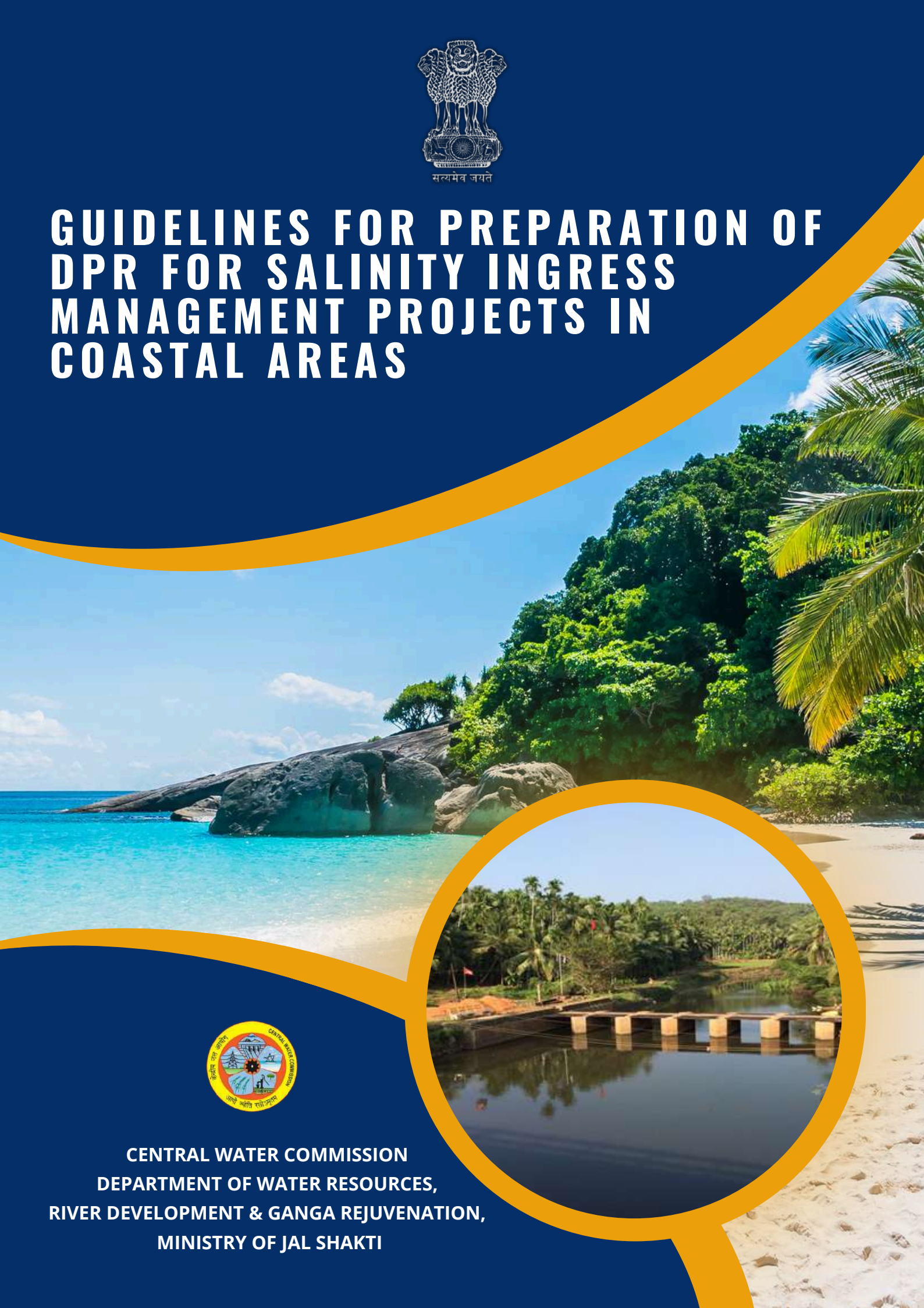
सत्यमेव जयते

GUIDELINES FOR PREPARATION OF DPR FOR SALINITY INGRESS MANAGEMENT PROJECTS IN COASTAL AREAS



CENTRAL WATER COMMISSION
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION,
MINISTRY OF JAL SHAKTI

GOVERNMENT OF INDIA
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RIVER DEVELOPMENT & GANGA REJUVENATION

GUIDELINES FOR PREPARATION OF DETAILED PROJECT REPORTS (DPRs) FOR SALINITY INGRESS MANAGEMENT PROJECTS IN COASTAL AREAS

CENTRAL WATER COMMISSION
NEW DELHI

May, 2025

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केंद्रीय जल आयोग
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Chairman,
Central Water Commission
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Foreword



India's vast and diverse coastline, stretching over 11000 kilometers, supports numerous ecosystems, livelihoods, and critical infrastructure. However, increasing anthropogenic pressures and the impact of climate change have made coastal regions increasingly vulnerable to challenges such as salinity ingress. The intrusion of saline water into freshwater systems and coastal aquifers adversely affects agriculture, potable water availability, and the health of coastal communities.

The Ministry of Jal Shakti, through the Department of Water Resources, River Development and Ganga Rejuvenation, has been working proactively to strengthen the country's resilience to these emerging coastal hazards. These *Guidelines for Preparation of Detailed Project Reports (DPRs) on Salinity Ingress Management Projects in Coastal Areas* are a timely initiative to provide scientific, sustainable, and implementable solutions that can be adapted to local conditions across various coastal states and Union Territories. I commend the efforts of the officers of Central Water Commission and all other stakeholders involved in developing this important document.

I hope these guidelines will serve as a valuable reference for planners, engineers, researchers, and administrators in implementing nature-based and engineering solutions to mitigate salinity ingress

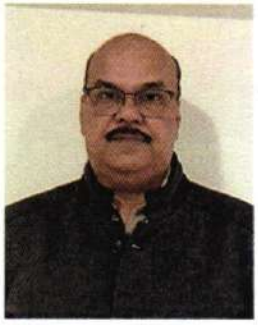
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Preface



Salinity ingress has emerged as a growing threat to India's coastal regions, particularly in low-lying areas affected by tidal influences, groundwater over-extraction, and the long-term impacts of sea-level rise. Recognizing the critical need for a structured and science-based approach to address this issue, the Central Water Commission has developed this comprehensive guideline.

This document is intended to support implementing agencies, consultants, researchers, and coastal planners in understanding the processes and impacts of salinity ingress, and in designing site-specific mitigation measures. It draws upon national and international best practices, field experience, and interdisciplinary research to promote integrated coastal zone management.

The guideline identifies several vulnerable regions requiring urgent intervention, including the **Sundarbans in West Bengal**, **Rann of Kutch and Saurashtra in Gujarat**, **Kharlands of Maharashtra**, **deltaic areas of Krishna, Godavari, and Cauvery rivers**, and **coastal tracts of Kerala, Tamil Nadu, Andhra Pradesh, and Odisha**. These areas face varied challenges such as tidal inundation, saline groundwater intrusion, degradation of agricultural lands, and loss of freshwater availability. Key recommendations in the guideline include the adoption of salinity control structures (e.g., tidal regulators, bunds, check dams), groundwater recharge techniques, and nature-based solutions such as mangrove restoration and shelterbelt plantations. A step-by-step framework for preparing Detailed Project Reports (DPRs) has also been provided to ensure technical rigor and field relevance.

We anticipate that these guidelines will strengthen institutional capacity at the state and national levels, and guide the preparation of effective, climate-resilient interventions for the protection of coastal communities and ecosystems.

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Acknowledgement



The preparation of the **"Guidelines for Preparation of Detailed Project Reports (DPRs) for Salinity Ingress Management Projects in Coastal Areas"** is the result of collaborative efforts and valuable contributions from a wide range of experts and institutions. We extend our sincere appreciation to the members of the Committee for their guidance and active involvement in the development of these guidelines. We are grateful to institutions such as the **National Institute of Hydrology (NIH), Roorkee**, **Central Water and Power Research Station (CWPRS), Pune**, **Central Ground Water Board (CGWB)**, and the **Government of Gujarat**, whose domain expertise, field insights, and technical feedback played a crucial role in shaping the framework of this document. Special acknowledgment is due to the officers of the **Coastal Management Directorate, CWC**, including **Shri Avanti Verma, Director**, **Shri Ashish Kumar Ranjan, Deputy Director**, **Shri Vishnu V.V., Assistant Director**, and **Shri Ankit Sharma, Assistant Director-II**, for their dedicated efforts in compiling, structuring, and enhancing the content of this guideline. Their meticulous coordination, and integration of interdisciplinary perspectives have ensured that this document serves as a practical and technically robust resource for salinity ingress management across coastal regions in India. We also thank all participating State Governments, technical experts, and supporting staff whose contributions have been invaluable in bringing this initiative to fruition.

D.P. Mathuria

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I. BACKGROUND

A study was undertaken by the Department of Water Resources, River Development and Ganga Rejuvenation (DoWR, RD & GR), Ministry of Jal Shakti (MoJS) to examine the issues of salination of land along the coast in a scientific manner and to suggest suitable remedial measures. For this purpose, an interdisciplinary technical committee was constituted under the Chairmanship of the Chairman, CWC.

A Report on "Problems of Salination of Land in the Coastal States/ Union Territories of India and Suitable Protection Measures" was prepared and submitted by a committee to DoWR, RD&GR. In line with decisions taken by DoWR, RD&GR on the report for preparation of Guidelines for preparing DPR & New scheme for Salinity Ingress Management Projects and setting up of National Centre for Scientific Study of Salinity Ingress in Delta Regions, a Committee has been constituted. (**Annexure-I**)

Salinity is a significant challenge and poses risks to the sustainable development of the Coastal regions of India. If left unmanaged, salinity has serious implications for water quality, biodiversity, agricultural productivity, supply of water for critical human needs and industry, and the longevity of infrastructure. The Coastal Salinity has become a persistent problem due to the ingress of the sea water inland.

Indiscriminate large-scale pumping of groundwater may lead to progressive saltwater intrusion in the freshwater coastal aquifer system that ultimately renders the groundwater unfit for human consumption and other uses. Irrigation of crops using saline water may also result in degradation of soil and widespread destruction of fertile coastal lands. During extended droughts, decreased river flow allows the saline water to migrate up the estuary to inland areas that may further contribute to land salinization. In addition, the rise in sea level will also cause seawater to migrate upstream and inundate low-lying areas.

Coastal land salinization and saltwater ingress are major hazards encountered along the Indian coast, which can hamper the rapid socio-economic growth of the coastal states and the economy of the country as a whole. As India has a lengthy coastline spread over nine states and four union territories, the problem of salinity in coastal areas is a national problem. In coastal regions, which are in close proximity to the sea, salinization may lead to changes in the chemical composition of natural water resources, degrading the quality of water supply to the domestic, agriculture and industrial sectors, loss of biodiversity, taxonomic replacement by halotolerant species, loss of fertile soil, collapse of agricultural and fishery industries, changes in local climatic conditions, and creating health problems; thus, affecting many aspects of human life and posing major hindrance to the economic development of the region.

Salinity processes are natural processes closely linked with landscape and soil formation processes; however, human activities can accelerate salinity processes, thereby further aggravating the land and water degradation of the affected region. Salinity is taken as a water issue when the potential use of water is limited by its salt content or its salt composition. It becomes a land use issue when the concentration of salt or sodium adversely affects plant growth, degrades soil structure, or causes soil erosion. The quality of groundwater in coastal aquifers shows considerable variation from place to place, depending on a host of factors including climate, geomorphology, geology, hydrogeological setting, and extent of anthropogenic influence. Salt-affected soils occur within a narrow strip of land adjacent to the coast and up to 50 km wide. These areas generally have an elevation of less than 10

m above mean sea level and include the low-lying land of river deltas, lacustrine fringes, lagoons, coastal marshes, and narrow coastal plain or terraces along the creeks.

Coastal saline soils are different from inland saline soils in the sense that the inland soil salinity is due to secondary salinization from high water table conditions caused by the introduction of irrigation in arid and semiarid areas, or it may also be due to natural conditions from the dissolution of minerals. The salinity problem in coastal soils arises during the process of their formation itself due to marine influence and frequent tidal inundation of the coastal land with seawater and ingress of seawater along the estuaries, creeks, drains, and rivers. The repeated inundation with highly saline water renders the soil saline. The salinity of coastal soils varies with the season and is at its maximum in May. Salinity decreases with the onset of monsoon and is generally lowest during September in areas receiving rain from the southwest monsoon. Moreover, groundwater with high salt content is present at shallow depths in coastal areas because of the low-lying nature of these areas and their proximity to the sea. These salts accumulate on the surface of the soil due to the capillary rise of saline groundwater during dry periods of the year.

The important areas needing attention are the Sundarbans of West Bengal, the delta areas of Krishna, Godavari, and Cauvery, Kari soils in Kerala, Khar lands of Maharashtra, and coastal areas of Gujarat and Rann of Kutch. The saline soils are referred to as Khazan lands in Goa and Khar lands in Maharashtra. The nature of the problem is different in different parts, and so the problems associated with these lands also vary. The saline soils of Sundarban in West Bengal are probably the result of the inundation of backwaters from the sea. In Kerala, the Kari soils are peaty in nature, containing 10-40% organic matter. These soils are present in low-lying areas that remain submerged under water during the monsoon. In Maharashtra, the problem areas occur in the districts of Ratnagiri and Thane. Soil salinity also occurs in the Uttar Kannada district of Karnataka. In Gujarat, the problem is widespread in the Saurashtra region and in the districts of Ahmedabad, Amreli, and Bharuch. These soils have been primarily recovered from the sea and are further formed by gradual silting by the sediment brought down by the rivers draining into these areas. Thus, for example, Kathiawar (in Saurashtra) was formerly an island that has risen slowly and become connected with the mainland. Except for the Sundarbans in West Bengal and the Great and Little Rann of Kachchh in Gujarat, the coastal saline areas (with top layer saline) are limited to a strip along the coast, both on the east and the west of the Peninsula. The width of the saline zone tapers off on the east coast towards Kanyakumari in Tamil Nadu. On the west coast, the saline region is very narrow on account of the narrow width of the Western Coastal Plains. Inundation of the saline strip is more common on the west coast, where the tidal effect is quite substantial. On the east coast, because of the littoral drift and formation of land and the proximity of sand dunes to the sea, the tidal effect is not so prominent.

The adoption of suitable protection measures for prevention of salinity ingress depends upon various factors including site specific conditions, hydrology or availability of water resources; geology/ hydro-geology of area; suitability of site for construction of barrage or weir for storing surface water and for subsequently using them for maintaining the hydrological gradient towards sea side etc. In order to develop optimal solutions for managing coastal soil and water salinity, specific information about the climate, topography and hydrogeology of the region, Depth/Extent of freshwater/saline water interface, origin of water salinity, available water resources and land use etc. are required.

II. SCOPE OF THE SCHEME

The effective design and implementation of measures for control of groundwater salinity is very much dependent on the local context. Some potential measures have a mitigation objective and aim at keeping salinity levels below harmful thresholds. Other measures have a more adaptive approach and accept the high salinity encountered but adjust groundwater use in such a way that the salinity level is not harmful. Among the hydraulic measures to be considered are the optimization of the pattern and intensity of groundwater abstractions and the development of hydraulic barriers to reduce further seawater intrusions. Rainwater harvesting, conjunctive use of surface and brackish water, drainage in irrigated areas avoiding water-logging and the application of smaller quantities of chemical inputs in agriculture are also used to reduce the salinity build-up in rural areas. Reclamation of the salt-affected soils can be carried out by preventing the tidal water inundation through construction of protective embankments/bunds, leaching of salts from the soil profile and through application of suitable amendments in the case of the acid sulphate soils and sodic soils, and, adoption of other suitable soil-water and crop management practices. Methods for combating salinity intrusion are presented in the form of hard solutions such as construction of reinforced concrete and steel structures and bio-solution like mangrove plantation. However, more emphasis should be given to nature-based solutions like bringing back/restoring the lost mangrove trees (endemic species) stretches to reduce effects of salinity intrusion in land and ground water.

Broad category of salinity control/ management measures adopted by different States / UTs is:

A. **Salinity Control structures** - effective in preventing upstream movement of tidal water through river channels
B. **Recharge Techniques** - helpful in augmenting the groundwater recharge
C. **Management Techniques** – helpful as a long-term strategy

A. Salinity Control Structures

a) Tidal Regulators are structures that seal the mouth of rivers at the point of their confluence with sea. These are gated structures constructed with impervious cut off below the foundation down to relatively impervious strata, thus not only arresting the tides entering the estuary from sea but also preventing seepage of sea water into the land and polluting sweet ground water.

b) Tail end Regulator is installed wherever the flood discharges are heavy and where there is a need to quickly dispose the floods without inundation/flooding of up lands. This gated structure will help to store the receding flood waters and will also prevent the sea water ingress.

c) Tail end Regulators with Diaphragm Wall apart from preventing surface sea water ingress these structures will help in long way to prevent sub-surface intrusion. These structures are helpful in creating significant storages in upstream side and will play a major role in the last mile irrigation and storage of water for drinking purposes.

d) Regulator cum Bridge acts as a saline water intrusion barrier which is constructed across the river. It is a gated structure having a Bridge on top providing access to the people for

moving around. The water stored behind the regulator can be used for drinking water, agricultural uses and industrial use. This acts as a flood control structure by leading entire flood discharge into the sea during the monsoon season. This also protects against the tidal affects. During the summer months it acts as a barrier to protect the sea water intrusion into the land.

e) Lock cum Regulator a gated structure having a special arrangement for closing the gates.

f) Inlet Sluice/ Control Sluice at mouth of the creeks or sub creeks to control the saline ingress due to tidal effect in to the command area.

g) Bandharas are similar to Tidal Regulators, which are constructed on small rivers without gates as solid barriers/ concrete walls on rivers. Bandharas are also constructed with impervious cut off below the foundation down to relatively impervious strata.

h) Kharland Schemes consists of embankments along the banks of the creeks to restrict the tidal waters to enter into agricultural lands. The flood waters are allowed to go into the sea through the cross drainage works constructed in the embankments. One-way gates are provided to the cross drainage works in order to restrict the saline water from the sea to enter into the agricultural lands.

i) Salt Water Exclusion Dams (SWED) is **vented dams** constructed across rivers/streams at the confluence of the sea up to high tide level. Such structures are kept open during rainy season to mitigate floods in the river and later closed to prevent the ingress of sea water into the rivers.

j) Bunds/ Saline Embankments are constructed in the coastal areas to collect surface water runoff and protect the saline water ingress. The bund is mainly constructed on the contour lines and is constructed with either soil or stones.

k) Vented Cross Bars (VCB) are generally designed in discharge areas where direct irrigation is not feasible from the streams. During the lean sea season it protects the sea water from entering inland. Earthen canals are constructed for distribution of the raised up water behind the VCB flowing by gravity to the fields. Protection works upstream of the VCB and along the canals are also provided to protect earthen canals since earthen canals are often found to get damaged, resulting in deposition of large quantities of sand and silt in the paddy fields.

l) Nalla Plugs are used in the area where rainfall is not low, but continuous heavy withdrawal of ground water has resulted in lowering of the water table on account of extremely limited facility of irrigation water through irrigation projects and also no proper method employed for harvesting and hence permitting the ingress of sea water.

m) Gully plugging in Forest Areas-may be taken up for assisting retention/ percolation of rainwater by the impounding.

n) 5 Square Model deals with two critical issues namely water logging and soil salinity. It provides gentle slope to facilitate runoff which avoids water logging. Raised land bed facilitates leaching and surface wash of salinity, thus reducing it to a great extent.

B. Recharge Techniques

a) **Check dams/ In-stream Structures** are constructed in the beds of rivers with regulation device to check the monsoon flow, which otherwise passes away to the sea. The stored water contributes towards ground water recharge and utilisation by farmers for lift irrigation in nearby fields.

b) **Recharge Tanks -**Check dams usually being of low height and having small water spread area are proposed to be used for diverting surplus water to recharge tanks in the nearby area.

c) **Recharge Wells** are dug like open wells with 3 to 4 m in diameter filled with rubble and with sand filter at the top. These wells are useful to recharge pervious aquifers located at some depths below the ground level. Recharge wells can be constructed in the beds of rivers or inside the recharge tanks.

d) **Recharge Reservoirs/ Spreading Channels**

e) **Recharge Shafts** are the most efficient and cost-effective structures to recharge the aquifer directly. Water is put into the recharge shaft directly through pipes and the recharge is fast and immediately delivers the benefit.

f) **Afforestation** is known to improve the rate of infiltration by formation of root channels and reduction in evaporation from land.

g) **Shelterbelt Plantation** is a viable technique for significantly reducing both the direct and indirect adverse impacts of salinity on plants and water resources along the coastline. It acts as barriers that diminish damage from salt-laden winds in coastal areas and provide shelter to coastal life. The 'bio-shield' formed by planting a vegetation belt along coastlines besides other such soft measures also help in absorbing/ dissipating the force of severe coastal storms and cyclones.

