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Government of India Ministry of Water Resources, River Development & Ganga Rejuvenation

Technical Memorandum on

DETERMINATION OF SAFE GRADE LEVEL AND DESIGN OF STROM WATER DRAIN FOR POWER PLANTS



Compiled and Edited by Dr. C. Ramesh and Dr. (Mrs) Annapurna Patra

12th November, 2018



Central Water and Power Research Station Khadakwasla, Pune 411024

> Dr. (Mrs) V. V. Bhosekar Director

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DETERMINATION OF SAFE GRADE LEVEL AND DESIGN OF STROM WATER DRAIN FOR POWER PLANTS

(DESIGN FLOOD DUE TO RAINFALL)

Compiled and Edited by
Dr. C. Ramesh and Dr. (Mrs) Annapurna Patra
Hydrometeorology Division



Central Water and Power Research Station Khadakwasla, Pune 411024

Introduction of Contributors:

Dr. C. Ramesh, M.Sc.(Phy), AMIE(Civil), M.Tech.(Modeling & Simulation), Ph.D. (Civil)

Working as Scientist-C in Hydrometeorology Division, CWPRS, Pune

And

Dr. Annapurna Patra, M.Sc.(Phy), Ph.D.(Phy)

Working as Scientist-B in Hydrometeorology Division, CWPRS, Pune

The authors of this technical memorandum have long experience in hydrometeorology, flood routing techniques, statistical hydrology, application of remote sensing techniques in water resources, flood forecasting and model development in applied hydrology.

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FOREWARD

The Central Water and Power Research Station (CWPRS), Pune is a hydraulic research institute under MoWR, RD&GR established in 1916 and serving the nation through research. It is dedicated to research in the field of water resources development and water borne transport and has catered to various national, international, government and private sector organizations offering solutions through applied research in water sector.

CWPRS has recently celebrated the centenary year in 2016. Through its 100 years journey in water resources field, it has offered its expert services in multiple disciplines of water resources ranging from; basin hydrology and flood estimation, earth sciences and geotechnical aspects, water quality aspects, water resources structural (dams, barrages, spillways) aspects, river hydraulics and river training aspects, coastal and estuarine processes, ports and harbors, etc. Apart from undertaking the client sponsored works, it has been organizing and conducting trainings in these specialized fields to practicing engineers, planners and students. To record its expertise in water sector and to share its experiences with other researchers, water resources practitioners and academicians, it has been publishing technical papers and Technical Memorandums in these areas. This technical memorandum is one such effort towards knowledge dissemination process of CWPRS.

The need of the hour for our country is to meet the power demands through commissioning of Thermal Power Projects (TPP), wherein India has commissioned TPPs in the last two decades and some more are going to become functional in this decade. TPPs, apart from needing water intakes for the power generation and cooling process are exposed to flooding from surrounding area due to the existing site conditions added to which the storm water evacuation from its own area in the post project scenario. Thus, CWPRS has been contributing in this field also, through determination of Safe Grade Level (SGL) for the project area and storm water drain system design. CWPRS has thus developed its expertise in this field by conducting studies for various TPPs in the past three decades. With this experience, this Technical Memorandum has been brought out to provide a yard stick to practicing engineers, planners and academicians, which would aid in their understanding the intricacies and adopt safe practices in this area. I am sure that, this TM would be of immense use to the user community.

The contributing authors of this technical memorandum have put in their expertise in the field of area drainage and SGL studies and have given it an excellent shape to this document and segmented it in a easy to understand and use fashion. I am sure this work would be very useful to both, the executives and the practicing engineers as a standard tool for their efforts in this area.

Dr. (Mrs) V.V. Bhosekar Director, CWPRS

PREFACE

Technical memorandum serves the purpose of providing technical guidelines to studies in specialized areas of work. It is presumed that the user of this memorandum has certain basic knowledge in the techniques involved, i.e., hydrology, hydraulics and statistical hydrology to understand the underpinnings of many technical terminologies involved and their mathematical formulations. Efforts have been made in this memorandum to provide ready references to most of the relevant aspects. Thus this could be a yard stick in the field of 'Determination of Safe Grade Level (SGL) and Design of Storm Water Drains for Power Projects and other Industrial Installations'. This Technical Memorandum is the outcome of continued research experience of contributing authors and other officers of CWPRS.

Chapter 1, details the inundation issues of TPPs, the need for a safe formation level and storm water evacuation system. It also brings out the scope of this TM and existing real world situations. Chapter 2 briefly describes the methodology to be adopted in conducting area drainage and SGL determination studies for the flood resulting from rainstorms. Chapter 3, throw light on the site inspection, field data collection, survey data analysis and preprocessing of hydrometeorological data and development of Digital Elevation Model (DEM) of project area. Chapter 4, details the design flood estimation procedures, the relevant standards (BIS, IRC, etc.), extreme value analysis of rainfall and flood data, flood estimation using empirical and Unit Hydrograph methods. Chapter 5, presents the approaches in flood inundation estimations viz., ponding and flood routing (steady state and unsteady state). Brief details on boundary conditions, initial conditions to be adopted in flood routing model applications, analysis of model result for estimation of Highest Water Level (HWL) in the project area have also been described in this chapter.

Chapter 6, details on the determination of Safe Grade Level (SGL) for the project area based on the HWL, considering the slope to be adopted for storm drains and allowing freeboards for the storm drains (both inside and at outlet). Chapter 7 brings out the storm water drain design (dimensions) from the SGL and project layout plans, wherein the drain outlet invert, drain slope and freeboard are accounted meticulously. Chapter 8 discusses selected case studies undertaken at CWPRS to represent atleast four categories of area drainage in the study. The risk analysis and finalization of SGL is presented in chapter 9. While Chapter 10, puts forth the guidelines for area drainage and SGL studies for TPPs.

It is hoped that, this technical memorandum finds its user community cutting across the disciplines in the area of determination of SGL and storm water drain system. It is reiterated that, the memorandum aims at the SGL studies for which the driving factor is flood derived from rainfall and thus for cyclonic and other floods, additional flood estimation procedures are to be adopted. This technical memorandum also serves as tool to senior management executives of projects to grasp the crux of problem, the steps involved in such investigations, the applicability of results to their projects and also in technical auditing of such proposals.

Dr. C. Ramesh Scientist-C

Description of Symbols Used

Symbol	Description
α	Scale parameter of PDF/CDF
α^{\star}	Estimate of scale parameter of PDF/CDF
$\alpha_{_{1}}$	Velocity weighting coefficient at cross section 1 of a reach
α_2	Velocity weighting coefficient at cross section 2 of a reach
	Location parameter of PDF/CDF
β	
$\boldsymbol{\beta}^*$	Estimate of location parameter of PDF/CDF
λ	Shape parameter of PDF/CDF
Γ	Gamma function (used if frequency analysis)
γ	Skewness of the given population
σ	Standard deviation
$\Psi(\lambda)$	Digamma function used in frequency analysis
χ^2	Statistic used in GoF of frequency analysis
η	Manning's roughness coefficient
θ	Weighting factor used in solving unsteady equations adopting implicit scheme
Δt	Time step used (min, hours)
Α	Drainage area of catchment or watershed (km²)
A^2	Statistic used in GoF of frequency analysis (of Anderson Darling test)
A_c	Area of channel section (m ²)
A_{f}	Area of flood plain (m ²)
С	Expansion/contraction coefficient (used in flood routing equations)
С	Runoff coefficient (used in flood estimation formulae)
С	Chezy discharge coefficient
C ₀ , C ₁ ,	Coefficients used in Snyder and Clark unit hydrograph parameter
C_2 , C_3 , C_6	computations
C_s	Coefficient of skewness
CBA	Cost benefit analysis
CDF	Cumulative distribution function
DEM	Digital Elevation Model
E _i	Expected value of recorded value (O _i)
EDF	Empirical distribution function
Exp	Exponential
e	Exponential
F	Total rainfall (cm) in storm duration T as per IRC guideline
FB _{out}	Freeboard provided at storm water drain outlet (above HFL)
FB _{ch}	Freeboard provided in the storm water drains in TPP area
F(X)	Cumulative distribution function (used in frequency analysis)
H _{ch}	Height required to provide the required channel depth for storm water drain
H _{sl}	Height required to provide the required slope for storm water drain
HWL	High water level (m)
h _e	Energy head in m (used in steady state energy balance equation)
lc :	Critical rainfall intensity (cm/hr) used as per IRC guideline
i	Rainfall intensity (mm/hr) (used in flood estimation formulae)

Description of Symbols Used (Contd...)

Symbol	Description			
K	Conveyance of a section (used in flood routing)			
K_P	Frequency factor corresponding to the coefficient of skewness (C _s)			
1,1c	Main stream length and length from centroid of drainage area to the outlet(km)			
L	Discharge weighted length (steady state flood routing)			
L	Time period for flood in years (used in risk analysis)			
Ln	Natural log			
LTEC	Least total expected cost			
N	Sample size in frequency analysis (total length of AMS)			
Oi	Recorded value			
Q_c	Lateral inflow in to channel (m ² /s)			
Q_{f}	Lateral inflow in to flood plains			
Q_{ρ}	Peak rate of runoff (m ³ /s)			
q	Peak runoff rate or flood (m ³ /s)			
q_l	Lateral inflow into channel per unit length (m²/s)			
q_c, q_f	Exchanges water between channel to flood plains			
р	Number of parameters of distribution			
PDF	Probability Density Function			
P(E)	Probability of exceedance of flood			
R	Hydraulic radius (m)			
R_0	Residual function (used in frequency analysis – LP III)			
Rc	Storage coefficient used in Clark UH method			
R_{E}	Uniformly distributed rainfall excess			
S_{o}	Channel bottom slope			
SGL	Safe grade level (m)			
T_c	Translation coefficient used in Clark UH method			
T_R	Time duration used in Snyder UH method			
T(X)	Return period of flood event (years)			
t	Time period (min, hours)			
t_b	Time base used in Clark UH method			
t_c	Time of concentration (min or hr)			
t_p	Basin lag used in Snyder UH method			
V_1	Average velocity of flow (m³/s) at cross section 1 (steady state equation)			
V_2	Average velocity of flow (m ³ /s) at cross section 2 (steady state equation)			
W_{50}	Width of the UH measured at 50% of peak discharge ordinate (hr)			
W ₇₅	Width of the UH measured at 75% of peak discharge ordinate (hr)			
W_{R50}	Width of the rising limb of UH measured at 50% of peak discharge ordinate (nr.			
W_{R75}	Width of the rising limb of UH measured at 75% of peak discharge ordinate (hr			
X_i				
Y_T	Reduced variate used in EVA			
Z_1, Z_2	Elevation of main channel inverts at cross section 1 and 2 respectively			

Definition of Terms Used

- **Annual Maximum Series –** Series of the variate (rainfall or flood) generated by selecting one maximum event per year is known as 'Annual Maximum Series'.
- Catchment Factors Catchment factors are: topography, shape, size, slope soil type and land use (paved or roofed areas).
- Chart Datum- The lowest water level in creeks and estuarine region.
- Critical Depth It is the depth of water flowing in an open channel or conduit, partially filled, and corresponding to one of the recognized critical velocities.
- Cross Section A section formed by a plane cutting through an object, usually at right angles to an axis. If the object is a channel then it is called 'channel cross section'.
- **DEM** Digital Elevation Model is the digital representation of elevation of topography of the area of interest upon which mathematical operations could be applied.
- **Design Frequency** A design frequency should be selected commensurate with the facilities cost, amount of traffic, potential flood hazard to property, expected level of service, political considerations, and budgetary constraints as well as the magnitude and risk associated with damages from larger flood events.
- **Design Flood** The maximum flood (m³/s) that any structure (spillway, highway drainage, bridge, etc.) can safely pass (handle) is called the Design Flood.
- **Discharge** A graph showing the rate of flow (discharge) or depth of flow (runoff) per unit time at a specific point in a river.
- **Drainage Basin -** A drainage basin (also known as a watershed) is an extent or area of land where surface water from rain and snowmelt or ice converges to a single point, usually exit of the basin, where the waters join another water body, such as a river, lake, reservoir, estuary, wetland, sea, or ocean.
- **Exceedence Probability** Hydrologically, the probability that an event selected at random will exceed a specified magnitude.
- Flood Plains The position occupied along the river course (both side) of a stream during a particular flood.
- Flood Routing A mathematical procedure to study the moderation of flow characteristics (flow velocity, energy, flow volume, etc.) as the flood wave travel at successive points along a river channel. If the flow is assumed to be constant with respect to time it is called 'steady state' routing and if it is assumed to change with respect time it is called as 'unsteady state' routing.
- Flow-Duration Curve It is a cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.
- Freeboard The vertical distance between the water level corresponding to the design discharge (Q) including afflux and the formation level of the approach banks or the top level of guide banks

Definition of Terms Used (Contd...)

- **Frequency** The number of times a flood of a given magnitude can be expected to occur on an average over a long period of time.
- High Flood Level Highest recorded water level during flood periods at a location in river reach is known as 'High Flood Level'.
- High Water Level The highest water level reached (estimated using models) in an inundated area when the design flood (or flood with 100yr return period)
- **Hydraulic Radius** It is defined as the flow area divided by the wetted perimeter. The wetted perimeter does not include the free surface.
- **Hydraulic Roughness** A composite physical characteristics which influence the flow of water across the earth's surface, whether natural or channelized. It affects both the time response of a watershed and drainage channel as well as the channel storage characteristics.
- **Hydrograph -** A graph relating stage, flow, velocity, or other characteristics of water with respect to time
- Hyetographs A graph of the time history distribution of rainfall depth at a point.
- **Infiltration** A process in hydrologic cycle from catchment wherein the water penetrating through the ground surface soils (downward entry) and flowing through the upper soil layer.
- **Lag Time** The time interval from the center of mass of rainfall excess to the peak of the resulting hydrograph is also known as 'Basin Lag'.
- Levee (Dike) A long, narrow embankment usually built to protect land from flooding. If built of concrete or masonry the structure is usually referred to as a flood wall. Levees and floodwalls confine streamflow within a specified area to prevent flooding. The term "dike" is used to describe an embankment that blocks an area on a reservoir or lake rim that is lower than the top of the dam.
- L-Section Section formed by a plane cutting along a river reach (usually min. bed level)
- **MSL-** Mean sea level (MSL) is the average (mean) height of the sea, with reference to a suitable reference surface
- Normal Depth This is also known as Uniform depth that occurs when the discharge, slope, cross-sectional geometry, and roughness characteristics are constant through a reach of stream.
- **Outlier:** Extreme observations that is well separated from the remainder of the data in regression analysis.
- **Parameter** Parameter is a measurement on a population that characterizes one of its features. An example of a parameter is mode, i.e. the value in the population that occurs most frequently. Other examples are population's mean and variance.
- **Peak Discharge** It is the maximum instantaneous volume rate of water passing a given point during a runoff event.

Definition of Terms Used (Contd...)

- **Partial Duration Series -** Collection of all values of a variable say flood peaks that exceed a threshold value of discharge, regardless of the number of peaks occurring in a year.
- **Probability Distribution Function:** A function which gives for each number x, the probability that the value of a continuous random variable X is less than or equal to x. For discrete random variables, the probability distribution function is given as the probability associated with each possible discrete value of the variable.
- Rainfall Excess The rainfall excess is the water available to runoff after satisfying basin abstractions (interception, depression storage, and infiltration).
- **Reach -** The length of a channel of a river between two gauging stations or more generally, any length of a river between two cross section.
- Return Period It is the average interval of time (years) within which the given flood will be equaled or exceeded once. It is the reciprocal of annual exceedence probability (AEP). This is also known as Mean Recurrence Interval (MRI)
- Risk Analysis It is the study of underlying uncertainty of a given course of action. Risk analysis refers to the uncertainty of forecasted future say safe grade level (SGL) and statistical analysis to determine the probability of a project's success or failure.
- Safe Grade Level It is the formation level of a project with respect to a datum (say MSL), above which the project is safe due to flood inundation.
- Stage The elevation of the water surface above some elevation datum.
- **Statistic -** A measure on the items in a random sample. Statistic calculated is an estimate of corresponding parameter of the population from which the sample was drawn. An example of a statistic is the mean of the measures in the sample.
- Stage-Discharge Curve (Rating Curve) A graph showing the relation between the gauge height, usually plotted as ordinate, and the amount of water flowing at a point in a channel, expressed as volume per unit of time(m³/s), plotted as abscissa.
- **Time of Concentration** Time taken by a drop of water falling at a hydraulically most remote point in watershed to travel through the watershed to a desired outlet point
- Time to peak Time interval from the start of the resulting hydrograph.
- **Tsunami** Long period ocean wave resulting from earthquake, other seismic disturbances or submarine landslides.
- Unit Hydrograph The unit hydrograph for a catchment is defined as the discharge hydrograph resulting from a unit of effective rainfall generated uniformly over the catchment at a uniform rate during a specified period of time. The ordinates of the unit hydrograph are such that the volume of direct runoff represented by the area under the hydrograph is equal to one unit (mm) of runoff from the area.
- Velocity Rate of motion of fluid (water) in stream/pipe, usually expressed in m/s.

