm runoff to sea starting from the simplest of water-proofing of the area to the isolation of the plant area with diversion of Mithakhari nala, a separate arrangement for storm runoff channels and undersluice, increase in the frame-work of solar panels, and so on. These were evaluated in terms of availability of earth-work; involvement of cost in construction of the associated structures, O&M, and R&R issues. Finally, a flood control scheme without diversion Mithakhari nala as given below is recommended:

- Raise the ground level of Solar Plant area by 0.70 m requiring 74700 $m^3$ of earth fill.
- Raise the solar panels by 0.44 m (=1.14 – 0.70) = 0.45 m (say) from the raised ground level of the Solar Plant area to avoid flooding due to 1 in 50-year flood. Normally, a clearance of 0.5 m above ground level is provided for the tilted panel. Here, to avoid flooding, additional 20 cm clearance for free board is desirable. Thus, height of solar panel = 0.65 m.
- The existing approach road dividing the Solar Plant area into two parts may be strengthened and retained for inspection purpose.
- The above scheme is economical and robust, it requires earth filling and peripheral drains without involvement of any additional flood control structure and without affecting the design of solar panels/frame-work, and thus, may be preferred.

**ANNEXURE – 6A**

**FREQUENCY ANALYSIS OF ANNUAL MAX TIDAL LEVELS 2005 to 2015**

Annual maximum tidal levels for the years 2005 to 2015 are shown in table. Graphical frequency analysis on Gumble probability paper has been carried out. Highest water level of different return period is as given below.

Wp (5) = 2.48

Wp (10) = 2.49

Wp (25) = 2.5

Wp (50) = 2.51

Wp (100) = 2.52.

| Sl. No | Date of Reoccurrence | Maximum Water level in m | Maximum Water level in meter arranged in ascending order(Wp) | No. of times the maximum W.L. is equaled or exceeded i.e. ranking of W.L (b) | Reoccurrence internal i.e. frequency $a=\frac{Y+1}{b}$ | Chance percentage or exceedance Probability $\frac{100}{a}$ | $Wp^2$ |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 1 | 21-08-2005 | 2.46 | 2.49 | 1 | 12 | 8.33 | 6.20 |
| 2 | 08-10-2006 | 2.47 | 2.48 | 2 | 6 | 16.67 | 6.15 |
| 3 | 27-10-2007 | 2.49 | 2.48 | 3 | 4 | 25.00 | 6.15 |
| 4 | 16-10-2008 | 2.44 | 2.47 | 4 | 3 | 33.33 | 6.10 |
| 5 | 23-07-2009 | 2.45 | 2.47 | 5 | 2.4 | 41.67 | 6.10 |
| 6 | 12-08-2010 | 2.47 | 2.47 | 6 | 2 | 50.00 | 6.10 |
| 7 | 27-10-2011 | 2.48 | 2.46 | 7 | 1.71 | 58.33 | 6.05 |
| 8 | 14-11-2012 | 2.46 | 2.46 | 8 | 1.5 | 66.67 | 6.05 |
| 9 | 24-07-2013 | 2.45 | 2.45 | 9 | 1.33 | 75.00 | 6.00 |
| 10 | 12-08-2014 | 2.48 | 2.45 | 10 | 1.2 | 83.33 | 6.00 |
| 11 | 28-10-2015 | 2.47 | 2.44 | 11 | 1.09 | 91.67 | 5.95 |
| Y=11 | | 27.12 | 27.12 | | | | 66.87 |

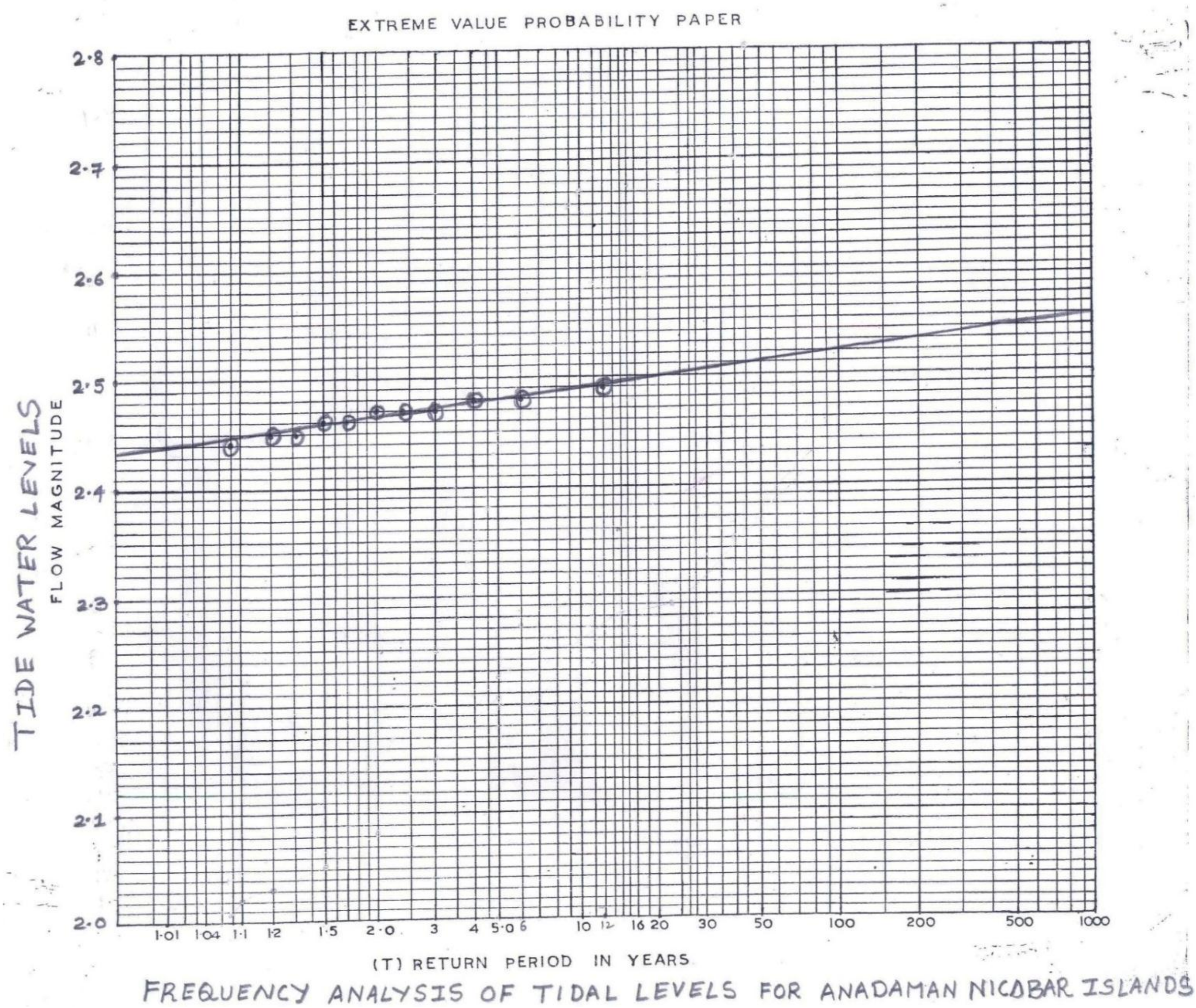



Figure .. Frequency analysis of annual maximum tidal levels (2005 to 2015).

**ANNEXURE – 6B**

## ANALYSIS OF DAILY TIDE LEVEL FROM 2005 TO 2015

Two tides called "Semi-diurnal tides are found to differ from each other. Another interesting feature of tides lies in the fact that the tidal range at any location fluctuates steadily and gradually from day to day in accordance with the lunar phase. The tidal range at the full and new moon is found to be the maximum. This phase is called the "Spring Tide". After the occurrence of the Neap Tide at the middle of moon cycle when the tidal range is the minimum.

The tidal curve at the sea face of a tidal estuary in Bay of Bengal is found to have a symmetrical harmonic shape, the periods of both flow and Ebb tide being practically equal. As it goes upwards, the period of Ebb tide increases more than flow tides. Thus the flow velocities are more than the subsequent Ebb velocities along the tidal channel as proceeded upward. There is another interesting point in this connection viz. the tidal range starts increasing steadily and gradually upwards from the sea face, attains maximum value at the certain point and starts diminishing thereafter till at the terminal point of tidal propagation it becomes practically nil.

## STUDY OF TIDAL DATA AT PORT BLAIR

The daily tide water levels at port Blair (Andaman Islands) for the year 2005 to 2015 have been downloaded from tides.mobilegeographics.com. Ongoing through readings it would be apparent that there are two consecutive values (i.e. new moon & full moon) in each month during which H.W.L (High water level) is high compared to other days of the same month.

Data corresponding to new moon day & full moon day are shown in table 6B-1. Average of the H.W.L is 2.4m (i.e. in the month of August & October), Similarly, average of L.W.L is 0.1m (in the month of March).

Figure 6B-1 shows graphical depiction of New Moon Tidal events in each month from the year 2005 to 2015. Figure 6B-2 shows graphical depiction of Full Moon Tidal events in each month from the year 2005 to 2015.