C. Management Techniques

a) **Scientific data collection, monitoring, assessment and modelling** form an essential starting point for effective management of seawater intrusion. These are primary tools that hydrologists use to understand ground water flow and salt water movement in coastal aquifers. Data required for groundwater studies in coastal and deltaic areas, where saltwater intrusion plays a role, relate to records of geophysical surveys, hydro-geological parameters, water levels, groundwater quality, ecology, sea-level rise etc.

b) **Behavioural and Institutional Approaches** aimed towards ensuring sustained water quality and quantity over the long term.

- **Water supply and demand management** – **Regulation/ limiting of Ground Water Extraction** by enforcing ground water legislation for future expansion of construction of wells farther inland, educating the farmers to reduce their present withdrawal to achieve ground water balance and adopting water saving practices viz. reduction of non-beneficial evaporative and leakage losses, increase of irrigation efficiency, a change to less water demanding production processes and land uses and to find alternative sources of water other than groundwater (surface water or re-use of waste water).

- **Crop adaptation - Cropping pattern**can be changed to manage salinity in soils and water, through introducing crops with lower water requirements; introducing salt tolerant and semi salt tolerant crops; incorporating Boron-resistant crops. Crop adaptation is accompanied by nutrients augmentation (in fertilizers) and soil quality improvement (e.g. adding gypsum sulphuric acid, and iron pyrite to reduce the negative effects of soil sodicity).

c) Engineering Measures can be employed as a way to prevent seawater intrusion into estuaries and as control measures where groundwater withdrawals have caused water levels in aquifers to fall significantly below mean sea level.

- **Minimum flow in rivers**–through river operations and flow management can have a significant effect on salinity. With greater volumes of environmental water available there is greater potential to improve river salinity through increased dilution. Environmental watering can also, in some circumstances, increases salinity. Those circumstances need active management to minimize salinity impacts.

- **Reclamation of Land** – protective embankments, surface and sub-surface Drainage, leaching, adoption of suitable varieties of crops at various stages depending upon their salt-tolerance. The crop of paddy has been found to be one of the most suitable crops during early stages of reclamation.

- **Anti-sea erosion works –** seawalls, groynes, breakwaters/artificial headlands or offshore breakwaters influence coastal processes to stop or reduce the rate of coastal erosion which in turn will reduce the salinity ingress. Natural protection like dunes and mangrove vegetation, shelterbelt plantation with high and dense trees, afforestation of waste lands can limit the susceptibility to salinization. Further, in coastal areas with high evaporation rates, shelterbelts also help in reducing evaporation losses.

- **Desiltation of Lakes –**The Lakes present along the coastal areas may be desilted to ensure that it is filled in by the fresh rainwater.

III. Affected Zone of Salinity Ingress in India: An Overview

1. GUJARAT

With the longest share of the Indian coast line, the coastline of Gujarat runs for a distance of about 1215 km. Along the coastal tracts of Gujarat, salinity of groundwater broadly varies with geological formations and their disposition with reference to the coast. It is influenced by factors like sea water ingress, inherent salinity of the formations deposited under marine conditions and the structural features. Also, several creeks under tidal influence allow the sea water to invade and deteriorate the groundwater quality in the phreatic aquifers. Thus, the soil and groundwater salinity is a combined effect of inherent formation water salinity, sea water encroachment due to groundwater overdraft, tidal water incursion through creeks/ estuaries, saline water percolation in low lying marshy lands inundated by sea water, irrigation with saline water, and salt laden winds / sea sprays. In addition, in such fresh-saline aquifers, where freshwater is underlain by saline water at deeper depths, the overdraft of groundwater causes salt water upconing of the underlying saline water.

2. MAHARASHTRA

The length of the coastal region in the State of Maharashtra is 653 km and is located between the state of Gujarat in the North and the Union territory of Goa in the South.
The region receives plentiful rainfall from the south west monsoon. In a width of about 15 km from the coast line, deep deposits of soil exist on account of erosion on the steep slopes of Sahyadri and transportation of this eroded material by rapidly flowing streams down the Western Ghats to the low-lying coastal tracts. In this state extensive area of Kharland (coastal saline soils) occur along with coast which have become unfit for cultivation on account of unproductivity of the soil mainly due to salinity. The sea water enters through the creeks during high tides and submerges large area of cultivable land. These periodical inundations render the land progressively saline and in time make it completely unfit for growing any crop. Even if the encroachment of saline, creeks water over such land is stopped by putting an embankment, on account of evaporation process in summer, the brackish water from local high water table rises through the capillary enriching the upper crust of the soil with soluble salts and thus the salinity problem persists.

3. KARNATAKA

The 280 km long coast line of Karnataka is indented with a number of river mouths, creeks, promontories and cliffs. Its width varies from a few metres to kms at places. Total annual rainfall in the coastal areas of Karnataka varies from 3000 to 5000 mm, resulting in heavy floods during monsoon. Flood waters in the rivers of the coastal area discharge in the Arabian Sea. Though there is abundant flow during monsoon, there is shortage of water for drinking and other purposes during summer. In summer season, when there is lean flow in these rivers, sea water enters the river course during high tide and mixes with freshwater enhancing the salinity and making it unfit for agricultural and drinking purposes. Further this saline water encroaches upon the inhabited lands and adjoining agricultural lands rendering these unfit for agriculture. If water is drawn from open or bore wells adjoining the river channels, the saline water movement is induced into the subsurface that affects groundwater quality. Groundwater extracted from such open and bore wells cannot be used for meeting the drinking water needs, resulting in acute shortage of drinking water supply. The

soil becomes more and more saline ('Kharland') from October onwards. Coastal land inundation is at its peak in January and February due to high tidal waves.

4. KERALA

The state of Kerala, located on the South-western tip of India, has a coastline about 570 km long bordering the Arabian Sea.

All the coastal districts experience salinity issues arising from salinity in rivers (and lakes) that discharge directly to the sea through estuaries/backwaters particularly during summer months. Salinity is experienced in reaches up to few kilometres from the river mouth and affects the agricultural, industrial and drinking water supply of these regions. The extent of salinity varies depending on the tidal action from place to place and the intensity of rain. During summer months when fresh water flow is less, salinity intrusion is considerable. Also, construction of break waters for fishing harbours/ fish landing centres causes entry of saline water freely into rivers and lakes and through river mouths during summer season. Increase in salinity may result in closure of several factories, industries, refineries etc.

Since the water recharging the groundwater is also affected by salinity, intrusion of saline water contaminates shallow groundwater and drinking water supplies. Uncontrolled sand mining and dredging has also resulted in increase in salinity thereby making the water unreliable for any purpose.

5. TAMIL NADU

Tamil Nadu having a coastal length of about 907 Km spread over 14 districts. Tamil Nadu, the southern-most state of India, is bounded by Bay of Bengal in the east, the Indian Ocean in the south and the states of Kerala, Karnataka and Andhra Pradesh in the west, north-west and north, respectively. In this State, the problem of salinity exists both in coastal areas and inlands. The soils of coastal areas offer many unique problems like salinisation, water logging, clay pan formation and sea water inundation.

In the coastal tracts of Tamil Nadu, the location of fresh-saline groundwater interface has varied with time depending on the groundwater pumpage and recharge conditions. The use of groundwater for irrigation, drinking and for industrial sector has increased manifold over the past three decades in coastal areas of Tamil Nadu, resulting in over-exploitation of groundwater in many blocks. In spite of various safe guarding measures taken to conserve and properly manage the groundwater in Tamil Nadu, the groundwater table is depleting and the state is experiencing shortage/scarcity of water accompanied by seawater ingress, leading to increased groundwater salinity in coastal tracts.

6. ANDHRA PRADESH

Andhra Pradesh has the second largest coast line in the country with a length of about 974 km. In Andhra Pradesh, in many commands, there has been a rise in the water table and consequent degradation of soils through water logging and secondary salt build-up, which leads to reduction in crop yields. Major reasons cited for increasing salinity include groundwater withdrawal for drinking and agriculture purposes that leads to saltwater upconing in areas where freshwater is underlain by saline water; water logging in canal commands resulting in rise of water table and soil degradation; intrusion through surface channels during high tides; possible seepages from aqua farms with localized impacts; overuse of fertilizers; and, drainage congestion near natural depressions.

7. ODISHA

The length of the coastal region of Odisha is about 477 km. The coastal tract of Odisha is one of the most disaster prone areas, frequently subjected to cyclones as well as severe flooding induced by storms. The number of cyclonic disturbances (depressions and cyclonic storms) in a year ranges from 4 to 15. The frequent cyclonic storms create havoc in the coastal area causing the agricultural low-lying areas to remain submerged under a sheet of seawater for a period of time, thereby adversely affecting the soil and the water quality of the shallow coastal fresh water aquifers. Groundwater salinity in this region is mainly of geogenic origin. Broadly, fresh/saline groundwater zones are found to exist in the multi-aquifer system as follows: i) fresh water zone overlying saline water zone, ii) saline water zone overlying fresh water zone, iii) alternate fresh and saline water zone and iv) saline water with or without fresh water zones (< 4 m thick).

8. WEST BENGAL

The state of West Bengal has a coastline about 158 km long consisting of two coastal districts, namely, Purba Medinipur and South 24 Parganas. The salinity problem in coastal aquifers of West Bengal is mostly due to the presence of sea water (as connate water) with different degrees of salinity getting entrapped during marine transgression or through deposition of sediments under marine depositional environment. Slow movement of groundwater in coastal area with a long residence time (that permits contact with a stationary coastward salt water body) also causes quality deterioration. The coastal areas are prone to frequent cyclonic storms. During the cyclonic storms, high tidal waves enter deep into inland areas and also along the tidal creeks, the influent seepage from which further deteriorates the quality of groundwater.

Other factors contributing to water salinity include coastal erosion and storm surges during cyclones that are frequent on the east coast and inundate vast areas of coastal tracts with seawater. Coastal erosion is a key issue, since it increasingly shifts the coastline inland making more areas susceptible to groundwater salinity.

9. PUDUCHERRY

The Union Territory of Puducherry has a coastline of about 31 km which lies in the southern part of Indian Peninsula consists of four small unconnected districts. The areas of Puducherry district and Karaikal district are bounded by the state of Tamil Nadu, while Yanam district and Mahe district are enclosed by the states of Andhra Pradesh and Kerala, respectively.

Due to the expanding needs and consequent over-exploitation, groundwater levels in general are witnessing a decline throughout the region resulting in sea water encroachment along the coastal tracts. Due to intrusion of sea water into shallow alluvial and top portion of tertiary aquifer along the costal tract of Puducherry Region, the quality of ground water in shallow tube wells as well as in deep tube wells located especially in the southern part of coastal region have gradually become saline. The above problem ultimately deteriorates the quality of soil in the coastal area. Additionally, sand mining in the river courses has also increased the extension of back water, which also aggravated the problem of sea water intrusion.

10. GOA

The coastline of Goa runs for nearly 161 km on the western coast. Most of the state constitutes part of the Konkan region. Due to its proximity to the Arabian Sea, the climate of Goa is warm and humid for most of the year. The state receives copious rainfall with an average of 3000 mm from the South-west monsoon.

Groundwater salinity in coastal tracts exists due to marine depositional environment and tidal influence in rivers/ streams. In North Goa district, groundwater in dug wells and borewells in areas around the seasonal river is brackish to saline due to seawater ingress. Similarly, in South Goa district, groundwater in locations close to and in the vicinity of creeks shows brackish to saline nature of groundwater. Salinity is more pronounced during May when fresh water flow is minimum and maximum seawater ingress takes place through creeks.

11. ANDAMAN AND NICOBAR ISLAND

The coastal region of Andaman and Nicobar Islands is about 1962 km long whereby the coastal areas are affected by salinity primarily due to sea water intrusion and capillary rise of saline water. The area under agriculture cannot be increased to meet the growing demand for vegetables, fruits and other food items of the island. At the same time the demand for intensification of agriculture and irrigation water for vegetable cultivation during dry season has been increasing. In addition, due to the subsidence of land masses during the December 2004 due to Indian Ocean tsunami sea water intrusion increased resulting in movement of sea water into the shallow wells located along the coastline. Land subsidence of 0.8 to 1.3 m has occurred at Andaman and Nicobar due to the 26 December 2004 Tsunami and has resulted in shoreline erosion in some of the islands.

IV. CONTENT OF DPR

CHAPTER 1: INTRODUCTION

Salinity is the presence of soluble salts in soil or water. Salinity processes can be natural linked with landscape and soil formation processes. The human activities can, however, accelerate salinity processes, thereby further aggravating the land and water degradation of the affected region. It can be a water issue when the potential use of water is limited by its salt content or its salt composition. It also becomes a land use issue when the concentration of salt or sodium adversely affects plant growth, degrades soil structure or causes soil erosion. Salinity is an acute problem in the coastal States of Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Odisha, West Bengal and the UTs of Daman & Diu, Puducherry, Andaman & Nicobar Islands and Lakshadweep Islands.

States/UTs may solicit guidance and technical assistance of expert agencies like IITs, NITs, WAPCOS, NIH, ICFRE and related institutes etc. for the preparation of various chapters of the DPR related to Salinity Ingress Management Projects.

Salinity Ingress or Saltwater intrusion is the movement of saline water into freshwater aquifers, which can lead to contamination of drinking water sources and other consequences. Saltwater intrusion occurs naturally to some degree in coastal aquifers, owing to the hydraulic connection between groundwater and seawater. Because saline water has a higher mineral content than freshwater, it is denser and has a higher water pressure. As a result, saltwater can push inland beneath the fresh water. Certain human activities, especially groundwater pumping from coastal freshwater wells, have increased saltwater intrusion in many coastal areas. Water extraction drops the level of fresh groundwater, reducing its water pressure and allowing saltwater to flow further inland. Other contributors to saltwater intrusion include navigation channels or agricultural and drainage channels, which provide conduits for saltwater to move inland, it can also make sea level rise. Saltwater intrusion can also be worsened by extreme events like hurricane storm surges.

Groundwater extraction is the primary cause of saltwater intrusion. Groundwater is the main source of drinking water in many coastal areas in India, and extraction has increased over time. Under baseline conditions, the inland extent of saltwater is limited by higher pressure exerted by the freshwater column, owing to its higher elevation. Groundwater extraction can lower the level of the freshwater table, reducing the pressure exerted by the freshwater column and allowing the denser saltwater to move inland laterally.

Groundwater extraction can also lead to well contamination by causing upwelling, or upcoming, of saltwater from the depths of the aquifer. Under baseline conditions, a saltwater wedge extends inland, underneath the freshwater because of its higher density. Water supply wells located over or near the saltwater wedge can draw the saltwater upward, creating a saltwater cone that might reach and contaminate the well.

The construction of canals and drainage networks can lead to saltwater intrusion. Canals provide conduits for saltwater to be carried inland, as does the deepening of existing channels for navigation purposes. Drainage networks constructed to drain flat coastal areas can lead to intrusion by lowering the freshwater table, reducing the water pressure exerted by the freshwater column.

Saltwater intrusion has been globally, and continues to be considered as one of the most significant coastal issues due to its multiple potential consequences in different fields. Excessive salt within the drinking water can lead to salt toxicity owing to different salt tolerances among different species of animals. Besides animals and human being, the decreases in agricultural production also show the impacts of high concentration of salt in irrigation water. Even though according to some cases, brackish water irrigation helps reduce the risk of soil salinization, it is still uncertain and under evaluation for further sustainable feasibility. Saltwater intrusion is to some degree responsible for wetland deterioration as well. Plants die when the salinity is above the tolerance threshold; hence biodiversity within the region correspondingly decreases as the essential survival environments are damaged by the high salinity. In addition to the severe environmental and ecological problems caused by saltwater intrusion, enormous economic losses arising from it can also not be neglected, especially from long-term perspective.

The following important items and additional items, if any as relevant to the project shall be discussed briefly under this chapter:

1. Aim(s) of the project and description of works
2. History (Earlier proposals)
3. The surveys and Investigations carried out for the various alternatives considered to justify the final choice of components of the project shall be discussed.
4. Stages/Phases of development of the project.
5. Cost and Benefit of the scheme.
6. Public Cooperation and participation etc.

CHAPTER 2: SALIENT FEATURES

Sl.No.	Items	Details	Appendix/Page No.
1	Name of Work		
2	Estimated Cost & Price level		
3	Reference of State TAC clearance		
4	Whether covered under State Plan		
5	Master Plan for the basin, fitment of the project and priority , if any		
6	Name of State		
7	Name of District		
8	Name of Basin/sub-basin		
9	Name of rivers/tributaries		
10	Latitude & Longitude of the project		
11	Nearest GD site		
12	Details of local Hydrogeology		
13	Distance along with direction from nearby major district(HQ)/town		
14	B.C. Ratio		
15	Benefitted population in nos.		
16	Benefitted area in ha.		
17	Salinity affected area of the State in mha		
18	Protected area of the State so far in mha		
19	Details of Annual Average Rainfall, Climatic Conditions and Available Ground water Resources		
20	Details of proposed works and Details of the Completed/ongoing works under the Scheme		
20.1	Regulators		

20.2	Bandharas		
20.3	Kharland Schemes		
20.4	Salt Water Exclusion Dams (SWED)		
20.5	Bunds/ Saline Embankments		
20.6	Vented Cross bar		
20.7	Nalla Plugs		
20.8	5 Square Model		
20.9	Recharge Techniques – Check Dams, Recharge Tanks/Wells/ Shafts/Reservoirs, Afforestation		
20.10	Management Techniques – Crop Pattern, Reclamation of Land, Anti Sea Erosion Works, Min flow in Rivers, Desiltation of Lakes etc.		
20.11	Aquifer Storage and Recovery		
20.12	Others		
21	Phasing of the project		
22	Completion Schedule		
23	Any Other Relevant Information		
24	Maps & Drawings		

***Details of each item may be enclosed in relevant chapters/appendix.**

CHAPTER 3: EXECUTIVE SUMMARY OF PROJECT

3.1 Introduction

3.2 Need and Objective of the Project

3.3 Location of the Project

3.4 Scope of the Project

3.5 Description of the Problem of the Area

3.6 Details of Earlier Executed/ Ongoing Projects vis-à-vis master plan.

3.7 Brief description of constraints, if any

3.8 Brief description of various agencies involved and their role

3.9 Formulation of the Scheme

(i) The details of investigation carried out.

(ii) Coastal data available and used.

3.10 Details of works proposed

(i) Salinity Control Structures

(ii) Recharge Techniques

(iii) Management Techniques

3.11 Various Alternatives &Present Proposal

3.12 Design Features

3.13 Basis of Rates and Cost Estimate

3.14 Benefit Cost Ratio

3.15 Construction Material and Construction Program

3.16 Socio-Economic Aspects

3.17 Environmental Impact Assessment

3.18 Recommendations

3.19 Pre-project and post-project scenario description with satellite imageries

3.20 Evaluation (Concurrent and Post Project)

Check list to accompany with the Detailed Project Report

(To be attached in beginning of DPR)

1. Planning				
Sl No	**Particulars**	**Yes**	**No**	**Remarks**
1.1	Master plan for overall salinity ingress management project been prepared?			
1.2	Does the scheme fit in the overall development of the Master plan in terms of priorities?			
1.3	Has the scheme been affected the adjacent areas of the coastline?			
1.4	Have the various alternatives for providing adequate control structures/techniques been studied?			
1.5	Is the present proposal superior to any other alternative? If no, justification for the selection of proposed structure may be provided.			
2. Surveys & Investigations				
Sl No	**Particulars**	**Yes**	**No**	**Remarks**
2.1	Have the topographical surveys of the area been carried out?			
2.2	Have the property surveys been carried out? If so, give details (No. of Coastal Villages, No. of Households, no. of ponds, area of agricultural lands, other important assets – existing& destroyed over the years)			
2.3	Have regular measurements of the shoreline changes been carried out? If so, since when?			
2.4	Have these shoreline changes been plotted &enclosed with the report?			
2.5	Have the ground cross-section been prepared for various shoreline changes & appended with the report?			
2.6	Have any hydro-geological studies been carried out for this area?			
2.7	Have any observations of the wave climate been made? (Type of wave, wave height, wave direction, breaker distance from the shore etc.)			
2.8	Have any observations in respect of tidal levels and currents been made during non-monsoon and monsoon seasons?			
2.9	Have any observations been made for salinity values of surface and ground water during non-monsoon and monsoon seasons?			

2.10	Have any observations with regard to littoral drift been carried out in respect of net and gross quantities, net drift direction and seasonal changes in the beach profiles?			
2.11	If the areas subject to cyclonic storms, have the details of such storms over the 10 years & the specific damages occurring under the influence of such storms been appended with the report?			
2.12	Has classification of the beach material been given?			

3. Material Survey				
Sl No	**Particulars**	**Yes**	**No**	**Remarks**
3.1	How far is the quarry site from the project area?			
3.2	Is the quarry capable of yielding uniform quality material for construction of the control structure work?			
3.3	In case of stones, does the quarry yield cubical stones? If not, are flat stones proposed to be used? Have any studies been conducted in the use of flat stones in the construction of suggested structures?			
3.4	Have adequate investigations of filter material proposed to be used been carried out, as to its availability & suitability?			
4. Design				
Sl No	**Particulars**	**Yes**	**No**	**Remarks**
4.1	Have the detailed calculations of design components been appended with the report?			
4.2	Has any model studies been carried out to assess the adequacy of the proposed design?			
4.3	Is the design now proposed based on scientific calculations using actual data collected for the site?			
5. Estimate				
Sl No	**Particulars**	**Yes**	**No**	**Remarks**
5.1	Has the estimate been prepared as per the guidelines of CWC?			
5.2	Are the rate adopted in the preparation of the estimate latest & approved by the State Govt?			
5.3	Have the analysis of rates for various major items of works furnished along with the basis for such analysis?			