List of National and International Organizations Referred

Organization Name and Country
American Association of State Highway and Transportation Officials, USA
Atomic Energy Regulatory Board, Mumbai/ New Deini, India
Rhabha Atomic Research Center, Mumbai/New Deini, India
Bureau of Indian Standards, Kolkata/New Delni, India
Coastal Andhra Power Limited, Mumbai/Noida, India
Central Water Commission, New Delhi, India
Central Water and Power Research Station, Pune, India
Danish Hydraulic Institute, Copenhagen, Denmark
Damodar Valley Corporation, Kolkata, India
Environmental Systems Research Institute, CA, USA
Government of India
Undralagic Engineering Center, Davis, CA, USA
India Meteorological Department, Pune/New Deini, India
Indian Road Congress, New Delhi, India
Light Research Department, from various State Govt. In India
At State of Environment and Forests and Climate Change, New Dellii, India
Ministry of Environment and Forest State of Ministry of Water Resources, River Development and Ganga Rejuvenation
Normada Control Authority
National Highway Authority of India, New Delni, India
National Highway Authority, Maryland, USA
Netional Institute of Oceanography, Goa, India
National Oceanic and Atmospheric Administration, Washington, USA
Nuclear Power Corporation of India Limited, Mumbai/New Deini, India
National Thermal Power Corporation, New Delhi, India
National Weather Services, Washington DC, USA
Reliance Energy Limited, Mumbai/Noida, India
Boliance Infra Group, New Delhi/Mumbai, India
Tata Power Consultancy Limited, Mumbai/New Delhi, India
United States Army Corps of Engineers, Washington DC, USA
Water and Power Consultancy, Gurgaon, India
World Meteorological Organisation, Geneva, Switzerland
Water Resources Council, California, CA, USA
Water Resources Department, from various State Govt. in India

List of Relevant Models/ Softwares

Model /software	Description	Organization and Country		
I. Flood Routing & Inundation Mapping Softwares				
HEC-RASv5.0.3	HEC River Analysis System	HEC, Davis, CA, USA		
HEC-HMSv4.2	HEC Hydrologic Modelling System	HEC, Davis, CA, USA		
MIKE-11	Flood Routing Software	DHI, Denmark		
MIKE-FLOOD	Flood Mapping Software	DHI, Denmark		
DAMBRK/ FLDWAVv1.0	Dam Break/ Flood Wave Modeling Software	NWS, USA		
CHARIMA	Channel Routing Implicit Modelling	USA		
II. Statistical Softwares				
HEC-FFA	Flood Frequency Analysis Software	HEC, CA,USA		
HYDROGNOMON	Hydrologic Frequency Analysis	Zografou, Greece		
HYFRAN-Plusv2.2	Hydrologic Frequency Analysis Software	WRC, USA		
III. GIS and General Purpose Softwares				
ArcGIS10.5.1	Industry Standard Geographical Information System	ESRI, CA, USA		
TerrSet (Idrisi)	Image Processing and GIS Software	Clark University, USA		
DIDGERv5.11.1438	Digitization and Map Projection Software	Golden Software, Co, USA		
SURFERv15.5.382	Surface Modelling Software	Golden Software Co., USA		
GRAPHERv13.1.668	Data Plotting Software	Golden Software Co., USA		
MS Excel 2016	Data Processing, Graph Plotting and Statistical Tools Software	Microsoft, CA, USA		
AutoCAD Civil 3D	Computer Aided Design Software for Civil and Mechanical Engineers	Autodesk, Inc., USA		

EXECUTIVE SUMMARY

Real world problems in water resources sector (say floods, drought, Irrigation water, etc.) require application of techniques developed in different fields and analyzing the results for obtaining techno-economically feasible solutions. Technical memorandum enlightens different aspects and techniques in the respective fields, say hydrology and hydraulics in the present case, the associated mathematical procedures, probabilistic approaches, their simplifications, applications and limitations with case studies where in these have been successfully applied. This technical memorandum is intended to cater to such needs and also acts as yard stick while conducting studies in the field of 'Determination of Safe Grade Level' (SGL). In this, flood inundation of the project area considered is due to the design (extreme) rainfall only and thus flood due to dam break or cyclonic storms is beyond the scope of this memorandum as they require special treatment as regards design floods.

Broadly, the memorandum is divided into five sections viz., (i) Data (collection, scrutiny and pre-processing), (ii) Design flood estimation (EVA of flood or rainfall, peak flood computations adopting empirical and UH methods), (iii) Estimation of flood inundation level (steady/unsteady methods, boundary and initial conditions, analysis of results), and (iv) Determination of SGL (risk analysis, refinement of results) and (v) guidelines section.

Data section elaborates the site inspection, field data collection especially survey data (instructions for field survey) and comprehending the existing project scenario and also understanding the post project scenario in respect of area drainage. Data (rainfall and/or flood) screening and filtering operations are critical in the SGL studies. For a better presentation of the pre and post project flooding scenario, DEMs are essential from which project layout plan of project area could be developed and used to generate flood inundation maps. It is essential that, the local survey of the project area is carried out at a detailed level with proper instructions to collect cross section (CS) details well above HFL marks.

Design flood estimation is a critical issue in flood routing and flood inundation study. As requisite flood data is generally not available and streams are ungauged, many a times flood is determined using design rainfall estimated from EVA,. The statistical tests applied to the annual maximum series of rainfall in particular the outlier test, if encounter a high observed value, may be reviewed and the value may be included if found reliable/ acceptable in the series with proper noting. In the SGL studies, design floods are approximately taken as equivalent to 100yr return period flood. From the estimated extreme rainfall of 100yr return period, flood hydrograph are estimated with CWC unit hydrograph (UH) method for Indian catchments. Thus peak flood estimation in general is carried out from flood hydrograph generated from UH or by adopting rational formula.

The estimation of flood inundation level through flood routing is typically a deciding factor in determination of SGL. The selection of model type (steady or unsteady) is dependent on the data availability and project requirements. In flood routing the first and foremost step is, to ascertain the true representation of the river/ stream geometry so that it replicates the real world drainage topography. Assigning proper roughness coefficients (Manning's η), expansion and contraction coefficients, model boundary and initial conditions form the final stages of flood routing model. Once the model results are available, it is analyzed with respect to geometry (order of CS, levees wherever flood plain details not given) and thus become check point. Analysis should also view the effect of roughness

coefficients and any discrepancy in the boundary conditions specified on water surface profiles estimated. Subsequent to model results being found acceptable, High Water Level (HWL) is extracted at points of interest say critical areas (main plant, switchyard, etc.). From these and considering invert level of storm water drain outlet, height required for storm water drainage system for maintaining desired slopes and appropriate freeboards for storm water drains, SGL for the project is determined. Based on the SGL and project layout plan storm drain network for project is designed.

The SGL determined should be discussed with project authorities to evaluate the risks and the cost benefit factors in providing the determined SGL. If the initial project costs are found to be high, refinement of flood routing results with modified CS (dredging and widening), terracing of project layout by keeping critical project units at higher SGL and others (less critical) at a lower level, accepting flood with lower return period (50yr) with pumping and gated storm water outlet facility and / or more storm water drain outlets could be explored. The memorandum hints at the risks involved in the options of pumping of storm water and also in gated outlets for storm water from projects, as there could be failures due to electrical, mechanical and manual errors involved in operating them.

CWPRS has carried out studies on determination of SGL for a number of power projects, refineries and steel plants. Brief details of few of these case studies have been presented in this technical memorandum (Annexure-4), where in the procedures discussed have been implemented for the SGL determination. In preparing the technical memorandum, a number of relevant standards such as BIS, IRC, IRS and NHWA have been referred and wherever necessary in SGL determination and have been presented in Annexure-2.

Procedural approaches and guidelines for the SGL determination and design of storm water drains are presented in the technical memorandum. However, each project in itself has many dimensions and typical site conditions that need to be addressed either explicitly or implicitly, while carrying out the studies. Hence, a combined effort by modelers, project authorities and their design consultants could offer a better solution for project flood inundation problem. The risks and cost benefit aspects have been presented briefly in the memorandum for completion and thus are not exhaustive.

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1.0 Preamble

The socio-economic development of any nation depends on its industrial and agriculture performances. Both for agriculture and industrial growth, electric power is an essential commodity. Added to this, present life style has put tremendous stress on the power generation. New techno-feasible locations for hydro-power production have become limited. Thermal power is the apt and feasible solution for this situation. Accordingly, Govt. of India has accorded permissions to private and Govt. sector to generate more power adopting thermal energy. Design of any industrial structure such as Thermal Power Plant (TPP) is based on certain anticipated period of useful life (say 25yr, 50yr, 100yr). It is also essential that, it functions satisfactorily in the span of its designed life. At this juncture, it becomes mandatory during the project proposal stage to anticipate the adverse situations such as severe flood events that could occur during the active life period of the project leading to inundation of TPP and impair its normal functioning and thereby resulting in losses associated with it.

It is a well established fact that, TPP needs water (steam) for driving turbines and also for its cooling systems. At the same time, flooding of water near the plant, switchyard and other vital installations in a TPP would impair the functioning of the units. Hydrological studies are necessary to estimate the extreme value of floodwater reaching a TPP area, its drainage efficiency and the resulting inundation problems thereof. This technical memorandum details one such situation i.e., flood inundation under which the power project could be exposed to the risk of flooding. The memorandum attempts to discuss the different site and climatic conditions of power projects and put forth certain procedural approaches in attempting to assess the area drainage of the region. The High Water Levels (HWL) due to inundations estimated from such studies would aid the determination of Safe Grade Levels (SGL) for the power plants. Some typical case studies from India have also been presented to highlight the methods adopted, models used, boundary conditions used in the studies of these projects, storm water drain design also has been briefly presented in this technical memorandum to complete the aspects in area drainage studies for power projects.

This memorandum could be extended for application to other industrial and commercial projects also, but their requirements and inherent project constraints may be considered in study planning stage. As the study primarily deals with the drainage of flood water through the existing drainage network (pre project) in the vicinity of project and storm water drainage (post project) within the project, it is synonymously called as 'Area Drainage Study'. Summary section of the memorandum also presents some guidelines in estimating the HWL in project area and the determination of SGL for different site conditions, based on project requirement and the project cost.

The Central Water and Power Research Station (CWPRS) Pune working under the Ministry of Water Resources, River Development & Ganga Rejuvenation (MoWR, RD&GR) is the premier research institute conducting research in the field of water resources development

and water borne transport since 1916. Apart from undertaking varied disciplines of water sector, CWPRS has successfully completed over 50 studies in area drainage and SGL for power projects, industrial projects, offshore projects, petroleum projects. Some of the prestigious organizations for which CWPRS had conducted area drainage and SGL include, BARC, NPCIL, NTPC, ONGC, WAPCOS, DVC, TPCL, REL, RIL, L&T, ESSAR, TPCIL, etc.

1.1 Scope of Memorandum

This technical memorandum presents the essential features, material and methods required for the determination of SGL for power projects; nonetheless it is adequate for carrying out an extensive work for SGL. It offers a general guideline required in the determination of SGL. However, the typical site conditions, project requirement and the associated data available would have to be considered in conducting such type of studies. The project costs, socioeconomic considerations needs to be assessed and suitable risk factor have to be worked out for such situations before finalizing the SGL. Thus the scope is restricted to the flood inundations in the region of power project due to extreme/ design flood resulting from extreme/ design rainfall only and the effects of floods due to dam break, cyclonic storm or Tsunami effects are not included as these require certain additional aspects to be considered in the study.

1.2 Real World Situations

In the real world scenario TPP may be located in the region of flood bank of river, near the local stream, coastal areas affected by the tidal wave and estuarine regions which have varied effects on the flooding in the region. Thus the studies are site specific involving varied applications of flood routing method with different boundary conditions for solving flow regimes. Specific case studies carried out for typically situated TPP in India at different geographic locations by CWPRS are explained at the end of the memorandum to showcase the real world situations that have been studied.

It is essential in any technical study to chalk out the method of approach, which acts as a guide for conducting the study and also brings out the assumptions made, the course of study and the short comings. Following section details the methodology that should be adopted and the probable tools/ models that could be used in conducting studies for determination of SGL for power projects;

- Site inspection of project area to comprehend the existing hydrologic conditions
- Data collection from field and data analysis such as
 - > Rainfall and storm data say, from India Meteorological Department (IMD),
 - > Stream and river flow data from Central Water Commission (CWC) and state Water Resources Department (WRD)/ Irrigation Departments (IRD)
 - > Water level and tide data from field agencies (Maritime Boards)
 - > Pre-processing of rainfall and flow data, scrutiny, statistical tests (outliers, homogeneity, randomness, skew, etc.)
 - > Study of land survey data (spot levels, cross sections, L-sections) and relate to base maps and topomaps if necessary
 - > Catchment/s contributing to the drainage system (in the region of the project) to be delineated
 - > Catchment characteristics to be estimated (area, time of concentration t_c, average slope, drainage density, etc.)
 - > Develop Digital Elevation Model (DEM) of project area
 - > Estimation of design flood or extreme (peak) flood for streams/ rivers
 - In case stream flow data not available, conduct Extreme Value Analysis (EVA) of daily and sub daily rainfall to estimate extreme rainfall values with a 50yr/100yr return period
 - If sufficient records are available on stream flow, conduct EVA of flood data to estimate extreme flood in stream/ river
 - Subject EVA results to Goodness of Fit (GoF) Tests
 - Adopt suitable rainfall-runoff transformation methods (Rational formula/ Unit Hydrograph techniques) to estimate extreme/ design flood
 - Storm surge levels are either estimated or obtained from agencies such as National Maritime Agencies, Ports, National Institute of Oceanography (NIO), etc.

- Using survey data; model layout (geometry) is prepared for flood routing in the existing riverine system
- Based on the availability of time series data on floods, tidal heights, gauge rating tables suitable flood routing method i.e. steady state or unsteady state is selected for routing the extreme floods through the river network. The model selection is also dependent on the project requirement.
- Based on site conditions and model selected, boundary conditions and initial conditions for the model need to be prepared. (HEC-RAS, MIKE 11, CHARIMA)
- Once the model geometry and flood data are ready, the inputs for the flood routing model (steady state/unsteady state) are prepared and model runs are taken.
 - > From the results of flood routing model i.e. water surface profiles High Water Level (HWL) at critical locations (plant, switchyard, coal handing area, etc.) are estimated
 - > From the HWL at critical locations, invert level at storm drain outlet and the total slope available for the storm drains, 'Safe Grade Level' for the power project is determined
- In determining SGL, the free boards for storm drains and their roughness are to be governed by BIS standards for design of surface drain/canals
- Subsequent to determination of SGL, project layout plan needs to be obtained from project authorities
- Brief Cost Benefit Analysis (CBA) in optimizing the SGL may be carried out.
- Based on the SGL and project layout plan, storm water drains are designed
- If situation needs, the risk analysis has to be carried out for the SGL determined based on the design considerations of return period

To summarise the method of approach for conducting SGL and area drainage studies, the following aspects are needed; (i) Catchment (contributing area) analysis, (ii) Rainfall and flood data analysis, (iii) Estimation of design flood for the stream/ river, (iv) Flood routing and estimation of highest flood levels, (v) Determination of SGL and (vi) Storm water drainage which is based on CBA/ Risk analysis. However, the critical steps in SGL studies are (a) Design flood estimation, (b) Flood routing (inundation levels), (c) Determination of SGL and, (d) Storm water drain design

3.0 Data Collection

In any study, data forms the back bone; the quantity and quality of the data have definitely a bearing on the results of the model studies. For SGL studies the important data required include, rainfall (hourly and daily) from the rain gauge stations in the region of project area, stream gauge data from stream / river in and around project area and / or high flood level river / stream cross section etc. (A-1). If unsteady model is being adopted, stage-discharge data of stream/ river or tide level data is essential for model to fulfill the model downstream boundary conditions. Rainfall and stream flow data are required for at least a period of 30 years or more for estimating design/ extreme/ peak flood. These data could be obtained from various agencies such as India Meteorological Department (IMD), Central Water Commission (CWC), State Irrigation/ Water Resources Departments, Indian Railway authorities and/ or National Highway authority. The channel cross section details, L-section of stream/rivers in the study region and spot elevation data for the project area are surveyed with requisite resolutions. If the project area is lying in the estuarine region, tidal data for at least one lunar cycle or longer period are to be collected.

The data collected should be compiled to assess the adequacy of the data for the studies, scrutinized to identify absurd and spurious data. Missing data if any should be noted and working series should be prepared accordingly.

3.1 Site Inspection and Field Data

Area drainage and flood inundation studies could be better performed by the modeling engineers and hydrologists provided, an in-depth understanding of the site conditions and data acquisitions are possible. A detailed inspection of the existing system would thus form an integral part of the data collection and model development process. The information other than data would assist in comprehending the system and equip the modeler with visualization of the processes at site. Site inspection also provides the platform for project authorities and modeler to interact and define the modeling strategies and data collection programme for the study. Site inspection aids in planning the survey data collection, discussions on project layout alternatives and drain diversion plans. More so it is the step during which time planning of storm water drain outlets (which forms important aspect in SGL determination) could be considered for finalization of SGL determined.

3.2 Analysis of Rainfall and Stream flow Data

Scrutiny and validation of the data received for the modeling purpose is essential as junk data would lead to garbage results from model that may be misleading or could be disastrous. Time series plots of the data (rainfall, stream flow) are plotted with the help of general purpose softwares (Excel, Grafer, etc.) to study the trends in data. In the event of non availability of design flood for the stream/ river affecting the area drainage of the region of project, it is to be

estimated (extreme flood with 100 years return period) from the available flood records adopting flood frequency analysis. If flood data is not available, it may be estimated adopting flood estimation formulae or converting extreme rainfall into runoff adopting suitable rainfall runoff transformation methods such as unit hydrograph techniques or simple rainfall-runoff equations. In either event for the rainfall (hourly, daily) data or recorded flood data Annual Maximum Series (AMS) are extracted by picking one maximum event from each year for subjecting it to frequency analysis.

3.3 Survey Data Scrutiny

Flood routing model requires the details on spot elevation of project area, cross section (CS) and L-section of the nallas, streams in and around project area. It is essential to conduct the survey of the project on the above aspect to the required accuracy for modeling purposes. In general, the survey should be carried out to cover the following details

- Spot elevation of project area to be conducted at a scale of 1:5,000 or finer
- CS describing the station vs. elevation to cover the full water spread area in the section and flood banks or at least 1m above observed high flood level
- CS details should sufficiently cover the details of channel section; at least 5 observations for simple section to more than 15 points for complex CS geometry.
- The reach of stream/ river should properly be measured; i.e. CS to be surveyed at intervals of 20m or finer for small stream (nalla) while the river CS should be surveyed at intervals of 200m to 500m depending on the site.
- The survey data should be made available to modeler in the form of hard copies (AutoCAD drawings) and also in digital data formats (MS Excel sheets)
- Scrutiny of survey data is essential as these need to be mapped with respect to Survey of India (SoI) toposheets of appropriate scale (say 1:25,000 or 1:50,000)
- Interaction of survey team with modeler is essential for getting an accurate and desired Survey data for model purpose. Carefully surveyed stream network geometry would greatly reduce modeling efforts, and results in better model output.