Table 6B-1 Low and High Tide Levels on full moon day and new moon day

| **Year** | **Month** | **Day** | **Low** | | | **High** | | | **Low** | | | **High** | | | **Moon** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | January | Mon 10 | 2:55 | AM | 0.29 | 8:45 | AM | 1.8 | 2:45 | PM | 0.32 | 9:05 | PM | 2.31 | New Moon |
| 2006 | January | Sun 29 | 3:02 | AM | 0.27 | 8:54 | AM | 1.82 | 2:55 | PM | 0.3 | 9:09 | PM | 2.29 | New Moon |
| 2007 | January | Fri 19 | 3:20 | AM | 0.32 | 9:10 | AM | 1.77 | 3:10 | PM | 0.35 | 9:24 | PM | 2.23 | New Moon |
| 2008 | January | Tue 8 | 3:09 | AM | 0.46 | 9:00 | AM | 1.65 | 2:53 | PM | 0.47 | 9:12 | PM | 2.09 | New Moon |
| 2009 | January | Mon 26 | 3:22 | AM | 0.4 | 9:20 | AM | 1.71 | 3:11 | PM | 0.43 | 9:27 | PM | 2.08 | New Moon |
| 2010 | January | Fri 15 | 3:18 | AM | 0.43 | 9:16 | AM | 1.68 | 3:02 | PM | 0.47 | 9:25 | PM | 2.08 | New Moon |
| 2011 | January | Tue 4 | 3:06 | AM | 0.39 | 9:01 | AM | 1.74 | 2:51 | PM | 0.44 | 9:13 | PM | 2.16 | New Moon |
| 2012 | January | Mon 23 | 3:11 | AM | 0.28 | 9:07 | AM | 1.85 | 3:04 | PM | 0.34 | 9:20 | PM | 2.22 | New Moon |
| 2013 | January | Sat 12 | 3:20 | AM | 0.16 | 9:17 | AM | 1.97 | 3:18 | PM | 0.22 | 9:33 | PM | 2.36 | New Moon |
| 2014 | January | Wed 1 | 2:47 | AM | 0.24 | 8:40 | AM | 1.94 | 2:44 | PM | 0.22 | 9:00 | PM | 2.37 | New Moon |
| 2014 | January | Fri 31 | 3:19 | AM | 0.1 | 9:17 | AM | 2.05 | 3:22 | PM | 0.15 | 9:33 | PM | 2.38 | New Moon |
| 2015 | January | Tue 20 | 2:52 | AM | 0.2 | 8:45 | AM | 1.9 | 2:51 | PM | 0.2 | 9:04 | PM | 2.3 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | February | Wed 9 | 3:31 | AM | 0.14 | 9:28 | AM | 1.95 | 3:28 | PM | 0.23 | 9:41 | PM | 2.34 | New Moon |
| 2006 | February | Tue 28 | 3:22 | AM | 0.06 | 9:23 | AM | 2.1 | 3:28 | PM | 0.14 | 9:35 | PM | 2.35 | New Moon |
| 2007 | February | Sat 17 | 3:02 | AM | 0.23 | 8:59 | AM | 1.9 | 3:01 | PM | 0.27 | 9:10 | PM | 2.26 | New Moon |
| 2008 | February | Thu 7 | 3:25 | AM | 0.28 | 9:21 | AM | 1.84 | 3:21 | PM | 0.33 | 9:29 | PM | 2.18 | New Moon |
| 2009 | February | Wed 25 | 3:24 | AM | 0.25 | 9:25 | AM | 1.93 | 3:28 | PM | 0.3 | 9:31 | PM | 2.12 | New Moon |
| 2010 | February | Sun 14 | 3:25 | AM | 0.32 | 9:29 | AM | 1.83 | 3:23 | PM | 0.37 | 9:34 | PM | 2.07 | New Moon |
| 2011 | February | Thu 3 | 3:25 | AM | 0.33 | 9:26 | AM | 1.81 | 3:17 | PM | 0.39 | 9:33 | PM | 2.12 | New Moon |
| 2012 | February | Wed 22 | 3:24 | AM | 0.23 | 9:28 | AM | 1.96 | 3:26 | PM | 0.3 | 9:36 | PM | 2.15 | New Moon |
| 2013 | February | Sun 10 | 3:08 | AM | 0.17 | 9:07 | AM | 1.99 | 3:10 | PM | 0.23 | 9:21 | PM | 2.28 | New Moon |
| 2015 | February | Thu19 | 3:16 | AM | 0.1 | 9:16 | AM | 2.1 | 3:24 | PM | 0.1 | 9:31 | PM | 2.4 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | March | Thu 10 | 3:11 | AM | 0.12 | 9:12 | AM | 2.06 | 3:17 | PM | 0.2 | 9:24 | PM | 2.28 | New Moon |
| 2006 | March | Wed 29 | 2:54 | AM | 0.07 | 9:00 | AM | 2.22 | 3:11 | PM | 0.14 | 9:13 | PM | 2.26 | New Moon |
| 2007 | March | Mon 19 | 3:08 | AM | 0.05 | 9:13 | AM | 2.21 | 3:23 | PM | 0.11 | 9:25 | PM | 2.29 | New Moon |
| 2008 | March | Fri 7 | 2:57 | AM | 0.22 | 8:57 | AM | 1.99 | 3:04 | PM | 0.26 | 9:07 | PM | 2.18 | New Moon |
| 2009 | March | Thu 26 | 2:49 | AM | 0.24 | 8:55 | AM | 2.06 | 3:05 | PM | 0.28 | 9:03 | PM | 2.07 | New Moon |
| 2010 | March | Tue 16 | 3:18 | AM | 0.25 | 9:25 | AM | 2.02 | 3:31 | PM | 0.29 | 9:32 | PM | 2.04 | New Moon |
| 2011 | March | Sat 5 | 3:23 | AM | 0.27 | 9:31 | AM | 1.96 | 3:29 | PM | 0.32 | 9:37 | PM | 2.06 | New Moon |
| 2012 | March | Thu 22 | 2:53 | AM | 0.29 | 9:04 | AM | 2.01 | 3:06 | PM | 0.33 | 9:13 | PM | 2.03 | New Moon |
| 2013 | March | Tue 12 | 3:18 | AM | 0.16 | 9:25 | AM | 2.11 | 3:30 | PM | 0.22 | 9:37 | PM | 2.17 | New Moon |
| 2014 | March | Sat 1 | 3:01 | AM | 0.1 | 9:03 | AM | 2.11 | 3:11 | PM | 0.15 | 9:18 | PM | 2.31 | New Moon |
| 2014 | March | Mon 31 | 3:12 | AM | 0.11 | 9:21 | AM | 2.24 | 3:32 | PM | 0.16 | 9:36 | PM | 2.18 | New Moon |
| 2015 | March | Fri 20 | 2:53 | AM | 0.10 | 8:58 | AM | 2.2 | 3:09 | PM | 0.10 | 9:14 | PM | 2.3 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | April | Sat 9 | 3:10 | AM | 0.1 | 9:21 | AM | 2.2 | 3:31 | PM | 0.2 | 9:33 | PM | 2.1 | New Moon |
| 2006 | April | Fri 28 | 2:55 | AM | 0.2 | 9:11 | AM | 2.3 | 3:29 | PM | 0.2 | 9:26 | PM | 2.1 | New Moon |
| 2007 | April | Tue 17 | 2:35 | AM | 0.1 | 8:46 | AM | 2.3 | 3:03 | PM | 0.1 | 9:01 | PM | 2.2 | New Moon |
| 2008 | April | Sun 6 | 2:53 | AM | 0.1 | 9:02 | AM | 2.3 | 3:18 | PM | 0.2 | 9:15 | PM | 2.2 | New Moon |
| 2009 | April | Sat 25 | 2:43 | AM | 0.2 | 8:55 | AM | 2.3 | 3:17 | PM | 0.2 | 9:10 | PM | 2.0 | New Moon |
| 2010 | April | Wed 14 | 2:42 | AM | 0.3 | 8:53 | AM | 2.1 | 3:08 | PM | 0.3 | 9:03 | PM | 2.0 | New Moon |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2011 | April | Sun 3 | 2:48 | AM | 0.3 | 9:02 | AM | 2.0 | 3:07 | PM | 0.4 | 9:10 | PM | 2.0 | New Moon |
| 2012 | April | Sat 21 | 2:44 | AM | 0.4 | 9:02 | AM | 2.1 | 3:13 | PM | 0.4 | 9:13 | PM | 1.9 | New Moon |
| 2013 | April | Wed 10 | 2:48 | AM | 0.3 | 9:01 | AM | 2.1 | 3:10 | PM | 0.3 | 9:13 | PM | 2.0 | New Moon |
| 2014 | April | Tue 29 | 2:43 | AM | 0.3 | 8:58 | AM | 2.2 | 3:14 | PM | 0.3 | 9:14 | PM | 2.0 | New Moon |
| 2015 | April | Sun 19 | 3:04 | AM | 0.10 | 9:16 | AM | 2.3 | 3:33 | PM | 0.10 | 9:24 | PM | 2.2 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | May | Sun 8 | 2:36 | AM | 0.3 | 8:54 | AM | 2.22 | 3:10 | PM | 0.34 | 9:08 | PM | 1.94 | New Moon |
| 2006 | May | Sat 27 | 2:26 | AM | 0.36 | 8:49 | AM | 2.28 | 3:14 | PM | 0.37 | 9:08 | PM | 1.87 | New Moon |
| 2007 | May | Thu 17 | 2:43 | AM | 0.23 | 9:03 | AM | 2.38 | 3:28 | PM | 0.24 | 9:23 | PM | 1.98 | New Moon |
| 2008 | May | Mon 5 | 2:20 | AM | 0.2 | 8:36 | AM | 2.33 | 2:59 | PM | 0.22 | 8:53 | PM | 2.05 | New Moon |
| 2009 | May | Sun 24 | 2:14 | AM | 0.33 | 8:32 | AM | 2.3 | 3:01 | PM | 0.32 | 8:52 | PM | 1.93 | New Moon |
| 2010 | May | Fri 14 | 2:40 | AM | 0.35 | 8:56 | AM | 2.22 | 3:22 | PM | 0.35 | 9:11 | PM | 1.89 | New Moon |
| 2011 | May | Tue 3 | 2:40 | AM | 0.37 | 8:57 | AM | 2.12 | 3:15 | PM | 0.39 | 9:08 | PM | 1.85 | New Moon |
| 2012 | May | Mon 21 | 2:43 | AM | 0.45 | 9:05 | AM | 2.13 | 3:25 | PM | 0.44 | 9:19 | PM | 1.8 | New Moon |
| 2013 | May | Fri 10 | 2:45 | AM | 0.38 | 9:06 | AM | 2.16 | 3:21 | PM | 0.39 | 9:21 | PM | 1.87 | New Moon |
| 2014 | May | Thu 29 | 2:50 | AM | 0.41 | 9:12 | AM | 2.22 | 3:32 | PM | 0.39 | 9:31 | PM | 1.87 | New Moon |
| 2015 | May | Mon 18 | 2:39 | AM | 0.3 | 8:56 | AM | 2.3 | 3:17 | PM | 0.3 | 9:15 | PM | 2.0 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | June | Tue 7 | 2:37 | AM | 0.49 | 9:05 | AM | 2.17 | 3:28 | PM | 0.48 | 9:22 | PM | 1.75 | New Moon |
| 2006 | June | Sun 25 | 2:07 | AM | 0.56 | 8:37 | AM | 2.18 | 3:08 | PM | 0.51 | 9:00 | PM | 1.74 | New Moon |
| 2007 | June | Fri 15 | 2:24 | AM | 0.42 | 8:50 | AM | 2.31 | 3:22 | PM | 0.38 | 9:15 | PM | 1.85 | New Moon |
| 2008 | June | Wed 4 | 2:39 | AM | 0.32 | 9:01 | AM | 2.39 | 3:33 | PM | 0.28 | 9:26 | PM | 1.93 | New Moon |
| 2009 | June | Tue 23 | 2:44 | AM | 0.39 | 9:04 | AM | 2.38 | 3:39 | PM | 0.30 | 9:32 | PM | 1.94 | New Moon |
| 2010 | June | Sat 12 | 2:18 | AM | 0.44 | 8:38 | AM | 2.24 | 3:10 | PM | 0.40 | 8:59 | PM | 1.86 | New Moon |
| 2011 | June | Thu 2 | 2:46 | AM | 0.45 | 9:04 | AM | 2.18 | 3:33 | PM | 0.43 | 9:21 | PM | 1.82 | New Moon |
| 2012 | June | Tue 19 | 2:23 | AM | 0.55 | 8:47 | AM | 2.11 | 3:12 | PM | 0.51 | 9:04 | PM | 1.76 | New Moon |
| 2013 | June | Sat 8 | 2:19 | AM | 0.52 | 8:46 | AM | 2.12 | 3:06 | PM | 0.50 | 9:03 | PM | 1.77 | New Moon |
| 2014 | June | Fri 27 | 2:31 | AM | 0.54 | 8:57 | AM | 2.16 | 3:19 | PM | 0.49 | 9:17 | PM | 1.81 | New Moon |
| 2015 | June | Tue 16 | 2:18 | AM | 0.4 | 8:40 | AM | 2.3 | 3:06 | PM | 0.4 | 9:02 | PM | 1.9 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | July | Wed 6 | 2:22 | AM | 0.64 | 8:54 | AM | 2.11 | 3:21 | PM | 0.58 | 9:16 | PM | 1.69 | New Moon |
| 2006 | July | Tue 25 | 2:44 | AM | 0.64 | 9:09 | AM | 2.16 | 3:37 | PM | 0.52 | 9:34 | PM | 1.79 | New Moon |
| 2007 | July | Sat 14 | 2:20 | AM | 0.57 | 8:44 | AM | 2.24 | 3:20 | PM | 0.46 | 9:13 | PM | 1.82 | New Moon |
| 2008 | July | Thu 3 | 2:31 | AM | 0.45 | 8:54 | AM | 2.35 | 3:30 | PM | 0.34 | 9:23 | PM | 1.91 | New Moon |
| 2009 | July | Wed 22 | 2:39 | AM | 0.42 | 8:56 | AM | 2.39 | 3:30 | PM | 0.27 | 9:25 | PM | 2.03 | New Moon |
| 2010 | July | Mon 12 | 2:53 | AM | 0.42 | 9:08 | AM | 2.37 | 3:42 | PM | 0.29 | 9:35 | PM | 2.01 | New Moon |
| 2011 | July | Fri 1 | 2:31 | AM | 0.52 | 8:49 | AM | 2.2 | 3:21 | PM | 0.44 | 9:10 | PM | 1.85 | New Moon |
| 2011 | July | Sun 31 | 3:01 | AM | 0.42 | 9:11 | AM | 2.34 | 3:40 | PM | 0.28 | 9:36 | PM | 2.09 | New Moon |
| 2012 | July | Thu 19 | 2:47 | AM | 0.54 | 9:02 | AM | 2.18 | 3:29 | PM | 0.44 | 9:23 | PM | 1.9 | New Moon |
| 2013 | July | Mon 8 | 2:38 | AM | 0.57 | 9:02 | AM | 2.13 | 3:24 | PM | 0.5 | 9:21 | PM | 1.81 | New Moon |
| 2014 | July | Sun 27 | 2:53 | AM | 0.55 | 9:14 | AM | 2.16 | 3:33 | PM | 0.47 | 9:34 | PM | 1.89 | New Moon |