6. B.C Ratio				
Sl No	**Particulars**	**Yes**	**No**	**Remarks**
6.1	What is the B.C ratio for the scheme?			
6.2	Has it been justified on the basis of detailed analysis after collecting reliable data?			
6.3	Is the B.C ratio worked out on prescribed standard & annual loss supported by documents from the concerned Govt departments?			
7. Construction Plan and Man-Power Planning				
Sl No	**Particulars**	**Yes**	**No**	**Remarks**
7.1	Are the major components of the work proposed to be done departmentally or through contractor? Will the work be done manually or by machines?			
7.2	Have the details of plants & Machinery, Spares etc. been worked out?			
7.3	Will it be necessary to import any equipment?			
7.4	Has the scheme been cleared by State TAC?			
7.5	Has the clearance of the State Finance Department been obtained?			
7.6	Is the scheme included in the State Development Plan?			
7.7	Has the Construction programme with physical and financial target been appended with DPR?			
8. Environmental and social Aspects for schemes				
Sl No	**Particulars**	**Yes**	**No**	**Remarks**
8.1	Have the ecological aspects been discussed, particularly the adverse effects resulting from implementation of the scheme?			
8.2	Any improvement in the existing environment resulting from implementation of the scheme?			
8.3	Has Environmental Impact assessment (EIA) been done for the project?			
8.4	Has Socio-economic analysis been done?			
8.5	Does the scheme envisage acquisition of any private land temporarily or permanently for construction of the protection works?			
8.6	Does it involve any rehabilitation of the affected people?			

Reference of details may be mentioned (Page No. /Appendix) in Remarks.

CHAPTER 4: HYDROLOGY

4.1 GENERAL

Coastal areas have been affected adversely by the problem of salinity ingress. Saline water intrusion has affected surface water as well as ground water resources. In the case of surface water, intrusion may be detectable and accordingly situation may be improved by adopting suitable protection measure; but in the case of ground water salination, the monitoring as well as protection measures are not so straightforward. The variable hydrologic characteristics and the different history of ground water withdrawals have contributed to the different patterns of salinity intrusion.
The economics and sizing of every structural and non-structural component of the project is dependent on hydrology. Hydrological inputs play a major role in planning, designing, execution and successful operation of a water resources development project. The Hydro-Meteorological data is a basic input to finalize the hydrological design parameters of any hydraulic structure.

4.2 DESIGN FLOOD SELECTION CRITERIA

4.2.1 Embankment for predominantly agricultural areas

The design flood for this type of embankment is kept 25 years for fixation of crest level as per IS 5477: Methods for fixing the capacities of reservoirs (Part I, II, III& IV) and IS 11223: Guidelines for Fixing Spillway Capacity.

4.2.2 Embankments for township or areas having industrial installations

The design flood for this type of embankment is kept 100 years for fixation of crest level. In the cases where anti erosion measures are proposed along with the embankment then design flood may be kept as 50 years for rural areas and 100 years for urban/industrial areas. In certain special cases, where damage potential justifies, maximum observed flood may also be considered for fixing the crest level as per IS 5477: Methods for fixing the capacities of reservoirs (Part I, II, III & IV) and IS 11223: Guidelines for Fixing Spillway Capacity.

4.3 BASIC HYDROLOGICAL DATA REQUIREMENT AND COMPILATION

The DPR shall contain the following basic information/data:

4.3.1 Geo-spatial details of various hydrological observations sites maintained by the CWC/States/Other agencies within the drainage area along with their locations.

4.3.2 Details of specific data collected with method of observation along with summary.

4.3.3 The long terms Gauge and Discharge data of nearby sites and hydro-meteorological (rainfall) data within the drainage area.

4.3.4 Annual peak discharges and levels for all G&D sites in and around of project at upstream and downstream shall be furnished for entire period of record. Instantaneous flood peak series may be prepared from hourly water level records available at G&D site for frequency analysis.

4.3.5 Drainage area map showing locational detail of all observation sites, proposed location of embankment, location of rain gauge stations, G&D sites and important hydraulic structures, etc.

4.4 DESIGN FLOOD COMPUTATIONS

For selection of design flood, the IS 5477: Methods for fixing the capacities of reservoirs (Part I, II, III& IV) and IS 11223: Guidelines for Fixing Spillway Capacityfor the specific structure shall be referred. For design flood estimation, procedure recommended in CWC's "Manual on Estimation of Design Flood" and other guidelines on the subject shall also be referred. For hydraulic structures, design flood of appropriate return period shall be computed using following approaches:

4.4.1 Flood Frequency Analysis

4.4.2 Hydro-meteorological Approach

For small structures empirical formulae may also be uses as per hydro-meteorological conditions.

4.5 FLOOD FREQUENCY ANALYSIS

To estimate the design flood using flood frequency approach, the following procedures shall be adopted:

4.5.1 The flood peak series shall be checked for randomness, homogeneity, trend, jump, outliers, etc. using appropriate statistical methods.

4.5.2 Flood frequency analysis shall be carried out using time series of instantaneous annual flood peak. Based on the hourly gauge data the observed annual flood peak shall be converted into instantaneous flood peak.

4.5.3 Using the instantaneous annual flood peak time series, the flood frequency analysis shall be carried out using standard frequency distributions such as Gumbel, log Pearson Type-III and Log Normal distributions, etc. to estimate the desired return period flood.

4.5.4 Goodness of fit test for the frequency distribution shall be carried out using standard statistical tests such as Chi Square, D-Index, etc. to assess the appropriate frequency distribution for the data set and decide the appropriate design flood.

4.6 HYDRO-METEROLOGICAL APPROACH

Where the observed flood peak series is not available, desired return period flood shall be estimated by hydro-meteorological approach using the following procedure:

4.6.1 The rainfall of appropriate return period shall be assessed using standard meteorological approaches and tools such as iso-pluvial maps published by IMD/ PMP Atlas of CWC.

4.6.2 The drainage area representative observed concurrent short interval rainfall and runoff data of 4 to 5 flood events shall be collected to develop the catchment response function/ unit hydrograph.

4.6.3 Where the observed concurrent short interval rainfall and runoff data is not available, the flood estimation reports for different subzones published by CWC can be used to develop synthetic unit hydrograph.

4.6.4 Infiltration loss rate, base flow and hourly rainfall distribution coefficients of rainfall can be assessed from the relevant reports/ flood estimation reports.

4.6.5 Critical sequencing and convolution shall be carried out as per standard procedure. In this regard Manual on Estimation of Design Flood published by Central Water Commission in March, 2001 may be followed.

4.6.6 When the catchment area is very small and unit hydrograph may not be derived, rational formula may be used for design flood estimation.

4.7 WATER SURFACE PROFILE

Water level corresponding to estimated design flood shall be computed using gauge and discharge data of nearest G&D site. If gauge and discharge data is not available, the water surface profile for the estimated design flood shall be computed using hydrodynamic study on appropriate hydrodynamic model such as HEC-RAS, Mike11, etc. For hydrodynamic simulation, sufficient number of surveyed river cross sections shall be used to represent the study river reach. Tidal influence should also be accounted in coastal regions.

CHAPTER 5: HYDRO-GEOLOGY

5.1 HYDRO-GEOLOGICAL SETUP

Aquifers along the coastal tracts of India can be broadly classified into those in porous sedimentary formations and in fissured hard rock formations. The sedimentary tracts, all along the east coast and the coastal plains of Kerala and Gujarat are mostly occupied by 'porous' aquifers while a major part of the west coast and parts of Andhra and Tamil Nadu coast are occupied by 'fissured' aquifers. Aquifers in the sedimentary tract can further be grouped depth-wise into two main groups, viz., the shallow aquifers, mostly in the Quaternary alluvium and the deeper aquifers in the underlying sediments ranging in age from Tertiary to Permo-Carboniferous. The shallow aquifers are mostly separated from the underlying deeper aquifers by clay layers. In the hard rocks, the shallow aquifers are, in general, in the weathered zone and deeper aquifers are in the underlying fracture zones. General hydraulic gradient of the ground water table in the unconfined shallow aquifers and piezometric surface of the deep aquifers in the coastal tract is towards the sea.

5.2 GROUNDWATER RESOURCES AVAILABILITY

5.2.1 In Tamil Nadu, the coastal aquifers show wide variation both laterally and vertically. The sediments in the extreme northern coastal tract of Tamil Nadu in the districts of Tiruvallur, Kancheepuram and Chennai are represented by alluvium both younger and older, boulder bed and the coastal sands of Quaternary age, underlain by a sequence of Tertiary sandstones, clays and shales and the Gondwana sandstones and shales. The area falls in the sub-basins of rivers Cooum, Kortalaiyar, Araniyar and Palar and the alluvium forms the important repository of ground water. Ground water occurs both under water table and confined conditions. The aquifers in Tertiaries and Gondwanas in this area have only limited yield prospects. The coastal part of Ponnaiyar river basin, the nonproductive zones occur towards north, highly productive e zones in the central part and fresh water aquifers overlain by saline water in the southern part. In the area around Puducherry and Cuddalore, the potential aquifers in the area are confined to alluvium, Tertiaries & Creataceous formations. Ground water occurs both under unconfined and confined conditions in these aquifers. Further south, the Cauvery delta forms the coastal tract. The shallow aquifers occurring within 100m bgl have one to five granular zones with a total thickness of 3 to 54 m, while the deeper aquifer groups between 100 to 450 m bgl have one to five zones with a cumulative thickness of 11 to 103 m. The quality of water in alluvial aquifers deteriorates towards the coast. The Vaigai basin of Ramanathapuram district is completely influenced by marine environment and there are a number of water-bearing zones but the quality of formation water is highly saline. In the southernmost district of Kanyakumari, the sedimentary sequence is mostly absent and the crystalline are exposed. In some areas of the coastal tract, sand dunes are the only source for fresh water as in Rameswaram, Mandapam, etc.

5.2.2 In Andhra Pradesh, coastal areas of East and West Godavari districts have exposures of Tertiary sandstones-Rajahmundries. Due to highly porous and permeable nature, these sandstones hold potential aquifers in parts of West Godavari district. In the upland areas towards east of Godavari river, Tertiary sandstones are more of fine-grained nature holding poor aquifer system. Towards south, in the lower deltaic plain of Pennar River, Tertiary sandstones occur in the depth range of 150 to 450 m bgl and hold potential aquifers. The Upper Gondwanas, forming potential aquifers in the upland areas, where they are exposed, occur at depths beyond 600 m in the coastal plain underlying the crystalline basalts. The unconsolidated sediments constituting

the coastal and deltaic plains, are highly porous and permeable with sustainable ground water resource consisting Gravel, sand and silty sand. Ground water in the shallow layers of these sediments occurs under unconfined conditions whereas at deeper levels it develops high pressure heads due to confining conditions. Dunes, consisting mainly of sand are formed near the sea coast of Andhra Pradesh due to aeolian action across the coast. These sand dunes, which are linear and formed parallel to the coast line, are found all along the coastline.

5.2.3 In the coastal tracts of Orissa, the sand and gravel layers in alluvium and the semi-consolidated or loosely cemented sand and gravel layers of the underlying Tertiary (Mio-Pliocene) deposits from the prolific aquifers. The shallow or phreatic aquifers occur more or less throughout the coastal tract. The phreatic aquifers in the western part, are generally formed by the older alluvium while in the eastern part they are formed by the younger alluvium. Ground water extraction from phreatic aquifers is mainly through dug wells and shallow filter point tube wells. The alluvial deposit extends down to 50 to 60 m in the western part and to 150m in the eastern coastal tract. The sand and gravel layers in alluvium and the semi-consolidated or loosely cemented sand layers in the underlying Tertiary deposits from the prolific aquifers at depth. The alluvial aquifers occurring in parts of Mahanadi and Brahmani basins are generally of the flood plain deposits and are of coarser material with higher hydraulic conductivity than those in Budhabalang and Jamira. Wells in the outfall areas of the rivers Baitarani, Brahmani and Mahanadi indicated auto-flowing condition. In general, the well yield varies from 25 to 35lps for Tertiary aquifers for a cumulative thickness tapping of 35 to 45 m within 300m depth.The yield of Tertiary aquifers progressively reduces with increase in depth. Sand dunes are common in the coastal tracts of Orissa and exist as thin elongated bands parallel to the coast.

5.2.4 In the coastal tract and salinity-affected areas of West Bengal encompassing the 4 districts of S 24 Parganas, N 24 Paraganas (part), Howrah (part) and Purbi Medinipur (part), alluvium of Recent to Pleistocene ages and the Tertiary sediments form the aquifers. The alluvium comprises sands of varying grades, micaceous, with gravels and kankar. The sands are, in general, fine to very fine. Medium to coarse grained sands are of limited occurrences. In general, there is a thick blanket of clay at the top whose thickness varies from 15 to 76 m with increasing thickness towards south. Also, a thick basal clay bed occurs at depths ranging from 152 (N 24 Parganas district) to 414 m (Kolkata area). The aquifers in between these shallow and deep clay layers in the general depth range of 70 to 360 m bgl are under confined condition and are mostly tapped either for irrigation or drinking water supplies. In the northern part of S 24 Parganas district, however, there exists a shallow aquifer system within 50 m bgl mostly tapped for domestic use by shallow tube wells. It is followed by second and third aquifer systems in the depth ranges of 70to 160m bgl and 170 to 400 m (depth explored) respectively. Each aquifer system comprises one or several interconnected aquifers. The ground water resource availability in these coastal districts constitutes about 12.7 % of the utilizable dynamic ground water resource annually available in the country.

5.2.5 In coastal plains of Kerala, the recent alluvial deposits form the most potential phreatic aquifer in the state. It is being tapped by dug wells and filter point wells extensively. Laterite forms potential aquifers along valleys and topographic lows, where the thickness of saturated zone ismore and can sustain large diameter open wells. In the Tertiary sediments, ground water occurs under unconfined to confined conditions. Out of the Tertiary formations, viz., Warkali,Quilon, Vaikom and Alleppey, the Warkali and Vaikom hold the most potential aquifers. Warkali constitute the most extensively developed aquifer amongst the Tertiaries. The

water supply system between Quilon and Ernakulam mostly depends on this aquifer. Limestone beds in Quilon formation forms local aquifers of low yield. Vaikom Bed constitutes prolific aquifer system amongst the Tertiaries.

5.2.6 Along the 225 km long coast line of **Karnataka**, in the three districts of Uttara Kannada, Dakshina Kannada and Udupi, there occurs a narrow strip of coastal alluvium underlain by the Precambrian crystalline. Its width varies from a few meters to 4 km at places. Tertiary laterite cappings on schists and granites are seen at places. Coastal alluvium comprises fine to medium grained sand, clay and gravels. The thickness of alluvium is around 35 to 45 m near the coast and gradually decreases landward up to 10 m. The yield of the dug wells ranges from 1.8 to 297m^3/day in sand. Laterites form productive aquifers in areas close to valley portions. The yield of wells in laterites ranges from less than 2 to 280 m^3/day.

5.2.7 In coastal Goa, the recent alluvium and the thick laterite cappings form potential aquifers. The fine to coarse sand, gravel with intercalation of sandy loam in the alluvium, constitute the aquifers. Thickness of alluvium varies from a few meters to about 22 m. Exploratory wells constructed in the coastal alluvium vary in depth from 15.5 to 22 m. Laterites as well as fissured crystalline formations constitute aquifers of importance in the State.

5.2.8 In Maharashtra, semi-consolidated calcareous sandstone occurs along the Konkan coast underlying the beach deposits and at places exposed as outcrops. The thickness of this formation is up to 10 m at places but may be more, which yields good discharge to dug wells.
Laterites, both primary and secondary, occupy extensive areas of low-lying tracts, coastal parts and high plateau of Sahyadri ranges. All along the Konkan coast a narrow strip of unconsolidated beach sands occurs, varying in width from a few tens of meters. The coastal alluvium, wherever it is locally extensive, assumes importance as moderate ground water reservoirs. In coastal Goa the alluvium and the thick laterite capping form the potential aquifer. The fine to coarse sand, gravel with intercalation of sandy loam in the alluvium, constitute the aquifers. Thickness of alluvium varies from a few meters to about 22 m. The thickness of sand and gravel bed varies from 3 to 3.5 m in the depth range of 10 to 20 m bgl. The yield ranges from 155 to 260 m^3/day. The laterites are another most important water bearing formation. The laterites are either in-situ, particularly in plateau areas, or detrital in origin generally occupying the valley portions. The thickness of laterite extends up to 30m.

5.2.9 Along Gujarat coast, the sedimentary formations ranging in age from Upper Cretaceous to Quaternary form the major aquifer systems. They occur under unconfined to confined conditions. In general, the unconfined aquifers occur down to 40 m bgl, whereas the semi-confined to confined aquifers extend from 30 m to more than 200 m bgl. The major aquifers are formed by Miliolitic Lime stone (Recent), Manchar Series (Tertiary) and alluvium and blown sands. The quality of water in the shallow aquifer is also saline with few localized pockets of brackish to fresh water. Miliolitic Lime stones form prolific aquifer but are effected by poor quality due to proximity of sea. Manchar Series also have moderate to high yield at economical drawdown. The quality of ground water in deeper aquifer is saline in large parts.

5.3 REQUISITE PARAMETERS FOR HYDRO-GEOLOGICAL STUDY

5.3.1 Aquifer disposition:

In sedimentary rock area: Lithology of the area, nature of aquifer (unconfined/confined/leaky confined), Nature of aquifer system (single aquifer unit/Multiple aquifer units), Aquifer distribution (Vertical and Horizontal distribution of each aquifer unit), Presence of aquiclude (impermeable unit (Clay/shale etc.) which controls the vertical movement of groundwater/seawater, Thickness of each aquifer units, 2 Dimensional and 3 Dimensional image of the aquifer system.

In Hard rock area: rock type, depth of weathered zone, occurrence of fractures/joints with depth, presence of fault/sheer zone in connection with the coastal area.

5.3.2 Aquifer characteristics:

Hydraulic properties; Porosity, Permeability, conductivity, transmissivity, specific yield, storativity etc., of each aquifer units and soil infiltration rate.

5.3.3 Ground water regime:

Depth to water level (Pre-Monsoon & Post-Monsoon with water level range 0-2, 2-5, 5-10, 10-20, >20 mts.), Seasonal groundwater fluctuation, long term groundwater level trend (with tables and maps), reduced water levels and water table contour maps.

5.3.4 Changes in groundwater scenario over the years:

Comparison of groundwater scenario with present scenario, long term water level trend analysis.

5.3.5 Groundwater development prospects:

Number and type of groundwater abstraction structures and utilization of groundwater for various sectors (Industries, Infrastructure, domestic, agriculture and agriculture related uses)

5.3.6 Groundwater resource availability:

A dynamic groundwater resource which includes groundwater recharge, groundwater draft, net groundwater availability, status of present utilization, demand for future use and saline zone demarcation / notification.

5.3.7 Delineation of extent of seawater intrusion:

Map of the project area showing the depth/ extent of freshwater/saline water interface.

Pathways for saline water intrusion:

- Lateral intrusion from the ocean;
- Up-coning/ upward intrusion from deeper saline zones of a groundwater system;
- Downward intrusion from coastal waters to deeper fresh water aquifer units;
- Saltwater contamination may also occur along open boreholes and within abandoned, improperly constructed, or corroded wells that provide pathways for vertical migration across interconnected aquifers.

5.3.8 Groundwater quality:

Aquifer unit wise groundwater quality, spatial distribution (horizontal and vertical) of Electrical conductivity, pH, SAR, Boron, Fluorine etc., and its suitability for different uses with various plots. Also, water quality of the surface water and sea water.

5.3.9 Remediation of brackish or saline groundwater intrusion:

Sustainable water resources management in coastal areas;

- Source Water Availability: Quantity and Quality of fresh water available for mitigating the sea water intrusion.
- Exploring the feasibility of conjunctive use of surface and groundwater.
- Identification/delineation of area for reduction in pumping rates.
- Identification/delineation of area for relocation of pumping wells.
- Identification of sites for physical surface or subsurface barriers.
- Identification of sites for natural or artificial recharge/ water conservation (pressure or positive barriers).
- Identification of sites for pumping of saline water along the seacoast (abstraction or negative barriers)
- Identification of sites for tidal regulators.

Note: Each of these hydraulic (and physical) approaches has its own advantages and limitations in terms of practical operation and control of SWI.