3.4

Visual assessment of the ground levels in and around the project area would aid in Visual assessment of the ground levels in and abstract using the elevation data comprehending the site drainage conditions. DEM is developed using the elevation data obtained. obtained by digitizing (using softwares such as Didger, TerrSet[Idrisi], ArcGIS) the contours from the C from the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data obtained from the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data obtained from the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or from stereo data of the Survey of India (Sol) toposheets or spot elevation data from survey or spot elevation data from obtained from satellites. Various softwares (Surfer, AutoCAD, TerrSet[Idrisi], ArcGIS, etc.) adapt different different approaches to develop DEM from elevation i.e., x, y, z (latitude, longitude and elevation) elevation) data. It is essential that, the data is geo-registered to a particular map projection say Polyconia. Polyconic, Lambert Conical or Universal Transverse Mercator (UTM). For uniformity in Geograph. Geographic Information System (GIS) data set, the UTM map projection for Indian sub continent is taken as the set of the is taken as 43/44 N zone may be adopted based on the location of project. The details on GIS database database and map projections could be found in GIS literature (ESRI, 2011; Idrisi, 2001;

Didger3, 2001). From the point (xyz) data, surface interpolation techniques (Krigging, Spline, etc.) are applied and raster data in grid form with desired grid size (say 10m, 25m, 30m...) could be obtained with these softwares (Surfer, ArcGIS, Idrisi). The process of converting the point (xyz) data to DEM vary with the software being used, i.e., if ArcGIS are used, Triangulated Irregular Networks (TIN) data is generated from which contours of desired intervals are computed and then raster grid data are generated with specified grid resolutions. Typical DEM developed with a grid resolution of 10m for one of the TPP area is presented in Fig. 3.1.

The DEM not only offers a perspective view of project area, but also depicts the low lying and elevated areas for preparing project layout plan. Simultaneously, DEM could be trimmed to the project boundary and the extent of project area, general slopes, cut-and-fill volume computations and associated inundation levels could be mathematically processed and viewed. Thus, it is one of the handy tools in pre-project planning stage, and also post project stage which offer visual inundation extents in project area.

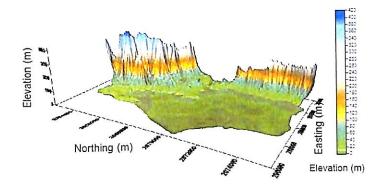


Fig. 3.1: DEM of Watershed near Dehrand TPP

3.5 Summary

Data collection should be aimed at acquiring all the required data for the studies. The data sources should be carefully chosen so as to suit to data validation process. Always collect all possible field data for avoiding repeated site visits. The survey data of the channels/streams should be discussed with the surveyors before incorporating into the model. While processing the geometry data two things need to be carefully considered i.e. (i) the channel orientation (ii) Survey of channel bank to incorporate the levels beyond HFL. Another important point to check would be to ascertain the bench mark or GTS adopted in survey.

4.0 Design Flood

Design flood estimation has a typical importance in hydraulic structure design in the field of water resources. However, in this technical memorandum, the flood events that affect the anticipated useful life of project only are covered. In general the life of these projects is assumed to be 100years unless the project has specified special norms for their project such as NPCIL (AERB, 1998; AERB, 2002). Design flood frequencies proposed for culverts and surface drains by NHWA standards are presented in Annexure-3. In this memorandum design flood is taken as flood with 100year return period. This could be obtained by subjecting flood data of the streams to flood frequency analysis i.e., EVA as detailed in the subsequent sections. Many a times the streamflow data for the stream/ river in the vicinity of the projects are not available and hence to estimate peak/ design flood, EVA of rainfall is conducted to compute extreme rainfall with 100yr return period and extreme flood is computed adopting one of the suitable rainfall-runoff (R-R) transformation techniques (empirical, conceptual or unit hydrograph).

There are various methods by which the design flood could be estimated. Some of them are purely empirical, while others are based on statistical analysis of the historic records. The methods are,

- 1. Observation of the highest flood level or maximum historical flood,
- 2. Empirical formulae,
- 3. Enveloping curves,
- 4. Flood frequency studies, and
- 5. Derivation of design flood from storm studies
 - a. Application of unit hydrograph principle, or
 - b. By application of instantaneous hydrograph principle

In this memorandum only the widely used methods such as, flood frequency analysis of rainfall/ flood data and design flood estimation with empirical and unit hydrograph methods are presented.

4.1 Extreme Value Analysis

Probabilistic modeling is one of the techniques in vogue (Singh et al., 1990) for design flood estimations. The annual peak rainfall and annual peak discharge series are considered in EVA need to be independent (random). In reality these are controlled by a large number of causative factors. For EVA of Hydrometeorological data, various probability distributions such as Extreme Value Type 1 (EV-1), Log Normal 2-parameter (LN2), Log Pearson Type III (LP III), Pearson Type III (P III), etc., are used (Haktanir, 1991; Naghavi et al, 1993; Ramesh et al., 2008; CWC, 2011; Singh et al, 1990). These probability distributions have different properties and are defined by two or three parameters. The parameters describing these distributions are; (i) location, (ii) scale and (iii) shape. Based on the combinations of parameters used and the Continuous Distribution Function (CDF), the behavior of the distribution takes its shape.

In case of EVA studies of hydrometeorological parameters for NPCIL and BARC projects, AERB guidelines (AERB, 2008) advocate specific probability distributions and flood frequency analysis to be followed. The discussions on this are beyond the scope of this technical memorandum. However, it is suggested that readers could refer to AERB literature (AERB, 2008) in this regard. The frequency analysis for extreme rainfall estimation is to be carried out for area drainage studies adopting different methodology such as EV-1 (two parameter – location and scale), LP III (3 parameter – location, scale and shape) probability distributions etc. It is worthwhile to state that, EVA is governed by parametric approaches while, statistical tests is governed by non-parametric approaches.

From the time series data (rainfall/ flood), working series or sample population is prepared as (i) Annual Maximum Series (AMS), (ii) Partial Duration Series (PDS) and/ or Peak over Threshold (PoT). Each of this have different characteristic feature and used for different purposes. However, for EVA in the present context, AMS is used. The AMS of rainfall or flood needs to be subjected to basic statistical tests before carrying out flood frequency analysis. The statistical tests are; (i) test of Independence (randomness), (ii) test of homogeneity and (iii) outlier test.

4.1.1 Extreme Value Type - 1 Distribution

EV-1 distribution, commonly known as Gumbel distribution, is widely used probability distribution for estimation of extreme rainfall/ flood for different return periods (Gupta, 1989; Mutreja, 1986). EV-1 distribution is basically a 2 parameter distribution (location and scale). The Cumulative Distribution Function (CDF) of Gumbel distribution is:

$$F(X) = \exp\{-\exp[-(x-\alpha)/\beta]\}, -\infty < x < \infty, -\infty < \alpha < \infty, \beta > 0 \qquad \dots (4.1)$$

where α and β are the location and scale parameters of the distribution.

4.1.2 Log Pearson Type III Distribution

Log Person Type III (LP III) is a 3 parameter distribution (location, scale and shape). The probability distribution function of LP III is given by:

$$f(x;\alpha,\lambda,\beta) = \frac{|\alpha|}{\Gamma(\lambda)} \left(\frac{e^{\alpha\beta}}{x^{1+\alpha}} \right) [\alpha(\ln x - \beta)]^{\lambda-1}, \ x>0, \ \lambda>0, \ -\infty < \beta < +\infty$$
 ... (4.2)

where α , λ and β are the scale, shape and location parameters of the distribution. The parameters of LP III are estimated using the method of maximum likelihood, with an iterative procedure. The theoretical description of the probability distribution function, the parameter estimation procedures and their analysis can be found in the literature (Ramesh et al., 2008; Stedinger et al., 1983; Naghavi et al., 1993).

4.2 Design Flood Estimation

The design flood is defined as 'flood considered for the design of a structure corresponding to a maximum tolerable risk'. The design flood (IS, 1982) could be (a) Flood of Specific Return Period, (b) Probable Maximum Flood (PMF) or (c) Standard Project Flood (SPF).

4.2.1 Flood of Specific Return Period

The flood of specific return period is estimated based on availability of observed stream flow data. If sufficient length of observed flood records is available for the stream/ river in question, EVA is applied on the annual maximum series of the flood to estimate extreme flood of different return periods. From the estimated extreme floods the design flood is chosen as the extreme flood of specific return period (25/ 50/ 100yr). On the other hand, in absence of observed stream flow data for the stream/ river in question; the EVA of rainfall data is conducted on annual maximum series of rainfall and a suitable design storm is selected (specific return period) from the EVA results and adopting appropriate R-R method design flood is estimated.

4.2.2 PMF and SPF Estimation

The PMF and SPF are estimated using a design storm viz., Probable Maximum Storm (PMS) or Standard Project Storm (SPS) over the catchment and adopting a suitable R-R transformation method. The design storm is defined as the storm which gives rise to design flood to flood for the particular catchment and has to be selected based on basin 'lag time' and the design storm is designed. Peak flood estimations are desired return period of flood for which the structure is designed. Peak flood estimations are used by extrapolating the observed runoff records (Haan et al., 1982) through applying it on the historic historic rainfall data. Based on analysis of a number of combinations of storms and basin lags, it has he has been found that for a given watershed the critical storm has duration equal to the basin lag. Brief Brief extract of IRC (IRC, 1998) guidelines as regards the critical or design rainfall intensity computations are presented in Annexure-3. The design storm may be estimated by one of the following following methods

- Probabilistic method for estimation of extreme precipitation for designed storm
- Method of rainfall-depth-duration curves or rainfall-intensity-duration curves
- Method of storm transposition, i.e., transposition of worst storm recorded in the neighborhood of catchment so that catchment lies at the centre of the storm

After the design storm is estimated, the design flood may be computed (PMF or SPF) by Dication of the the application of the appropriate rainfall-runoff method.

4.2.3 Flood Estimation by Empirical Formulae

Empirical models are developed (Chow, 1964) using observed rainfall and runoff data Empirical models are developed (Chow, 1964) using observed rainfall intensity and correlating with other basin parameters (drainage area of catchment, rainfall intensity and runoff coefficients). There are runoff coefficient) that are found to influence the runoff transformation process. There are umpteen number of flood estimation formulae in hydrology and water resources literature, some of widely used in India are Rational formula, Dicken's formula, Ryves formula and Inglis formula.

Rational Formula

Rational formula is based on (Haan, et al., 1982; Chow, 1964) the catchment area, rainfall intensity and a runoff coefficient that depends on the land use, and is given as,

$$q = 0.0278 \, Ci \, A$$
 ... (4.3)

where, q is design peak runoff rate in m³/s, C is runoff coefficient, i is rainfall intensity in mm/hr uniformly occurring over the basin and over a period equal to or greater than time of concentration of the basin, and A is the watershed area in km²

Dicken's Formula

Dickens formula for moderate size basins of north and central India is given as,

$$Q = CA^{3/4}$$
 ... (4.4)

Where the coefficient C is 11–14, when the average annual rainfall is 60 to 120 cm, 14 to 19 in Madhya Pradesh, 32 in western Ghats, and up to 35, maximum value.

Ryve's Formula

Ryves formula is derived from a study of rivers in south India and given as below,

$$A = CA^{2/3}$$
 ... (4.5)

Where coefficient C is 6.8 within 80 km of coast, 8.3 for areas between 80 and 2400 km from the coast, 10.0 for limited area near the hills and up to 40, actual observed values

Inglis Formula

Inglis formula for fan-shaped catchments of Bombay state (Maharashtra) is given as,

$$Q = \frac{124 A}{\sqrt{A + 10.4}}$$
 ... (4.6)

Many of these formulae are developed based on the site specific limited data collected for developing the empirical relationship. In general, for peak flood estimation rational formula has been adopted, as the runoff coefficient implicitly accounts for the soils and landuse/landcover factors of the project area in question.

Time of Concentration (t_c) is defined as the time taken by a drop of water falling at a hydraulically most remote point in the watershed to travel through the watershed to a desired outlet point in the valley. It is estimated (IRC, 1998) as given below,

$$t_c = \left(0.87 \frac{L^3}{H}\right)^{0.885} \tag{4.7}$$

Where t_c is time of concentration (hrs), L is distance from the critical point to the desired outlet point (km) and H is fall in level from the critical point to the outlet (m).

4.2.4 Flood Estimation by Unit Hydrograph Method

Widely used UH methods are Synthetic UH techniques; Snyder method, Clark method, and locally developed UH. CWC (CWC, 1992; CWC, 1994) have derived UH adopting Snyder's method for different regions in India (7 sub-zones based on the climate and basin conditions) by collecting local data for certain period on rainfall and runoff for these basins. Brief description of the UH methods is presented in Annexure-2. This could be easily adopted with computer codes or using MS Excel software while computing direct runoff using this UH. The time distribution coefficients for different storms (duration) i.e., hourly distribution coefficients are to be re-arranged for selecting critical sequence of rainfall distribution, which plays an important role in obtaining a severe flood peak.

4.3 Summary

Design floods are estimated in general using deterministic rainfall-runoff model/ or adopting probabilistic approaches through flood frequency analysis. However for ungauged catchments as encountered in area drainage studies for TPP, the design flood could be estimated using unit hydrograph techniques or empirical R-R formula (say Rational formula) from the extreme rainfall (design rainfall) with appropriate return period. While computing design flood adopting UH method re-arranging of sequence to obtain a critical sequence of hourly rainfall is essential. However design flood from empirical formula such as Rational formula the rainfall intensity computation may consider critical rainfall intensity (IRC, 1983). However, it is to be noted that selection of design flood for the stream/ river in question as regards the TPP needs to be selected from the experience and also on the judgments of hydrology in the vicinity of project as selection of an illogically large design flood (PMF or SPF) would land in high initial costs of projects. On the other hand, lower flood selection would involve risk of inundating project area in the event of higher than the flood selected occurs. This forms the stage-1 process of optimization.

5.0 Flood Inundation

Estimation of flood inundation level is essential for planning of mitigation measures for the flood affected area. The generally used approaches for inundation estimation are (i) Desk studies, (ii) Using DEM and (iii) Flood routing. Out of these three, desk studies and ponding approach adopting DEM are generally used as quick tools for inundation studies. However hydraulic Flood Routing is a robust approach in estimating flood inundation level.

5.1 Desk Studies

Desk studies adopting bank full stage computations of the streams in project area offers very crude flood levels. In this approach, the slope of stream and the cross section are used with the manning's equation to compute the depth of flow.

5.2 Ponding Approach using DEM

In general, the ponding approaches adopting DEM needs to use GIS tools. In this approach the flood volume computed for the estimated design/ peak flood discharge is superposed on the DEM (developed for the project area as detailed in chapter 3.4) maintaining the downstream end at high flood/ high spring tide or high tide. Typical DEM developed for a project is presented in Fig. 5.1. The resulting inundation levels in the DEM of project area due to this flood water offer the high water level that could be used for determining the SGL for the project. The inundation levels thus obtained could be used for determining SGL as a 'preliminary estimate' for project planning. Thus amenability to mathematical operations of DEMS of project area could be used for developing inundation map. Further, the DEM and the resulting flood inundation map become visual tools in assessing the extent of inundation in the vicinity of TPP.

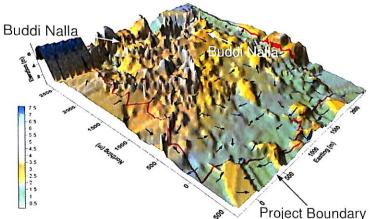


Fig.5.1: DEM of Krishnapattanam Ultra Mega Power Project (KUMPP)

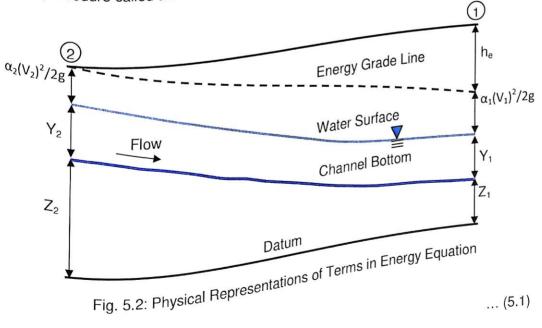
5.3 Hydraulic Flood Routing

Flood routing in the drainage system (channel network) is essential to estimate the water surface profile at desired locations of stream in the study area. For this purpose, channel routing adopting hydraulic techniques are essential to account for the energy transitions and the associated flood moderation in channels (and flood overbanks) as the flood wave traverses through the river/stream reaches. As the lateral movements of flood wave in a channel are assumed to be negligible, 1-D flood routing models are sufficient to estimate the high water levels in the project area. This could be achieved in two ways i.e., (i) steady state and (ii) unsteady state.

5.3.1

Flood routing for water surface profile calculations in this model assumes the flow to be Constant with respect to time (steady flow). Water surface profiles are calculated for subcritical, Superanting and local acceleration in channel. supercritical, and mixed flow regime adopting energy balance and local acceleration in channel. The base The basic computational procedure is based on the solution of one dimensional energy balance equation. equations (Bernoulli equation) which are carried out in reaches as presented in Fig. 5.2

Energy losses are evaluated by friction (Manning's equation) and contraction/expansion Energy losses are evaluated by friction (Manning's equation. The momentum equation is (coefficient multiplied by the change in velocity head) equation. The momentum equation is utilized in all utilized in situations where the water surface profile is rapidly varied. These situations include mixed floor. mixed flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at all water surface profiles at all water surface profiles could be computed for the profiles at river confluences (stream junctions). Water surface profiles could be computed for the reach from reach from one cross section to the next by solving the energy equation (eqn. 5.1) with an iterative preiterative procedure called the standard step method.