| 2015 | July | Thu 16 | 2:44 | AM | 0.5 | 9:06 | AM | 2.2 | 3:29 | PM | 0.4 | 9:29 | PM | 1.9 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | August | Fri 5 | 2:54 | AM | 0.63 | 9:16 | AM | 2.14 | 3:39 | PM | 0.51 | 9:38 | PM | 1.82 | New Moon |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2006 | August | Thu 24 | 3:08 | AM | 0.55 | 9:24 | AM | 2.18 | 3:40 | PM | 0.42 | 9:44 | PM | 1.98 | New Moon |
| 2007 | August | Mon 13 | 2:59 | AM | 0.54 | 9:15 | AM | 2.25 | 3:39 | PM | 0.4 | 9:40 | PM | 1.97 | New Moon |
| 2008 | August | Fri 1 | 2:31 | AM | 0.51 | 8:48 | AM | 2.32 | 3:21 | PM | 0.35 | 9:17 | PM | 1.98 | New Moon |
| 2008 | August | Sun 31 | 3:03 | AM | 0.41 | 9:11 | AM | 2.32 | 3:30 | PM | 0.27 | 9:35 | PM | 2.17 | New Moon |
| 2009 | August | Thu 20 | 2:33 | AM | 0.41 | 8:44 | AM | 2.37 | 3:11 | PM | 0.24 | 9:11 | PM | 2.16 | New Moon |
| 2010 | August | Tue 10 | 2:44 | AM | 0.38 | 8:55 | AM | 2.4 | 3:23 | PM | 0.22 | 9:22 | PM | 2.16 | New Moon |
| 2011 | August | Mon 29 | 2:46 | AM | 0.35 | 8:51 | AM | 2.36 | 3:14 | PM | 0.2 | 9:16 | PM | 2.26 | New Moon |
| 2012 | August | Fri 17 | 2:31 | AM | 0.51 | 8:41 | AM | 2.2 | 3:04 | PM | 0.38 | 9:02 | PM | 2.04 | New Moon |
| 2013 | August | Wed 7 | 3:00 | AM | 0.52 | 9:12 | AM | 2.18 | 3:33 | PM | 0.42 | 9:32 | PM | 1.97 | New Moon |
| 2014 | August | Mon 25 | 2:39 | AM | 0.55 | 8:54 | AM | 2.13 | 3:08 | PM | 0.45 | 9:13 | PM | 1.98 | New Moon |
| 2015 | August | Fri 14 | 2:34 | AM | 0.6 | 8:52 | AM | 2.2 | 3:10 | PM | 0.5 | 9:13 | PM | 1.9 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | September | Sun 4 | 3:11 | AM | 0.5 | 9:21 | AM | 2.17 | 3:36 | PM | 0.38 | 9:39 | PM | 2.05 | New Moon |
| 2006 | September | Fri 22 | 2:48 | AM | 0.5 | 8:57 | AM | 2.11 | 3:05 | PM | 0.39 | 9:15 | PM | 2.09 | New Moon |
| 2007 | September | Tue 11 | 2:45 | AM | 0.5 | 8:55 | AM | 2.18 | 3:09 | PM | 0.38 | 9:15 | PM | 2.07 | New Moon |
| 2008 | September | Mon 29 | 2:44 | AM | 0.4 | 8:48 | AM | 2.18 | 2:57 | PM | 0.3 | 9:08 | PM | 2.23 | New Moon |
| 2009 | September | Sat 19 | 2:59 | AM | 0.3 | 9:03 | AM | 2.33 | 3:17 | PM | 0.18 | 9:26 | PM | 2.34 | New Moon |
| 2010 | September | Wed 8 | 2:30 | AM | 0.3 | 8:36 | AM | 2.37 | 2:58 | PM | 0.17 | 9:02 | PM | 2.31 | New Moon |
| 2011 | September | Tue 27 | 2:27 | AM | 0.3 | 8:28 | AM | 2.3 | 2:45 | PM | 0.16 | 8:53 | PM | 2.39 | New Moon |
| 2012 | September | Sun 16 | 2:48 | AM | 0.3 | 8:48 | AM | 2.27 | 3:06 | PM | 0.22 | 9:11 | PM | 2.31 | New Moon |
| 2013 | September | Thu 5 | 2:41 | AM | 0.5 | 8:47 | AM | 2.16 | 3:04 | PM | 0.37 | 9:06 | PM | 2.1 | New Moon |
| 2014 | September | Wed 24 | 2:50 | AM | 0.5 | 8:54 | AM | 2.1 | 3:03 | PM | 0.36 | 9:11 | PM | 2.15 | New Moon |
| 2015 | September | Sun 13 | 2:49 | AM | 0.5 | 9:00 | AM | 2.1 | 3:09 | PM | 0.4 | 9:18 | PM | 2.1 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | October | Mon 3 | 2:49 | AM | 0.5 | 8:50 | AM | 2.1 | 3:00 | PM | 0.3 | 9:08 | PM | 2.2 | New Moon |
| 2006 | October | Sun 22 | 2:51 | AM | 0.4 | 8:49 | AM | 2.0 | 2:52 | PM | 0.4 | 9:05 | PM | 2.20 | New Moon |
| 2007 | October | Thu 11 | 2:50 | AM | 0.5 | 8:53 | AM | 2.1 | 2:55 | PM | 0.4 | 9:10 | PM | 2.2 | New Moon |
| 2008 | October | Wed 29 | 2:53 | AM | 0.4 | 8:52 | AM | 2.0 | 2:48 | PM | 0.4 | 9:08 | PM | 2.2 | New Moon |
| 2009 | October | Sun 18 | 2:41 | AM | 0.3 | 8:40 | AM | 2.1 | 2:45 | PM | 0.3 | 9:00 | PM | 2.3 | New Moon |
| 2010 | October | Fri 8 | 2:54 | AM | 0.2 | 8:54 | AM | 2.3 | 3:04 | PM | 0.2 | 9:17 | PM | 2.5 | New Moon |
| 2011 | October | Thu 27 | 2:51 | AM | 0.2 | 8:48 | AM | 2.2 | 2:55 | PM | 0.2 | 9:10 | PM | 2.5 | New Moon |
| 2012 | October | Mon 15 | 2:27 | AM | 0.3 | 8:24 | AM | 2.2 | 2:36 | PM | 0.2 | 8:47 | PM | 2.4 | New Moon |
| 2013 | October | Sat 5 | 2:52 | AM | 0.4 | 8:49 | AM | 2.2 | 3:02 | PM | 0.3 | 9:09 | PM | 2.3 | New Moon |
| 2014 | October | Fri 24 | 2:58 | AM | 0.4 | 8:53 | AM | 2.0 | 3:01 | PM | 0.3 | 9:11 | PM | 2.3 | New Moon |
| 2015 | October | Tue 13 | 2:57 | AM | 0.4 | 9:00 | AM | 2.00 | 3:04 | PM | 0.4 | 9:16 | PM | 2.2 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | November | Wed 2 | 2:54 | AM | 0.37 | 8:45 | AM | 2.01 | 2:52 | PM | 0.28 | 9:05 | PM | 2.3 | New Moon |
| 2006 | November | Tue 21 | 3:00 | AM | 0.43 | 8:49 | AM | 1.83 | 2:50 | PM | 0.38 | 9:07 | PM | 2.21 | New Moon |
| 2007 | November | Sat 10 | 2:56 | AM | 0.45 | 8:51 | AM | 1.86 | 2:47 | PM | 0.4 | 9:07 | PM | 2.18 | New Moon |
| 2008 | November | Thu 27 | 2:37 | AM | 0.5 | 8:32 | AM | 1.74 | 2:21 | PM | 0.46 | 8:48 | PM | 2.13 | New Moon |
| 2009 | November | Tue 17 | 2:59 | AM | 0.39 | 8:55 | AM | 1.88 | 2:48 | PM | 0.38 | 9:12 | PM | 2.25 | New Moon |
| 2010 | November | Sat 6 | 2:38 | AM | 0.29 | 8:35 | AM | 2.06 | 2:38 | PM | 0.24 | 8:56 | PM | 2.39 | New Moon |
| 2011 | November | Fri 25 | 2:39 | AM | 0.26 | 8:33 | AM | 1.99 | 2:35 | PM | 0.24 | 8:55 | PM | 2.4 | New Moon |
| 2012 | November | Wed 14 | 2:51 | AM | 0.22 | 8:46 | AM | 2.09 | 2:51 | PM | 0.18 | 9:08 | PM | 2.46 | New Moon |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2013 | November | Sun 3 | 2:31 | AM | 0.34 | 8:24 | AM | 2.05 | 2:33 | PM | 0.25 | 8:46 | PM | 2.34 | New Moon |
| 2014 | November | Sat 22 | 2:39 | AM | 0.38 | 8:30 | AM | 1.92 | 2:36 | PM | 0.31 | 8:50 | PM | 2.27 | New Moon |
| 2015 | November | Wed 11 | 2:36 | AM | 0.4 | 8:33 | AM | 1.9 | 2:35 | PM | 0.4 | 8:50 | PM | 2.2 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | December | Thu 1 | 2:34 | AM | 0.4 | 8:22 | AM | 1.9 | 2:26 | PM | 0.3 | 8:44 | PM | 2.3 | New Moon |
| 2006 | December | Wed 20 | 2:50 | AM | 0.5 | 8:35 | AM | 1.7 | 2:34 | PM | 0.4 | 8:55 | PM | 2.2 | New Moon |
| 2007 | December | Sun 9 | 2:43 | AM | 0.5 | 8:34 | AM | 1.7 | 2:25 | PM | 0.5 | 8:50 | PM | 2.1 | New Moon |
| 2008 | December | Sat 27 | 3:03 | AM | 0.5 | 8:57 | AM | 1.6 | 2:42 | PM | 0.5 | 9:09 | PM | 2.1 | New Moon |
| 2009 | December | Wed 16 | 2:53 | AM | 0.5 | 8:46 | AM | 1.7 | 2:32 | PM | 0.5 | 9:01 | PM | 2.1 | New Moon |
| 2010 | December | Sun 5 | 2:30 | AM | 0.4 | 8:22 | AM | 1.8 | 2:18 | PM | 0.4 | 8:42 | PM | 2.3 | New Moon |
| 2011 | December | Sat 24 | 2:35 | AM | 0.3 | 8:27 | AM | 1.8 | 2:25 | PM | 0.4 | 8:47 | PM | 2.3 | New Moon |
| 2012 | December | Thu 13 | 2:42 | AM | 0.3 | 8:35 | AM | 1.9 | 2:38 | PM | 0.2 | 8:57 | PM | 2.4 | New Moon |
| 2013 | December | Tue 3 | 2:56 | AM | 0.3 | 8:48 | AM | 2 | 2:53 | PM | 0.2 | 9:09 | PM | 2.4 | New Moon |
| 2014 | December | Mon 22 | 3:04 | AM | 0.3 | 8:54 | AM | 1.9 | 2:59 | PM | 0.3 | 9:14 | PM | 2.3 | New Moon |
| 2015 | December | Fri 11 | 2:52 | AM | 0.4 | 8:42 | AM | 1.8 | 2:45 | PM | 0.4 | 9:00 | PM | 2.2 | New Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | January | Tue 25 | 3:23 | AM | 0.45 | 9:20 | AM | 1.64 | 3:06 | PM | 0.48 | 9:27 | PM | 2.05 | Full Moon |
| 2006 | January | Sat 14 | 3:18 | AM | 0.47 | 9:12 | AM | 1.63 | 2:55 | PM | 0.51 | 9:22 | PM | 2.07 | Full Moon |
| 2007 | January | Wed 3 | 2:57 | AM | 0.42 | 8:48 | AM | 1.69 | 2:39 | PM | 0.46 | 9:03 | PM | 2.17 | Full Moon |
| 2008 | January | Tue 22 | 3:05 | AM | 0.31 | 8:58 | AM | 1.77 | 2:53 | PM | 0.38 | 9:11 | PM | 2.23 | Full Moon |
| 2009 | January | Sun 11 | 3:10 | AM | 0.22 | 9:03 | AM | 1.87 | 3:03 | PM | 0.28 | 9:20 | PM | 2.34 | Full Moon |
| 2010 | January | Fri 1 | 3:20 | AM | 0.24 | 9:11 | AM | 1.9 | 3:13 | PM | 0.26 | 9:29 | PM | 2.36 | Full Moon |
| 2010 | January | Sat 30 | 3:08 | AM | 0.16 | 9:05 | AM | 1.96 | 3:07 | PM | 0.21 | 9:19 | PM | 2.36 | Full Moon |
| 2011 | January | Thu 20 | 3:23 | AM | 0.2 | 9:17 | AM | 1.93 | 3:20 | PM | 0.24 | 9:31 | PM | 2.32 | Full Moon |
| 2012 | January | Mon 9 | 3:09 | AM | 0.37 | 9:01 | AM | 1.77 | 3:00 | PM | 0.38 | 9:13 | PM | 2.17 | Full Moon |
| 2013 | January | Sun 27 | 3:19 | AM | 0.34 | 9:16 | AM | 1.8 | 3:14 | PM | 0.36 | 9:25 | PM | 2.12 | Full Moon |
| 2014 | January | Thu 16 | 3:16 | AM | 0.4 | 9:16 | AM | 1.74 | 3:06 | PM | 0.42 | 9:26 | PM | 2.09 | Full Moon |
| 2015 | January | Mon 5 | 3:10 | AM | 0.4 | 9:08 | AM | 1.8 | 2:58 | PM | 0.4 | 9:20 | PM | 2.1 | Full Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | February | Thu 24 | 3:30 | AM | 0.3 | 9:31 | AM | 1.84 | 3:28 | PM | 0.36 | 9:36 | PM | 2.09 | Full Moon |
| 2006 | February | Mon 13 | 3:32 | AM | 0.4 | 9:34 | AM | 1.76 | 3:23 | PM | 0.42 | 9:39 | PM | 2.07 | Full Moon |
| 2007 | February | Fri 2 | 3:29 | AM | 0.4 | 9:26 | AM | 1.75 | 3:15 | PM | 0.43 | 9:33 | PM | 2.13 | Full Moon |
| 2008 | February | Thu 21 | 3:25 | AM | 0.2 | 9:25 | AM | 1.93 | 3:23 | PM | 0.3 | 9:34 | PM | 2.19 | Full Moon |
| 2009 | February | Mon 9 | 3:00 | AM | 0.2 | 8:57 | AM | 1.91 | 2:58 | PM | 0.27 | 9:10 | PM | 2.29 | Full Moon |
| 2010 | February | Sun 28 | 2:49 | AM | 0.1 | 8:50 | AM | 2.06 | 2:57 | PM | 0.18 | 9:03 | PM | 2.3 | Full Moon |
| 2011 | February | Fri 18 | 3:03 | AM | 0.1 | 9:02 | AM | 2.04 | 3:09 | PM | 0.17 | 9:16 | PM | 2.32 | Full Moon |
| 2012 | February | Wed 8 | 3:24 | AM | 0.2 | 9:21 | AM | 1.97 | 3:26 | PM | 0.23 | 9:32 | PM | 2.25 | Full Moon |
| 2013 | February | Tue 26 | 3:24 | AM | 0.2 | 9:24 | AM | 2.01 | 3:32 | PM | 0.24 | 9:34 | PM | 2.17 | Full Moon |
| 2014 | February | Sat 15 | 3:25 | AM | 0.3 | 9:27 | AM | 1.87 | 3:25 | PM | 0.34 | 9:35 | PM | 2.09 | Full Moon |
| 2015 | February | Wed 4 | 3:26 | AM | 0.3 | 9:28 | AM | 1.8 | 3:20 | PM | 0.4 | 9:37 | PM | 2.1 | Full Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | March | Sat 26 | 3:22 | AM | 0.20 | 9:26 | AM | 2.1 | 3:36 | PM | 0.3 | 9:34 | PM | 2.1 | Full Moon |