CHAPTER 6: SURVEY& FIELD INVESTIGATION

6.1 INTRODUCTION

Due to dynamic behaviour of the most of coastal processes, understanding of various processes associated with salinity ingress are quite complex. Without field data collections, it will be difficult to analyse impact of all the factors that contribute to salinity ingress. As such, these data are required to be collected depending on the requirement of the project. The systematic collection of field data viz. Salinity in river and sea, Tide, Currents in sea, River discharges, Rainfall, Beach levels, Bathymetry and Shoreline changes play vital role for making decision about efficacy of controlling salinity ingress and provide vital inputs for the further studies to be carried out. The accuracy and success of the project mainly depends upon the quality of input field data. Hence, it is very essential that the data should be collected by the state-of-art instruments as well as by experienced staff. The field data collection frequency and its methods govern their quality and accuracy. Before carrying out any field survey, proper knowledge about site, nearby topography & morphology and type of water body i.e. river, estuary, ocean etc. is essential. Necessary reconnaissance survey is required beforehand to establish the baseline field conditions.
The surveys and investigations carried out for the various alternatives considered to justify the final choice of the location and type of various components of the project shall be discussed.

6.2 RECONNAISSANCE SURVEY

Before start of survey, a site visit or Reconnaissance survey is very important step in carrying out the field data campaign. It gives insight about the topographical / actual judgments required for carrying out field data collection campaign. A site visit must then be made by those responsible for the field data collection effort and the local staff familiar with the project. The prior visit for "Field Data Collection and Analysis" will allow discussion of the past and existing conditions, define the problem, and document the area with general information on the acting physical processes and potential locations for deploying equipment/instruments.
During the site visit, knowledge is obtained about the site by means of conversations with local community groups or individuals familiar with the site and from existing documentation of the conditions that exist for various tidal and storm events. These data provide valuable insights for further defining the problem and assessing its magnitude of measurements. Specific attention must be paid to available mounting platforms in the project area. Additionally, resource use must be determined. Knowledge gained from conversations with local residents and users is valuable in trying to determine locations for deployment of the equipment. Information gained from older data sets helps to determine the seasonal variability at the site. If a site has significant changes in currents, wave conditions, and wind directions, then longer data collection programs might be necessary to capture the seasonal variability.
Following aspects should be considered for finalization of parameters to be collected for site.

- Review of availability of any existing historical data near / at the site.
- Data collection programme of any other agency for any specific parameters and avoiding duplication of effort with any other agency engaged in such activity.
- The parameters to be observed and their frequency, duration etc. as accepted by Coastal Protection and Development Advisory Committee (CPDAC) and this should be further refined keeping in view the technical requirement and site conditions.
- The Data should be collected for a period of minimum one year during different seasons.

6.3 PARAMETERS ANDMETHODOLOGY FOR FIELD INVESTIGATIONS

This describes the different parameters to be monitored at a coastal stretch, data collection strategy and analysis method.

Sl No.	Type of Survey and Investigation	Particulars/Details
1.	Site Characterization Investigation	• Involves identifying, distinguishing qualities and features of a region that have a direct and indirect effect on the planning, design, economics, construction and maintenance of a coastal project. The total project area encompasses not only the physical limits of the problem area but also the area in which the project has an effect. • Soil Explorations/Investigations data/ material characterization. • Hydrodynamic processes (waves, water level, currents), Seasonal variability of waves and currents, Storm Characteristics/ Meteorology, Topography & bathymetry, Geomorphology/Geometry and Sediment Characteristics, Littoral Drift and Sediment transport patterns, Shoreline Change Trends, Land/Shore Use, Geotechnical Requirements, River Discharge/Sediment Load etc. • Studies using physical model, mathematical model, remote sensing etc done shall also be included.

Sl No.	Type of Survey and Investigation	Particulars/Details
2.	Material Survey	• Availability, Accessibility and Suitability of the various kinds of materials involved in the work. • Background/Reason for the choice of materials.
3.	Available Coastal Data for the site/adjoining area.	• The details of data required is given below: Field Measurements: Bathymetry, Hydrography, Topography Survey, Shoreline Survey, Geo-morphological studies. (A project planner and designer should also be aware of the effects of the project on the adjoining coasts. The amount of data needed for a project varies with the type and scope of the problem.)

6.3.1 Current

Rising and lowering of water levels with respect to time is known as tide which generates the velocities in water, which is known as Tidal Currents. In coastal environment, the currents vary spatially and temporally in both magnitude and direction. Knowledge of currents is essential in assessing siltation in channels and harbour waters, aligning coastal structures, shape of reclamations, in understanding geomorphic changes taking place etc.

The instrument like Marine ADCP will provide the velocity profile across the water column. This unit should be installed at about 10m depth to measure current direction and magnitude at that location. The coastal currents have its real importance. Hence, site specific data collection based on vulnerability alone is possible.

6.3.2 Tide

The rhythmic rise and fall of sea water level over a period of tidal day (24Hr 50min) is referred as tide. The rising of water level is known as Flood tide while lowering of water level as Ebb tide. When the Sun, Moon and earth are in same line then water level rises as well as lowers down to its maximum amplitude and is known as Spring tide, whereas when the sun and moon are at quadrature to the earth then water level rises as well as lowers down to its minimum amplitude and is known as Neap tide. Tide having one cycle per day then it is known as diurnal tide while two cycles in one tidal day, as semi-diurnal tides. Combination of these two tides is called as mixed tide. The tides occurring in Indian Ocean are semi-diurnal in nature.

The measurements of magnitude of tide is important to decide the crest level of the coastal structures viz. breakwaters, seawalls, groins, bulkheads etc. which are subjected to tidal variations to avoid overtopping and endanger the areas on leeside of the structures.

The tide data should be collected in a gridded layout as like wave data at a specific site. The tidal amplitudes in shallow waters are important. The tidal patterns and the approximate level can be obtained through software packages (which are based on tidal epoch). However, these

models are not capable of simulating the variations in water level due to the combinations of extreme events like cyclones. The bottom mounted Pressure Tide Gauge may be utilized to collect the data.

6.3.3 Rainfall, Humidity, Wind and Air Temperature

The rainfall has a direct impact on salinity of the region .Higher the rainfall, lower will be the salinity .Similarly, higher evaporation causes increase in salinity of water body .Thus, Salinity of a region is impacted by weather parameters directly or indirectly, an Automatic Weather Station (AWS) may be installed over an existing building along the shore .

6.3.4 Salinity

Water quality data loggers measure conductivity and temperature and compute salinity concentrations corrected to a known calibration. This type of recorder uses a specific conductance electrode cell and a thermistor-type temperature sensor. The salinity concentrations are calculated from the measured conductivity and temperature. The range and accuracy of these recorders vary with individual instruments. The user must choose the one that will be the most appropriate for their needs. Salinity measurements are required in estuaries where saline and fresh water flows are mixing. The salinity measurements indicate type of mixing which is very important from siltation point of view. When tide rises, and seawater from the ocean pushes its way up the estuary, estuarine salinity increases. When tide falls, and seawater drains from the estuary back into the ocean, estuarine salinity decreases. In many estuaries, the degree of mixing that occurs between freshwater and seawater depends on the strength of tidal currents. Stronger the tidal current, the more freshwater and saltwater mixes. The salinity can be obtained by collecting water samples and by chemically analyzing it. The salinity may be measured by a Salinometer or by a Salinity/Conductivity temperature depth (STD/CTD) Unit. The portable salinometer is used to measure salinity in the range 0-35 ppt. Since salinity is a function of temperature, the temperature is also measured simultaneously. The salinity is normally expressed in terms of ppt. For most waters, TDS in mg/l is equivalent to approximately 0.64 or 0.67 times EC in µS/cm. The conductivity is measured through CTD meters.

6.3.5 Bathymetry for Intertidal zone

The term "bathymetry" originally referred to the ocean's depth relative to sea level, although it has come to mean “submarine topography,” or the depths and shapes of underwater terrain. In the same way that topographic maps represent the three-dimensional features of overland terrain, bathymetric maps illustrate the land that lies underwater. Variations in sea-floor relief may be depicted by colour and contour lines called depth contours or isobaths.

The bathymetry beyond a water depth of 20m offshore can be obtained from Hydrographic / Naval charts. Obtaining the shallow water bathymetry all along the considered stretch of the coast is not possible and even if obtained may not be useful after few years (due to its dynamic nature). However, the shallow water bathymetry survey up to 10m water depth has to be carried out in three different stages at the selected sites. For relatively deep waters (i.e., from -3m to -10m), Echo-sounder and GPS should be used. From shoreline to -2m contour, the depths should be arrived through the measurement of beach profile through RTK-GPS.

6.3.6 Shoreline changes and beach profile changes

Various survey techniques are used to monitor shoreline changes starting from chain survey to advanced methods such as laser tracking. Each method has its own advantages and limitations.

Shoreline changes are to be monitored on a monthly basis, wherein, the shoreline should be mapped every month during the low tide, using RTK (Real Time Kinematics) GPS, which has dual frequency GPS to get the position accuracy up to 1 cm. A base reference station should be established at near center of the study area and its vertical coordinate Z with reference to MSL should be arrived from the established GTS (Great Trigonometric Survey) of Survey of India. The mobile part of the instrument with radio modem covering a radius of 4km from the base station will help in arriving at the coordinates and levels. Similarly, monthly profiles should be measured at the selected locations from the berm up to the low water line, using the RTK GPS and the profile variation from LTL to 5m water depth should be measured either by a sled or by sounding rope and hand held GPS and moving over a small boat.

6.3.7 Riverine Data

River discharge is a function of meteorological runoff (precipitation minus evaporation) and drainage basin area. River basins with high runoff but small drainage area can have discharges as great as rivers with much larger basin areas but low runoff .In contrast, some rivers with low runoff may have high discharges by virtue of their large drainage basin areas .Not only are the coastal waters are affected by this enormous discharge, but also rivers turn saline due influence of tide .

Data related to Riverine processes such as Discharge, TDS etc .should be collected .The River ADCP installed in a boat may be utilized to measure the discharge across the river cross section appropriately.

*Some of the important parameters for salinity ingress project and frequency of data may be adopted as provided in **Annexure V**.*

CHAPTER 7: DESIGN OF WORKS

7.1 Introduction

The planning and design process should consider the various natural features and man-made structures in the vicinity of the site. It should be ensured that the proposed anti-sea erosion scheme does not transfer erosion problem to other areas. The dynamic coastal processes are constantly changing with time. The changes in coastal phenomenon observed at any site at the time of project implementation than what was at the time of project formulation should be accounted for and suitable modifications should be made. Both, structural as well as non- structural works shall be considered to minimize the investment required. Study of various alternatives for providing adequate protection shall be included.

7.2 Salinity Control Structures

7.2.1 Regulators

- **Tidal Regulator**

  The river beds have flat slopes near the mouth and tides are running into the land for considerable distance due to which the village wells surrounding the estuaries have turned saline due to the constant process of tidal ingress into the land. As a result of over drawl of sweet water from these wells process of contamination increase year by year and more and more number of wells are turn saline which affects agricultural lands and production there from. Besides, direct infiltration of sea water takes places through river beds and contaminates ground water. To stop the tidal ingress into the land, the mouths of these rivers are sealed by constructing suitable structures near their mouths. The height of these structures would be kept as to keep submergence of land to the minimum and yet the projects remain economically viable.

  The structures with gates on the large rivers are known as Tidal regulators which will be constructed with impervious cut off below the foundation. Such cut off will be taken down to relatively impervious strata which will enable to prevent tidal ingress even through foundation strata to directly contaminate the ground water. Thus, the tidal regulator will be designed and constructed in such a way that it would not only arrest the tides entering the estuary from surface but it would also be possible to prevent seepage of sea water into the land and polluting sweet ground water. The top of the gate will be kept above maximum tide level during the year. For design of Tidal Regulator one has to deal with maximum tide level or highest tide level. Normal practice of keeping the top of the gate is about 1 meter above highest tide level so that the waves from the sea do not splash above the gates and pollute the sweet water reservoir on the upstream side. Extra exercise is also necessary to study the submergence on the upstream of this structure when the maximum design flood passes over the structure. If a suitable depression is available on the upstream of the structure and if it is convenient to store water at a higher level without increasing the submergence substantially and affecting surrounding villages it can be attempted to raise the crest of the Tidal Regulator to store more sweet water for irrigation use. High tide range indicates the difference between H.W.O.S (High water of Spring tide) and L.W.O.S (Low water Spring Tide). While high tide level indicates level corresponding to the highest high water of spring tide (H.H.W.O.S.), the lowest low water of spring tide

(L.L.W.O.S.) represents the chart datum. High level tide is connected with the G.T.S Bench mark which is normally fixed on every port. The tide levels are measured from chart datum. The main function of the Tidal Regulator is to prevent the tidal ingress into the lands by sealing the mouth of the river. Hence, generally the gates remain in closed condition around the year to prevent the entry of tide water into the lands. During floods, gates are opened and regulated as per flood forecast so as to allow the flow of the excessive flood water without creating undesirable submergence of the land in the upstream. As soon as the flood starts receding the gates are closed to store fresh water on upstream side. The stored sweet water will improve the existing water supply of the affected villages situated near Tidal Regulators. The sweet water reservoir which will be created behind Tidal Regulator will be used for irrigation in the surrounding command areas through lift. It is proposed to install pumps of suitable capacities and lay the pipelines in the surrounding fields to do irrigation. It will be possible to do such irrigation three to four times during monsoon and protect Kharif crop. As the gates are provided on the Tidal Regulators, it will be possible to fill the reservoir during every flood in the monsoon by proper regulation of gates. Incidentally, it will also be possible to increase recharge to the ground water through the command area. Thus the recharge of sweet water through the command area will be over and above that which will take place through the bed of the reservoirs. The reservoir water will improve the surrounding village wells; thereby water supply problems of the surrounding villages will also be solved to a great extent. The lands around the reservoirs will be leached out of salts through the use of sweet water for irrigation and will make it possible to fetch higher yields from the same fields. For structural and hydraulic designs relevant BIS codes need to be followed.

- ***Tail End Regulator***

This concept is adopted wherever the flood discharges are heavy and where there is a need to quickly dispose the floods without inundation/flooding of up lands. This gated structure will help to store the receding flood waters and will also prevent the sea water ingress. The fresh water stored in upstream side acts as storage for lift irrigation, besides recharging the ground water levels and preventing sea water intrusion through the sub surface.

Tail end regulators can serve three important functions:

i.To head up the irrigation supply adequately with gates closed so that there could be effective withdrawals in the channels above to feed the irrigation lands by gravity or pumps.

ii. To allow passing of flood flows to the sea with minimum head loss

iii. To halt the ingress of sea water inland to protect farms and communities from salinity intrusion especially at high tides and during storm surges. There may be a need for additional tail end regulators on the minor drains.

The tail end regulators to be fully functional may also require some sea side bunds to protect the farms from higher tides and storm surges; effective drainage through the bunds would have to be incorporated into the planning.

The regulators would have some environmental impacts especially for water users taking water below the regulator. The river would effectively become saline with possible impacts on the coastal communities.

- ***Tail end Regulators with Diaphragm wall***

  This type of structure is being proposed in major rivers such as Kollidam and Palar of Tamil Nadu State. Apart from preventing surface sea water ingress these structures will help in long way to prevent sub-surface intrusion. These structures are helpful in creating significant storages in upstream side and will play a major role in the last mile irrigation and storage of water for drinking purposes.

- ***Regulator cum Bridge***

  The Regulator Cum Bridge acts as a saline water intrusion barrier which is constructed across the river. It is a gated structure having a Bridge on top providing access to the people for moving around. The water stored behind the regulator can be used for drinking water, agricultural uses and industrial use. This acts as a flood control structure by leading entire flood discharge into the sea during the monsoon season. This also protects against the tidal affects. During the summer months it acts as a barrier to protect the sea water intrusion into the land.

- ***Lock cum Regulator***

  The Lock cum Regulator is a gated structure having a special arrangement for closing the gates.

- ***Inlet Sluice/Control Sluice***

  Control sluice are being constructed at mouth of the creeks or sub creeks to control the saline ingress due tidal effect in to the command area.

7.2.2 Bandharas

- ***Introduction***

  The Structures constructed on small rivers without gates as solid barriers/concrete walls on rivers are called Bandharas. No gate will be installed on these Bandharas as submergence is not likely to pose problems in this case. As a normal practice, the top of the Bandharas shall be kept 1 meter above the highest tide level so that the waves from the sea side will not splash above Bandharas and pollute sweet water reservoirs behind them. In case where submergence does not become a problem, the Bandharas shall be raised even highest to store more sweet water. Individual case shall be examined on this line to take maximum benefits of the sweet water reservoirs for the purpose of irrigation. The irrigation may also be proposed three to four times during monsoon from the reservoirs behind Bandharas also. This will facilitate to protect Kharif irrigation and at the same time increase recharge from larger areas by spreading reservoir water in the command areas through lift. The surrounding villages will get benefit through the probable improvement of their well water. Bandhara will be constructed with impervious cut off below the foundation. Such cut off will be taken down to relatively impervious strata and will enable to prevent tidal ingress through foundation strata directly to contaminate ground water. For structural and hydraulic designs IS-12094: Guidelines for Planning and Design of River Embankments (levees) need to be followed.

- ***Hydrology***

  1 in 50 return period flood is considered as design flood for the design of Bandhara, when there is no possibility of downstream hazard. 1 in 100 return period flood is adopted when there is downstream hazard prevails. Village/ Town, Road, Bridge, Monuments, Important

structures located on banks very near in downstream of Bandhara can be taken into consideration to decide potential hazards.

Design flood is calculated from the catchment area of the spillway. All existing major structures are considered for routed flood for the Bandhara. Estimation of flood is done using the formulas prescribed by Center Water Commission, New Delhi. For small catchment area up to 25 square kilometers, standard project flood(S.P.F.) can be derived by the formulas prescribed for the different meteorological zones of the state. Design flood of different frequency is calculated by multiplying the SPF flood by a constant. The value of constant is different for different return periods.

- ***Fixing Full Reservoir Level (FRL)***

Bandhara is a structure normally constructed near sea. Factors which are of prime importance in determining the F.R.L. is High Tide Level (H.T.L.) recorded at or nearby the site of bandhara. High tide level is a level observed during the high tide coming in Ocean. Tides are coming 2 times a day. 2 times a month which has significant level of Tide. There are Highest tide and High tide for the particular costal area. High tide level (H.T.L.) value is obtained from concerned authentic authority. Bandhara does not have the highest importance, high tide and not the highest tide (H.H.T.L.) is considered for the fixation of F.R.L. Generally, F.R.L. is kept 1.0m. higher than H.T.L. In some cases, where high tide level is too low and banks are relatively high, F.R.L. can be fixed higher. In this case height of banks, availability of storage area, land acquisitions etc are taken into consideration.

- ***Components of Bandhara:***

Spillway(Waste weir) is constructed normally in river/gorge portion, whereas Earthen bunds are constructed on both or one side of Waste weir and extended upto such a length where height of the ground levels are equal to the top of Earthen dam (i.e.H.F.L. + free board). Length of Waste weir is provided such that it can safely pass the design flood (1 in 50).

Spillway structure consists of Abutments, Sidewalls, Apron, Key walls, Return walls, Block protections, Launching Aprons, upstream and downstream Cut-off for safety of the structure. They are designed &provided as per prevailing related IS Code.

I. Spillway(Waste weir):

Generally Broad crested type waste weir is preferred as spillway. In some cases,Ogeetype of spill over section has to be adopted due to inadequate availability of length for the spillway. Length of the Waste Weir is derived by using formula given below:

$Q= C*L*H^{3/2}$
Where L= Length of Waste Weir,
H= Flood lift,
C= constant which depend upon type / shape of crest & flood lift.

Ogee shaped Spill over section has greater value of constant ‘C’ and hence higher discharging capacity. Broad crested waste weir has smaller value of constant ‘C’ and hence lower discharging capacity.

Coastal area mainly consists of poor quality soil. So generally rock is not found in river bed /gorge.In that case Spillway structure is designed based on Khosla theory.Khosla theory gives methodology to design different parts of the hydraulic structure whose foundation rest on permeable soil/ strata.

a. Required data:

Data for the designing the Bandhara mainly requires:

(1)River cross section covering all spillway and earthen bund length along the alignment of Bandhara
(2) Four cross section at every 30m of river on u/s & d/s side of alignment.
(3) Longitudinal section of river upto 500.0m in downstream & 1500.0m. in upstream.
(4) Longitude & Latitude of the site.
(5) Catchment area of site in 1:50000 scale.
(6) High tide level at the site.
(7) Observed flood level at the site & surrounding area.
(8) Geological report of the site through geological note, plan & section of the alignment.
(9) Downstream hazard.
(10) Vicinity plan (contour map) of the site & surrounding area.
(11) Existing structures on the river in vicinity of the site.
(12) Soil properties of the soil at the site, in the foundation and of the borrow area etc.

b. Soil Sampling & Geological Investigation:

Knowing soil characteristics of the foundation strata is invariably necessary for the design of Bandhara. Soil samples are taken (as per IS 2720 and as per the procedure prescribed in technical circulars by taking Drill holes / trial pits on alignment of Bandhara) & sent it to Government / government approved Soil testing laboratory. Test results of the sample gives idea of soil characteristics of the foundation strata below the alignment. Looking to the length of Spillway portion and Earthen bund portion, total no. of drill holes / trial pits required are decided. In case of spillway, one drill hole on both the banks and three in the gorge portion are considered adequate. Sampling at every 1.5 m. depth is taken. In many cases soil available at the foundation level are of poor characteristics, like CH, MH, MI, PT etc. type as per soil classification. Special treatments to improve its characteristics, specially bearing capacity of soil at foundation level are suggested. Rubble soling and CNS layer are common measures that can be suggested for enhancement of soil based on IS Code 13094:1992.