... (5.1)

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$
14

Where, Y_1 , Y_2 are depth of water at cross sections, 1 and 2, Z_1 , Z_2 are elevation of the main channel inverts, V_1 , V_2 are average velocities (total discharge/ total flow area), α_1 , α_2 are Velocity weighting coefficients, g is gravitational acceleration, h_e is energy head loss given by,

weighting coefficients,
$$g$$
 is gravitational acceleration, v_e \dots (5.2)
$$h_e = L\overline{S}_f = C \left| \frac{\alpha_1 V_1^2}{2g} - \frac{\alpha_2 V_2^2}{2g} \right| \dots (5.2)$$

Where, L is discharge weighted reach length, $\overline{S}_{\!f}$ is representative friction slope between two sections, C is expansion or contraction loss coefficient, the discharge Q at any CS is given by M. by Manning's equation as below, ... (5.3)

ning's equation as below, ... (5.3)
$$Q = K S_f^{1/2}$$

$$K = \frac{1}{\eta} A R^{2/3}$$
in Manning's roughness coeffice

Where, K is conveyance for subdivision, η is Manning's roughness coefficient for Subdivision, A is flow area for subdivision, and R is hydraulic radius for subdivision (area / Wetted next) Wetted perimeter). Typical manning's η values used in area drainage studies is presented in Table 5. Table-5.1. An extensive list of this friction coefficient could be found in literature (Chow, 1959; USACE 2007) USACE, 2008). Simultaneously, K could be estimated using discharge Q and friction slope S_t as below below,

$$S_f = \left(\frac{Q}{K}\right)^2$$
 Significant Goefficients used in SGL Studies

Table-5.1: List of Typical Manning's Friction Coefficients used in SGL Studies

Τ	able-5.1:	Manning's η	
	SI. No.	Description of Channel Condition	0.012
	01. 110.	Concrete – finished	0.020
	1	- clean	0.025
	2	Earth channel – gravelly, masonry Earth channel – gravelly, masonry	0.030
	3	Earth channel s clean and straight, earth	
	4	Earth channel – gravelly, mason, Natural streams – clean and straight, earth channel – weedy Natural streams – major rivers, farmland, Natural streams – major rivers, farmland,	0.035
	5	floodplain promise with deep promise the witness that deep promise the with deep promise the witness the wit	
	6	Natural streams - Sluggis	surface profiles i.

Stream geometry is generally specified in terms of ground surface profiles i.e., cross s (CS) and the specified in terms of ground surface profiles i.e., cross stream geometry is generally specified in terms of ground surface profiles i.e., cross stream geometry is generally specified in terms of ground surface profiles i.e., cross stream geometry is generally specified in terms of ground surface profiles i.e., cross stream geometry is generally specified in terms of ground surface profiles i.e., cross stream geometry is generally specified in terms of ground surface profiles i.e., cross stream geometry is generally specified in terms of ground surface profiles i.e., cross stream geometry is generally specified in terms of ground surface profiles i.e., cross stream geometry is generally specified in terms of ground surface profiles i.e., cross stream geometry is generally specified in terms of ground surface profiles i.e., cross stream generally specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profiles i.e., cross specified in terms of ground surface profi Stream geometry is generally specified in terms of ground standard define (reach lengths). CS at intervals define them (reach lengths). CS at intervals define and dog-legged alignment) carrying the actual at the the actual stream characteristics, i.e., shapes (curved and portions of pairs of station-elevation data and over bank portions. actual stream characteristics, i.e., shapes (curved and dog loggest angular, starting capacity, flood plains, main channel and over bank portions. CS specifications vary one model to model, for incomplete the models require specification of pairs of trapezoidal sections. to model, for instance HEC family models require specification of one or more number of trapezoidal sections while NWS family while NWS family models require specification of one or more number of trapezoidal sections

- (1) Flow is assumed to be steady.
- (2) Flow is gradually varied, except at hydraulic structures (bridges, culverts and weirs) where it can be rapidly varied; at these the momentum equation or other empirical equations are used.
- (3) Flow is one dimensional (i.e., velocity components in directions other than the direction of flow are not accounted for).
- (4) River channels have "small" slopes; say less than 1:10.

Flow is assumed to be steady because time-dependent terms are not included in the energy equation (Eqn 5.1). Flow is assumed to be gradually varied because Eqn 5.1 is based on the premise that a hydrostatic pressure distribution exists at each cross section.

Modelling Inline and Lateral Hydraulic Structures in the Reach:

Special features in the model such as multiple bridge and/or culvert opening, and split flow optimization at stream junctions and lateral weirs and spillways, are required to be included, if these exist in the project area. These features form the internal boundary conditions for that particular reach and are modeled based on the particular type of flow equations. The details on these features could be found in literature (USACE, 2008; Chow, 1954), and beyond the scope of this technical memorandum.

5.3.2 Unsteady State Model

The physical laws which govern the flow of water in a stream are: (1) the principle of conservation of mass (continuity), and (2) the principle of conservation of momentum. These are expressed mathematically in the form of Partial Differential Equations (PDEs), which are referred as the continuity and momentum equations and widely known as St. Venant equations. The continuity equation describes conservation of mass for the one dimensional system. With the addition of a storage term S, the continuity equation for the channel and the floodplain can be written as:

$$\frac{\partial A_c}{\partial t} + \frac{\partial Q_c}{\partial x_c} - q_f = 0 \qquad \dots (5.6)$$

$$\frac{\partial A_f}{\partial t} + \frac{\partial S}{\partial t} + \frac{\partial Q_f}{\partial x_f} = q_c + q_f \qquad \dots (5.7)$$

Where, x is distance along the channel, t is time, Q is flow, A is cross-sectional area, S is storage from non conveying portions of cross section, q_l is lateral inflow per unit distance. In the above equations, the subscripts c and f refer to the channel and floodplain, respectively, q_l is the lateral inflow per unit length of floodplain, and q_c and q_f are the exchanges of water between the channel and the floodplain.

The momentum equation states that the rate of change in momentum is equal to the external forces acting on the system.

$$\frac{\partial Q}{\partial t} + \frac{\partial (VQ)}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0 \qquad \dots (5.8)$$

Where, g is acceleration due to gravity, S_f is friction slope, V is velocity.

The detailed descriptions and modifications adapted to these flow governing equations could be found in literature (USACE, 2008; Fread, 1974; Fread. 1976; Liggett and Cunge, 1975). The above equations are approximated using finite difference scheme.

Solving St. Venant Equations Adopting Numerical Techniques

The unsteady flow represented by St. Venant equations (Eqn. 5.6 to 5.8) are in partial difference form. These PDEs could be solved by first converting them to a set of algebraic equations and then adopting numerical solution techniques such as, Finite Difference Schemes (FDS) or Finite Element Method (FEM). For 1-D problems, it is sufficient to adopt FDS with either implicit or explicit difference schemes (Fread, 1976; Marek, 2011; USACE, 2008). The most successful and accepted procedure for solving the one dimensional unsteady flow equations is the four-point implicit scheme, also known as the *'box scheme'*. Details on these solution schemes are available in literature (Fread, 1974; Fread, 1976; Liggett and Cunge, 1975; USACE, 2008) and hence not elaborated in this technical memorandum. For unsteady modeling tolerance of result needed, the time step (Δt), reach length (Δx), the solution convergence factor (e) are important parameters to be selected to obtain speedy convergence and avoid oscillations. Schematic space-time representation for discretisation of continuity equation is presented in Fig. 5.4.

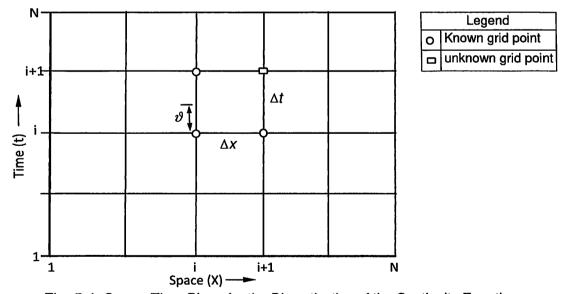


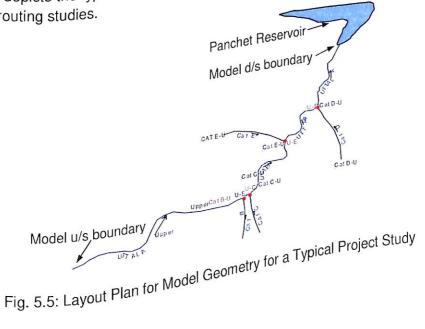
Fig. 5.4: Space-Time Plane for the Discretisation of the Continuity Equation

5.3.3 Model Selection

Selection of a particular flood routing approach say steady or unsteady and thereby a model (HEC-RAS, MIKE 11, CHARIMA, NETWORK, DWOPER, FLDWAV) is based on the project conditions, data availability and project requirements. From the preceding discussions on flood routing models, it is evident that, steady state model could be the first choice and easily applied due to data simplicity. It also offers considerably good to better results. However, unsteady state model has an edge over the steady state for being able to describe the time history variations of flood discharge and associated flood height (stage). If sufficiently fair data (discharge, stage data and spring-to-ebb tidal data in case of estuarine projects) are available, it also offers the time duration of flood inundation in a project area. Unsteady model also causes Concern if the input data for such a study i.e., severe flood combined with high downstream Water I Water level are not modeled accurately, which may be misleading. Thus, care should be taken in Selection Selecting a particular model type and then carefully preparing the flow profiles and boundary and interest an and initial conditions. Special attention required in case unsteady model is selected, as it needs additional additional parameters viz., time step (Δt), convergence coefficient (e) and model tolerance (tol) to be defined by the step (Δt), convergence meticulously, the model would not to be defined for solving the PDEs. If these are not chosen meticulously, the model would not achieve aachieve convergence and may run in to oscillations also.

Layout of cross sections of the stream / river network for a flood routing model is known 5.3.4 Layout of cross sections of the stream / river network to a state models. Model layout as model layout, which is same for steady state and unsteady state models. Model layout describes the real world stream / river describes the real world stream / river describes the flow geometry used in flow modeling and lateral hydraulic structures (pipe and network NA). network. Model layout should also bring in the inline and lateral hydraulic structures (pipe and box culvors.) box culvers, bridges, weirs, spillways, sluices, etc.) that may have bearing on the flood wave propagation. propagation through them. Modelling details of these structures could be obtained from the details of these structures and hence not elaborated in this user's many user's manual of respective flood routing models adopted and hence not elaborated in this memorand. memorandum. Model layout for a typical project for flood routing studies is presented in Fig. 5.5.

Model layout for a typical project for flood routing studies is presented in Fig. 5.5. Model layout depicts the type of boundary condition (river junction, reservoir, tide, etc.) required for the flood for the flood routing studies.



5.3.5 Application of Flood Routing Model

Once the required input data is processed, and input files for the selected flood routing models are prepared, it is essential to ascertain the model geometry (stage 1). This is defined in particular by the CS, flood over bank details (wherever necessary), network alignment, tributary and flow adding junctions, Manning's roughness coefficient, expansion-contraction coefficients, inline and lateral structural details. Once the model geometry check is made, the next stage comprises of providing the boundary and initial conditions (stage 2) as applicable to steady state or unsteady state models. Subsequently, appropriate flow conditions are created and flood routing model is applied (stage 3) to study the flood moderation in the study network. Thus, it is a three stage process involving; geometry check, boundary and initial condition check and finally providing the flow profiles to be studied.

5.3.6 Boundary and Initial Conditions for Flood Routing Model

Boundary conditions are necessary to establish the water surface at the ends of the river system (upstream and downstream). Boundary conditions (both internal and external) must be established at all open ends of the river system being modeled. Downstream boundary conditions are required at the downstream end of all reaches which are not connected to other reaches or storage areas.

Steady State Model:

In a subcritical flow regime, boundary conditions are only necessary at the downstream ends of the river system. Boundary conditions are only necessary at the upstream ends of the river system. If a mixed flow regime calculation is to be made, then boundary conditions must be entered at all ends of the river system. In flood routing model, flow junctions are considered as internal boundary conditions. There are four types of boundary conditions namely; known water surface elevation, critical depth, normal depth and rating curve.

Unsteady State Model:

Boundary conditions in unsteady state model also could be specified in four types at downstream boundary i.e., (a) a stage hydrograph, (b) a flow hydrograph, (c) a single-valued rating curve, and (d) normal depth from Manning's equation. Upstream boundary of a river system can be flow hydrograph, while downstream boundary are stage hydrograph; flow and stage hydrograph as boundary conditions. For super critical flow condition, only upstream boundary condition is essential and the downstream conditions become superfluous.

Initial Conditions:

A starting water surface (initial condition) is necessary in order for the program to begin the calculations, in case of steady state model. On the other hand, for unsteady state model, in addition to boundary conditions, it is required to establish the initial conditions (flow and stage) at all nodes in the system at the beginning of the simulation. Initial conditions can be established in two different ways. The most common way is to enter the flow data for each reach, and then allow the model to compute water surface elevations by performing a steady flow backwater analysis. However, each of the models (HEC-RAS, MIKE 11, CHARIMA, NETWORK, DWOPER, FLDWAV) has different approach to specify this and modeler has to refer to users' manual for the type of model being adopted for their work.

5.3.7 Analysis of Flood Routing Results and HWL Estimation

It is essential that the results of models should be subjected to analysis to assure that meaningful and technically sound results are obtained. Analysis of results of flood routing model (steady state or unsteady state) is necessary to ascertain the computed water surface profiles for severe flooding conditions in the project. The analysis should comprise, (i) channel geometry, (ii) flow conditions simulated and flood profile buildup.

The first and foremost check should target flow adding junctions, tributary additions, and order of the geometry to be represented for the model, i.e., u/s to d/s or d/s to u/s. Wrong representation of stream geometry order would result in erroneous water surface profiles. A proper representation of the flood plain zones and the associated Manning's coefficient would result in near accurate water surface profiles.

The next stage of analysis should target on the model simulated flow characteristics, such as flow area, flow velocity (Channel and flood plain), water surface computed at internal boundaries and critical sections, flow regime simulated i.e., sub critical or critical and the Froude number. The higher velocities associated with Froude number greater than 1 should be meticulously checked and reach slope and friction coefficients should be adjusted if required. In case of unsteady modeling oscillations leading to non-convergence should be rectified by changing the model time step (Δt) or weighting factor (ϑ).

The final stage of analysis encompasses, the backwater profile build up during extreme flood conditions. Some models automatically generate a levy along the banks of reaches where ever water surface raises beyond top of CS level. This would lead to a higher HWL estimation and thus chance of an abnormal SGL for the project. To avoid such situation always it is advisable to give channel sections beyond the observed HFLs in the region.

5.3.8 Flood Flow and Geometry Refinements

Once the HWL are estimated from the flood routing model, taking in to account the site conditions and applying the standard guidelines, refinements to flow and geometry such as deepening and widening of existing CS should be attempted. To revise the HWL, sometimes the project may opt for taking certain risks by flood levels with lower return period floods (say 50yr) than the 100yr flood. In such events, it becomes binding on the project to keep itself ready with flood evacuation system such as pumping options from the plant area or provide gated outlets for the storm water drainage outlets. It is advised that the TPP authorities may explore the possibilities of geometry refinements and achieve the required conveyance rates in the existing drainage system than risking the project with other constraints. The risks involved may be failure in operating pumps during floods, failure of gate operation (mechanical or electrical) and considering lower flood discharge for design as the flood of higher return period may occur in the initial stages of project also. In either event, it would be project's responsibility to satisfy the environmental (hydrology of project area) guidelines laid down by MoEFCC (Annexure-3) for evolving an effective storm water drainage for its plant area.

5.3.9 Flood Inundation Map from Results of Flood Routing

The flood inundation level i.e., HWL from flood routing model could be superposed on the DEM developed to obtain the flood inundation map (Fig. 5.6) of the project and also to compare this with that of ponding approach. The DEM depicting the resulting flood inundation map become visual tools in assessing the extent of inundation in the vicinity of TPP that could be used in rehabilitation of the settlements and also becomes a handy tool for pre and post flood inundation scenario comparisons.

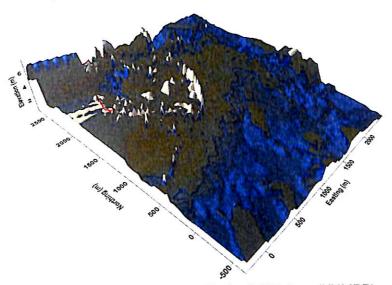


Fig. 5.6: Inundation Map of a Typical TPP Area (KUMPP)

5.4 Summary

Flood routing through the channels could be applied in two states i.e. (i) steady state and (ii) unsteady state. The choice of either of these depends on the project site condition, flow and other downstream boundary conditions and data availability. Though the steady state models provide fairly acceptable flood levels, the unsteady model application should be preferred as these define flows by full dynamic wave equation. Geometry of the channel section should be defined in detail (to cover levels above flood overbanks). In case unsteady model is adopted, for obtaining convergence of solution and reasonable estimates of water surface levels, value of θ may be chosen 0.5-0.7 and time step Δt may be as small as possible and also the reach lengths (Δx) may be shorter. The bed roughness should be carefully chosen to represent the site condition as these have a bearing on the flood levels estimated. Internal boundary condition in study reach should be appropriately modeled to represents the flow regimes.

DETERMINATION OF SAFE GRADE LEVEL

Safe Grade Level (SGL) for a project is the ground formation level at which, the flood water from design flood would not affect the normal functioning of the project. SGL for any project would be determined by estimating the HWL obtained in the project area through desk studies using DEMs and / or flood routing as discussed in preceding chapters at critical locations of a project and considering the elevation required for storm water drains (channel depth, slope and free board) for safe disposal of storm water from the project area.

Schematic sketch of SGL determination for a functional unit of TPP in graphical form is shown Fig. 6.1. It is to be noted that, the outfall location of storm drains and the invert level at the outfall form important parameters in determining the SGL. Considering these issues, SGL determined for the projects are subjected to Cost-Benefit-Analysis (CBA) and Risk Analysis. In arriving at the SGL, appropriate BIS standards of channel design should be adopted in respect of slopes free board provision and roughness factors for storm drains.

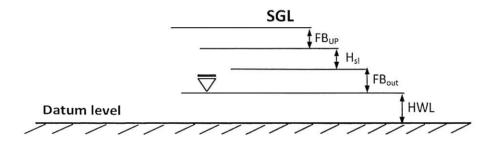


Fig. 6.1: Schematic Diagram Depicting SGL Derivation

Main component that have a bearing on the determination of SGL are presented in following eqn.

$$SGL = HWL + FB_{out} + H_{sl} + FB_{up} \qquad ... (6.1)$$

Where, SGL is safe grade level (m), HWL is high water level (m) estimated from flood routing approach or ponding approach, FB_{out} is freeboard provided at storm drain outlet (m), FB_{up} is freeboard provided in storm drain at upstream most point (m), H_{sl} is height required for maintaining desired slope for storm water drain from upstream most point to drain outlet (m).