| 2006 | March | Wed 15 | 3:25 | AM | 0.3 | 9:32 | AM | 2 | 3:33 | PM | 0.3 | 9:37 | PM | 2.1 | Full Moon |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2007 | March | Sun 4 | 3:29 | AM | 0.3 | 9:35 | AM | 1.9 | 3:31 | PM | 0.3 | 9:40 | PM | 2.1 | Full Moon |
| 2008 | March | Sat 22 | 3:19 | AM | 0.2 | 9:29 | AM | 2.1 | 3:33 | PM | 0.3 | 9:38 | PM | 2.1 | Full Moon |
| 2009 | March | Wed 11 | 3:12 | AM | 0.1 | 9:17 | AM | 2.1 | 3:22 | PM | 0.2 | 9:28 | PM | 2.2 | Full Moon |
| 2010 | March | Tue 30 | 2:57 | AM | 0.1 | 9:06 | AM | 2.3 | 3:19 | PM | 0.1 | 9:20 | PM | 2.2 | Full Moon |
| 2011 | March | Sat 19 | 2:36 | AM | 0.1 | 8:41 | AM | 2.2 | 2:53 | PM | 0.2 | 8:55 | PM | 2.3 | Full Moon |
| 2012 | March | Thu 8 | 2:57 | AM | 0.1 | 8:59 | AM | 2.1 | 3:10 | PM | 0.2 | 9:12 | PM | 2.2 | Full Moon |
| 2013 | March | Wed 27 | 2:53 | AM | 0.2 | 8:58 | AM | 2.1 | 3:12 | PM | 0.2 | 9:10 | PM | 2.1 | Full Moon |
| 2014 | March | Sun 16 | 2:56 | AM | 0.3 | 9:02 | AM | 2 | 3:07 | PM | 0.3 | 9:10 | PM | 2 | Full Moon |
| 2015 | March | Thu 5 | 3:02 | AM | 0.3 | 9.1 | AM | 1.9 | 3:05 | PM | 0.4 | 9:17 | PM | 2.0 | Full Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | April | Sun 24 | 2:44 | AM | 0.24 | 8:55 | AM | 2.2 | 3:12 | PM | 0.28 | 9:05 | PM | 2.02 | Full Moon |
| 2006 | April | Thu 13 | 2:47 | AM | 0.31 | 8:59 | AM | 2.06 | 3:08 | PM | 0.35 | 9:05 | PM | 1.96 | Full Moon |
| 2007 | April | Mon 2 | 2:53 | AM | 0.31 | 9:05 | AM | 2.01 | 3:07 | PM | 0.36 | 9:12 | PM | 1.99 | Full Moon |
| 2008 | April | Sun 20 | 2:42 | AM | 0.33 | 8:59 | AM | 2.11 | 3:09 | PM | 0.36 | 9:09 | PM | 1.92 | Full Moon |
| 2009 | April | Thu 9 | 2:40 | AM | 0.23 | 8:51 | AM | 2.16 | 3:02 | PM | 0.28 | 9:03 | PM | 2.05 | Full Moon |
| 2010 | April | Wed 28 | 2:26 | AM | 0.24 | 8:42 | AM | 2.26 | 3:01 | PM | 0.26 | 8:58 | PM | 2.01 | Full Moon |
| 2011 | April | Mon 18 | 2:44 | AM | 0.11 | 8:57 | AM | 2.35 | 3:16 | PM | 0.13 | 9:14 | PM | 2.15 | Full Moon |
| 2012 | April | Sat 7 | 3:02 | AM | 0.07 | 9:12 | AM | 2.34 | 3:30 | PM | 0.1 | 9:29 | PM | 2.2 | Full Moon |
| 2013 | April | Fri 26 | 2:56 | AM | 0.16 | 9:08 | AM | 2.34 | 3:30 | PM | 0.17 | 9:26 | PM | 2.1 | Full Moon |
| 2014 | April | Tue 15 | 2:51 | AM | 0.25 | 8:59 | AM | 2.15 | 3:16 | PM | 0.27 | 9:11 | PM | 2.03 | Full Moon |
| 2015 | April | Sat 4 | 2:56 | AM | 0.3 | 9:07 | AM | 2.0 | 3:14 | PM | 0.3 | 9:16 | PM | 2.0 | Full Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | May | Tue 24 | 2:45 | AM | 0.3 | 9:03 | AM | 2.32 | 3:31 | PM | 0.31 | 9:21 | PM | 1.94 | Full Moon |
| 2006 | May | Sat 13 | 2:37 | AM | 0.36 | 8:52 | AM | 2.18 | 3:15 | PM | 0.39 | 9:04 | PM | 1.87 | Full Moon |
| 2007 | May | Wed 2 | 2:38 | AM | 0.37 | 8:56 | AM | 2.11 | 3:11 | PM | 0.4 | 9:05 | PM | 1.85 | Full Moon |
| 2008 | May | Tue 20 | 2:34 | AM | 0.46 | 8:59 | AM | 2.12 | 3:19 | PM | 0.47 | 9:13 | PM | 1.76 | Full Moon |
| 2009 | May | Sat 9 | 2:35 | AM | 0.37 | 8:57 | AM | 2.18 | 3:14 | PM | 0.39 | 9:11 | PM | 1.85 | Full Moon |
| 2010 | May | Fri 28 | 2:35 | AM | 0.42 | 9:00 | AM | 2.23 | 3:24 | PM | 0.4 | 9:20 | PM | 1.83 | Full Moon |
| 2011 | May | Tue 17 | 2:18 | AM | 0.27 | 8:37 | AM | 2.33 | 3:02 | PM | 0.27 | 8:57 | PM | 1.99 | Full Moon |
| 2012 | May | Sun 6 | 2:35 | AM | 0.17 | 8:51 | AM | 2.39 | 3:15 | PM | 0.17 | 9:11 | PM | 2.09 | Full Moon |
| 2013 | May | Sat 25 | 2:32 | AM | 0.25 | 8:49 | AM | 2.38 | 3:17 | PM | 0.23 | 9:11 | PM | 2.04 | Full Moon |
| 2014 | May | Thu 15 | 2:55 | AM | 0.27 | 9:08 | AM | 2.3 | 3:34 | PM | 0.26 | 9:26 | PM | 2.01 | Full Moon |
| 2015 | May | Mon 4 | 2:52 | AM | 0.3 | 9:04 | AM | 2.1 | 3:23 | PM | 0.3 | 9:16 | PM | 1.9 | Full Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | June | Wed 22 | 2:27 | AM | 0.41 | 8:49 | AM | 2.33 | 3:24 | PM | 0.36 | 9:14 | PM | 1.89 | Full Moon |
| 2006 | June | Sun 11 | 2:08 | AM | 0.48 | 8:29 | AM | 2.18 | 3:01 | PM | 0.47 | 8:46 | PM | 1.79 | Full Moon |
| 2007 | June | Fri 1 | 2:37 | AM | 0.48 | 8:59 | AM | 2.14 | 3:26 | PM | 0.48 | 9:13 | PM | 1.75 | Full Moon |
| 2007 | June | Sat 30 | 2:21 | AM | 0.59 | 8:44 | AM | 2.12 | 3:17 | PM | 0.54 | 9:04 | PM | 1.73 | Full Moon |
| 2008 | June | Wed 18 | 2:12 | AM | 0.6 | 8:43 | AM | 2.08 | 3:09 | PM | 0.57 | 9:00 | PM | 1.68 | Full Moon |
| 2009 | June | Sun 7 | 2:07 | AM | 0.55 | 8:37 | AM | 2.11 | 3:01 | PM | 0.53 | 8:55 | PM | 1.71 | Full Moon |
| 2010 | June | Sat 26 | 2:20 | AM | 0.58 | 8:48 | AM | 2.16 | 3:17 | PM | 0.51 | 9:12 | PM | 1.76 | Full Moon |
| 2011 | June | Thu 16 | 2:42 | AM | 0.43 | 9:05 | AM | 2.30 | 3:35 | PM | 0.36 | 9:30 | PM | 1.88 | Full Moon |
| 2012 | June | Mon 4 | 2:14 | AM | 0.31 | 8:34 | AM | 2.37 | 3:04 | PM | 0.27 | 8:58 | PM | 1.99 | Full Moon |
| 2013 | June | Sun 23 | 2:16 | AM | 0.35 | 8:35 | AM | 2.38 | 3:06 | PM | 0.28 | 9:00 | PM | 2.01 | Full Moon |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2014 | June | Fri 13 | 2:35 | AM | 0.34 | 8:51 | AM | 2.34 | 3:21 | PM | 0.29 | 9:13 | PM | 2.00 | Full Moon |
| 2015 | June | Tue 2 | 2:23 | AM | 0.4 | 8:39 | AM | 2.2 | 3:04 | PM | 0.4 | 8:54 | PM | 1.9 | Full Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | July | Thu 21 | 2:21 | AM | 0.48 | 8:42 | AM | 2.33 | 3:18 | PM | 0.35 | 9:10 | PM | 1.94 | Full Moon |
| 2006 | July | Tue 11 | 2:38 | AM | 0.50 | 8:58 | AM | 2.27 | 3:34 | PM | 0.40 | 9:23 | PM | 1.88 | Full Moon |
| 2007 | July | Mon 30 | 2:54 | AM | 0.53 | 9:08 | AM | 2.25 | 3:39 | PM | 0.39 | 9:32 | PM | 1.94 | Full Moon |
| 2008 | July | Fri 18 | 2:41 | AM | 0.62 | 9:03 | AM | 2.12 | 3:31 | PM | 0.52 | 9:25 | PM | 1.78 | Full Moon |
| 2009 | July | Tue 7 | 2:31 | AM | 0.64 | 9:00 | AM | 2.10 | 3:26 | PM | 0.56 | 9:22 | PM | 1.73 | Full Moon |
| 2010 | July | Mon 26 | 2:50 | AM | 0.60 | 9:12 | AM | 2.16 | 3:34 | PM | 0.48 | 9:35 | PM | 1.85 | Full Moon |
| 2011 | July | Fri 15 | 2:35 | AM | 0.54 | 8:56 | AM | 2.24 | 3:25 | PM | 0.43 | 9:22 | PM | 1.88 | Full Moon |
| 2012 | July | Wed 4 | 2:50 | AM | 0.40 | 9:09 | AM | 2.37 | 3:40 | PM | 0.30 | 9:36 | PM | 1.99 | Full Moon |
| 2013 | July | Mon 22 | 2:07 | AM | 0.43 | 8:25 | AM | 2.35 | 2:56 | PM | 0.31 | 8:52 | PM | 2.04 | Full Moon |
| 2014 | July | Sat 12 | 2:21 | AM | 0.39 | 8:37 | AM | 2.36 | 3:09 | PM | 0.29 | 9:03 | PM | 2.04 | Full Moon |
| 2015 | July | Thu 2 | 2:42 | AM | 0.40 | 8:57 | AM | 2.30 | 3:28 | PM | 0.4 | 9:19 | PM | 2.0 | Full Moon |
| 2015 | July | Fri 31 | 2:29 | AM | 0.40 | 8:42 | AM | 2.30 | 3:11 | PM | 0.3 | 9:06 | PM | 2.1 | Full Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | August | Fri 19 | 2:19 | AM | 0.48 | 8:33 | AM | 2.34 | 3:05 | PM | 0.3 | 9:02 | PM | 2.06 | Full Moon |
| 2006 | August | Wed 9 | 2:33 | AM | 0.48 | 8:47 | AM | 2.32 | 3:19 | PM | 0.32 | 9:14 | PM | 2.02 | Full Moon |
| 2007 | August | Tue 28 | 2:41 | AM | 0.45 | 8:48 | AM | 2.29 | 3:13 | PM | 0.28 | 9:13 | PM | 2.13 | Full Moon |
| 2008 | August | Sun 17 | 3:05 | AM | 0.49 | 9:13 | AM | 2.23 | 3:37 | PM | 0.35 | 9:35 | PM | 2.04 | Full Moon |
| 2009 | August | Thu 6 | 2:58 | AM | 0.58 | 9:15 | AM | 2.15 | 3:35 | PM | 0.46 | 9:35 | PM | 1.9 | Full Moon |
| 2010 | August | Tue 24 | 2:38 | AM | 0.59 | 8:53 | AM | 2.13 | 3:08 | PM | 0.46 | 9:14 | PM | 1.96 | Full Moon |
| 2011 | August | Sun 14 | 3:02 | AM | 0.51 | 9:17 | AM | 2.23 | 3:35 | PM | 0.39 | 9:39 | PM | 2.01 | Full Moon |
| 2012 | August | Thu 2 | 2:43 | AM | 0.45 | 8:58 | AM | 2.32 | 3:25 | PM | 0.33 | 9:24 | PM | 2.04 | Full Moon |
| 2012 | August | Fri 31 | 2:34 | AM | 0.47 | 8:43 | AM | 2.24 | 3:02 | PM | 0.35 | 9:06 | PM | 2.11 | Full Moon |
| 2013 | August | Wed 21 | 2:46 | AM | 0.36 | 8:56 | AM | 2.38 | 3:19 | PM | 0.23 | 9:21 | PM | 2.21 | Full Moon |
| 2014 | August | Sun 10 | 2:11 | AM | 0.40 | 8:24 | AM | 2.36 | 2:53 | PM | 0.27 | 8:51 | PM | 2.13 | Full Moon |
| 2015 | August | Sun 30 | 2:59 | AM | 0.30 | 9:06 | AM | 2.4 | 3:29 | PM | 0.2 | 9:31 | PM | 2.3 | Full Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | September | Sun 18 | 2:52 | AM | 0.3 | 8:57 | AM | 2.38 | 3:17 | PM | 0.16 | 9:22 | PM | 2.3 | Full Moon |
| 2006 | September | Fri 8 | 3:03 | AM | 0.3 | 9:09 | AM | 2.43 | 3:30 | PM | 0.13 | 9:34 | PM | 2.32 | Full Moon |
| 2007 | September | Thu 27 | 2:58 | AM | 0.3 | 8:59 | AM | 2.34 | 3:15 | PM | 0.12 | 9:22 | PM | 2.41 | Full Moon |
| 2008 | September | Mon 15 | 2:44 | AM | 0.4 | 8:46 | AM | 2.22 | 3:04 | PM | 0.27 | 9:07 | PM | 2.21 | Full Moon |
| 2009 | September | Fri 4 | 2:40 | AM | 0.5 | 8:50 | AM | 2.13 | 3:04 | PM | 0.4 | 9:09 | PM | 2.04 | Full Moon |
| 2010 | September | Thu 23 | 2:46 | AM | 0.5 | 8:51 | AM | 2.09 | 2:58 | PM | 0.38 | 9:08 | PM | 2.13 | Full Moon |
| 2011 | September | Mon 12 | 2:44 | AM | 0.5 | 8:54 | AM | 2.14 | 3:03 | PM | 0.39 | 9:13 | PM | 2.1 | Full Moon |
| 2012 | September | Sun 30 | 2:49 | AM | 0.4 | 8:53 | AM | 2.13 | 2:58 | PM | 0.34 | 9:12 | PM | 2.21 | Full Moon |
| 2013 | September | Thu 19 | 2:33 | AM | 0.4 | 8:38 | AM | 2.27 | 2:54 | PM | 0.25 | 9:01 | PM | 2.26 | Full Moon |
| 2014 | September | Tue 9 | 2:45 | AM | 0.3 | 8:51 | AM | 2.4 | 3:11 | PM | 0.16 | 9:16 | PM | 2.33 | Full Moon |
| 2015 | September | Mon 28 | 2:43 | AM | 0.2 | 2:46 | AM | 2.4 | 3:03 | PM | 0.1 | 9:10 | PM | 2.4 | Full Moon |