Based on soil parameters, silt factor& SBC of the strata at foundation level of structures, type of structure to be built is decided and its stability calculated. As height of structure is less, stability is checked with factor of safety 2.5instead of 3.0. Due to low height of Waste weir, routine solid gravity structure is proposed as body. In some cases, glacis type body is proposed when there is very low SBC Value available at the foundation level.

Scour depth (R) is the governing factor to arrive at the foundation levels.

$R = 1.35 X(q2/f)^{1/3}$; if looseness factor < 1.
$R = 0.473 X (Q/f)^{1/3}$; if looseness factor > 1.
as per the IS Code 6966(part1):1989

Abutments' foundation is kept at 1.0 X R below Afflux High flood level, whereas Sidewalls foundation is kept at 1.0 X R below Tail water level.

Apron is suggested at average ground level of main gorge. Length of apron is calculated as per the IS Code 4997:1968(R2004) for the full design discharge+additional 20% design flood. Thickness of apron is calculated considering uplift pressure value.
Upstream cutoff foundation is kept at 1.25 (allowable range 1.25 to 1.75) X R below Afflux High flood level, downstream cutoff foundation is kept at 1.75 (allowable range 1.75 to 2.25)X R below Tail water level as suggested range in IS Code 6966(part1):1989.
Moreover, cross cutoffs below Abutments & Sidewalls can also be provided for the safety of the structure as per CBIP Volume.
Block protections having C.C. Blocks size of 1.50m. x 1.50m. x 0.90m. in upstream of Body wall& downstream of Apron are also provided. Length of Upstream block protection is kept equal to depth of upstream cut-off & Length of downstream block protection is kept equal to 1.5 x depth of downstream cut-off are provided.
Launching apron having variable thickness (2.40m. at far end & 1.60m. at near end) is also provided in upstream of u/s block protection and downstream of d/s block protection for safety of the structure. Lengths of launching aprons are kept two times the depth of nearby cut-off.
Stone Masonry was used in early days to construct waste weir. M:20 grade concrete is used now for Bandhara as per IS Code for concrete gravity structure. Apparatus work like C.C. Blocks (block protection) are made from M:15 grade concrete. Concrete prepared, placed, cured as per IS Codes 456:2000 & 457: 1957(R 2005).
Spill way body wall and apron are built with nominal temperature steel which has Anti corrosive characteristic. Sulfate resistant cement is used in all concrete masonry works as the structure directly comes in contact with saline sea water as per clause 8.2.2.1 of IS Codes 456:2000 (see page no.18 table:3 & page no.19 table 4)

II. Earthen Bund:

Earthen bunds are constructed with suitable selected soil which can be locally available. Stability analysis by Swedish slip circle is not required due to low height (less than 10 m.) of Earthen bund. Earthen bund section is directly adopted from IS Code 12169-1987 for "Design criteria for small embankment dams". Necessary cut off trench is to be provided below earthen bund to prevent possible seepage of water from upstream as well as downstream of earthen bund. 1.5m. free board is provided over High flood level (H.F.L.) to decide top of Earthen bund.

a.Breaching section:

Breaching section can be provided in Earthen dam to protect Bandhara and prevent downstream hazards in case of heavy flood. Breaching section is provided to pass more than design flood or in case where sufficient length of W.W. is not provided due to site situation. Top of bund of breaching section is kept at H.F.L.
Pitching of stone having sufficient weight and size with sand filter (as per relevant IS Code 8237:1885) below is provided on both the slopes of bund up to the Top of bund in Reservoir side and up to the High Tide Level on Sea side.
Relevant seismic coefficient as per IS: 1893-2002 (part-1) are adopted while designing components of Bandhara. Guide line for "Quality control & quality assurance" by Gujarat Engineering Research Institute(GERI), Vadodara may be followed for general guidance.

b. Relaxation in design criteria:

In some cases, relaxation in the design criteria has to be granted by competent authority considering site situation where banks are not available of sufficient height up to long distance, or to reduce the area of land acquisition. Relaxations are generally required for free board of Earthen dam &for F.R.L. of waste weir.

i) 1.0m (or less than 1.50m) free board instead of 1.50m for fixing the Earthen dam top level and

ii) 0.5 m (or less than 1.0m.) above HTL instead of 1.0 m for fixing FRL.

7.2.3 Salt Water Exclusion Dams (SWED)

Salt Water Exclusion Dams (SWED) is vented dams constructed across rivers/streams at the confluence of the sea up to high tide level. Such structures are kept open during rainy season to mitigate floods in the river and later closed to prevent the ingress of sea water into the rivers.

Design considerations of SWED

- The height of dam (storage) is fixed considering the high flood level and high tide level (HTL). Top level of dam is fixed at a height of 0.30 m above HTL.
- The soil met with usually being sandy in coastal regions, the foundations are designed based on Khosla's theory of design of weirs on permeable foundations. The total length of upstream and downstream aprons provided will be 8 to 10 times the gross head on the structure, so that exit gradient shall be well within the critical gradient.
- Cut of walls are provided up to the hard strata or impervious strata as per scour depth calculations. The minimum depth of upstream cut off wall is the difference between the HTL and the lowest nala bed level.
- The downstream cement concrete apron is provided at about 0.60 to 0.90 m below stream bed level with toe walls for effective dissipation of energy.
- One meter thick clay puddle filling will be provided in front of cut off walls to arrest seepage.
- RCC Piers are provided at 2m interval. They are provided with grooves to facilitate fixing of wooden shutters for storage of water. Foot slab is generally provided over Piers for the operation of shutters.
- For R.C.C. works sulphate resistant cement should be used as per I.S. Specifications.
- Fiber glass shutter is recommended for gates instead of steel or wood shutters.

Model Study

The performance of the proposed Tail end Regulator/Salt Water Exclusion Dam to be constructed at the river mouth may be analysed before construction by conducting necessary Physical Model studies to a suitable scale. These section/comprehensive Model studies will help in the finalization of various level of important components of the proposed structure and also the hydraulic performance of the structure for various discharges and tidal value at the confluence point may be ascertained. Based on the outcome of the study, improvements, if any can be finalized prior to the commencement of the project which will avoid unnecessary cost overrun.

7.2.4 Embankments/ bunds

Embankment Manual, CW&PC, 1960 stipulates that an embankment is designated as low, medium or major according to its height above natural sea level (NSL). The details are as under in Table .

S.No.	Classification of embankment	Criterion
1	Low Embankment	Height < 10 ft (3 m)
2	Medium Embankment	10 ft (3 m) <Height> 30 ft (9 m)
3	Major Embankment	Height > 30 ft (9 m)

Table 7.1: Classification of embankment

Design of embankment should be done as per provisions of BIS code 12094: Guidelines for Planning and Design of River Embankments (Levees). Some major provisions stipulated in the code are given as under:

- ***Design Flood:*** The design flood as per relevant BIS code for embankment to protect rural areas & urban areas may be kept as 25 years & 100 years respectively for fixation of crest level. In the cases where anti erosion measures are proposed along with the embankment then design flood may be kept as 50 years for rural areas and 100 years respectively for fixation of crest level. In the cases where anti erosion measures are proposed along with the embankment then design flood may be kept as 50 years for rural areas and 100 years for urban/industrial areas. In cases where gauge & discharge sites are not present, discharge may be worked out using the Empirical formula using the catchment area, extent of rainfall, catchment characteristics etc. Further hydrological data may be adopted using the regional hydrological booklets/manuals, prepared by the Hydrological Studies Organization, CWC.

- ***Alignment of Embankments:*** The embankments should be aligned on the natural bank of the river, where land is high and soil is available for the construction of embankments. The alignment should be such that important township, vital installations, properties, cropped area is well protected by the embankment. The alignment should be such that high velocity flow is quite distant from the toe of embankment to avoid scouring of the same and if embankments' alignment is near the high velocity flow then slope and toe protection in the form of pitching along with launching apron using the boulders, geo-bags, sand filled geo-mattress may be given. RCC porcupine screens along the toe line may also be used to retard the flow to induce siltation and check scouring of the toe-line. Alignment should also be planned so that land acquisition is feasible and not prolonged.

- ***Spacing of Embankments:*** The spacing of embankments along the jacketed reach of the river should not be less than 3 times Lacey's wetted perimeter for the design flood discharge. The minimum distance of the embankment from the river bank and midstream of the river should be one times Lacey's wetted perimeter and 1.5 times Lacey's wetted perimeter [Lacey's wetted perimeter (P) =4.75 $(Q_{design})^{½}$] respectively. In the tidal reach of the river, embankments should be constructed with due regard to their effect on navigation requirements in the channel as embankments in such cases may reduce the tidal influx causing a reduction in available navigation depth.

- ***Free Board:*** Free board should be taken as 1.5 m for discharges less than 3000 cumecs and 1.8 m for discharges more than 3000 cumecs.
  The top width of the embankment should be sufficiently enough to accommodate the vehicular traffic. The top width of the embankment may be kept as 5.0 m. Turning platform of length 15 m to 30 m and 3 m width at C/S side slope at an interval of 1 km or more may be provided.

- ***Hydraulic Gradient:*** It is desirable to know the approximated line of seepage or hydraulic gradient line (HGL). The following guidelines may be used for determining the HGL.

Clayey soil: **4H:1V**
Clayey sand: **5H:1V**
Sandy soil: **6H:1V**

- ***River Side Slope:*** The river side (R/S) slope should be flatter than the underwater angle of repose of the material. Up to an height of 4.5 m, the slope should not be steeper than 2H:1V and in case of high embankments, slope should not be steeper than 3H:1V, when the soil is good and to be used in the most favorable condition of saturation and drawdown.

- ***Country Side Slope:*** A minimum cover of 0.6 m over the HGL should be maintained. For embankment up to height of 4.5 m, the country side slope should be 2H:1V from the top up to the point where the cover over HGL is 0.6 m after which a berm of suitable width, with country side slope of 2H:1V from the end of the berm up to the ground level should be provided.

  For drainage, longitudinal drains should be provided on the berm and cross drains at suitable places should be provided to drain the water from the longitudinal drains. Toe drain should be provided to prevent sloughing of toe. Perforated pipe embedded in properly designed graded filter with arrangements for disposal of water in the country side should be provided. Use of geo-textile material is also useful for safe drainage.

- Sluices with regulating arrangements should be provided for country side drainage. The size of sluice will depend upon the intensity of rainfall and the catchment area to be drained. Sluices may be designed as per provision of BIS code IS 8835:1978.

- ***Stability Analysis:*** The criterion for stability analysis for high embankment is based on the stability analysis of embankment dams. Slope stability is generally analyzed by two methods depending upon the profile of failure surface viz. (a) Circular Arc method and (b) Sliding Wedge method. In the 'Circular Arc' method or 'Swedish Slip Circle' method, the rupture surface is assumed cylindrical or in the cross-section by an arc of a circle. The sliding wedge method assumes that the failure surface is approximated by a series of planes.

- ***Protective embankments:*** As a first step towards reclamation of the coastal saline soils and control further salinization, the land must be protected from inundation of sea water by constructing protective embankments/ bunds. Such embankments can be constructed usually with a free board of about 1 m above the high tide level. The top width of the embankments ranges from 1 m to 4 m. To reduce damage from constant erosive action of

waves, a suitable shelter with trees or grasses around these structures is effective to minimize wave action (shelterbelts also prevent the drifting of saline sands into the inland areas). The embankments are provided with oneway sluice gates. The purpose of the sluice is to prevent the ingress of sea water into the land side and at the same time, allowing the inland excess water to drain to the sea.

- ***Design of Revetments:*** The design of revetment may be done as per provisions of IS Code 14262:1995. Main provisions are given as under.

- The design flood for pitching/ revetment may be calculated for 50 years return period using the flood frequency analysis. The design HFL should be obtained from gauge discharge relationship (G-D curve). In cases where G&D site are not present, discharge may be worked out with the Empirical formula using the catchment area, extent of rainfall, catchment characteristics etc.

- ***Revetment using boulders:*** The weight of stones on slopes (W in kg) may be worked using the formula given below

$W \text{ (in kg)} = 0.02323 * S_s * V^6 / K * (S_s - 1)^3$;

Where, K (correction factor for slope) $=[1-\text{Sin}^2\theta/\text{Sin}^2\Phi\ ]^{1/2}$

S_s=specific gravity of boulders (may be adopted as 2.65)

θ= Angle of sloping bank 2 (H):1 (V) (26.56^0); V= Velocity in m/s

Φ = Angle of repose of material of protection works (adopted as 30^0 for boulders)

$K =[1-\text{Sin}^2 26.56^0/\ \text{Sin}^2 30^0]^{1/2} = 0.447$;

Hence, weight of stones for 2H:1V slope: **$W \text{ (in kg)} = 0.02323 * Ss * V^6 / 0.447 * (Ss-1)^3$**

For normal bank protection works, a slope of 2H:1V or flatter may be taken**.**
Size of stone (Ds in m) may be determined from the following relationship.

$Ds \text{ (in m)} = 0.124 * (W/S_s)^{1/3}$;

Where, W= Weight of stone in kg;

S_s= Specific gravity of stone (may be adopted as 2.65);

Minimum dimension of stones > Ds

Generally, the size of stone should be such that its length, width and thickness are more or less same i.e. stones should be more or less cubical. Round stones or very flat stones having small thickness should be avoided.

Minimum thickness of pitching (t) or protection layer is required to withstand the negative head created by the velocity. This may be determined by the following equation.

Minimum thickness of pitching (t in m) $= V^2/2g\ (S_s - 1)$;

Where,V= Velocity in m/sec,

g= Gravitational acceleration in m/sec^2;

S_s= Specific gravity of stone (may be adopted as 2.65).

Therefore, thickness of pitching should be higher than t as obtained above. Two layers of stones of minimum size‘t’ should be provided, when pitching is being provided with boulders in loose.

At high velocity, required weight of stones comes out to be higher, which makes handling and placing of stones a bit difficult. In such cases or in case when requisite sized stones are not available, small size stones filled in GI (Galvanized Iron) wire crates may be used for pitching purpose. In this case single layer of GI wire crates filled with stones having thickness more than 't' may be used as pitching. The specific gravity of the crate is different from the boulders due to presence of voids. Porosity of the crates (e) may be worked out using the following formula.

E = 0.245+ 0.0864/ (D50)0.21;

Where, D50= mean diameter of stones used in mm.

Let us assume D50 as 250 mm; e = 0.245 + 0.0864/ (250)0.21= 0.27

The opening in the wire net used for crates should not be larger than the smallest size of stone used. The mass specific gravity of protection (S_m) can be worked out using the relationship $S_m = (1\text{-}e) * S_s$. This mass specific gravity may be used to work out the weight of the crates and this weight should be more than weight of stone required.

A graded filter of size 150 mm to 300 mm thickness may be laid beneath the pitching to prevent failure by sucking action by high velocity. Geo-synthetic filter may also be used as that is easy to lay, durable, efficient and quality control is easy. A 150 mm thick sand layer over the geo-synthetic filter may be laid to avoid rupture of fabric by the stones.

Paneling may be provided in the pitching where slope length is more so that slopes may remain more stable. The size of panel may be varied depending upon the length of river reach to be protected and the length of slope length.

In case of revetment on slopes up to NSL, which is below HFL, a top key or capping berm should be provided for allowing flow of water over the top surface of the revetment.

- ***Pitching in mortar:*** Stones, bricks or concrete blocks may be used for construction of pitching in mortar. Size of stones/bricks/concrete blocks in this type of pitching is not a critical aspect of design as every individual complement is bounded by mortar. Average size of available stone can be used for this purpose. But thickness of such pitching should be more than 't'. Mortar revetment should not be constructed in continuous or monolithic form. To avoid cracks, joints at suitable interval may be provided. Generally, revetment may be provided in panels of size 3mx3m or 3mx5m. The size of panel may be varied depending upon the length of river reach to be protected and length of slope. Standard stone filter or geo-synthetic filter may be provided beneath the joints. Drain holes or weep holes may be provided in each panel for free drainage of pore water from saturated bank soil beneath it. Depending upon the size of panel, one or more weep holes may be provided for a panel. The pipe provided in the drain hole should be up to the natural bank. Stone graded filter or geo-synthetic filter may be provided at the end at the contact of the bank soil.

- ***Revetment using Geo-bags:*** The pitching may also be provided using sand filled geo-synthetic bags. The size of bags may be 1.1m x 0.7m x 0.15m. The weight of such bags is around 126 kg which is generally safe for the velocity up to 3 m/s. For higher velocities,

size of Geo-bag may be higher so that weight of bag is higher than the required weight (worked out by the equation No.1). The geo-synthetic material should be safe against the UV rays and abrasion. If the pitching is being provided in geo-bags, then generally filter in not provided because material of Geo-bags itself work as filter. But for safety purpose (for taking care of bank soil in joints), a geo-synthetic filter layers beneath the geo-bags may be provided.

- ***Toe protection:*** To prevent the sliding and failure of the revetment on slope, toe is required to be protected. This may be in the form of simple toe-key, toe wall, sheet pile or launching apron. Simple key may be provided at the toe (may be called as toe key) when rock or un-erodible strata is available just below the river bed and the overlaying banks are erodible. The key is in the form of stone/bricks or concrete blocks filled in the trench below the hard river bed for depth equal to the thickness of pitching "t" for proper anchorage. Sole purpose of this key is to provide lateral support to the pitching. The key may be of mortar or in geo-bags, if the pitching is provided in mortar or geo-bags. When a hard stratum is available below the river bed at a reasonable depth, toe wall is recommended. The thickness of the toe wall depends upon height of wall and height of overlaying pitching. The toe wall may be design as retaining wall and be constructed in masonry along with provisions of weep holes etc. When firm strata are not available at reasonable depth below the river bed, toe protection in the form of sheet pile or launching apron may be provided. The sheet pile may be made of RCC, steel or bamboo. The sheet piles may be drilled below the river bed up to maximum scour depth.Sheet piles are difficult to drive; therefore, Launching Apron is preferred and provided with revetment. Launching apron should be laid at low water level (LWL). The launching apron may be laid using the stones or geo-bags. The stones/geo-bags in the apron should be designed to launch along the slope of scour and provide a protection layer so that scouring is checked. The size of launching apron should be such that it should form a protection layer up to level of maximum scour depth. Slope of launching apron may be taken as 2H:1V. Filter below the launching apron may also be provided so that river bed material is safe against suction.

- ***Size of Launching apron:*** Width of the launching apron depends upon the scour depth below HFL. Depth of scour below HFL (D) may be worked out using the following formula:

$D = 0.473\ (Q/f)^{1/3}$ and $D = 1.33\ (q^2/f)^{1/3}$;

Where, Q = design discharge in cumecs and
q = design discharge per unit width or design discharge intensity in cumecs/m
f is silt factor;
Silt factor (f) may be calculated using the formula **$f = 1.76\ (d)^{1/2}$**
where, d is mean particle diameter of river material in mm.

Generally, scour depth (D) below HFL should be calculated using the design discharge Q. In some cases, (for braided rivers) scour depth may be calculated using the design discharge intensity q.

Maximum Scour depth $(D_{max})_{\text{below HFL}} = 1.5 *$ Scour depth $(D_{\text{below HFL}})$
Maximum Scour depth $(D_{max})_{\text{below LWL}} = (D_{max})_{\text{below HFL}}$ - (HFL-LWL)

- If the launching apron is being laid at LWL then width of the launching apron should be calculated as 1.5 * $(D_{max})_{\text{below LWL}}$
- Thickness of launching apron (T) = 1.5* thickness of pitching (t).
- In some cases, thickness of the launching apron is kept different from 'T' due to size of crates etc (if launching apron is being provided in crated stones), then width of the launching apron may be revised keeping the volume of stones/geo-bags same per unit length of the apron.

- ***Anchoring:***Proper anchor is required for keeping the revetment in place and serving the desired function. Upstream edge from where the revetment starts should be secured well to the adjoining bank. Similarly, downstream edge where the revetment ends also needs to be secured well to the adjoining bank. Anchorage is also required to be provided on the top of submerged bank. If the top of bank is above HFL, the revetment should be provided above HFL with an adequate free board say 1.0 m. Under such situation, anchorage at top is not required.
- **Design of RCC Porcupines spurs & screens:** Permeable structures envisaging construction of RCC porcupine screens & spurs are a cost effective alternative to the impermeable bank protection works for the rivers carrying considerableamount of silt.RCC porcupine is a prismatic type permeable structure, comprises of six members of made of RCC, which are joined with the help of iron nuts and bolts. Prima facie, the purpose, overall behavior and layout of the above mentioned structures can be compared to those of submersible bunds, spurs and revetment respectively. The permeable structures can be used either independently or with a support of other impermeable boulder structures or river training and bank protection measures. Depending upon the purpose, the permeable structures like RCC porcupines may be constructed in transverse or parallel to direction of flow. Only partial obstruction to the flow of about 15 to 20% only is envisaged in the design. Higher obstruction causes more diversion of flow resulting in undesired scouring around the proposed structures, particularly at the nose portion. Additional protection to the nose and flanks is required to avoid such scour. Therefore, obstruction more than 20% is avoided. Submergence of RCC porcupine screens & spurs may be kept up to 50% of depth of flow. For example, single layer of RCC porcupines, comprising 3 m long members is sufficient for depth of water till 6 m.