Finalization of SGL has to be carried out jointly by modeler, project authorities and design consultants (if applicable) for the respective project after assessing the CBA of SGL if required. At this stage, based on the topographic conditions in project area and project requirement SGL could be set different for different functional units (terracing) based on their importance (critical, and less critical). At times, the outfall of storm water drainage outlet could be opted as submerged for design discharge conditions or may be provided with special arrangements (lock & gate, pumping out, etc.) that may suite to a particular project which should be critically viewed. Thus, SGL for project could be more than one value resulting in terracing of project area based on the project location and the project costs. The terracing could be even a

feather in the cap as I would improve the aesthetic beauty of the project area. In case of NPCIL and BARC projects, SGL are further governed by the AERB guidelines (AERB, 2002) in considering the free board over the flood levels in drains. The details of estimation of flood hazard at inland and coastal sites are covered in AERB guides AERB/SG/S-6A and AERB/SG/S-6B, respectively.

Reviewing the above discussions along with risk analysis and CBA, it would be worthwhile to consider the option of providing more than one storm water drain outlet for TPP, unless there are no restrictions from MoEF&CC on providing only one outflow location for the storm water drainage system; such as 'Green Belt' zones. It should be noted that the freeboards as specified by the BIS and other international standards should be duly considered in the design of storm water drainage and also in area drainage study of the project area. An extract of BIS codes and MoEF&CC norms are presented in Annexure-3.

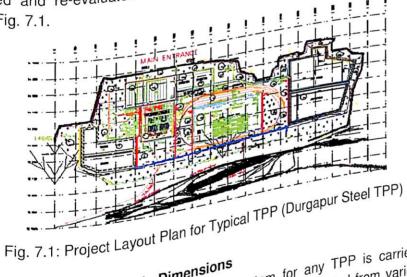
Summary

The SGL is determined from the HWL at points of interest in the project area. Appropriate care should be taken to provide the essential slopes for the storm drains and freeboards both at the outfall and at the upstream end of the storm water drains. In case the HWL computed are higher values and found not acceptable to project authorities, recourse may be taken to provide more number of outlets for storm drains from the project to minimize the flood levels in storm drains. However this needs to be in compliance with the MoEF&CC guidelines. It is cautioned that lowering of slopes of the storm drains should be verified in accordance with the BIS code (IS 8835:1978). In general slope of drains may be maintained 1:1000 for providing sufficient slope so that the debris is self drained. In case drains are flatter than 1:1500, to make the SGL effective, drains should be maintained i.e. cleaning the debris and other deposits and also keeping the drains smooth by plastering with cement as and when required (IS 4439 [part- I]: 1979). This forms the stage-1 process of optimization. The other options of lowering the HWL are channel modifications such as widening and deepening of channel.

7.0

The determined SGL is a function of estimated high water levels in the area of interest and the efficacy of storm drains in draining flood water from the project area. The SGL determined to the determined to the design of storm water drain systems determination for a project is followed by a layout plan and design of storm water drain systems for safe for safe evacuation of storm water from the critical functional units.

Once the SGL is determined for a project considering the CBA and risk factors involved, 7.1 Once the SGL is determined for a project considering the operation of project layout plan (for various functional units) forms the next important step. This is usually This is usually carried out by project authorities or their design consultants. In preparing the layout plan layout plan, care should be taken to place the critical units of the project such as main plant, switchyard Switchyard, coal handling units at an elevated location away from the main drains of storm water and the storm and the storm water outlet locations. To keep the Total Expected Cost (TEC) of the project low, optimization to the storm water outlet locations. To keep the Total Expected Cost (TEC) of the project low, and the storm water outlet locations. For optimization to the storm water drainage systems. optimization has to be performed in project layout, sometimes, som this, sometimes the exercise of SGL determination, project layout and storm drain systems have be modified. to be modified and re-evaluated for performance. Project layout plan of a typical TPP is presented in Eq. presented in Fig. 7.1.



Design of Storm Water Drain the flood water accumulated from various functional that it is Design of Storm Water Drainage (SWD) system for any IPF is carried structional (SWD) system for any IPF is carried structional (SWD) system for any IPF is carried structional system for any IPF is carried structional forms one of the important elements in SGL units of project are design storm. It forms one of the important of elevation constraints details. Units of project area resulting from design storm. It forms one of the important elements in SGL eftermination as a storm on solution and slopes impose certain amount of elevation considering and slopes impose drain network is prepared considering determination as drain dimensions and slopes impose certain network is prepared considering vario. (refer to 5) Project area resulting from design storii. It is certain amount or elevation sonatants on SGL (refer to Fig.6.1). Based on the layout plan, storm drain to design the storm drain layout plan, storm drain between to design the storm drain carrious crucial and stories on the layout plan, storm drain to inundation. It is layout plan carrious crucial and stories of the layout plan affluxes leading to inundation. Various crucial and non crucial functional units. Care should be taken to design the storm drain list of any affluxes leading to inundation. It is essentially near the storm of any affluxes to BIS codes (IS 12094:2000; IS essentially near the storm drain network is prepared considering and slopes impossing the storm drain network is prepared considering to storm drain network is prepared to storm drai Junction near the crucial units to avert building up of any affluxes leading to inundation. It is essential that the essential that the design of storm water drain of any affluxes leading to mondation. It is a storm water drain conforms to BIS codes (IS 12094:2000; IS 12095:2000; IS 1209

10751:1994; IS 8835:1978;). A brief extract of relevant BIS codes is presented in Annexure-3. Further, the maintenance of the SWD should conform to BIS (IS 4439(Part II): 1979) for an efficient efficient performance during its span of designed life. In computation of the drain dimensions, it is considered that the flow is steady sate, thus the Manning's equation and Chezy equations considered that the flow is steady sate, thus the Manning's equation is presented in Eqn. 5.4. could be used. Mathematical description of Manning's equation is presented in Eqn. 5.4. However, Chezy equation is presented as below, ... (7.1)

er, Chezy equation is presented as below, ... (7.1)
$$V = C\sqrt{RS_0}$$
 ... e. is channel bottom sl

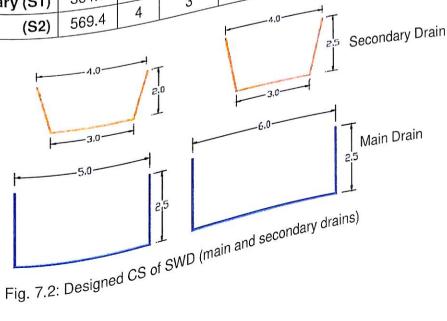
Where, C is Chezy coefficient, R is hydraulic radius, So is channel bottom slope. Chezy coefficient that Coefficient that could be adopted in drain design could be found in standard books (Chow, 1954). 1954).

Considering the slope of drains as assumed in SGL determination (H_{sl}) the drain cross (CS) and design flood (100vr return period). Mostly Section (CS), dimension are designed assuming design flood (100yr return period). Mostly, trapezoidal trapezoidal sections are considered for SWD design, but for main drains where heavy discharge capacity. Capacity are required by SWD leading to large CS and slopes are limited by Eqn. 6.1.

Rectangular Rectangular sections are opted as the top width of trapezoids demand more space from TPP area. In the contractions are opted as the top width of trapezoids demand more space from TPP area. In the contract of velocity of storm water discharge should be area. In the SWD design, back computations of velocity of storm water discharge should be checked in checked in each of the reaches (main, secondary and tertiary) and ascertain that they conform to BIS code are to BIS code (IS 8835:1978). For a typical project, sample computations of sections are presented in T. 1. presented in Table-7.1 and sectional drawings in Fig. 7.2.

mple Computations of Storm Drain Design

	Table	-7.1: Sam	ple Computation	of Storr Depth	Bed Level (m) Di	Design ischarge (m³/s)
SI. No	Drain Name and Details	Length (m)	Width (m) Top Bottom 5	(m)	Start E1	.00	15.25 26.18
1	Main (M1)	919.4	5 6	2.5	149.00 148	.75	14.38 12.65
2	(M2) Secondary (S1)	197.0 364.7	4 3	2.5	152.00 151	.00	
	(S2)	569.4	4	 	-4.0		Jany Drain



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7.3 Summary

Storm drains are designed to carry the storm water from the various functional units of project area without inundating it and evacuate the storm water through outfall. It is advisable to provide the drain shape as trapezoidal in general. However for main drains which collect the storm water from whole or part of the project area may be provided as rectangular shape to safely discharge large quantum of storm water. The storm drain should have sufficient slope (generally 1: 1000) so as to avoid the siltation in the drain section. The junctions near the main plant and switch yard should not have a converging flood situation which may be disastrous in the events of the flash floods. Though slopes of flatter order 1:1500 are being adopted for storm drains, it is cautioned as these may lead to siltation and also reduce velocity of flows that drain out of plant area. The option of more than one outfall of storm water drain from project area is a better choice, This forms the stage-3 process of optimization. The other option is, outfall could be planned to be submerged or gated to evacuate the storm water from plant area, but the failures associated with the operation of outlet gates need to be considered in planning. The option of pumping storm water by temporarily collecting in sumps near outlet could be subject to failures of pumps or power supply failure during the flood events. Thus the risks involved in the options selected need to be weighed for potential failures.

8.0 SGL Studies at CWPRS

The systematic steps to be adopted in SGL studies detailing data assimilation, method of approach for study, design flood estimation, flood routing procedures for flood level estimation, determination of SGL and storm drain system for TPP have been presented in earlier chapters of this memorandum. Some of the bottlenecks in the SGL studies and the different boundary conditions that needed to be considered in flood routing are presented in this chapter with some real world case studies. This also throws light on the technical details, modeling tools used, practical problems studied through brief presentation. CWPRS has carried out SGL and area drainage studies for over 60 projects pertaining to power, industry petroleum and offshore terminals. List of typical projects for which CWPRS has carried out SGL studies are presented in Annexure-4. All these studies followed the method of approach as presented in chapter-2 through the supervision of CWPRS experts for arriving at rational and logical solutions, without compromising on the safety of the project and its surroundings. Out of these, four case studies are selected based on the typical project conditions, location of project and the boundary conditions to be adopted for the flood routing model application.

8.1 Selected Case Studies

There have been varied dimensions in the SGL studies that were under taken by CWPRS. However, to show case the typical site conditions of projects and the model choices and boundary conditions adopted for specific studies carried out four case studies have been short listed and included in this memorandum. The trivial site descriptions of project to be considered for flood routing model in these studies are given as below.

- Durgapur Steel TPP (DSTPP) of DVC Inland taal area, project situated in the flood bank region of Damodar river; flooding due to upstream flood from Singaran nalla and downstream HFL in Damodar due to Durgapur barrage.
- 2. Raghunathpur TPP (RTPP) of DVC Inland area (on elevated plateau); flooding due to local stream draining to Uttala from TPP area. River Uttala outfall into Panchet reservoir.
- Krishnapattanam Ultra Mega Power Project (KUMPP) of REL/CAPL Estuarine region, situated adjacent to the creek and Buckingham canal (presently inoperative); flooding due to upstream catchment flood from Buddi nala and downstream high tides in the creek.
- 4. **Triangular Plot, RIL, Hazira** Estuarine region, situated on the bank of Tapi river in creek; Inundation due to upstream riverine flood of Tapi and downstream tidal water levels from Arabian sea

The case studies (1), (2) and (3) are carried out at CWPRS using steady state hydraulic flood routing model (HEC-RAS) for flood level estimation in project area, while the case study (4) was studied with unsteady state flood routing model (HEC-RAS and also MIKE11).

8.2 Critical Analysis of Case Studies

The case studies selected have been categorized into four types, viz.; (i) Riverine flood for Taal area with steady state routing model, (ii) Localised flooding on hilltop terrain with steady state routing model, (iii) Coastal creek zone with high tide and steady state routing model and, (iv) Coastal zone with tidal boundary and unsteady model. Brief analytical presentations of these are given below.

8.2.1 Riverine Flood for Taal Area with Steady State Routing Model

In case study (1), flood levels obtained in river Damodar were higher when surveyed river sections were used, as model assumed levees on both the banks which is not a real world situation. To tide over this situation, the surveyed cross sections of river Damodar were refined by providing extended flood banks on either side of Damodar using relevant toposheets of project area. Further, the Singaran nalla passing through the DSTPP area was diverted along the DSTPS boundary by performing river training works to increase its conveyance capacity. To reduce SWD dimension (width and depth) two outlets were designed to optimize SGL. Post CWPRS recommendations on SGL, storm water drain system and diversion of nalla from project area, no flooding has been reported.

8.2.2 Localised Flooding on Hilltop Terrain With Steady State Routing Model

In case study (2) there were no flow records available for Uttala to which the stream from RTPP joins. To obtain downstream boundary for flood routing model, the water level for nalla from RTPP area, which joins Uttala which in turn outfalls in to the Panchet reservoir, design flood estimated using UH method was routed through Uttala with RTPP nalla as tributary and Panchet reservoir at MWL as downstream boundary for flood routing model. SGL was recommended in benches. From this study four SWD outlets were designed as the local topography doesn't allow drains to cross over from one end of project to other. Moreover, there were two local streams that drain across RTPP and outfall into Uttala, these could not be blocked as they pose of impounding the boundary wall of RTPP. For efficient area drainage a these outside drains (from northeast and west sides) were allowed to pass through the project area and outfall with one SWD at northern end of plant, into nalla which is trained for efficient discharge (CWPRS recommendation). The project is presently running and post CWPRS recommendations, no flooding incident was reported.

8.2.3 Coastal Creek Zone with High Tide and Steady State Routing Model

In case study (3) as KUMPP is located in a flat region with Buddi nalla draining to creek and passing along boundary, guide bunds were proposed to be provided along the boundary to restrict flood water from entering project area. SGL was suggested in benches 4.0m for critical and 3.5m for non critical unites. Simultaneously proposal of dredging and widening of Buddi nalla was also made to reduce backwater levels in it so as to obtain reduced SGL. Multiple

storm water drain outlets were suggested. To protect the boundary wall of project along Buddi nalla proposal of embankment has been suggested based on the flood levels estimated for the stream (Buddi nalla).

8.2.4 Coastal Zone with Tidal Boundary and Unsteady Model

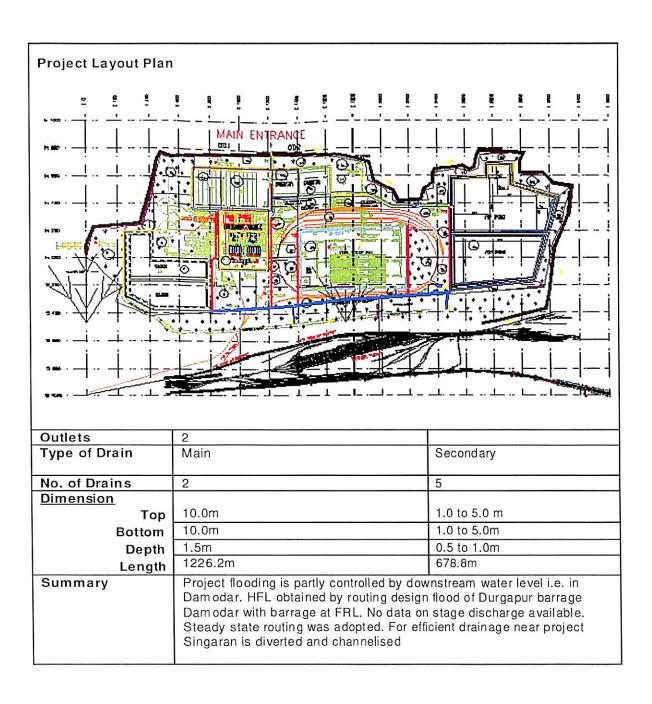
In case study (4) i.e. Triangular Plot of RIL at Hazira, uniform SGL was determined for the project with multiple outlets of storm drains discharging directly into the estuarine regions. For determining SGL unsteady flood routing model was adopted with observed flood of 2006 in Tapi that devastated Surat city. Thus with flood hydrograph as upstream upstream and tidal cycle (levels) in the Tapi estuary as downstream boundary highest water levels in the project area was estimated. SGL was optimized by providing 60 m length storm drains. Brief technical details of these case studies are presented below.

8.3 Summary

An observation of the case studies discussed indicates that each project is different from other both in geographic location and the adjoining drainage system and thus calls for an appropriate approach in arriving at the flood inundation levels using steady sate or unsteady state models for the project in question. Added to this, the downstream boundary of the models is also different with typical site location and controls the inundation levels in project area, thus in case(i), HFL in river Damodar; in case(ii), the local flood and outlet from project (microtopography); in case(iii), it is tide level in creek and in case(iv), tidal cycle in estuary with flood hydrograph in Tapi. Further, efforts were required to optimize the SGL for TPP through improving channel conveyance and also providing more number of outlets for storm drains. In none of these cases pumping option and gated control at SWD outfalls were recommended as the volume of storm water to be evacuated was high. However for DSTPP more number of SWD outlets were suggested, for RTPS re-orientation of local streams and SWD were performed, in finalizing SGL for KUMPP, CBA was done to optimize the SGL, while for RIL, Hazira estuarine section detailing with tidal cycle boundary and flood hydrographs were used to find inundation levels.