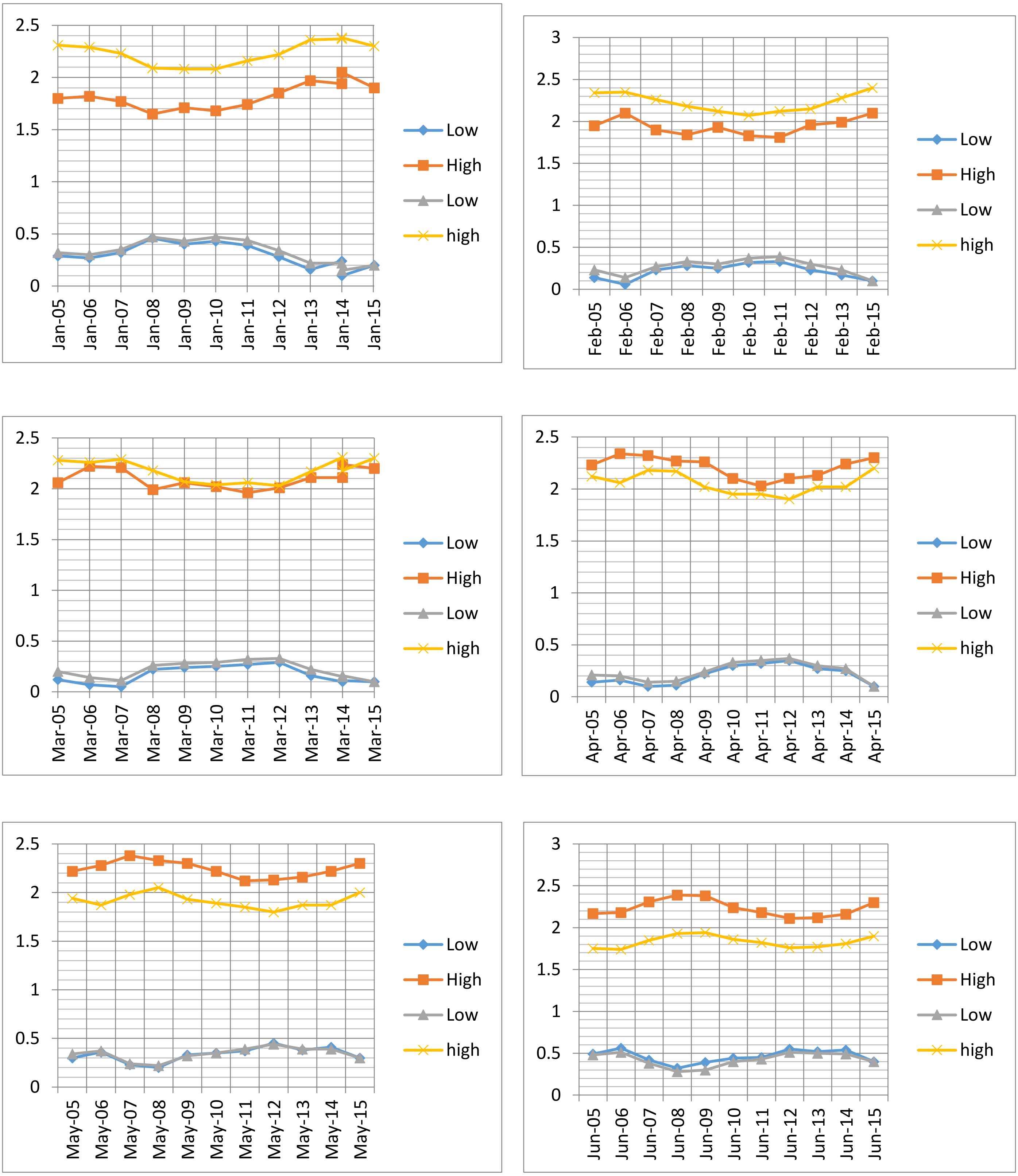
| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | October | Mon 17 | 2:34 | AM | 0.32 | 8:34 | AM | 2.22 | 2:45 | PM | 0.19 | 8:57 | PM | 2.35 | Full Moon |
| 2006 | October | Sat 7 | 2:45 | AM | 0.24 | 8:46 | AM | 2.33 | 3:00 | PM | 0.11 | 9:10 | PM | 2.43 | Full Moon |
| 2007 | October | Fri 26 | 2:38 | AM | 0.23 | 8:34 | AM | 2.20 | 2:44 | PM | 0.14 | 8:58 | PM | 2.46 | Full Moon |