Layout of RCC porcupine spurs

(a) The porcupines (comprising of six members of size 3mx0.1mx0.1m) are laid in a row across the river bank protruding into the river at spacing generally adopted as 3m c/c. If size of member is 2m x 0.1m x 0.1m, then spacing between the porcupines may be kept as 2m c/c.

(b) Each porcupine spur is made up of 3 to 7 rows of porcupines (Higher rows for higher flow). The spacing of rows is kept at same as spacing of each porcupine in each row (3 m or 2 m c/c depending upon size of the member).

(c) If the flow depth is more than 6 m, RCC porcupine spurs may be provided in double vertical layers.

(d) On a straight reach, RCC porcupine spurs are placed at 3 to 5 times the length of spur. On a curved channel, the spacing can be kept as 2 to 4 times the length of spur.

(e) The length of spur into the river shouldn't exceed the 1/5 of the width of the flow. Generally, length of spurs may be kept less than 100m to 150 m.

(f) In order to resist the tendency of outflanking, additional porcupines may be provided along the sloping bank at u/s and d/s of the RCC porcupine spurs.
(g) At least three RCC porcupine spurs may be provided for a reach to be protected. A single permeable spur is generally not effective.
(h) At several locations facing severe erosion, where revetment with apron is not feasible or justified due to space and cost constraint, provisions of RCC porcupine spurs along with porcupine dampeners/screens along the eroded bank may be provided.

The practice of providing one or two additional spurs u/s and d/s of the eroding reach, pointing towards u/s with reference to flow may be followed for the RCC porcupine spurs also.

Layout of RCC Porcupine screens

(a) The RCC porcupine screens are used to block the secondary channels.
(b) Each porcupine screen is made up of 5 to 9 rows of porcupines (Higher rows for higher flow). The spacing of rows is kept at same as spacing of each porcupine in each row (3 m or 2 m c/c depending upon size of the member).
(c) At least two screens are provided to block the secondary channel. A single screen is generally not found effective.
(d) One screen is normally provided at the entrance of the secondary channel. The second screen is provided at a distance of 1 to 1.5 times width of the secondary channel.
(e) The screens are constructed covering a part or the whole width of secondary channel. If the screen covers the whole width, the screens are extended on both banks for a length $1/3^{rd}$ of the channel width.
(f) Depending upon the importance, the possibility of development of bypass channel, a third screen can also be provided further d/s at a suitable location.

If the screens are located near the bank, the extension towards bank should be restricted to the design HFL.

7.2.5 Design of Drainage Improvement Works.

- IS code 8835:1978 stipulates that drains are constructed with the object of relieving excess water from agricultural and other areas and disposing of surplus water which is not required for normal agricultural operations. The proper disposal of surplus rain water is also essential to avoid its percolation down to the water level which may otherwise lead to rise in the water table thereby aggravating or creating the problem of water logging.
- It stipulates that drains may be designed for 3 day rainfall of 5 year return period. Studies carried out indicate that 5 year frequency gives optimum benefit cost ratio. However, in specific cases requiring higher degree of protection, return period of 10 or 15 year may also be adopted. Adoption of higher return period rainfall should be justified in term of economics. Cross drainage works should be designed for 3 day rainfall of 50 year return period.
- The drains should generally follow the drainage line i.e. lowest valley line. As far as possible the alignment of the main or outfall drain should be in the centre of the area to be drained. If the alignment crosses any depressions, ponds or marshes, the drain should not pass through these, as apart from the difficulties in excavation, it affects the hydraulic performance of the drain. In such cases, it is preferable to take the drain away from the depression or pond, and suitably connect it to the drain if it is required to drain the pond or

depression. In selecting alignments, care should be taken to see that as far as possible these do not pass through village habitation. In the forced reaches, care should be taken to see that the embankments of the drains are not of an excessive height in order to minimize the danger of flooding in the event of breaches in the embankments.

- Normally the drain is provided to accommodate the design discharge where drains follow natural valley lines. In such cases, no embankments should be provided along the drain so as to allow free flow of water from the surroundings areas. Wherever embankments are necessary for accommodating a portion of the design discharge or where disposal of excavated soil will be very costly, large gaps should be provided in the embankments on either side so as to allow unrestricted inflows, and in case of discharges higher than the channel capacity, the water should spill over the area and return to the channel freely when the discharge in it recedes. In the forced or diversion reaches, embankments on both sides are, however, provided as the design discharge cannot be accommodated within the cut section of the drain. However, even in such cases attempts should be made by selecting a proper alignment to keep the height of the embankments to the minimum. In such cases, inlets of adequate size should be provided in the embankments to admit the water from surrounding areas.
- The period of disposal of the excess rainfall is entirely dependent on the tolerance of individual crops. Crops Like paddy can generally stand submersion for a period of 7 to 10 days without suffering any significant damage. Therefore, in paddy growing areas, the drainage should aim at disposing of the rain water in a period varying from 7 to 10 days. Based on experience the following periods of disposal are recommended.

S.No.	***Crops***	***Period of Disposal***
(i)	Paddy	7 to 10 days
(ii)	Maize, Bajra and other similar crops	3 days
(iii)	Sugarcane and bananas	7days
(iv)	Cotton	3 days
(v)	Vegetables	1 day (in case of vegetables, 24 hour rainfall will have to be drained out in 24 hours)

Table 7.2: ***The following table gives the Crops and their Period of disposal***

- Run-off coefficients depends on the type of soil, crops, general topographical conditions like land slopes, etc. In plain areas, the run-off percentage is generally of the order of 15 to 20. In semi- hilly areas the percentage may be higher. Until precise data becomes available, the following run-off coefficients for different soils are recommended for plain areas.

S.No.	***Type of catchment***	***Run-off Coefficient***
(i)	Loam, lightly cultivated or covered	0.40
(ii)	Loam, largely cultivated and suburbs with gardens, lawns, macadamized roads	0.30
(iii)	Sandy soils, light growth	0.20
(iv)	Parks, lawns, meadows, gardens, cultivated area	0.05-0.20
(v)	Plateaus lightly covered	0.70
(vi)	Clayey soils stiff and bare and clayey soils lightly covered	0.55

Table 7.3: ***The following table gives the type of Catchment and their Run-off Coefficient***

- IS code 8535:1978 stimulates that cross drainage works are always designed for a higher discharge than the cut sections of the drains. This is mainly on account of the fact that the damage caused to the structures in the event of flows resulting from rainfall higher thanthe designed rainfall, can be much more than to the drain. Besides, any remodeling of the structures at a later date for higher discharges will not only be costly but time consuming, apart from involving dislocations to facilities like roads, railways, irrigation canals, etc. The drains can, however, be remodeled without much dislocation. All the cross drainage structures should, therefore, be designed for a 3day rainfall of 50 year frequency, time of disposal remaining the same depending on the type of crop. In fixing the waterways, care should be taken to see that afflux is within the permissible limits. The drain should be designed as per Lacey's regime theory so that no silting/scouring is occurred in the drain section. Design procedure for the drainage channel may be done as per design of irrigation channel by Lacey's theory. The design procedure is as under.

Velocity of the flow (V in m/sec) = $(Qf^2/140)^{1/6}$;

Where, Q= design discharge in cumecs and,
f is the silt factor, which can be worked out using the formula f = 1.76 (d) $^{1/2,}$
where, d is the average bed material size in mm
Hydraulic mean depth (R in m) = 2.5* (V^2/f); Area of channel section (A in m^2) = Q/V
Wetted perimeter (P in m) = 4.75 (Q) ^{½} and Bed slope (S) = ($f^{5/3}$) / ($3340*Q^{1/6}$)

The drain section shall be adequate to carry the designed discharge and the velocity shall be non-silting, non-scouring to be determined by Manning's formula.In selecting the side slopes for the drain, it will be necessary to consider the kind of material through which the drain is to be excavated. Generally side slopes of 1.5H : 1V are provided.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 1 m should be provided between the toe of the embankment and the section of the drain. The top of the embankments should be 1 m higher than the design full supply level. Wherever, there is likelihood of backing up effect on account of floods in a river into which the drain outfalls, the top of the embankments should be so designed that the flood levels on account of back water conditions are accommodated within the section over which the minimum freeboard is to be provided.

Whenever the drain is out falling into a river, the FSL should be slightly higher than the dominant flood level. The dominant flood level is the stage of river/outfall which is

(a) attained and not exceeded for more than 3 days at a time; and also

(b) attained and not exceeded 75% of time over a period of preferably not less than 10 years.

In cases 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 level. 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. The FSL of the drain as far as possible should be at or below the ground level. Where it cannot be ensured, the FSL should in no case be more than 0.3 m above the average ground level at the starting point of the drain. The hydraulic should then be determined adopting the stipulation and the criteria laid down for fixation of FSL at outfall.

7.2.6 Design of Sluice works

Sluices with regulating arrangements should be provided for country side drainage. The size of sluice will depend upon the intensity of rainfall and the catchment area to be drained. If discharge is high, sluice needs to be replaced with a barrage. For planning and design of a barrage, Central Board of Irrigation and Power (CBIP) "Manual on Barrages and Weirs on Permeable Foundation" and BIS codes, IS-11130: "Criteria for Structural Design of Barrages and Weirs", IS-11150: "Construction of concrete barrages - Code of practice", IS-6966-1 "Hydraulic design of barrages and weirs - Guidelines, Part 1: Alluvial Reaches" d other relevant BIS codes may be followed.

A separate volume discussing in details (unless otherwise stated) the following points and additional points if any as relevant to the project shall form an appendix of the project report. It shall include structural and hydraulic design calculations for the sluice.

Summary of the report appended for the relevant items shall be furnished under this Chapter. Scales of maps and other relevant details shall be furnished. Cross reference shall be given to other chapters and appendices wherever necessary.

- ***Structure and layout***

I. General: -

a) **Headworks:** its site and vicinity--stage of the river (Plain with slope of the river in the vicinity of the structure). The sluice should be as near the lowest part of the area to be drained as possible. And should be accessible at the time of need.
b) **Note of selection**-of the layout of the project
c) **Layout** of the sluice/ barrage/approach channel and tail channel in case of spillway is located in other than main river gorge and appurtenant/auxiliary works, reasons for choice of site.

II. Geology, seismicity and foundation—brief

a) Geology of the entire project areas as par IS 6955: Code of practice for subsurface exploration for earth and rockfill dam and IS 15662: Geological Exploration for Gravity Dams and Overflow Structures - Code of practice
b) Geo technical evaluation of foundations, abutments, and other major components as per IS 6065: Recommendations for the preparation of geological and geotechnical maps for river valley projects
c) Geological log of bore/drill holes, pits, drifts, geo-physical data etc as per IS 1892: Code of practice for Subsurface Investigation for Foundations and other relevant codes.
d) Evaluation of foundation and abutments and other major components for treatment (including grouting, drainage etc.)
e) Engineering properties of the foundation materials as per relevant BIS code including results of the in-situ tests like density, permeability, shear, bearing capacity, penetration, modulus of elasticity, bulk modulus, Deformation Modulus etc. and evaluation of design parameters.

III. Alternative studies carried out for selection of sluice/ barrage site

IV. Choice of final layout of all major components of the project and reason – details

- ***Design Flood–brief***
    a) Design flood approved by CWC, its frequency, stage discharge curve at the proposed site with supporting data etc.
    b) Basis for fixing control levels (FSL, Ruling Level, and Dominant Flood Level etc.)
    c) Afflux and back water studies (special attention to be paid at confluence pointsof major rivers/tributaries).
    d) Appendix A (clause 2.11) of IS 8835 – 1978 may be followed for calculating the dominant flood level.

- ***Fixation of Design Discharge, Period of Disposal and Ruling Level***
    a) The design discharge for sluice may be calculated as provided in IS 8835-1978. Generally, the drains should be designed for 3 day rainfall of 5 year frequency. Studies carried out indicate that 5 year frequency gives optimum 'benefit cost ratio. However, in specific cases requiring a higher degree of protection, the frequency of 10 or 15 year can also be adopted. Adoption of such higher frequencies will need to be justified in terms of the economics.
    b) The period of disposal of the excess rainfall is entirely dependent on the tolerance of individual crops. In absence of precise data, the recommendations of IS 8835-1978 may be followed to arrive at the period of disposal of the excess rainfall.
    c) IS code 8835:1978 stimulates that cross drainage works are always designed for a higher discharge than the cut sections of the drains.

- ***Run-off Coefficient****:*
    Run-off coefficients depends on the type of soil, crops, general topographical conditions like land slopes, etc. Until precise data becomes available, value of run-off coefficient may be adopted from the recommendations of IS 8835-1978.

- ***Free Board***
    Free board calculations by relevant IS standards for FRL and MWL conditions in the Reservoir to fix the top elevation of the structure.

- ***River Diversion arrangements***–choice of design flood with Hydrographs.
    a) Coffer dames
    b) Tunnel(s), Construction Sluices etc.

- ***Construction materials– brief***
    a) Qualitative and quantitative assessment of availability of construction material. Transport constraints if any.
    b) Engineering properties of the materials and evaluation of design parameters (shear/compression/tensile strength, permeability, gradation, density, moisture etc.)
    c) Special considerations with regards to the scarce materials, if any,
    d) Details of tests undertaken for assessing the suitability of the construction materials.

- ***Details of the model studies, if any, for important structure***

- ***Sluice Design:***
    Waterway of sluice should be sufficient enough to drain out the accumulated water within evacuation time. Crest level of sluice/ barrage may be kept sufficiently low so

that lean period flow also gets drained easily. Exit gradient, Floor thickness should be sufficient enough for both condition of flow i.e. drainage and backwater flow. Hydraulic jump consideration may be checked only for drainage flow condition. Scour depth of d/s cut-off may be decided based on lower of (i) design flood of drain or (ii) design flood of out-fall river. Hydraulic design of sluice regulator may be carried out by referring to "IS 6531: CRITERIA FOR DESIGN OF CANAL HEAD REGULATORS". The design calculations should include the following:

- Assumed retrogression at maximum and minimum discharges.
- Looseness factor.
- Scour factor.
- Intensity of discharge under design/super flood condition.
- Co-efficient of discharge.
- Exit gradient value.
- Stress allowed (Concrete/ Masonry/Steel Foundation, etc.).
- Type (concrete/ masonry) profile cutoffs up-stream and downstream aprons, uplift pressure relief arrangements etc.
- Various conditions of MWL, TWL, Drainage, etc. considered for stability analysis of the different components of Sluice and values of factor of safety.
- Gates, type, size and hoist arrangement and stop-logs including operating cranes.
- Detail of spillway, bridge, Guide and afflux bunds, sheet piles, abutments, divide wall, wings wall, flare out wall, upstream/downstream protection etc.
- further, following data shall be appended in the chapter:
  - Area to be drained
  - 3 day rainfall of 50 year frequency
  - Dominant flood level from historical hydrograph
  - Capacity – stage curve of area to be protected
  - Evacuation time available based crop data or other relevant data
  - Rating curve of drain
  - Flood study Outfall River
  - Details of vital installation and their levels
  - Geotechnical investigation report

7.3 Recharge Techniques

7.3.1 Check Dams

Check dams are constructed in the beds of rivers with regulation device to check the monsoon flow, which otherwise passes away to the sea. The stored water contributes towards ground water recharge and utilisation by farmers for lift irrigation in nearby fields.

This is a simple and quick method for increasing recharge to ground water in areas of increasing salinity and lowering of water table. Construction of as many check dams as possible on all streams is required to be done wherever site conditions are favourable. Besides, if more numbers of suitable sites are available on one stream, then these are also to be considered for construction of check dams. Thus the construction of check dams need not be restricted to certain proposed sites only. If additional prospective sites area available these should also be considered.

The good system of recharge can be built up if a series of check dams are constructed downstream of all reservoirs sites and arrangements made in the concerned project, for release of stored water into the stream, to fill up check dams. Where ever the bridges or culverts are located on the coastal highway, these may be combined with check dams wherever feasible.

The check dams are a key element in the overall recharge plan. The structure utilizes flap gates to store water at the recession of each flood. During prolonged stream-flow periods, gates remain open so that the flood waters flow down the stream channel unrestricted. Through the repeated filling of the pool behind the gates, the water will percolate through the wetted lake area into the ground, some water will also be available for supplementary irrigation to kharif crops by lift and for the essential early watering for the planting and establishing rabi crops.

7.3.2 Recharge Tanks

Check dams usually being of low height and having small water spread area are proposed to be used for diverting surplus water to recharge tanks in the nearby area. Recharge tanks, will not only help in increasing the rate of recharge but will also improve the quality of ground water. The intake of water of recharge tanks without feeding device will be restricted to its local catchment. This is however not considered to be sufficient to serve the purpose. It is, therefore, necessary to connect such recharge tanks to existing or proposed check dams by constructing regulators and feeder channels. During monsoon, flood waters from check dams, fitted with flap gates, can be diverted to recharge tanks, through regulators and feeder channels.

In monsoon, the flap gates of the check dams will store part of monsoon flow in the river and divert a flow to feed the recharge tanks.

7.3.3 Recharge Wells

The recharge wells will be dug like open wells with 3 to 4 m in diameter (the dimensions depend on the locations of the well). They will then be filled with rubble and with sand filter at the top. These wells will be useful to recharge pervious aquifers located at some depths below the ground level. Such conditions prevail in this area, where the limestones are highly cavernous at different levels. Recharge wells can be constructed in the beds of rivers. During the monsoon surplus flood waters in river will cater these wells through top filler and clear water will enter through aquifers. Recharge wells can also be constructed inside the recharge percolation tanks or feeder channels. If they are constructed in river beds, no feeding arrangements will be necessary and if properly located they will not be silted and will require less maintenance. In cases where they are constructed inside recharge of percolation tanks, there will be some problem of silting at top every year. This problem of silting can be solved to some extent by constructing conical top for such recharge wells.

7.3.4 Recharge Reservoirs/Spreading Channel

Spreading Channel is one of the acceptable devices, when recharge is desired along a narrow but a continuously long area. The sweet water impounded through induced recharge acts as a barrier, to check the movement of saline water from sea side. Therefore, if spreading channels are provided near the coastal line they would act as a good recharge cum salinity control device.

The section and length of spreading channel would depend on the quantum of the supply of fresh water. A Channel of considerable length would definitely be advantageous, but the dimensions would have to be restricted depending upon the availability of quantum of fresh water. The channel should be constructed in small lengths at different locations in the reach depending upon availability of water from proposed recharge reservoirs.

The benefits can be achieved by making optimum use of waters of all the big rivers and the small rivers of corresponding locations.

For effective planning of getting maximum benefit of available storage the waters of all schemes, the reservoirs of medium and minor capacities may be constructed on all big and small rivers depending upon condition and feasibility of sites.

7.3.5 Recharge Shaft

Recharge Shafts are the most efficient and cost effective structures to recharge the aquifer directly. These can be constructed in areas where source of water is available either for some time or perennially. Following are the site characteristics and design guidelines:

i. To be dug manually if the strata is of non-caving nature.
ii. If the stratum is caving, proper permeable lining in the form of open work, boulder lining should be provided.
iii. The diameter of shaft should normally be more than 2 m to accommodate more water and to avoid eddies in the well.
iv. In the areas where source water is having silt, the shaft should be filled with boulder, gravel and sand to form an inverted filter. The upper-most sandy layer has to be removed and cleaned periodically. A filter should also be provided before the source water enters the shaft.
v. When water is put into the recharge shaft directly through pipes, air bubbles are also sucked into the shaft through the pipe, which can choke the aquifer. The injection pipe should therefore be lowered below the water level.

The main advantages of this technique are as follows:

i. It does not require acquisition of large piece of land as in case of percolation tanks.
ii. There are practically no losses of water in the form of soil moisture and evaporation, which normally occur when the source water has to traverse the vadose zone.
iii. Disused or even operational dug wells can be converted into recharge shafts, which do not involve additional investment for recharge structure.
iv. Technology and design of the recharge shaft is simple and can be applied even where base flow is available for a limited period.
v. The recharge is fast and immediately delivers the benefit. In highly permeable formations, the recharge shafts are comparable to percolation tanks. The recharge shafts can be constructed in two different ways viz. vertical and lateral. The details of each are given in the following paragraphs.

The construction procedure of recharge shaft is illustrated below:

i. Drilling of bore hole of diameter 0.200 m to a various depth of 35m, 55m and 70 m.
ii. Reaming of bore hole of diameter 0.200 m to 0.35 m to a various depth of 35m, 55m and 70m.
iii. Necessary PVC casing (plain & ribbed screen) pipes are to be erected up to the total depth. End caps on both ends of the bore holes are to be provided.
iv. Compressor development for bore hole has to be done.

v. After completing the bore hole, filter trench is to be constructed by erecting the RCC Hume Pipe of 600 mm Dia and top of the Hume pipe with RCC circular slab.
vi. The Gap between the bore hole and the filter trench is to be filled to 0.30 depth of 40mm broken stone jelly and then with 0.15 m coarse sand.
vii. Top of the recharge trench is to be covered with RCC circular slab with holes.