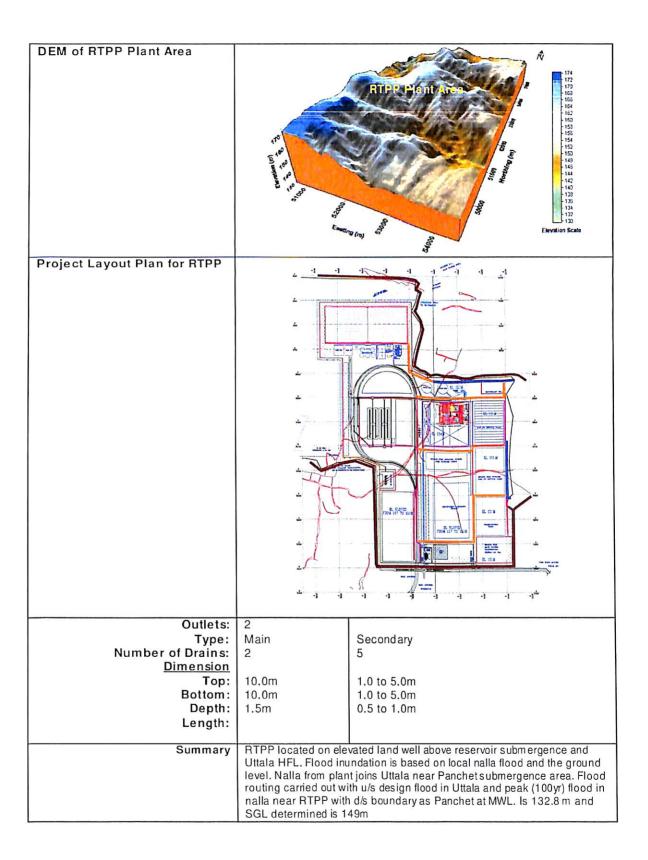
Case Study 1: Inundation due to u/s Catchment Flood and d/s River HFL-DSTPP

Project Name	Area Drainage S	Study for P	roposed Durgapur S	teel Thermal Power Project
Location	Village Andal, W	lest Benga	Meshpul	GREA Xonnu
	Lat. L	ong.	Falsatabad Ludhiana	Project
	23°35'08" N 8	37°09'15" E	PAAIS (at New Band	schmade, 3
Installed Capacity	1000MW		Ahmail D. M. Jadore Calr	THE WALL BOTTOM
Extent of	2.98 sq. km		Surat Rash Ragpur	Values Values
Project	2.00 04. 11.11		Pune Hada Hyderahad	Bangt
Project Type in	Inland, HFL of ri		Bangalore Chenna	Damoda
Flood	downstream bou		Cochin Sri Jayer	rdenatura BIVEI
Project Constraint			ar the flood zone of rea is governed by	Damodar river. Flood
Constraint				om Singaran nalla and
				flood of Durgapur barrage
Data Used	Rainfall : Daily -			gapa. baage
Butu Occu				near Durgapur barrage
			L- Section and Proj	
			ge of Durgapur bar	
EVA	Asansol 1-day Max Rainfall (mm)			
			Observed 269.7	EVA (100 yr return period) 263.69
Flood			ngaran nalla catchm	
Computation	Catchment area			5 sq km.
	Rainfall (Extrem			Flood estimation report, 1994
			all contains access a	Service de la companya del companya de la companya de la companya del companya de la companya del la companya del la companya de la companya del la companya de la companya del la companya d
Flood Details	Singaran nalla p	beak flood		hydrograph – 271.31 m ³ /s
Flood Routing				ng Model Layout Plan
Model Name	HEC-RAS(1-D)	Sin	garan Nalla	
Type	Steady state			DSTPP Project Area
U/s	Singaran flood		Diguesed	_
D/s	HFL in Damoda		Disused f Bridge	Durgapur Barrage
		'	III	Dallade
				-
			15	20 5 1
				Damodar River
Flood Routing	U/s of projects E			73.07m
Results – HWL	At D/s of project	ι		72.48m 75.00m
		rveved CS	of Damodar exter	nded to account for flood plain
				essed datum as MSL)
Project Layout	Critical Area:	Mair	Plant, Switchyard,	Coal stock, Cooling tower
Plan	Less Critical Are			Raw water, Railway line,
	Other Area:	Gree	enfield (open land),	



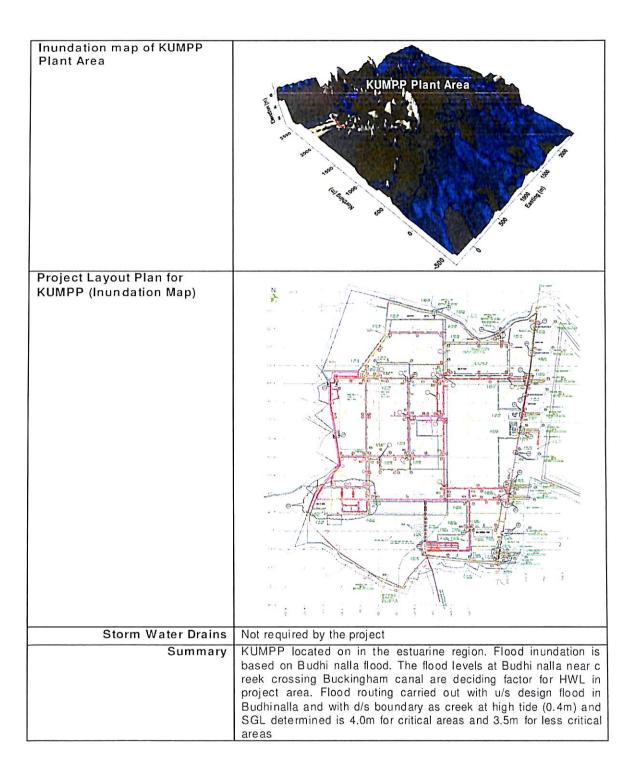
Case Study 2: Inundation due to u/s Local Catchment Flood - RTPP

Project Name	Area Drainage S Bengal	study for F	ropose	ed Raghunathpur	Thermal Power Project, West
Location	Village Raghunat			Bhat was	CHINA XIII Panchet Dam
	West Bengal Stat	te		Kabul Marahad IDET	Damodar
	Lat. 23° 37' 30" N	Long. 86° 42' 00)"E	Falsalabati Ludhiana Li FANSTAN Reviteda Jailpurg	hees
Installed Capacity	1000MW			thmadahad gindere Cal	Prince RTPP Area
Extent of Project	3.55 sq. km			Puno Hyderabad Bangalora Chennal	Yangan Ba
Project Type in Flood	Inland: MWL of P design flood in U	ttala as bo	undary		Ultiala River
Project Constraint		ervoir on N	ortheas	t side. Flood inund	on north, river Uttala on south ation near the project is due to
Data Used	Rainfall: Daily – Survey data: CS of Drawings: CS, L- Salient Features	of Uttala Riv Section and	er and lo I Project	ocal nalla Layout Plan (Auto)	GAD) 32.8m)
EVA	Salient Features of Panchet Dam (MWL of reservoir 132.8m) 1-day Max Rainfall (mm)				
	Asansol			Observed 269.7	100 years return period 263.69
Flood Computation	Catchment area (Uttala): Rainfall (Extreme 1-day): Sub-daily Rainfall: Flood Estimation Method: 124.47 sq km. 263.69 mm Rainfall distribution chart (CWC,1994) CWC Flood estimation report, 1994 and local nalla flood using Rational formula			mation report, 1994 and	
Flood Details	Uttala nalla peak	flood extra	acted fro		
Flood Routing Model Name Type U/s D/s	HEC-RAS (1-D) Steady state Flood and Uttala Panchet at MWL (No Gauge-Disch	132.8m		Catchment A R	Panchet Dam F iver Uttala B C mg Model Layout Plan
Flood Routing Result	U/s of project Bo D/s of project SGL Comments:	in the second	ed CS o	14 1: 14	4.68m 35.64m 49.00m o account flood plain beyond HFL
Project Layout Plan	Critical Area: Less Critical Are Other Area:	Main a: Admi	Plant, S nistrativ		tock, Cooling tower



Case Study 3: Inundation due to u/s Catchment Flood and d/s Tide in Creek – KUMPP

Project Name	Area Drainage S (KUMPP)	Study for P	roposed Krishnapatnam	Ultra Mega Power Project
Location	Krishnapatnam, I Andhra Pradesh	Nellore Dist	eshpali Kabu	CHBIA X
	Lat.	Long.	Feisplahad Ludhiana	Lhess Creek
	14 ⁰ 20'40" N	80 ⁰ 07'35'	Jaipur_	ebmendd Budi Nalla
Installed Capacity	4000MW		hmadahát Indara Calcu	Divare KUMPP
Extent of Project	5.22 sq. km		Pung Hung Hydres Bangalora Chenna	Bay of Bengal
Project Type in Flood	Coastal u/s by Buc storm surge in cree		Cochin Madural	y of Emgal
Project Constraint				nukuru mandal of Nellore district butheast direction of Nellore.
Data Used	Drawings : CS , L- Details of Tanks:	of Budhi nall Section and Three tank Naltur Che	a and Buckingham canal Project Layout Plan (AutoC s (Krishnapatnam Cheruv ruvu) and high tide (0.4m	vu, Muttukur Chinna Cheruvu,) in the creek region
EVA	Station Na			ax Rainfall (mm)
	Nellore		Observed 523.4	100 years return period 369.76
Flood Computation	Catchment area Rainfall (Extreme Sub-daily Rainfa Flood Estimation	e 1-day): II:		n chart (CW C,1994) ation report, 1994 and local nalla nal formula
Flood Details	Budhi nalla peak	flood extra	cted from flood hydrograp	oh-124.3m³/s
Flood Routing Model Name Type U/s D/s	HEC-RAS (1-D) Steady state Budhi nalla flood High tide in creel (No Gauge-Disci	k 0.4m)	Krishnapatnam Tank Project Boundary Muttukur Chinna Cheruvu	Buckingham Canal Creek Budhi Nalla KUMPP AREA Bay of Bengal
Flood	U/s of project B	oundary		.24m
Routing Result	D/s of project SGL Comments:	9-3	1 4	.92m .0m for critical and 3.5 for others d to account flood plain in HFL
Project Layout Plan	Critical Area: Less Critical Are Other Area:	Main a: Admir	Plant, Switchyard, Coal st istrative building, Raw wa ifield (open land),	ock, Cooling tower



Case Study 4: Inundation due to upstream riverine flood from Tapi and downstream tidal water levels – Triangular Plot, RIL Hazira

Project Name	Studies for Determ	nination o	f Safe Grad	e Elevation For	Triangular Plot	of BIL at	
i rojest rame	Hazira	iiiidiioii o	ouic Grad	c Lievalion i oi	mangular i lot	or raile at	
Location	Village Hazira (Su	ırat).				10.05	
	Gujarat State		1	新 拉 用 2000	1		
		ngitude		1			
	210 22111	° 44' E					
Installed Capacity	380 MW		1	No. of the last between	Toolstiver	是三三人	
Extent of Project	0.14 sq. Km				有其可以	Source: Maps of India	
Inundation type	Estuarine region fl	looding. [Due to		设地 经营业	6 400	
for project	reverine flood fron				200		
	levels in estuarie.				《	1 1 1 1	
Project	Project situated in	n the est	uarine 📉			4	
Constraint	region of Tapi.		Ar	abian Sea		Source: Google Earth	
Data Used	Rainfall : Daily - 3	raingau	no etatione				
Data Oseu	Survey data: CS						
	Drawings: AutoC			avout Plan			
EVA of Rainfall	Station Name				th 100 yr returr	period	
	Station Hamo	1 -day	1-hr	3-hr	6-hr	24-hr	
	Olpad	289.83	-	-		-	
Ÿ	Palsana	406.83	-	-	-	-	
	Surat Observatory		111.54	176.30	226.67	359.80	
Flood	SGE- Using observed flood at Ukai in Tapi						
Computation	ADS- Catchment area of the adjoining region Method - Rational Formula						
		l Formula		,		٦.	
Flood Details	Stream code		Area in km ² Peak flood in m ³ /s			m°/s	
	N1		2.89		40.41	1	
	N12 N2		2.68 42.41 1.61 22.79				
Flood Routing	INZ		1.01		L Hazira		
Model							
Name	HEC-RAS			Triangular plot	Singarpo		
Туре	Unsteady state			Mora bet	Tapl River		
ВС	_	OC flood		1			
ВС	SGL-U/s Tapi 200	מסטוו אכ		Kadia bet			
	u/s ride level			1			
	ADS- U/s local						
	catchment flood of	i/s HWL		(/	Note: Not to Scale		
	in Tapi estuary.			Outer Hazira Arabian Sea			
					Model Lavout F	Plan	
Flood Routing	Flood Routing Model Layout Plan Magdala Bridge d/s HWL 10.54 m w.r.t CD						
Result		Branch HWL 7.93 m w.r.t CD					
	Near Project HW	ear Project HWL 7.70 m w.r.t CD					
	D/s of the Project HWL 7.28m w.r.t CD						
		s: Surveyed CS of creek and Tapi estuarie extended to account for					
	flood plain in HFL						
Project Layout	Critical Area:				ock, Cooling tov	ver .	
Plan	Less Critical Area			uilding, Raw wa	ter		
	Other Area:	Gree	nfield (oper	rianu)			
	1						

Project Layout Plan RIL-Hazira	BUSHES 3
Outlets: Shape:	14 Trapezoidal/Rectangular
Number of Drains:	60
Summary	RIL- Hazira is located in estuarine region of Tapi river. Inundation is due to reverine flood from Tapi and tidal fluctuation in the estuary. Flood routing carried out adopting unsteady 1-D model with u/s recorded (high) flood in Tapi with d/s boundary as high tide in the creek. HWL estimated is 7.70m w.r.t. C.D and SGL determined is 9.20m w.r.t. C.D

RISK ANALYSIS IN FINALIZATION OF SGL AND METRICS

Risk is defined as the consequences associated with the probability of flooding attributable to a given structure. There is a level of risk associated with every structure so does with the SGL for Power plants. It is needless to say that the entry of water into power plant units and switchyards could cause disruption in functioning of TPP leading to shut down in case of flood inundation. Risk analysis is a method to select a design, which will result in the Least Total Expected Cost (LTEC) of project commissioning or shutdown and associated damages of Thermal Power Plants. It involves analyzing the losses incurred to various design options due to possible flooding. The product is the annual economic risk associated with each design or restart option. Comparison of the TEC's for all the design options allow the designer to select the option with the least total expected cost. Risk analysis is used when the initial costs of a conventional design appear to produce either too much risk or excessive and also recurrent cost due to shutdown and restart operation costs in the event of inundations for a given site. Following list of metrics should be assessed in performing a risk analysis:

- Initial construction costs or recurring expenditure on maintenance is to be avoided
- Probable property damage in the event of flooding.
- Socio-economics of surrounding habitation
- Intangible considerations including loss of emergency unit shut down and legal costs and the potential loss of life which require a qualitative assessment.

The items to be used for a site-specific risk analysis may not be limited to this list but may include additional items also. The risk criteria P(E), i.e., the probability of a higher than X flood occurring within the life period L years of the structure is given by,

$$P(E)=1-\left[1-\frac{1}{T(X)}\right]^{L}$$
 ... (9.1)

Where, P(E) is the probability that at least one flood which equals or exceeds the T(X)- year flood will occur in any series of L-years, and T(X) is the true return period of the event X.

Example: The designed life of a TPP is 50 years. In determination of SGL for the TPP the design flood considered was with 100 year return period. Evaluate the risk criteria for the TPP.

Solution:

Data given is; Life of TPP L= 50yr; Design flood return period is T(X) = 100 year

The Risk Criteria is
$$P(E)=1-\left[1-\frac{1}{T(X)}\right]^{L}$$

$$P(E) = 1-[1-(1/100)]^{50} = 1-[1-(0.3)] = 1-0.605 = 0.395 \approx 0.40$$

Answer: Risk Criteria is $\underline{0.40}$ i.e., the chance of flood occurring equal to or above design flood during period of project life

The technical memorandum has brought out the technical details of hydrology, hydraulics and stochastic hydrology with respect to area drainage studies. It has presented the efforts to be made in estimating HWL in TPP area by studying inundation in project area due to floods from rainfall (not due to cyclone and storm surge effects).

Area drainage study leading to estimation of flood inundation levels in the region of project for design flood scenario considered under pre and post project commissioning, which is crucial for project planning, design and sustenance of TPP. From the preceding sections, it is evident that the study should be carried out in three stages namely; (i) EVA for estimating design flood (peak discharge) hydrograph, (ii) flood inundation estimation and SGL determination, and (iii) project layout followed by design of storm water drainage system. The importance of data (hydrometeorological, hydraulic and land survey) for the studies, its procurement, scrutiny and analysis for generating (near real world representative) valid input for the studies has been clearly brought out in this technical memorandum. In this regard, a clear understanding of the system, limitation of data and model are necessary for analyzing the model results at different stages. The interactions/ discussions between modelers, project authorities and design consultants of the concerned project would be useful and lead to lowered risk of project as regards SGL.

Guidelines and Recommendations:

Based on the discussions presented in preceding sections and CWPRS experiences in the conduct of studies on SGL determination, for various industrial and power projects following are some guidelines and recommendations are drawn.

- Data (maps, hydrometeorology, hydraulics, land topographic survey and project related documents) collection and analysis (processing) should be meticulously carried out. Maps should be studied to comprehend the project vicinity, water bodies, river courses and creeks. All maps should conform to toposheets (i.e., deformations, dislocations of map elements should be corrected). A list of data required for SGL studies is presented in Annexure-1.
- 2. Spurious (hydrometeorological and hydraulic) data should be dropped from analysis or corrected. Similarly, any statistically inferred outlier (extra-ordinary rainfall events) should be verified and if found to be factual need to be included for analysis.
- 3. Limitations of statistical procedures (especially, nonparametric tests) adopted their are to be kept in mind. In any case, results of statistical tools should not suppress hydrological realities. Very good statistical tools such as HFA, HYFRAN, HEC-FFA, Hydrognomon are available for flood frequency analysis that could be adopted for statistical analysis. This apart, other statistical software could also be employed for parametric and nonparametric analysis.

- 4. In estimating flood hydrographs using UH methods based on CWC method or peak flood estimation methods, their inherent limitations should be considered.
- 5. For obtaining the survey data on CS, it should be informed to survey party to collect channel sections to define their shapes (ups and down) and also take highest elevation of the channel section beyond the observed HFL marks (at least 1m or 2m above HFL for small to medium streams and about 2m or 5m for rivers).
- 6. In case of preliminary estimates of SGL are made with inundation maps developed using DEM, care should be taken to address the inaccuracies in the DEM (spurious levels generated) of project area.
- 7. Knowledge on capability of models being employed in SGL studies is essential to judge the results obtained. In handling the hydraulic routing procedures; assumption, models used, their limitation and accuracy of results are subjective and hence should be clearly mentioned in the reports.
- 8. If historic data on stage and discharge or tidal observations are available it is recommended that unsteady state model be adopted for flood routing. In such an event, the model convergence should be obtained by tactfully adjusting the model coefficients (Δt and ϑ). In all these, model results should be evaluated based on the errors and warnings reported by the model/ software adopted.
- 9. SGL determination is, partly technical and partly an art. The hydraulics of HWL estimations in inundated areas vary for every project. In considering the elevation required for storm water drain system, i.e., slope requirement and freeboard should conform to BIS standards and MoEF&CC norms. Compromises made (reduced slope) would either result in silting the drains during low flows or breaching of drains and inundating the area upstream during occurrence of severe floods.
- 10. In drain size computation of storm water drain appropriate (BIS standards) freeboard considerations should be incorporated.
- 11. Joint meetings of modelers say (CWPRS or other institute), project authorities and the design consultants of respective project is essential before finalization of SGL and also before finalization of storm water drain design wherein these should be technically tabled together for obtaining a best practicable solution.
- 12. Analysis of risk and CBA are essential in SGL studies. If CBA of SGL hints at higher initial costs, look for other alternatives, such as terracing plant area, providing multiple storm water outlets from plant area for a speedy evacuation of flood water as discussed in the chapter-6. Always a risk component is associated in lowering the SGL, the results of losses associated with such risks are at times irreversible. Similarly, project with higher SGL values determined, may lead to unnecessary rising of ground levels to meet the SGL and the associated costs, hence a re-cap and re-evaluation of these need to be carried.