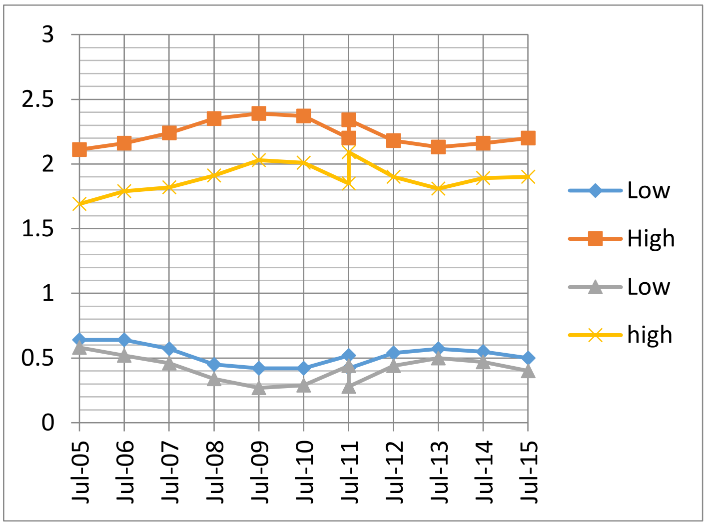
| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2008 | October | Wed 15 | 2:55 | AM | 0.28 | 8:50 | AM | 2.19 | 3:01 | PM | 0.18 | 9:12 | PM | 2.41 | Full Moon |
| 2009 | October | Sun 4 | 2:46 | AM | 0.41 | 8:44 | AM | 2.10 | 2:55 | PM | 0.30 | 9:03 | PM | 2.24 | Full Moon |
| 2010 | October | Sat 23 | 2:51 | AM | 0.42 | 8:46 | AM | 1.97 | 2:50 | PM | 0.35 | 9:03 | PM | 2.22 | Full Moon |
| 2011 | October | Wed 12 | 2:50 | AM | 0.44 | 8:53 | AM | 2.02 | 2:54 | PM | 0.37 | 9:09 | PM | 2.19 | Full Moon |
| 2012 | October | Tue 30 | 2:58 | AM | 0.42 | 8:58 | AM | 1.94 | 2:54 | PM | 0.38 | 9:13 | PM | 2.21 | Full Moon |
| 2013 | October | Sat 19 | 2:52 | AM | 0.35 | 8:53 | AM | 2.10 | 2:56 | PM | 0.30 | 9:11 | PM | 2.29 | Full Moon |
| 2014 | October | Wed 8 | 2:30 | AM | 0.29 | 8:32 | AM | 2.26 | 2:45 | PM | 0.19 | 8:55 | PM | 2.37 | Full Moon |
| 2015 | October | Tue 27 | 2:28 | AM | 0.2 | 8:27 | AM | 2.2 | 2:38 | PM | 0.1 | 8:50 | PM | 2.4 | Full Moon |

| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | November | Wed 16 | 2:52 | AM | 0.34 | 8:48 | AM | 1.97 | 2:46 | PM | 0.3 | 9:07 | PM | 2.31 | Full Moon |
| 2006 | November | Sun 5 | 2:27 | AM | 0.28 | 8:23 | AM | 2.13 | 2:30 | PM | 0.18 | 8:46 | PM | 2.41 | Full Moon |
| 2007 | November | Sat 24 | 2:23 | AM | 0.29 | 8:15 | AM | 1.99 | 2:19 | PM | 0.23 | 8:39 | PM | 2.4 | Full Moon |
| 2008 | November | Thu 13 | 2:36 | AM | 0.29 | 8:28 | AM | 2.03 | 2:34 | PM | 0.22 | 8:52 | PM | 2.41 | Full Moon |
| 2009 | November | Tue 3 | 2:57 | AM | 0.34 | 8:48 | AM | 2.01 | 2:54 | PM | 0.28 | 9:08 | PM | 2.34 | Full Moon |
| 2010 | November | Sun 21 | 2:32 | AM | 0.46 | 8:21 | AM | 1.81 | 2:23 | PM | 0.39 | 8:40 | PM | 2.19 | Full Moon |
| 2011 | November | Fri 11 | 3:00 | AM | 0.44 | 8:54 | AM | 1.85 | 2:53 | PM | 0.4 | 9:10 | PM | 2.19 | Full Moon |
| 2012 | November | Wed 28 | 2:42 | AM | 0.48 | 8:39 | AM | 1.77 | 2:30 | PM | 0.45 | 8:55 | PM | 2.13 | Full Moon |
| 2013 | November | Sun 17 | 2:36 | AM | 0.43 | 8:33 | AM | 1.89 | 2:29 | PM | 0.39 | 8:51 | PM | 2.21 | Full Moon |
| 2014 | November | Fri 7 | 2:54 | AM | 0.28 | 8:52 | AM | 2.08 | 2:55 | PM | 0.25 | 9:12 | PM | 2.35 | Full Moon |
| 2015 | November | Thu 26 | 2:56 | AM | 0.20 | 8:53 | AM | 2.1 | 2:55 | PM | 0.2 | 9:14 | PM | 2.40 | Full Moon |