Necessary display boards explaining the details of the recharge structure are to be displayed to have good exposure about ground water recharge.

7.3.6 Recharge Pond

Excavation of ponds in coastal areas may be explored to store surface water and/or rainwater during the monsoon season. The extent of such interventions depends on purpose and local context. Water stored in ponds can serve as a reservoir of freshwater for the local coastal community both for reducing its dependency on groundwater for crop irrigation and for meeting daily needs. This in turn reduces the extraction of groundwater and also aids in recharging groundwater.

All such measures that help in reducing extraction of groundwater and support groundwater recharge, aid in maintaining a sufficient hydraulic gradient towards the seaward side, thus minimizing the ingress of saltwater through the aquifer.

7.3.7 Afforestation

Vegetation is known to improve the rate of infiltration and thereby step up the irrigation rate in three ways given below:

- Formation of root channels
- Increase in detention time of rain water
- Reduction in evaporation from land
- Shelterbelt Plantation

Formation of Root Channels

When the root system gets old either in a living tree or a dead tree by a process of decay and decomposition they leave behind a network of channels which constitute path ways for movement of water into substrata.

Increase in detention time of rainwater

The total amount of water entering the soil is governed to a suitable degree by the time available for infiltration. It therefore follows that if water can be made to move slowly rather than rapidly across the land or, if it is impounded on the surface the percolation of water in the sub-soil is greatly increased. Increase in the detention time is obtained by fixing obstruction of trees to surface flow as well as presence of vegetative cover.

Soil under vegetative cover contains twigs and leaf litter in various states of deterioration which act like a sponge and absorb and holds larger quantity of water which then percolates into the soil.

Reduction in Evaporation from land

Tree belts are known to have salutary effects on evaporation. Evaporation reduces considerably under the influence of the shelter belt. Though the maximum benefits of shelter belt can be on its vicinity, its beneficial effects are discernible to the extent of a strip land 30 to 35 times the height of the trees.

Shelterbelt Plantation

Shelterbelt plantation along the coastline is a viable technique for significantly reducing both the direct and indirect adverse impacts of salinity on plants and water resources. Shelterbelts act as barriers that diminish damage from salt-laden winds in coastal areas and provide shelter to coastal life. The 'bio-shield' formed by planting a vegetation belt along coastlines besides other such soft measures also help in absorbing/ dissipating the force of severe coastal storms and cyclones.

7.4 Management Techniques

7.4.1 Cropping pattern

The problem of salinity has been created due to the change in rainfall pattern and injudicious use of irrigation water by cultivators. Substantial hectares of land have come under the effect both due to inherent salinity and the encroachment of sea water along the coastal belt. The present cropping pattern should be changed to suit the changed situation from the view point of soil, climatological and agro-economic conditions. The cropping pattern of an area depends upon mainly soil types, prevailing climate and the irrigation facilities available. The present cropping pattern may be reviewed keeping in view the existing position in respect of all the factors. As such, a single cropping system cannot be suggested in the coastal area of coastal states/UTs. A change in existing crop pattern as a sequel to increase in salinity in soils and water, can be adopted in a three-fold manner as follows:

1. Introducing crops with lower water requirements
2. Introducing salt tolerant and semi salt tolerant crops
3. Incorporating Boron-resistant crops

New crops like date palm, Bor, Bamboo, Eucalyptus, Guava, Coconut, may be grown if they are not grown by the cultivators at present. These all are moderately to highly salt tolerant crops. Among field crops Wheat, Bajra, Jowar, Mustard, Safflower, Cotton and Castor are some of the field crops which have been found to withstand the salinity upto some extent.The cultivation of Date Palm, Guava, Pomegranate, Ber, Eucalyptus, Subabul (LuceonLeucocaophela), etc. is also suggested wherever feasible because these crops are tolerant to salinity and can be grown even where the limited irrigation facilities are available. During the hot weather, the total salt content in water would be too high to permit a summer crop and therefore it would not be advisable to take any crop.

Table 7.4: The following table gives the crop selection in respect to the quality of irrigation water

Tolerance Class	Soil Type	E.C. of water (m.mhos/cm)	Field Crops	Orchard Crops	Forest Crops
Highly Tolerant	Light to Medium Texture	More than 10	Sugarbeet and Dhaincha	Date Palm	Babul Shrub
	Heavy Texture	5-10			
Tolerant	Light to Medium Texture	5-10	Sunflower, Mustard, Barley, Wheat, Bajri, Jowar, Cotton, Castor	Ber, Coconut and Guava	Eucalyptus hybrid, Saru
	Heavy Texture	3-5			
Semi Tolerant	Light to Medium Texture	3-5	Rice, Sugarcane, Maize, Sunflower, Sesamum, Gram and Groundnut	Cauliflower, Onion and Potato	Mango and Pomegranate
	Heavy Texture	1.5-3			

Table 7.5: ***The following table gives the crops which are Tolerant to Boron (B).***

Tolerant		**Semi-Tolerant**		**Sensitive**	
More than 1-2 ppm of Boron		1-2 ppm of Boron		Upto 1 ppm of Boron	
Date palm	Onion	Sunflower	Radish	Maize	Grape
Sugarbeat	Cabbage	Cotton	Barley	Potato	Orange
Lucerne	Carrot	Tomato	Wheat	Beans	Lemon
		Potato	Oat		
		Pumpkin	Maize		
		Sweet Potato			

Table 7.6: ***The following table gives the suggested cropping pattern.***

Field Crops				**Orchard Crops**	**Forest Crops**
Kharif		**Rabi**			
Bajri	Groundnut	Barley	Onion	Date Palm	Babul Shrub
Jowar	Math	Wheat	Isabgul	Ber	Eucalyptus
Cotton	Rice	Sunflower	Cumin	Coconut	(Hybrid)
Castor		Mustard		Guava	Saru
				Pomegranate	Subabul

Table 7.6: Irrigation water salinity tolerance for different crops (Source: Ayers and Westcot, 1976)

	Yield potential, EC_{iw}* (µS/cm)			
	100 %	**90%**	**75%**	**50%**
Field crops				
Barley	5000	6700	8700	12000
Bean (field)	700	1000	1500	2400
Broad bean	1100	1800	2000	4500
Corn	1100	1700	2500	3900
Cotton	5100	6400	8400	12000
Cowpea	900	1300	2100	3200
Flax	1100	1700	2500	3900
Groundnut	2100	2400	2700	3300
Rice (paddy)	2000	2600	3400	4800
Safflower	3500	4100	5000	6600
Sorghum	2700	3400	4800	7200
Soybean	3300	3700	4200	5000
Sugar beet	4700	5800	7500	10000
Wheat	4000	4900	6400	8700
Vegetable crops				
Bean	700	1000	1500	2400
Beet	2700	3400	4500	6400
Broccoli	1900	2600	3700	5500
Cabbage	1200	1900	2900	4600
Cantaloupe	1500	2400	3800	6100
Carrot	700	1100	1900	3100
Cucumber	1700	2200	2900	4200
Lettuce	900	1400	2100	3400
Onion	800	1200	1800	2900
Pepper	1000	1500	2200	3400
Potato	1100	1700	2500	3900
Radish	800	1300	2100	3400
Spinach	1300	2200	3500	5700
Sweet corn	1100	1700	2500	3900
Sweet potato	1000	1600	2500	4000
Tomato	1700	2300	3400	5000

	Yield potential, EC_{iw} *(µS/cm)			
	100%	**90%**	**75%**	**50%**
Forage crops				
Alfalfa	1300	2200	3600	5900
Barley hay	4000	4900	6300	8700
Bermuda grass	4600	5700	7200	9800
Berseem	1000	2100	3900	6800
Corn (forage)	1200	2100	3500	5700
Harding grass	3100	3900	5300	7400
Orchard grass	1000	2100	3700	6400
Perennial rye	3700	4600	5900	8100
Sudan grass	1900	3400	5700	9600
Tall wheat grass	5000	6600	9000	13000
Wheat grass	5000	6000	7400	9800
Fruit crops				
Almond	1000	1400	1900	2700
Apple, Pear	1000	1600	2200	3200
Apricot	1100	1300	1800	2500
Date palm	2700	4500	7300	12000
Pomegranate	1800	2600	3700	5600
Grape	1000	1700	2700	4500
Grapefruit	1200	1600	2200	3300
Lemon	1100	1600	2200	3200
Orange	1100	1600	2200	3200
Peach	1100	1400	1900	2700
Plum	1000	1400	1900	2800
Strawberry	700	900	1200	1700
Walnut	1100	1600	2200	3200

* EC_{iw}: Electrical conductivity of irrigation water

Ayers, R. S. and D. W. Westcot (1976). Water Quality for Agriculture. Food and Agriculture Organization of the United Nations, Rome

7.4.2 Reclamation of Land

An excessive accumulation of salts in the soil causes a decline in crop productivity. Soil salinity is the term used to designate a condition in which the soluble salt content of the soil reaches a level harmful to crops. Soil salinity affects plants directly through reduced osmotic potential of the soil solution and the toxicity of specific ions (such as boron, chloride and sodium). If the salts are mainly sodic salts, their accumulation increases the concentration of sodium ions in the soil's exchange complex, which in turn affects soil properties and behavior. Thus, salinity can also have direct effects on plant growth through deleterious modification of such soil properties as swelling, porosity, water retention, and permeability.

The classification of soil salinity is based on total salt concentration (as measured by its electrical conductivity) and on the relative concentration of sodium. Soil sodicity (or alkalinity) is characterized by ESP (exchangeable sodium percentage) which gives the amount of adsorbed sodium on the soil exchange complex expressed in percent of the cation exchange capacity in milli equivalents per 100 gm of soil. Since, experimental determination of ESP is tedious and time consuming; the sodium adsorption ratio (SAR) of the soil solution is taken as an index of the soil sodicity. SAR is defined by the ratio $\mathbf{Na^{+}/\sqrt{(Ca^{2+} + Mg^{2+})/2}}$, where all cation concentrations are in meq/litre.

The salt-affected soils can be separated into three groups: s*aline, saline-sodic, and nonsaline-sodic soils.* A saline soil is one whose saturation extract indicates an EC (electrical conductivity) > 0.4 S/m at 25^{o}C but whose ESP < 15. Such soils usually have pH values less than 8.5 and are ordinarily well flocculated. Saline-sodic soils are defined as having a saturation-extract EC > 0.4 S/m and ESP > 15. Such soils when leached become highly dispersed and exhibit higher pH values. Nonsaline-sodic soils EC < 0.4 S/m and ESP > 15. Such soils often exhibit very high pH values (8.5 - 10).

Saline and sodic soils account for a very large fraction of salt affected soils. Another category of salt-affected soils which, though less extensive, are commonly encountered in coastal zones are acid-sulphate soils. These soils have pH below 3.5 to 4.0 that is directly or indirectly caused by sulphuric acid formed by the oxidation of pyrite. Potential acid sulphate soils occur in tidal swamps. When exposed to oxygen through drainage or disturbance, these materials produce sulfuric acid, often releasing toxic quantities of iron, aluminium and other metals. Pyrite formation is favoured in brackish and saline mangrove swamps dissected by tidal creeks where deposition and buildup of coastal sediments is slow.

The problem of coastal soil salinity in India encompasses (1) coastal saline soils situated in humid and sub-humid areas (2) coastal saline soils of arid areas and (3) coastal acid saline soils. Salt affected soils occur within a narrow strip of land adjacent to the coast and up to 50 km wide. These areas generally have an elevation of less than 10 m above mean sea level and include the low-lying land of river deltas, lacustrine fringes, lagoons, coastal marshes, and narrow coastal plain or terraces along the creeks.

The salinity problem in coastal soils arises during the process of their formation itself due to marine influence and frequent tidal inundation of the coast land with sea water and ingress of seawater along the estuaries, creeks, drains and rivers. Depending on the local conditions, reclamation of the salt-affected land can be carried out by preventing the tidal water inundation through construction of bunds, introducing desired surface drainage or sub-surface drainage, leaching of salts from the soil profile and through application of suitable amendments in the case of the acid sulphate soils and sodic soils, and, adoption of other suitable soil-water and crop management practices.

(a) Protective embankments

As a first step towards reclamation of the coastal saline soils and control further salinization, the land must be protected from inundation of sea water by constructing protective embankments/ bunds. Such embankments can be constructed usually with a free board of about 1 m above the high tide level. The top width of the embankments ranges from 1 m to 4 m. To reduce damage from constant erosive action of waves, a suitable shelter with trees or grasses around these structures is effective to minimize wave action (shelterbelts also prevent the drifting of saline sands into the inland areas). The embankments are provided with one way sluice gates. The purpose of the sluice is to prevent the ingress of sea water into the land side and at the same time, allowing the inland excess water to drain to the sea.

(b) Surface drainage

In flat coastal lands, surface drainage is required to remove the standing water. For this purpose, ditches can be provided so that excess water will run off before it enters the soil. However, the water intake rates of soils should be kept as high as possible so that water which could be stored will not be drained off. Field ditches empty into collecting ditches built to follow a natural water course. A natural grade or fall should be present to carry the water away from the area to be drained. The location of areas needing surface drainage can be determined by observing where water is standing on the ground after heavy rain. The surface drainage problem becomes acute during monsoon months in the low lying flat coastal tracts due to heavy rainfall, low infiltration rate and lack of a well-defined drainage system. The surplus water that needs to be drained can be estimated by a simple water balance analysis involving rainfall and potential evapotranspiration. In addition to the rainfall, the runoff from the upstream watersheds also contributes to flooding of these areas as the rivers and drains overflow. If desired, introducing channelization in the catchment will directly route the excess rain water from the different zones to the discharge outlet. This is to be streamlined with opening of the sluice gate more frequently and for longer periods to maintain the desired water levels in the region. While designing the surface drainage system, the rainfall pattern and crop requirements should be taken into consideration. For example, in the Sunderbans, West Bengal, the most critical period for surface drainage is the month of July and beginning of August when the heaviest storms occur and the farm work is in progress; young transplanted rice seedlings may get damaged under prolonged submergence. On the other hand, the most critical period in. the south coastal areas of Andhra Pradesh and Tamil Nadu may be October and November due to the cyclonic storms and the harvesting time of kharif rice crop.

(c) Sub-surface drainage

A good sub-surface drainage system is required in areas that exhibit persistent shallow water table with poor quality groundwater. Due to marine origin and the impeded surface and subsurface drainage, soils in coastal regions can be highly saline and present unfavorable characteristics for crop growth. Open ditches as sub-surface drains with suitable drain spacing and dimensions (depending upon the soil hydraulic conductivity) can be employed effectively to leach out salts and keep the water table low. Open drainage ditches are advantageous for removing large volumes of either surface or subsoil water from land and for use where the water table is near the surface and the slope is too small. Other types of sub-surface drainage systems can consist of buried tiles or perforated pipes or in some cases pumped drainage wells.

(d) Leaching of soluble salts

To remove the soluble salts from the root zone, methods such as scraping, flushing and/or leaching can be adopted.

Scraping involves removing the salts that have accumulated on the soil surface, by mechanical means. This method shows limited success and might temporarily improve crop growth, however, the ultimate disposal of salts poses a major problem. To desalinize soils having surface salt crusts, **flushing** can be sometimes employed by washing away the accumulated salts on the surface by flushing water over the surface. Because the amount of salts that can be flushed from a soil is rather small, this method does not have much practical significance.

Leaching is the most effective procedure for removing salts from the root zone of soils. Leaching is most often accomplished by ponding fresh water on the soil surface and allowing it to infiltrate. Leaching is effective when the salty drainage water is discharged through subsurface drains that carry the leached salts out of the area under reclamation. Leaching may reduce salinity levels in the absence of artificial drains when there is sufficient natural drainage, i.e. the ponded water drains without raising the water table. Leaching should preferably be done when the soil moisture content is low and the groundwater table is deep. Leaching during the summer months is, as a rule, less effective because large quantities of water are lost by evaporation. The actual choice will however depend on the availability of water and other considerations. In some parts of India, leaching is best accomplished during the summer months because this is the time when the water table is deepest and the soil is dry. This is also the only time when large quantities of fresh water can be diverted for reclamation purposes. Other factors to be taken into consideration are described below.

- Quantity of water for leaching

  It is important to have a reliable estimate of the quantity of water required to accomplish salt leaching. The initial salt content of the soil, desired level of soil salinity after leaching, depth to which reclamation is desired and soil characteristics are major factors that determine the amount of water needed for reclamation.

- Water application method

  The quantity of salts removed per unit quantity of water leached can be increased appreciably by leaching at soil moisture content that is less than saturation, i.e. under unsaturated conditions. In the field, unsaturated conditions during leaching are obtained by adopting intermittent ponding or by intermittent sprinkling at rates less than the infiltration rate of the soil.

- Soil Amendments

  Whether an amendment (e.g. gypsum) is necessary or not for the reclamation of salt-affected soils is a matter of practical importance. Saline soils are dominated by neutral soluble salts and at high salinities sodium chloride is most often the dominant salt although calcium and magnesium are present in sufficient amounts to meet the plant growth needs. Since sodium chloride is most often the dominant soluble salt, the SAR of the soil solution of saline soils is also high. The decision to use an amendment for the reclamation of saline soils having excess neutral soluble salts and a high SAR of soil solution (i.e. saline-sodic soils) would depend on soil infiltration characteristics and the electrolyte level of the irrigation water. Light textured soils and those having a favourable infiltration rate are not likely to respond to gypsum application. In heavy textured soils, and where such soils are leached with low electrolyte water, application of an amendment is desirable to hasten reclamation. When any large-scale reclamation is undertaken, the need for application of amendments and their quantities must be established by trials on an experimental scale.

  Salinization of freshwater coastal aquifers also contributes to the accumulation of salts in the soil with deleterious impacts on the fertility of the land and regional economy. Reclamation of such salt-affected coastal aquifers entails huge effort, expenditure and may take many years. Sometimes damage to the affected land is irreversible. Management of the threat of seawater ingress is, thus, critical for protection of coastal land and water resources. Controls regarding land reclamation and soil salinity management have been discussed in Section 2. Strategies for sustainable development and management of coastal groundwater, which are more extensive in nature, are elaborated below.

7.4.3 Management of Coastal Groundwater Salinity

To preserve groundwater resources in the coastal zones, it is necessary to manage the threat of seawater ingress. Management strategies can generally be placed into following three categories with the ultimate goal of preserving groundwater resources for current and future use.

I. Scientific Monitoring, Assessment and Modeling
II. Behavioural and Institutional Approaches, and
III. Engineering Measures

I. Scientific Monitoring, Assessment and Modeling

Scientific monitoring and assessment form an essential starting point for effective management of seawater intrusion. As specific aquifer dynamics can vary greatly from location to location, these tools provide localized understanding of coastal freshwater resources and enable decision makers to make sound and informed decisions. The groundwater development and management

of coastal aquifer systems should form part of integrated water management, comprising surface water and groundwater, both in terms of water quantity and water quality, and taking into account the water demands.

(a) Data Collection and Monitoring

The types of data required for groundwater studies in coastal and deltaic areas, where saltwater intrusion plays a role, relate to records of (a) well logs, geophysical surveys and hydrogeological parameters (b) climate data and natural recharge, (c) Water levels (water table and piezometric levels, surface water levels, (d) groundwater quality (chemical and isotopic composition, particularly salinity, and sources of groundwater pollution), (e) Surface water (natural outflow, availability and quality of surface water for artificial recharge), (f) present and past abstractions of groundwater, present and past artificial recharge (if any), (g) Water demands, at present and estimates for the future (h) Ecology (flora and fauna, and their relation to the groundwater table regime, and (i) Relative sea-level rise.

Observation-well networks that monitor groundwater levels and groundwater quality are indispensable for determining the effects of groundwater development on groundwater levels and groundwater storage and for monitoring the location and movement of saltwater-freshwater interface; in essence, they serve as warning or detection systems of any landward flow of subsurface saltwater. It is particularly important to emphasize the long-term commitment required for effective monitoring and assessment of saltwater intrusion. Again, elevated salt content within a well does not necessarily reflect intrusion; rather, active saltwater intrusion (characterized by a prolonged shift in the saltwater-freshwater interface) can be definitively identified only with numerous samples over a longer period of time. Such monitoring and assessment contributes to a thorough understanding of existing conditions in coastal aquifers and constitutes a necessary first step for understanding human impact on water and ecological resources, for assessing whether available water supplies will be adequate to meet future needs, and in determining the severity of any seawater ingress.

(b) Scientific Assessment and Modeling

Another essential tool in the assessment of coastal aquifer dynamics is that of scientific modeling. Modeling is a numerical way of conceptualizing the physical processes by which groundwater flow and solute transport occur in the groundwater system. Modeling helps identify the different factors (such as recharge) that influence groundwater movement. Models can be further enhanced to incorporate the effect of water density (e.g., salinity) on groundwater flow, and they can be employed to identify conditions under which groundwater pumping and availability is optimized and seawater intrusion is limited. Specifically, these simulation-optimization models enable calculation of favourable groundwater yields by identifying the optimal pumping rates, well locations, and human interventions (such as artificial recharge) that are most efficient. Modifying the pumping pattern or relocating the pumping locations further

inland using the simulation-optimization model as a decision making tool can substantially reduce the intrusion.