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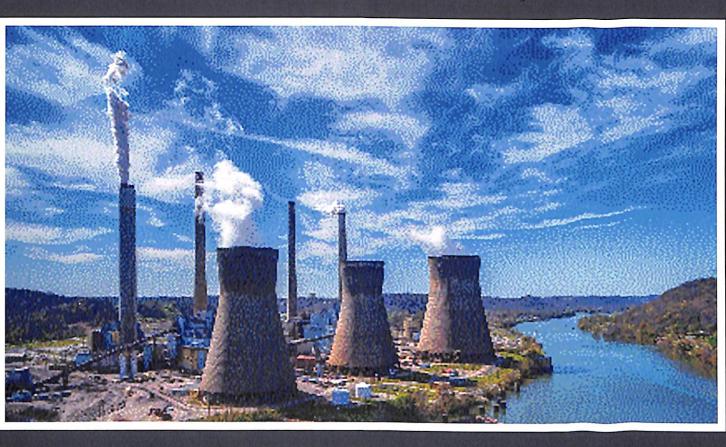
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Government of India Ministry of Water Resources, River Development & Ganga Rejuvenation

Technical Memorandum on DETERMINATION OF SAFE GRADE LEVEL AND DESIGN OF STORM WATER DRAIN FOR POWER PLANTS (DESIGN FLOOD DUE TO RAINFALL)



Compiled and Edited by

Dr. C. Ramesh and Dr. (Mrs) Annapurna Patra

Hydrometerorology Division

12th November, 2018

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Central Water and Power Research Station Khadakwasla, Pune 411024

> Dr. (Mrs) V. V. Bhosekar Director



GENERAL DATA REQUIREMENT FOR STUDIES ON SAFE GRADE LEVEL

Safe Grade Level determination studies require five types of data as below:

Map Data:

- Toposheets of the study area (scale preferably 1:25,000 or 1:50,000)
- · Location map and project vicinity map
- · Catchment area map of river/ streams
- · Project layout plan

Hydrometeorological Data:

- River gauge, raingauge locations
- Rainfall and stream flow data (at least 30 years or maximum available data)
- · Soil type, geology and land use information
- Water level data in the river (HFL), tidal data (creeks and estuaries)
 - > River/ stream flow data should cover the peak flood data
 - > Tidal data should be collected for at least one lunar cycle

Hydraulic Data:

- Structural details (bridges, barrages, culverts, etc.)
- · Manning's friction values
- · Rivers, tributaries, etc.
- Immediate u/s or d/s dam or barrage design discharge, design spillway discharge

Survey Data:

- River/stream cross sections in form of station vs elevation data beyond high flood
 - ➤ Main river 10 to 20 points to completely define the shape
 - ➤ Streams/nalla 10 to 15 points to completely define the shape
- · Cross section interval along the length of river/stream
 - ➤ Main river 50 to 200m or more to define the bends and inline structures
 - Stream/nalla 10 to 20m to define the bends and inline structures
- Channel type (lined/unlined/weedgrowth/abandoned)
- Spot elevation data of project area (Scale 1:5,000)

Technical Documents:

- Detailed project report prepared for MoEFCC
- Land survey report, tidal report (estuarine projects)
- Irrigation, command area development, land use, soil reports, bore logs, etc.
- Any other related reports for the study

The rainfall data should invariably be procured from India Meteorological Department (IMD), Central Water Commission (CWC) or state Water Resources Departments (WRD). Stream flow data is in general obtained from CWC or state WRD. Survey of project area and cross section and L-section details are got done by land survey agencies. Tidal data is obtainable from nearby ports, state maritime organizations, IMD and national maritime agencies.

The Unit Hydrograph (UH) is a commonly-used empirical model for relationship of direct runoff to excess precipitation. As originally proposed by Sherman in 1932, it is "...the basin outflow resulting from one unit of direct runoff generated uniformly over the drainage area at a uniform rainfall rate during a specified period of rainfall duration." The underlying concept of the UH is that the runoff process is linear, so the runoff from more than or less than one unit is simply a multiple of the unit runoff hydrograph. Basically, UH are two types, namely; (i) Instantaneous UH (ii) parametric or Synthetic UH. It is often necessary to plan constructions or operations for ungauged streams where in, it is helpful to develop synthetic unit hydrographs (Dooge, 1973). As this memorandum deals with ungauged streams, the latter type is described below,

Synthetic Unit Hydrograph Method

A synthetic UH relates the parameters of a parametric UH model to watershed characteristic which is defined by set of parametric equation that describes the basin response processes. By using these relationships, it is possible to develop UH for watersheds. The generally used parameters are peakdischarge, time to peak, time base length of stream, centroid of watershed, etc. With the peak, time of peak, and time base, all the ordinates on the rising limb and falling limb of the UH can be computed through simple linear interpolation. A synthetic UH model may relate the UH peak of the simple triangular UH to the drainage area of the watershed. With the relationship, an estimate of the UH peak for any watershed can be made given an estimate of the drainage area. If the time of UH peak and total time base of the UH is estimated in a similar manner, the UH can be defined "synthetically" for any watershed i.e., the UH can be defined in the absence of the precipitation and runoff data which is necessary to derive the UH. Synthetic UH are classified into three categories as below,

- 1. which relate UH characteristics (such as UH peak and peak time) to watershed characteristics such as Snyder UH.
- Which are based on a dimensionless UH such as SCS UH.
- 3. which are based on a quasi-conceptual accounting of watershed storage, such as Clark UH and ModClark models.

In the rainfall records of catchments, it is difficult to find unit or isolated single storms that produce stream rises not affected by other events. In such cases, the derivation of a unit hydrograph becomes more complex. One method of deriving a unit hydrograph under such circumstances is to assume an initial unit hydrograph, and to reconstruct the hydrographs of direct runoff for several storms using estimated runoff increments and refine the unit hydrograph by successive approximations as indicated by the results. This reconstruction is shown in Fig. A2.F1 and equation A2.E1 as below,

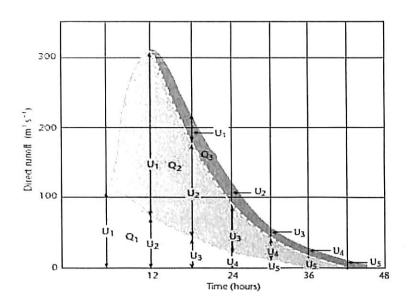


Fig. A2.F1: Reconstruction of Direct Runoff Hydrograph

$$q_0 + Q_0 U_1 + Q_{n-1} U_2 + Q_{n-2} U_3 + ... + Q_{n-i+1} U_i + ... + Q_1 U_0$$
 ... (A2.E1)

where q_n is the rate of discharge from direct runoff at time n, U_i is the i^{th} ordinate of -unit hydrograph and Q_{n-i+1} is the direct runoff for the i^{th} interval. This equation can also be used as the regression model for unit hydrograph derivation by adopting least squares.

Snyder Unit Hydrograph Method

A commonly used derivation of a unit hydrograph is the procedure derived by Snyder in which a large number of basins and unit hydrographs were analyzed to derive relationships between the shape of the unit hydrograph and the physical characteristics of the drainage basin. Snyder's description of a parametric UH was developed with relationships for estimating the UH parameters from watershed characteristics. The lag, peak flow, and total time base are selected as the critical characteristics of a UH. Snyder's UH model requires specifying the standard lag, t_p and the coefficient C_p . The important parameters in the shape of a unit hydrograph are its peakedness, the length of its base and the basin lag, which is defined as the time from the centroid of rainfall to the peak of the hydrograph. The basin lag, t_p , is given in hours as:

$$t_p = C_1 (ll_c)^n \qquad \dots (A2.E2)$$

where C_1 conversion factor for units and is an empirical coefficient, I is the length of the main stream in kilometres, I_c is the distance in kilometres from the centroid of the drainage area to the outlet and 'n' is an exponent.

For peakedness of the unit hydrograph, this method uses a standard duration of rain, t_0/C_2 , in which C_2 is derived empirically. Peakedness is given by,

$$Q_p = C_3 A/t_p$$
 ... (A2.E3)

where Q_p is peak rate of runoff in m³ s⁻¹, C_3 is an empirical constant, A is drainage area in km² and lag t_p is in hours. The time base in days T_b is given by

$$T_b = d + C_4 t_p$$
 ... (A2.E4)

The constants d and C_4 are estimated by the procedure used to separate base flow from direct runoff. For durations T_R other than the standard duration of rain, the corresponding lag, t_0 is given by,

$$t_c = t_p + f(t_R)$$
 ... (A2.E5)

where $f(T_R)$ is a function of duration. Snyder's coefficients were derived for streams in the Appalachian Mountains of United States. The method in general has been found to be applicable for other regions, for which different coefficients are to be derived to account for different types of topography, geology and climate.

Clark Unit Hydrograph Method

Clark's model derives UH for a watershed explicitly by representing the two critical processes in transformation of the excess precipitation to runoff i.e. (i) translation and (ii) attenuation. Movement of the excess rainfall from its origin throughout the drainage area to the watershed outlet is known as translation, while, reduction of the magnitude of the discharge as the excess is stored throughout the watershed is known as attenuation.

Clark's model adopts a linear reservoir approach to represent the aggregated impacts of all watershed storages. In addition to this, it accounts for the time required for water to move to the watershed outlet. The mathematical form of Clark's Instantaneous Unit Hydrograph (CIUH) is represented as:

$$Q_{i+1} = 2C_0R_{E(i)} + C_1Q_i$$
 ... (A2.E6)

Where i = index varying from 1 to N, and N is number of ordinates of the time area diagram, R_E is uniformly distributed rainfall excess (ordinates of time-area diagram in units of km² multiplied by a constant for unit conversion), Q_{i+1} is (i+1)th ordinate of the CIUH, C_0 and C_1 are weighting coefficients as used in Muskingham routing which is defined as

$$C_0 = 0.5t/(R+0.5t)$$
 and $C_1 = (R-0.5t)/(R+0.5t)$... (A2.E7)

Where t is computational time interval. A unit hydrograph for finite time interval T can be found by lagging IUH equal to time T and averaging the IUH ordinates for time period T. Application of the Clark model require, (i) properties of the time-area histogram and (ii) the storage coefficient (R). Development of time area diagram is required to define static model inputs. The base length of the time-area diagram gives the time of concentration of the catchment. The unit hydrographs of various durations are computed as below.

$$A/A_c = 1.414 \left(\frac{t}{T_c}\right)^{1.5}$$
 for $t \le \frac{T_c}{2}$... (A2.E8)

$$A/A_c = 1 - 1.414 \left(1 - \frac{t}{T_c}\right)^{1.5}$$
 for $t \ge \frac{T_c}{2}$... (A2.E9)

Thus, CIUH is derived and convolution of the same should be done with excess rain hyetograph to get the Direct Surface Runoff Hydrograph (DSRH). Shape of DSRH is more sensitive to R than T_c showing that runoff diffusion phenomenon is dominant as compared to translation flow effects when evaluating hydrologic response of catchments of large size. DSRH derived from Clark IUH model gives acceptable accuracy say \pm 15 % and model parameters can be easily updated as additional hydrometric data becomes available for catchments. It can also be applied to un-gauged catchments by simulating hypothetical storms and survey of highest flood marks at the outlet. A value of R determined for single flood event (corresponding to highest flood mark) can be used to compute different runoff hydrographs for different design storms.

CWC Method for - Flood Estimation

A systematic and sustained collection of hydro meteorological data for selected catchments in different climatic zones is required for estimating design flood. The recommended maximum flood discharge on record for period should not be less than 50 years (CWC, 2011). On this line CWC had taken up project for hydrological design of railways and road bridges across small and medium streams. It has suggested adoption of rational formula involving use of design storm and unit hydrograph for estimation of design flood. For this purpose, India was divided into climatic 7 subzones (CWC, 2011; CWC, 1992; CWC, 1994) for collecting the data as depicted in Fig A2.F2.

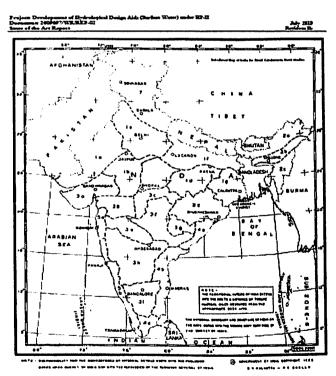


Fig. A2.F2: Sub-zonal Map of India for Flood Studies (Source: CWC, 2011) Based on the data collected, the duration and shape of Synthetic Unit hydrograph (SUH) for each sub zone was estimated. The SUH developed by CWC follows Snyder's method for these sub zones with parameters such as, t_p , Q_p , T_B , T_m , W_{50} , W_{75} , W_{R50} and W_{R75} which are pictorially described in Fig. A2.F3.

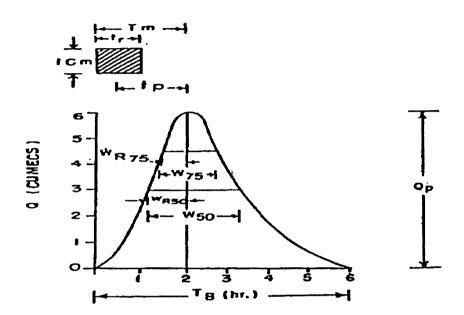


Fig. A2.F3: Unit Hydrograph Parameters as adopted by CWC

The SUH parameters estimated for lower Ganga basins (CWC, 1984) are given below as sample case (Eqn. A2.E10 to A2.E18),

$q_p = 0.6617 \left(L / \sqrt{S} \right)^{-0.515}$	(A2.E10)
$t_p = 1.8833(q_p)^{-0.940}$	(A2.E11)
$W_{50} = 1.7897 (q_p)^{-1.006}$	(A2.E12)
$W_{75} = 0.8955(q_p)^{-1.061}$	(A2.E13)
$W_{R50} = 0.5524 (q_p)^{-1.012}$	(A2.E14)
$W_{R75} = 0.2984 (q_p)^{-1.012}$	(A2.E15)
$T_B = 12.4755(t_P)^{0.721}$	(A2.E16)
$T_m = t_p + t_r/2$	(A2.E17)
$Q_p = q_p * A$	(A2.E18)

The relationships developed for each of the subzones are shown in Tables A2.T1. However, care should be taken to see that these regional formulae/ equations are not misused for large areas/structures. Further, these studies need to be updated with recent additional data. Table A2.T1: Synthetic Unit Hydrograph Relations for Small and Medium Catchments

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Table 2.8: Synthetic UG Relations for Small/Medium Catchments