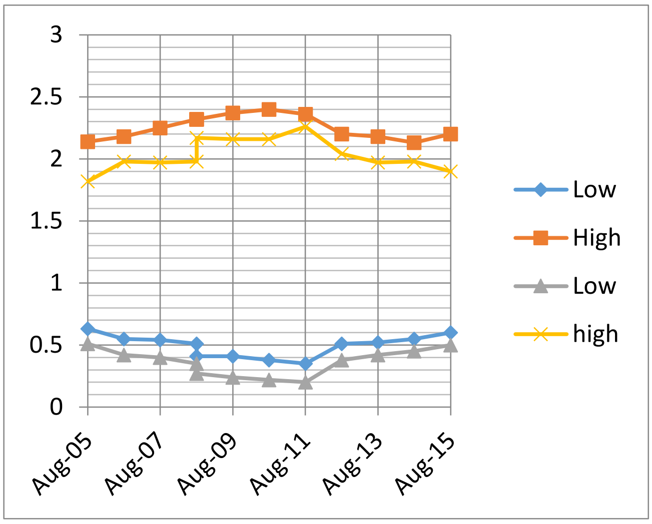
| Year | Month | Day | Low | | | High | | | Low | | | High | | | Moon |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | December | Thu 15 | 2:43 | AM | 0.45 | 8:35 | AM | 1.73 | 2:25 | PM | 0.44 | 8:53 | PM | 2.17 | Full Moon |
| 2006 | December | Tue 5 | 2:56 | AM | 0.32 | 8:49 | AM | 1.87 | 2:44 | PM | 0.33 | 9:08 | PM | 2.31 | Full Moon |
| 2007 | December | Mon 24 | 3:04 | AM | 0.3 | 8:55 | AM | 1.82 | 2:51 | PM | 0.34 | 9:14 | PM | 2.31 | Full Moon |
| 2008 | December | Fri 12 | 2:26 | AM | 0.34 | 8:15 | AM | 1.85 | 2:17 | PM | 0.3 | 8:39 | PM | 2.34 | Full Moon |
| 2009 | December | Wed 2 | 2:43 | AM | 0.36 | 8:31 | AM | 1.87 | 2:34 | PM | 0.31 | 8:53 | PM | 2.31 | Full Moon |
| 2010 | December | Tue 21 | 2:57 | AM | 0.39 | 8:44 | AM | 1.77 | 2:46 | PM | 0.38 | 9:03 | PM | 2.22 | Full Moon |
| 2011 | December | Sat 10 | 2:48 | AM | 0.48 | 8:39 | AM | 1.72 | 2:34 | PM | 0.45 | 8:54 | PM | 2.13 | Full Moon |
| 2012 | December | Fri 28 | 3:04 | AM | 0.45 | 9:00 | AM | 1.7 | 2:50 | PM | 0.45 | 9:11 | PM | 2.09 | Full Moon |
| 2013 | December | Tue 17 | 2:57 | AM | 0.45 | 8:55 | AM | 1.74 | 2:43 | PM | 0.45 | 9:08 | PM | 2.13 | Full Moon |
| 2014 | December | Sat 6 | 2:44 | AM | 0.37 | 8:39 | AM | 1.87 | 2:35 | PM | 0.36 | 8:57 | PM | 2.24 | Full Moon |
| 2015 | December | Fri 25 | 2:49 | AM | 0.3 | 8:44 | AM | 1.9 | 2:42 | PM | 0.3 | 9:02 | PM | 2.3 | Full Moon |

Figure 6B-1: Graphical Depiction of New Moon Tidal events in each Month from the year 2005 to 2015

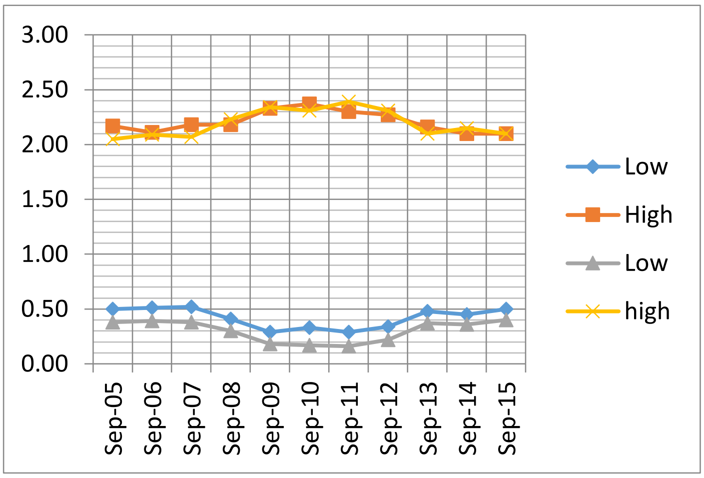




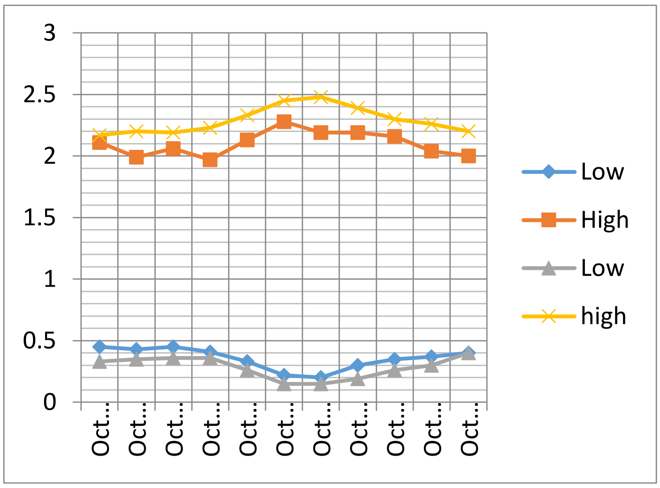
3
2.5
2
1.5
1
0.5
0
Jul-05
Jul-06
Jul-07
Jul-08
Jul-09
Jul-10
Jul-11
Jul-12
Jul-13
Jul-14
Jul-15
Low
High
Low
high

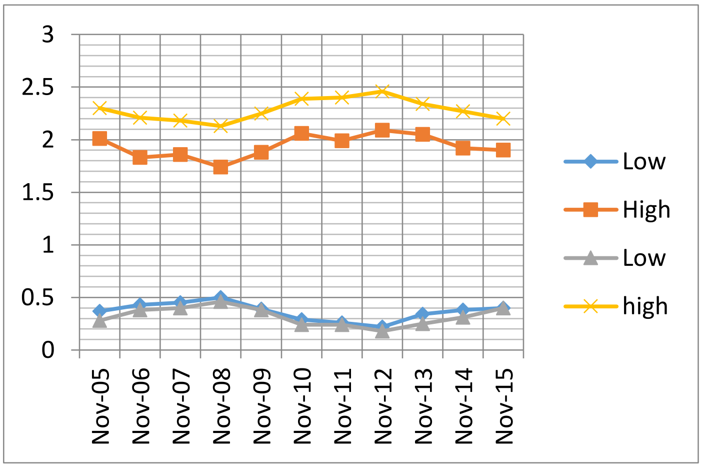
3
2.5
2
1.5
1
0.5
0
Aug-05
Aug-07
Aug-09
Aug-11
Aug-13
Aug-15
Low
High
Low
high

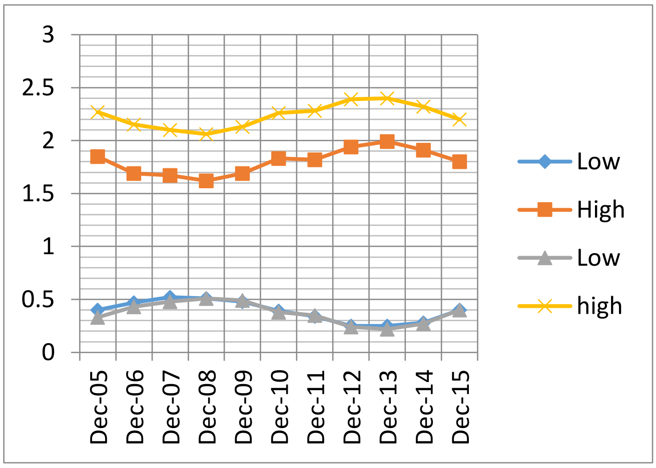
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Sep-05
Sep-06
Sep-07
Sep-08
Sep-09
Sep-10
Sep-11
Sep-12
Sep-13
Sep-14
Sep-15
Low
High
Low
high

3
2.5
2
1.5
1
0.5
0
Oct...
Oct...
Oct...
Oct...
Oct...
Oct...
Oct...
Oct...
Oct...
Oct...
Oct...
Low
High
Low
high