SI.	Sub	tr	SUH Parameters						
No.	Zone	(hr)	t _p	q _p	TB	Wa	W ₇₅	WRp	WR75
1.	1(a)	1	0.257(A) ^{C 409}	2.615(t _p) ^{0.893}	6.299 (t _p) ^{0.612}	2.654(q _p) ^{0,921}	1.672 (q _p) ^{0.\$16}	1.245(q ₂) ^{0,371}	0.816(q _p) ^{0.339}
2.	1(b)	1	0.339 (L/VS,)0 \$26	1.251(t _p) ^{0.610}	6.662(t _p) ^{0.613}	2.215(q _p) ^{1.034}	1.191 (q ₂) ^{1.057}	$0.834(q_p)^{1.077}$	0.502(q _p) ^{1.065}
3.	1(c)	1	2.195/ (q _p) ^{0 944}	1.331/(L/\S _e)0.492	3.917(ೄ) ^{0.990}	2.040(q _p) ^{1.026}	1.250 (q _p) ^{0.261}	0.739(q _p) ^{0.968}	$0.500(q_2)^{0.813}$
4.	1(d)	1	0.314(L/\s _•) ¹⁰¹²	1.664(t _p) ^{0.965}	5.526(t _p)0.856	2.534(q ₃) ^{0.976}	1.478 (q _p) ^{0.850}	1.091(q _p) ^{0.750}	0.672(ფ.) ^{0.719}
5.	1(e)	2	1.858(q ₂) ^{1 033}	2.030(L/√S ₂) ^{0.649}	7.744(ⴏ) ^{0.739}	2.217(g _a) ^{0.99}	1.477 (q _b) ^{0.876}	0.812(q _s) ^{0.907}	0.606(q _p) ^{0.791}
6.	1(f)	6	1.217(q _p) ¹⁰³⁴	0.409(L/\s.)0.456	16.432(t _p)0.546	1.173(q _p) ^{1.104}	0.902 (q _p) ^{1.108}	0.736(q _p) ^{0.928}	0.478(q _p) ^{0.902}
7.	1(g)	1	1.180(LL _c /√S _a) ^{0.255}	2.097 (t _p) ^{0 927}	5.583(t _a) ^{0 \$24}	1.262(g _n) ^{0.828}	0.789 (q ₂) ^{0.711}	0.535(g _b) ^{0.745}	0.382(t _a) ^{0.647}
8.	1(g)	1	1.883(q ₂) ^{0 940}	0.661 (L/\s_)0.515	12.475(t _p) ^{0.721}	1.789(q _p)0.9211.006	0.895 (q _p) ^{1.061}	0.552(q _p) ^{1.012}	0.298(q _p) ^{1.012}
9.	2(a)	1	2.164(q ₂) ^{0.940}	2.272 (LL/\s _a)0409	5.428(Ļ) ^{0.852}	2.084(q ₂) ^{1.065}	1.028 (q _p) ^{1.071}	0.856(q ₂) ^{0.565}	0.440(q ₂) ^{0.918}
10.	2(b)	1	2.870 (q _p) ^{0 \$39}	0.905 (A) 0.758	2.447(t _o) ^{1.157}	2.304(q _p) ^{1.035}	1.339 (q _p) ^{0.978}	0.814(q _p) ^{1.018}	$0.494(q_p)^{0.966}$
11.	3(a)	1	0.433 (L/√S _e) ^{0.704}	1.161 (t _p) ^{0.635}	8.375(t _p) ^{0.312}	2.284(q _p) ^{1.00}	1.331 (q ₂) ^{0.991}	0.827(q ₂) ^{1.023}	0.561(g _b)1.0.57
12.	3(b)	1	0.523 (LL _e /\S ₂)0323	1.920 (t _p) ^{0.780}	6.908(ೄ) ^{0.592}	1.830(q _p) ^{0.97}	0.924 (q _p) ^{0.792}	0.745(q _p) ^{0.725}	0.434(q _p) ^{0.616}
13.	3(c)	1	0.854(LL _c /√S ₁) ^{0.280}	2.009 (t _p) ^{0 850}	4.840(t _p) ^{0.740}	2.259(q _p) ^{1.080}	1.519 (q ₂) ^{0.990}	0.844(q _p) ^{1.340}	0.583(q ₂) ^{0.932}
14.	3(d)	1	1.757(LL _e /√S _e) ^{0.261}	1.260 (t _p) ^{0.725}	5.411(t _p) ^{0.826}	1.974(q _p) ^{1.104}	0.961 (q _p) ^{1.125}	1.150(q _p) ^{0.829}	0.527 (q _p) ^{0.932}
15.	3(e)	1	0.727(L/\s _e) ^{0.5990}	2.020 (t _p) ^{0.880}	5.485(ե) ^{0.730}	2.228(q _p) ^{L104}	1.301 (q _p) ^{0.960}	0.880(q _p) ^{1.01}	0.540(ფ.) ^{0.960}
16.	3(f)	1	0.348(L/\S _*) ^{0.454}	1.842(t _p) ^{0.804}	4.589(t _b) ^{0 894}	2.353(q _p) ^{1.005}	1.351(q _p) ^{0.992}	0.936(_წ ე ^{1.047}	0.579(q _p) ^{1.004}
7.	3(g)	1	0.353(LL _c /\s _e)0.45	1.968 (t _p) ^{0\$42}	4.572(t _p)0.900	2.300(q _p) ^{1.018}	1.356 (q ₂) ^{1.007}	0.954(g _b) ^{1.078}	$0.581(q_p)^{1.035}$
8.	3(h)	1	0.258(LL,/\s,)0.490	1.017 (t _p) ^{0.510}	7.193(t _p) ^{0.530}	2.396(q _p) ^{1.050}	1.427 (q _p) ^{1.05}	0.750(q _p) ^{1.250}	0.557(q _p) ^{1.12}
9.	3(i)	1	0.553(LL ₂ /√S ₂) ^{0.405}	2.043(t _p) ^{0.872}	5.083(t _p) ^{0.733}	2.197(q _p) ^{1.067}	1.325 (q _p) ^{1.088}	0.799(q _p) ^{1.138}	0.536(q _p) ^{1.109}
0.	4(a,b,c)	1	0.376(LL _c /v/S _c) ^{0.434}	1.215(t _p) ^{0.691}	7.621(k) ^{0.623}	2.211(q ₂) ^{1.07}	1.312 (գ _{.)} 1.003	0.808(q _p) ^{1.053}	0.542(g _b) ^{0.963}
1.	5(a,b)	1	1.560(q ₂) ^{1 0814}	0.917(L/\s_)0.4313	7.380(t _s) ^{0.7343}	1.925(q _p) ^{1.0396}	1.018 (q ₂) ^{1.043}	0.578(q _p) ^{1.1072}	0.346(9 ₆)1.0338
2.	7	1	2.498(LL _c /√S _•) ^{0 156}	1.048(t _p) ^{0.178}	7.845(t _p) ^{0.453}	1.954(LL√√S ₂) ^{0.099}	0.97(LL ₄ /\s ₂) ^{0.124}	0.189(W ₅₀) ¹⁷⁶⁹⁰	0.419(W75)1.2

While adopting the CWC (CWC, 2011) developed relationships, it is required to consider the following few aspects,

- a. Design Storm Duration: This should be equal to or greater than the time base (T_B) of SUH
- b. Point to Aerial Rainfall Ratios: These are required to be applied to the extreme rainfall of 25 yr, 50 yr and 100 yr return period as areal reduction factors.
- c. Time Distribution Coefficients: The Time Distribution Coefficients are required for converting 24-hr to 24 values 1-hr rainfall.
- d. Design Loss Rate: This depends on sub zones and range from 0.1 to 0.2 cm/hr.
- e. Design Base Flow: Excess: In estimation of design flood hydrograph, a base flow rate of 0.05 to 0.2 cumecs/ sqkm could be used based on the catchment.
- f. Critical Sequence of Rainfall Excess: The critical sequence of rainfall excess should be characteristic of the area under study. When data is not available, to facilitate the adoption of this principle, the arrangement of rainfall increments into design hyetograph may be made in the form of two bells of 12 hours each per day.

- g. Convolution: This is a vital step in developing DSRH from SUH, wherein the SUH ordinates at unit duration interval are multiplied by each of the rainfall excess ordinates of the design hyetograph and added by lagging one hour duration at a time.
- h. Computation of Unit Hydrograph: Using the basin physiographic parameters, two unit hydrographs are plotted and volume of each is calculated and adjusted to 1 cm. While adjusting the hydrograph the volumes Q_P, T_m and T_B are not changed. The DSRH are computed after the rainfall excess increments have been arranged in a critical sequence and convoluted. The base flow is added to the ordinates of the surface flow hydrograph to obtain total flood hydrograph. This process is pictorially shown in Fig. A2.F4.

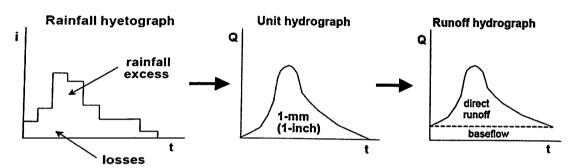
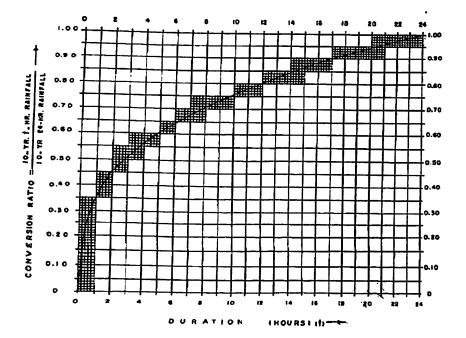


Fig. A2.F4: Synthetic Process for DSRH from Unit Hydrograph

Storm Distribution and Point Rainfall to Aerial Conversion

Rainfall data observed at raingauges using storage raingauges (SRG) are on daily basis; shorter duration rainfall records (hourly) are seldom available or even if available data gaps may exist. Also Rainfall data is recorded at a point, where as rainfall is distributed in time and space. The temporal distribution of storm rainfall is necessary to discretise 24-hr (daily) rainfall in to 24 1-hr rainfall or 6-hr storm into smaller duration rainfall events of 1-hr each for which conversion factors are required to be established and used accordingly. A typical example of converting rainfall storm of 24-hr duration to 1-hr rainfall events is presented in Fig. A2.F5.



Duration (hr)	Ratio
1	0.350
2	0.450
3	0.515
4	0.560
5	0.605
6	0.640
7	0.675
8	0.705
9	0.735
10	0.760
11	0.780
12	0.800
13	0.825
14	0.845
15	0.860
16	0.880
17	0.900
18	0.915
19	0.930
20	0.945
21	0.960
22	0.975
23	0.980
24	1.000

Fig. A2.F5: Conversion of 24-hr Rainfall to 1-hr Duration Rainfall (Source: CWC, 1992)

For better representation of spatial distribution of rainfall process, a dense network of rainguage should be available, or else the point rainfall is required to be converted to aerial rainfall with established relationships (CWC, 1992; CWC, 1994). Thus to account for the areal distribution of rainfall point to aerial conversion coefficients established for lower Ganga basin is presented as a sample case in Fig. A2.F6 (for 1-hr, 3-hr, 6-hr, 12-hr and 24-hr storms).

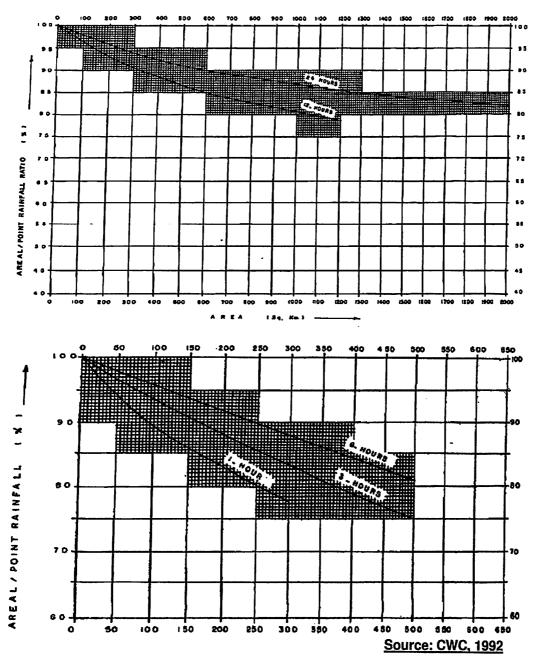


Fig. A2.F6: Aerial to Point Rainfall Ratio (%) for Lower Ganga Basin Different Durations

- 7.4 Cross Section of the Drain Although deeper sections of the drain may be desirable, the width to depth ratio should be so selected that the section is both hydraulically efficient as well as economical in excavation. In the case of drains with embankments, the berm width equal to the depth of the drain subject to a minimum of 1m should be provided between the toe of the embankment and the section of the drain. The top of the embankment should be 1m higher than the design full supply depth (FSL).
- 7.5 Fixation of FSL at Outfall Whenever the drain is outfalling in to a river, the FSL should be slightly higher than the dominant flood level. In case where the topography permits, the FSL can be above the highest flood level. However, if such a level results in flatter slopes or in FSL becoming higher than the natural ground level, FSL at outfall should be kept slightly above the dominant flood level. In such cases, there will be backing up in the drain when the river rises above the dominant flood. Such occurrences being infrequent and of short duration can be tolerated, Care shall, however, be taken in determining the dominant flood discharge and the level.
- 7.6 Hydraulic Slope The FSL of the drain as far as possible should be at the ground level. Where it cannot be ensured, the FSL should in no case be more than 0.3m above the average ground level at the starting point of the drain. The hydraulic slope should then be determined adopting this stipulation and the criteria laid down for fixation of FSL at outfall. The hydraulic slope should normally be such as to provide permissible velocities as indicated in 7.1 above.
- 7.7 Tidal Lockage In the case of drains outfalling into rivers subjected to tidal influence, the reaches of the drains which will be subjected to tidal lockage should be determined. In these reaches capacity of the drains should be increased to provide for duration of the tidal lockage gradually diminishing from the outfall towards the upstream. For this purpose, it will be necessary to plot the dominant tidal curves. The FSL of the drains in such cases should normally be fixed at mean tide levels. This will also be known as cut-off level. This will be the level at which the drain will cease to discharge on account of rising edge.

The release level will be the level at which the drain will again start discharging during the ebb tide. This will always be higher than the cut-off level.

4. IS 4439(Part II): 1979 Code of Practice for Maintenance of Canals

2. CANAL LINING

- 2.1 GENERAL: A lined canal shall be maintained so that it continues to function efficiently and serves the purpose, for which it has been constructed, throughout its effective span of life. In addition to maintaining to its imperviousness, the lining shall be maintained so that it also continues to have the same discharge capacity for which it has been designed and which it had when it started operating soon after the construction was over. The reduction in discharge may generally be due to accumulation of silt; cracking of lining; failure of the drainage; growth of weeds, algae and moss; etc.
- 2.1.1 Normally no silt deposition shall be permitted to take place in a lined canal.

2.7 Silt Clearance — If any silt deposition is detected during inspection, steps shall be taken to investigate causes thereof and to take remedial measures for the same. Only in exceptional circumstances it may be necessary to excavate the silt and remove it. If any silting tendency is noticed in the form of reduction of discharge carrying capacity, cross sections of the lined canal should be taken at frequent intervals to determine the extent of silting and to see if the silt deposited during monsoons can be flushed out during non-monsoon period when the water is silt free. Where silt clearance is unavoidable, it should be done carefully by manual labour to prevent damage to lining.

2.8 Weed Removal — Aquatic weed growth, if observed below the supply level should be removed. Land weed growing over the freeboard should also be controlled.

II. <u>Time of concentration t_c, critical design Intensity for catchments from IRC-13 standards</u>

4.7 Estimating the Concentration Time of a Catchment (t_c):

The concentration time depends on (1) the distance from the critical point to the culvert; and (2) the average velocity of flow. The latter is governed by the slope and the roughness of the drainage channel and the depth of flow. Complicated formulae exist for deriving the time of concentration from the characteristics of the catchment. For our purpose, however, the following simple relationship will do,

$$t_c = \left(0.87 * \frac{L^3}{H}\right)^{0.385}$$
 ... (A3.E1)

Where, t_c is the concentration time in hours, L is the distance from the critical point to the culvert in km, and H is the fall in level from the critical point to the culvert in metres.

4.8 The Critical or Design Intensity – The critical intensity for a catchment is that maximum intensity which can occur in a time interval equal to the concentration time t_c of the catchment during the severest storm (in the region) of a given frequency. Call it l_c since each catchment has its own t_c , it will have its own l_c .

The intensity of a storm can be expressed as a function of duration is

$$i = \frac{F}{T} \left(\frac{T+1}{t+1} \right) \tag{A3.E2}$$

Where, F is total precipitation in the storm duration T, and i is intensity corresponding to time t. For 'one-hour rainfall of say I_0 cm' the above Eqn can be written as

$$I_0 = \frac{F}{2} \left(1 + \frac{1}{T} \right)$$
 ... (A3.E3)

If we put $t = t_c$ in the above equation (A3.E2) we get critical intensity as

$$I_c = \frac{F}{T} \left(\frac{T+1}{t_c+1} \right) \qquad \dots \text{ (A3.E4)}$$

Substituting this in equation (A3.E3) we get l_c as below,

$$I_c = I_0 \left(\frac{2}{t_c + 1} \right)$$
 ... (A3.E5)

Equation (A3.E4) or (A3.E5) are used in estimating the critical intensity for design flood estimation of catchments.

III. MoEFCC Guidelines for Power Project in respect of EIA

Annexure VI

Application Form1 (for Obtaining EIA Clearance)

8. Risks of accidents during construction or operation of the project, which could affect human health or the environment

SI. No.	Information/Checklist Confirmation	Yes/ No	Details thereof(approx. quantities/ rates where ever possible) with source of information data
8.3	Could the project be affected by natural disaster causing environmental disaster (e.g., floods, earthquake impact, landslide, cloud burst, etc.)		

Annexure XA: Potential Sources of Data for EIA

SI. No.	Information	Source
	Natural Disasters	
17	of occurrence per decade, area affected and population affected	 Natural Disaster Management Division in Department of Agriculture and Cooperation India Meteorological Department

IV. Design Flood Frequency of Culverts on Surface Drains from NHWA Standards

TableA2.T1: AASHTO Flood Frequency Used for Design of Culverts

AASHTO Classification	#	SHA Functional Classification	Design Flood
			Frequency
Expressways		Principal Arterial	100
Arterial	11	Intermediate Arterial	50
	- 111	Minor Arterial	50
Collectors	IV	Major Collectors	25
	V	Minor Collectors	25
Local Roads & Streets	VI	Local Streets	10

Source: NHWA, (2003): "State Highway Access Manual – Hydraulic/ Hydrologic Guidelines, Appendix H, Guidelines for Development Adjacent to State Highways", Highway Hydraulics Division.

SELECTED STUDIES ON SGL CARRIED OUT AT CWPRS

SI. No.	Study Title	Project Authority
1	Area Drainage Studies and Determination of Safe Grade Elevation for Krishnapatnam Ultra Mega Power Project (KUMPP), Andhra Pradesh	WAPCOS/CAPL/REL
2	Area Drainage Studies for Solapur Thermal Power Project (STPP) of NTPC, Maharashtra	NTPC
3	Area drainage Studies for proposed Dehrand Thermal Power Project of Tata Power Company Limited	WAPCOS/TPCL
4	Determination of Safe Grade Elevation and Design of Storm Water Drainage System for proposed Thermal Power Project of M/s Reliance Energy Limited at Butibori, Nagpur (Maharashtra)	WAPCOS/ R Infra/REL
5	Area Drainage Studies for proposed Durgapur Steel Plant Thermal Power Project (DSTPP), West Bengal for M/s WAPCOS.	WAPCOS/DVC
6	Area Drainage Studies for proposed Raghunathpur Thermal Power Station (RTPS), West Bengal	WAPCOS
	Studies for Design of Storm Water Drains for Raghunathpur Thermal Power Station.	WAPCOS
7	Area Drainage Studies for Koderma Thermal Power Station, for Damodar Valley Corporation, Jharkhand	WAPCOS/DVC
8	Area Drainage Studies for proposed Thermal Power Project of TPCIL near Nellore, Andhra Pradesh	WAPCOS/TPCIL
9	Area Drainage Studies for Kudgi Super Thermal Power Project of NTPC, Karnataka	NTPC
10	Area Drainage Studies for Tilaiya UMPP, of M/s REL for M/s WPCOS	WAPCOS/DVC
11	Area Drainage Studies for proposed Power plant of RIL at Hazira, Gujarat	WAPCOS/RIL
12	Mathematical Model Studies for Safe Grade Level elevation for proposed Integrated Power Plant near village Darlipali, District: Sundargarh, Odisha	NTPC
13	Mathematical Model Studies for Safe Grade Elevation for proposed Super Thermal Power Plant (STPP) near village Lara Chhattisgarh.	NTPC
14	Determination of Safe Grade Level for Ms Nelcast energy Corporation Ltd. Andhra Pradesh	WAPCOS







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- 3. Foundation and Structure
- 5. Applied Earth Sciences

- 2. River and Reservoir Systems Modeling
- 4. Coastal and Offshore Engineering
- 6. Reservoir and Appurtenant Structures
- 7. Instrumentation Calibration and Testing Services