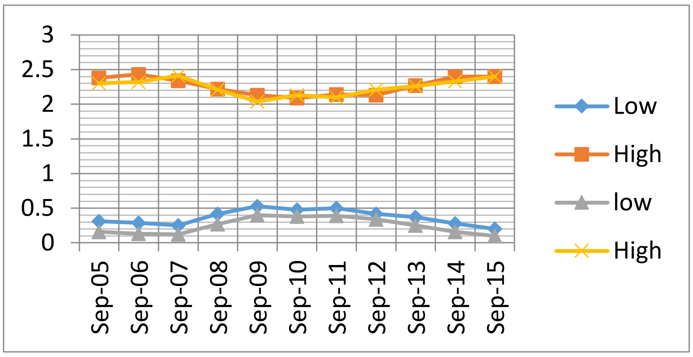



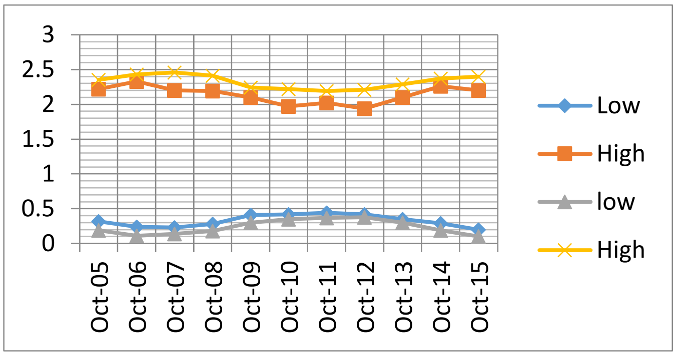
3
2.5
2
1.5
1
0.5
0
Nov-05
Nov-06
Nov-07
Nov-08
Nov-09
Nov-10
Nov-11
Nov-12
Nov-13
Nov-14
Nov-15
Low
High
Low
high

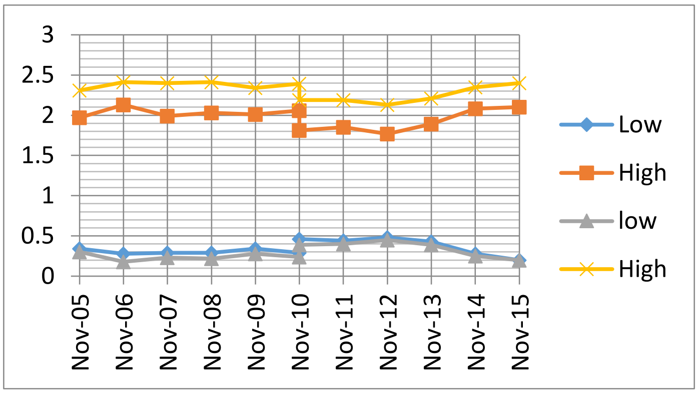



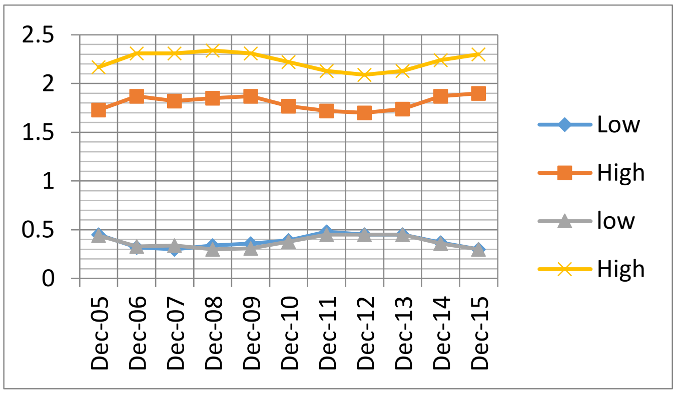
3
2.5
2
1.5
1
0.5
0
Dec-05
Dec-06
Dec-07
Dec-08
Dec-09
Dec-10
Dec-11
Dec-12
Dec-13
Dec-14
Dec-15
Low
High
Low
high

Figure 6B-2 Graphical Depiction of Full Moon Tidal events in each Month from the year 2005 to 2015




As discussed above, considering the spring tide (full moon tide & new moon tide), It has been graphically replicated as above. Monthly highest and lowest tide values of Port Blair, Andaman Islands from website tides.mobilegeographics.com from the period 2005 to 2015 was considered shown in table 6.3 and found highest tide ranging from 2.4 to 2.1 and lowest tide range from 0.1 to 0.5, the average highest tide was in the month of August & October i.e., 2.4 and lowest was in the month of month of march i.e., 0.1.

# REFERENCES


[1] Alpa Sheth, Snigdha Sanyal, Arvind Jaiswal, and Prathibha Gandhid 2004. Effects of the December 2004 Indian Ocean Tsunami on the Indian Mainland.

[2] Alexcia C. Gray, December 2009, Assessing coastal evolution by using GIS and remote sensing to model shoreline changes in Galveston over time and after intense storm events.

[3] Anjali Bahuuna, Shailesh Nayak, Dam Roy, 2008, "Impact of the tsunami and earthquake of 26$^{th}$ December 2004 on the vital coastal ecosystem of the Andaman & Nicobar island assessed using Resource sat A wifis data". International Journal of Applied Earth Observation and Geoinformation. Vol:10, issue 2, June 2008. Indian Remote Sensing Satellite, Resourcesat -1.

[4] Andra Pradesh struck over 60 cyclones four decades; http;//www.downtoearth.org.in

[5] B.Sindhu. "Return period estimates of extreme sea level along the east coast of India from numerical solutions". Journal of natural hazards (2011)

[6] CWC, 1987. "Flood Estimation report for eastern coast region upper, lower, and south sub zones-4 (a, b, & c)".

[7] Dimri.V. P, "Tsunami propagation of 2004 Sumatra earthquake the fractal analysis of the aftershock activity". Indian Journal of marine sciences.

[8] Disaster prevention and management, volume 15, issue 1 (2006-09-19)

[9] Dube., 2008 "Storm Surges: Worst Coastal Marine Hazard", Modelling and Monitoring of Coastal Marine Processes.

[10] Dube., 2009 "Storm surge modelling for the Bay of Bengal and Arabian Sea", Natural Hazards, Disaster Prevention and Management, Volume15, Issue 1 (2006-09-19).

[11] Dube, Shishir K., Tad S. Murty, Jesse C. Feyen, Reggina Cabrera, Bruce A. Harper, Jerad D. Bales, and Saud Amer, 2010, "Storm Surge Modeling and Applications in Coastal Areas", World, Scientific Series on Asia-Pacific Weather and Climate.

[12] EPASWMM manual 5.1; http://sdi.odu/mbin/swmm/win/epaswmm5.1 mnual.pdf

[13] Gahulut. V. K, B. Nagarajan, J. K. Catherine, S. Kumar, 2005, Constraints on 2004 Sumatra-Andaman earthquake rupture from GPS measurements in Andaman – Nicobar Islands.

[14] Ilayaraja. K, 2008, "Numerical modeling of the 26$^{th}$ December 2004 India Ocean tsunami at Andaman and Nicobar Islands", Journal of Coastal Conservation.

[15] K.V.K.R.K, "Observational analysis on the run-up height and inundation along Andhra coast during December 26. 2004 Indian Ocean tsunami". Journal of Asian Earth Sciences.

[16] Landis, Kathleen. “The science of tsunami:December;s deadly wave started with one of earth’s most violent earthquake”, Boy’s life, May 2005 Issue

[17] Lewis, Matt, Paul Bates.Kevin Horsburgh, JeffNeal, and Guy Schuman. “A storm surge Inundation model of the northern Bay of Bengal using publicily available data”, Quaterely Journal of the Royal meteorological society, 2013

[18] Md. Khalequazzaman, “Flood control in Bangladesh through Best Management Practices”. Georgia Southwestern State University, Americus, GA 31709, USA.

[19] Mahendra.R. S, P.C. Mohanty, H. Bisoyi, T. Srinivasa Kumar, S. Nayak, “Assessment and management of coastal multi-hazard vulnerability along the Cuddaloree Villupuram, east coast of India using geospatial techniques. Ocean & Coastal Management 54 (2011).

[20] Mehra P. M. Soumya. P. Vethamony K. Vijaykumar T M Balakrishnan nair, Y.Agarvadekar, K.Jyoti, K.Sudheesh, R. Luis, S.lobo, and Harimalkar. “Coastal sea level response to the tropical cyclone forcing in the northern Indian ocean”. Ocean Science. 2015

[21] Ministry of Home Affairs _MHA_, NDM Division. Situation reports. www.ndmindia.nic.in/ tsunami2004/sitrep31.htm

[22] Murty. T, 2005. Tsunami warning system in India by 2007, The Rediff Interview, September 29. http://in.rediff.com/news/2005/sep/29inter1.htm

[23] Murty, T. S., and Rafiq, M., 1991. A tentative list of tsunamis in the marginal seas of the North. Indian Ocean, Natural Hazards 4, 81–83.

[24] Murty, T, A Rao, G Muraleedharan, and M Sinha, 2006, "Validation of Tsunami Beach Run-up Height Predictive Model Based on Work‚ÄìEnergy Theorem", The Indian Ocean Tsunami.

[25] National Institute of Oceanography _NIO_. Tidal data. www.nio.org/jsp/tsunami.jsp

[26] Narayana. A. C, 2010, “Tectonic geomorphology, tsunamis and environmental hazards: reference to Andaman-Nicobar Islands", Journal of Natural Hazards.

[27] Paul, Gour Chandra, Ahmad Izani Md. Fazlul, and Md. Fazlul karim. “Implementation of method of lines to predict water levels due to a storm along the coastal region of Bangladesh”. Jpournal of Oceanography. 2014.

[28] Rameshbabu. K, “Impact of Tropical cyclonic storm ‘Hudhud’ on northeast coastal waters of Visakhapatnam”. American Journal of marine science.

[29] Rao, V. B., and Murty, B.V.R.S., 1970. “Earthquakes and tectonics in peninsular India”.Journal of Indian Geophysics. Union 7, 1–8.

[30] Reddy, P. R., and Chandrakala, K., 2004. “Seismicity in and around Ongole—an appraisal”. Journal of Indian Geophysics. Union 8 _2_, 143–146.

[31] Setyandito, Oki: Syafalni, S : Wijayanti, Yureana; C., Daralntan and Satrio, S., "Groundwater Quality Assessment and recharge well design of Cengkareng Area. West Jakarta". International Jounal of Applied Engineering Research, 2015.

[32] Shaji. C, S.K. Kar & T. Vishal. Storm surge studies in the North Indian Ocean: A review. India Journal of Geo-Marine Sciences vol. 43(2), February 2004.

[33] S.S.Shahapure. "coastal Urban Flood Simulation using FEM. GIS and remote sensing". Water resources management, 2010

[34] Tamil Nadu Industrial Development Corporation TIDCO. http://tidco.com/ tn_policies/tn_Infra_structure/nagapattinam.asp

[35] Titus, James G., Chin Y. Kuo, Michael J. Gibbs, Tom. LaRoche, M. Keith Webb, and Jesse O. Waddell, 1987, "Greenhouse Effect, Sea Level Rise, and Coastal Drainage Systems", Journal of Water Resources Planning and Management.

[36] Zhao, H, B Ingole, D Subba Rao, D Tang, and B Satyanarayana, 2006, "Tsunamis and Marine Life", The Indian Ocean Tsunami....