II. Behavioural and Institutional Approaches

The second group of coastal aquifer management strategies fit into the category of behavioural and institutional approaches aimed towards ensuring sustained water quality and quantity over the long term.

(a) Water supply and demand management

With regard to water supply-related policies, the natural choice can be to limit the amount of groundwater abstracted and, potentially, to relocate wells farther inland. In order to do this, water demand management in the form of water saving measures should be adopted. Various water saving measures can be implemented at locations that are highly prone to salinization. Other drivers like an overall water scarcity, naturally force people to adapt to such water saving practices. Possible water-saving measures are reduction of non-beneficial evaporative and leakage losses, increase of irrigation efficiency, a change to less water demanding production processes and land uses and to find alternative sources of water other than groundwater (surface water or re-use of waste water).

(b) Salt tolerant crops

Groundwater salinity is also managed by adjusting groundwater use to poorer groundwater quality levels. In many coastal agricultural areas where only marginal quality water is available and where soil conditions are negatively affected by salinity, farmers can still grow crops profitably by changing to more salt-tolerant crops. Often the crop adaptation is accompanied by nutrients augmentation (in fertilizers) and soil quality improvement (e.g. adding gypsum sulphuric acid, and iron pyrite to reduce the negative effects of soil sodicity).

(c) Usage of blended water

In cases of marginal quality groundwater, it is judicious to use this water in conjunction with better quality water. The poor quality groundwater could physically be blended with more freshwater to provide water with an acceptable salinity level for application. Alternatively, the poor quality groundwater could be applied in an alternating fashion with better quality surface water. The freshwater is used to meet the evaporative crop demand but also to flush the plot that prevents soil salinity build up significantly.

(d) Coastal protection measures

In coastal zones that are prone to regular seawater flooding and seawater spray, various coastal protection measures consisting of e.g. levees, dikes, natural protection like dunes and mangrove vegetation, shelterbelt plantation with high and dense trees, afforestation of waste lands can limit the susceptibility to salinization. Further, in coastal areas with high evaporation rates, shelterbelts also help in reducing evaporation losses.

(e) Institutional instruments

Farmers in salinity prone areas often rationally measure the investment costs needed for fighting salinity against the losses caused by salinity in case of non-action. On a larger scale, policymakers need to estimate how much groundwater salinity is allowed in a certain area before complex and strongly interrelated systems of nature and society are significantly affected. Some of the consequences caused by salinity in such complex systems may be irreversible or may trigger even larger scale problems (like socio-economic problems caused by unemployment and migration of farmers that abandon their land due to severe salinity problems). In such cases support is provided to help make individuals mitigate, adapt to or compensate for the salinity problems.

Institutional instruments that are practiced to control groundwater salinity are:

- regulatory (like well registration, licensing, groundwater abstraction rights and quota, land use restrictions, emission rules),
- economic (subsidies for individuals or groups/sectors to invest in new technologies to manage salinity, investments in governmental aquifer storage and recovery programs, environmental taxes to discourage salinity increasing practices, compensation for financial losses caused by salinity)
- advisory (enabling access to information, expertise, funding and creating awareness and training).

(f) Policy and plan development

The technical, scientific, behavioural and institutional approaches of coastal aquifer management (ideally) come together in the development of policies and plans that deal with coastal groundwater salinity in an integrated way. Such a policy should contain an integrated and strategic vision on coastal groundwater management for a certain area and for a certain period.

Aquaculture, better known as fish farming, can help produce healthy and nutritious food, while also contributing a number of benefits to the environment—but only if done correctly. If not done properly it is toxic. Due to aquaculture, the groundwater pollution is taking place as well the agriculture land is converting into waste land. Hence, Aquaculture using saline ground water in coastal areas must be banned.

It is important to note that the freshwater-saltwater interface in the coastal aquifer maybe thin or thick. A thick interface implies that the transition (diffusion) zone is wide. The TDS (mg/l) or EC (µS/cm) of groundwater in a transition zone varies from that of saltwater to that of freshwater. The interface may slowly move landward in response to regional lowering of the water table due to excessive pumping and low recharge. In case of reversal of water table gradient due to overexploitation, the movement of interface towards the land is faster and may reach the well field within a shorter duration. Thus, the delineation of extent of saltwater

intrusion i.e. mapping of the project area showing the depth and extent of freshwater-saline water interface is essential prior to any development activity.

In case groundwater needs to be extracted from the shallow freshwater zone existing above the saltwater interface, partially penetrating wells may be employed to skim the freshwater from above the interface. In case of a small cushion (distance between the pumping well screen and interface) and unplanned pumping, problem of local upconing of saltwater interface beneath the pumping well may occur, that may lead to the entry of saltwater in the freshwater well. Thus, the main factors to be considered in pumping shallow freshwater in areas underlain by saltwater layer are selection of suitable skimming technique (partially penetrating single or multi strainer well, radial collector well, compound well systems etc.), the proper design of well configuration in terms of screen positions, and operation of well in terms of permissible discharge and pumping schedules (refer note on 'Skimming wells' under 'Engineering Measures'). Further, in case of production well field pumping groundwater using several wells located / concentrated in a small area, the wells may be relocated / dispersed far apart to avoid excessive lowering of the water table near the coast.

Reducing pumping stresses on the aquifer and tapping of alternative aquifers to relieve pumping stress on the impacted aquifer.

Roof top rainwater harvesting structures should be constructed mandatorily for all RCC buildings in the coastal areas. If the house owner consents, the excess rain water from their premises can be stored in a community tank which can be used by common people.

III. Engineering Measures

The third group of coastal aquifer management strategies consists of various engineering measures that can be employed as a way to prevent seawater intrusion into estuaries and as control measures where groundwater withdrawals have caused water levels in aquifers to fall significantly below mean sea level.

The same techniques can and must be utilized also in those cases where continuity of a controlled groundwater exploitation must be assured. These include seawater barriers, aquifer storage and recovery (ASR) systems, increased recharge, and skimming wells. The effectiveness of engineering techniques depends a lot on local conditions.

(i) Control Measures for Seawater Intrusion into Estuaries

During extended droughts, decreased river flow allows the saline water to migrate up the estuary. A rise in sea-level will also cause seawater to migrate upstream. The general methods of preventing seawater intrusion up estuaries are similar for sea-level rise, drought conditions, and storm surge. Storm surge elevates the ocean in relation to the estuary water level, causing seawater intrusion. A major difference is that storm surge and drought

conditions last for a limited duration, whereas the sea-level rise is expected to last much longer.

In order to minimize seawater migration, provisions must be made for low-flow augmentation and water conservation requirements during periods of low flow. Water from rainfall is stored in large surface reservoirs and released continuously during droughts to maintain a flow that helps push back the seawater from migrating upstream. The planning agencies should recognize the need to sustain stream flows to protect freshwater intakes and in-stream uses (including fish migration and fish production), as well as treated-waste assimilation, recreation, and salinity repulsion. An economic justification is usually necessary, showing that the cost of the mitigation is less than the anticipated benefits.
The prevention of seawater ingress can be achieved by various measures including:

- ***Barriers*.** Dams can be constructed that physically prevent the seawater from moving past a certain point in the estuary. Injection barriers can also be employed successfully.
  - ***Tidal Regulator*:** It is a gated structure constructed near the mouth of a river to prevent the ingress of tidal water through the river channel. The tidal regulator is a solid wall with regulating gates. The top portion of the gates is kept above the maximum tide level. Generally, gates remain closed so that tidal water does not enter the upstream areas. During floods in the inland area, gates are opened and regulated so as to allow the discharge of the excessive flood water without creating undesirable submergence of the lands in the upstream area. The crest level of the masonry wall is kept below high tide level to avoid submergence beyond certain limits depending upon the location of adjoining coastal villages and cultivable lands. Cut-off wall is provided upto the impervious layer below the foundation. The upstream reservoir formed as a result of structure may be used for crop irrigation. The reservoir also acts as a source of recharge to the groundwater system.
  - ***Bandhara*:** Where the height of tide water is limited, the construction of a solid non-gated wall with crest 1 m above high tide level may be considered for reducing the overall construction cost.
- ***Restricting construction of pathways for seawater intrusion*.** Construction of drainage canals to reclaim land by lowering the water table in coastal areas where groundwater is present at shallow depths also permits seawater to migrate into inland areas and allows a pathway for saltwater intrusion to occur; this should be minimized.
- ***Alternate sources of water*.** Water users can obtain water from other sources that are not endangered by saltwater intrusion.
- ***Restrictions on use of water*.** During periods of higher sea-level or drought, stricter conservation and restrictions on export of water from the river basin can be considered for short durations.

(ii) Control Measures for Seawater Intrusion into Coastal Aquifers

Control methods for seawater intrusion have been employed or seriously considered only in areas where withdrawals of water have caused groundwater levels to fall significantly below

mean sea level. Because of the very slow velocity with which the saltwater moves, many areas with serious overdrafts have not yet lost their aquifers as sources of freshwater. However, the problem must be solved eventually because once seawater has invaded an aquifer, it could take hundreds of years to regain the groundwater quality. One of the dangers to freshwater aquifer supplies could be the migration of seawater up an estuary that recharges an aquifer. If the water levels in the aquifer fall below this saltwater level due to groundwater withdrawals, the saltwater would recharge the aquifer.

Several control strategies can be used to prevent or retard seawater intrusion into aquifers. The control strategies include:

- ***Seawater barriers.*** Seawater barriers prevent seawater from flowing inland, thereby protecting groundwater pumping zones. Different types of barrier designs can be considered: low permeability subsurface barriers, and, hydraulic barriers viz., injection hydraulic barriers, extraction hydraulic barriers and mixed hydraulic barriers
- ***Aquifer storage and recovery (ASR).*** Technique used is a particular type of artificial recharge whereby freshwater is injected into the aquifer (through a well) during high-supply seasons and then recovered (pumped to the surface) during low-supply seasons.
- ***Increased recharge.*** Spreading of water on the land in upland recharge areas allows more percolation (infiltration of water into the aquifer), which retards saltwater intrusion.
- ***Skimming wells.*** In coastal regions where freshwater is underlain by saltwater and saltwater upconing is a common problem, skimming wells are employed to restrict the salt concentration in the pumped water to an acceptable limit.

Combinations of above techniques can also be effectively employed. Combinations of an extraction and an injection hydraulic barrier, or, increased recharge with injection barrier are quite effective in preventing seawater ingress in coastal aquifers.

Low permeability subsurface barriers

Low permeability subsurface barriers consist of vertical walls placed inland to block seawater intrusion. There are three types of subsurface barrier walls: slurry walls, grout cutoffs, and steel sheet piles. Slurry wall construction involves pumping a slurry made of water and bentonite clay into a trench. Grout cutoffs are constructed by injecting a liquid, slurry, or emulsion under pressure into the soil. The injected fluid will occupy the pore spaces and will solidify to form an impermeable wall. Sheet piling involves driving lengths of steel that connect together into the ground to form a thin impermeable barrier to flow. These three types of barriers must be connected to an underlying impermeable geologic zone.

The subsurface barrier is located between the seawater and the production wells and constructed parallel to the coast. It is likely that such a barrier could be effective only in relatively shallow formations. The effectiveness of the barrier must be monitored to determine the magnitude of seawater penetration. Additionally, in cases of large fresh

groundwater discharges to sea, a barrier can be constructed at an appropriate location to intercept the flow and increase the aquifer freshwater capacity.

This system requires considerable engineering and investment. The drawback is that even in the uppermost aquifer layer where the cost may not be prohibitive, the backwater effect or storm surges could cause coastal lowlands to become waterlogged. Moreover, it may be counterproductive if pumping stops or sources of contamination exist in upstream areas. In such a scenario, a semi-impermeable barrier instead of an impermeable barrier should be constructed, through which contaminated groundwater may seep through seaward.

Hydraulic Barriers

(i) ***Injection hydraulic barriers*** inject water into the aquifer, which raises the water table / piezometric head and maintains a 'pressure ridge', thus preventing saltwater from flowing inland and protecting the inland groundwater production well fields. This pressure ridge may be achieved with a line of injection wells paralleling the coast that are located landward from the toe of the interface or seawater wedge to provide enough space for freshwater to flow seaward. Thus, the pressure of recharged water can push the interface seaward. The injected wells are injected with high quality water or highly treated, reclaimed water. Regular groundwater level and geochemical monitoring is needed to know about the efficient performance of the hydraulic barrier system and aquifer water quality improvement. It also allows managers to make an accurate, informed decision regarding the amount of water that should be injected in the system to prevent seawater intrusion.

The main disadvantages of this corrective measure are: the need for high-quality water whenever injection is undertaken through wells and the need for space if recharge through basins is necessary. Recharge wells overcome the high cost of the water spreading technique in areas where suitable land is scarce and/or expensive. These injection barriers also require considerable maintenance to control well-screen clogging. Injecting high-quality water reduces the frequency of well clogging, increases the operating life of the well, and reduces cleaning costs. In addition, chlorination of the injected water helps to protect the well casing, prevents potential leaks, and reduces nearfield biofouling of the formations. When there is clogging and the injection head has increased above acceptable levels, redevelopment of the injection wells is necessary.

Supply line pressure must be closely monitored and carefully controlled to prevent injection head fluctuations that could disrupt the well's gravel pack or even damage the injection well itself. Injection wells should be supplied with pressure either individually or in small groups. This will prevent the complete collapse of the pressure ridge barrier in cases of shut down due to accidents or malfunctions. Abandoned barrier wells should be thoroughly plugged to prevent the infiltration of contaminated surface waters into the

aquifer. Wells are typically plugged with cement slurries; the exact composition of the slurry should be tailored to the specific geology of the well site.

(ii) ***Extraction hydraulic barriers*** pump near the shore employing a line of wells that are constructed adjacent to the coast between the interface toe and the coastline and pumped to form a 'trough' at the groundwater level, thus intercepting inflowing seawater. The exact location of the barrier should be based on the shape of the interface. In addition to withdrawing seawater through extraction wells, the groundwater level along the line of extraction wells will also be lowered, which will cause seaward movement of freshwater. Eventually a new groundwater dynamic equilibrium may be achieved.

This technique requires that the amount of freshwater that can be withdrawn must be reduced. Without reducing the pumping rate, it is impossible for the system to achieve equilibrium. The amount of saltwater to be pumped should be estimated. Withdrawing less water than is actually required to control seawater wedge will lead to the following problems: (a) the freshwater region may be intruded by saline water; and (b) a positive seaward hydraulic gradient may not be formed. Conversely, pumping more water than the required amount causes saltwater and freshwater to be withdrawn from the aquifer. Ideally, the amount of saltwater pumped should be slightly higher than the rate at which seawater is intruding.

Seawater intrusion is impeded as long as the barrier pumps. The water pumped is brackish and normally is discharged into the sea. In practice, this system is often applied with minimum or no planning. It is a common knowledge that inland production wells are protected by coastal wells and inland well owners are prepared to go to great lengths to keep coastal wells pumping. However, these barriers often end up pumping much more freshwater than saltwater, leading to a mixing of freshwater with seawater at the wells and to a reduction in freshwater resources. Nevertheless, extraction barriers may be the only possible corrective measures to prevent seawater intrusion in aquifers where the water level cannot be raised. They may also be used to feed desalinization plants.

(iii) ***Mixed hydraulic barriers*** are injection-pumping systems. Such a system may be used to inject freshwater at inland locations, landward of the toe, while seawater intruded into the aquifer is extracted along the coast. Corrective measures may also be used to pump at locations of the aquifer that are well connected to the sea while injecting at locations that are well connected to the land. Therefore, a well-designed mixed barrier can prove to be much more sensitive in controlling ingress than other barrier systems.

To improve the operation and efficiency of the hydraulic barriers, groundwater modeling and optimization techniques can be employed to develop optimal operation and effective management strategies. Mathematical modeling and optimization tools can specifically be used to

- simulate the complex hydraulic barrier operations,
- determine the optimal management strategy of the existing barrier facilities,
- identify the optimal candidate sites for additional injection/extraction wells, and
- investigate alternative and competing management strategies that may be cost effective in addressing the seawater intrusion problem.

Aquifer Storage and Recovery (ASR)

Cyclic injection, storage, and withdrawal of freshwater in brackish aquifers is a form of aquifer storage and recovery (ASR) that can beneficially supplement water supplies in coastal areas. ASR is the cyclical storage of treated surface water in a suitable aquifer, when water is available, and subsequent recovery of the same water to augment flows in a coastal distribution system to meet peak daily and emergency demands. The ASR technology is an important groundwater management tool in coastal plains, where groundwater is the predominant source of water supply for public, agricultural, and industrial purposes, but its sustainability is threatened by increasing demand, seawater ingress, and limited freshwater recharge. ASR provides the opportunity for water users to store treated drinking water and manage water resource demands that often vary seasonally. In addition, ASR has many secondary benefits, such as the potential to reduce disinfection by-products during storage, improve regional groundwater levels during seasonal to long-term storage periods, and locally reduce the effects of seawater intrusion. The local hydrogeology can dramatically affect the success of an ASR program. It may be noted that although ASR is not a source of water, it is a powerful water management tool.

Advantages of ASR: -

- Drought and cyclone resistant water resource
- Reduces agricultural demand and competition for the 'sweet' water
- ASR Projects in Bangladesh have demonstrated Arsenic reduction and been used to improve water quality through filtration
- Depends on detailed lithology- small volume 'bubble' will have high surface area to volume in a thick aquifer.

Increased recharge

A different approach to combat salinization especially in areas affected by lateral seawater intrusion and upconing is the artificial recharge of aquifers with fresh groundwater. Artificial recharge can be accomplished by increasing the infiltration of freshwater from surface water bodies. For example, *check dams* constructed across stream beds, serve to slow the runoff, store or divert surplus water flowing to the sea towards the end of monsoon and enhance the infiltration of (fresh) surface water into the groundwater system. Also, specially designed *infiltration tanks* and *recharge basins* are useful in recharging the groundwater system. The intake of water to such tanks is restricted to its local catchment, which may not serve the purpose, and therefore, the infiltration tanks can be connected to the check dams by construction of regulators and feeder channels. Surplus monsoon flood water can be diverted through regulators to feed the infiltration tanks and recharge basins.

C*anals/channels* excavated parallel to the coast help in trapping monsoon overland flow and recharging the aquifer in the vicinity of coast. Such channels laid parallel to the coast also serve as link channels that support transfer of water from a water surplus basin to a basin affected by low rainfall and thus provide ready supply of water for irrigation to the croplands along the coast. Other artificial recharge techniques include recharge through *injection wells*, *gravity head recharge wells*, and *recharge pits and shafts*. The freshwater that is recharged may have various sources like harvested rainwater, river runoff, and treated (desalinized) waste water. Suitability of artificial recharge structures is to be determined as per site specific hydrogeological characteristics.

Skimming wells

The problem of 'saltwater upconing' is a common localized occurrence in coastal aquifers. The withdrawal of freshwater overlying saline groundwater results in saltwater upconing leading to inferior quality of pumped water and degradation of the aquifer. In such situations, skimming wells can play an important role in augmenting irrigation supplies as well as controlling water logging and soil salinity problems. Skimming wells are designed to restrict the salt concentration in the pumped water to an acceptable limit.

Traditionally, the skimming well configurations such as partially penetrating (single or multi strainer) well, radial collector well etc., have been employed to skim the freshwater. More recent configurations include the compound well systems comprising two closely spaced wells. The screens of these two wells are located at different depths with an objective of reducing the effective upconing. The commonly adopted arrangements are: scavenger and recirculation well systems. The scavenger well system consists of two wells viz. production well and scavenger well, in a single bore hole or side by side. The production well taps the freshwater zone while the scavenger well taps the saline water zone. These wells pump fresh and saline waters from the same site simultaneously without mixing, through two separate discharge systems. The rise of saline water due to upconing caused by pumping from production well is countered by the downconing of the interface caused by pumping from scavenger well. In a recirculation well system the screens of both the wells are located in the freshwater zone. The freshwater is pumped through the production well, and a portion of it is injected back into the aquifer through the recirculation well. The rise of saline water due to pumping of freshwater through production well is countered by the downconing of the interface caused by recharging through recirculation well.

The key factors in developing a sustained skimming technology for a given coastal field are: selection of suitable skimming technique, proper design of well configuration in terms of screen positions, and operation of well in terms of permissible discharge and pumping schedules. Proper design and optimal well operation can be achieved through simulation-optimization models.

It is to be noted that while engineering technologies can prove effective in addressing problems of groundwater quality and quantity in a coastal aquifer system, they are generally more expensive, invasive, and site-specific than the adaptation options of scientific monitoring, assessment and modeling, and, behaviour and institutional approaches.

7.4.4 Minimum Flow in Rivers

River operations and flow management can have a significant effect on salinity. With greater volumes of environmental water available there is greater potential to improve river salinity through increased dilution. Environmental watering can also, in some circumstances, increase salinity. Those circumstances need active management to minimise salinity impacts. The salinity risks associated with flow management therefore need to be identified and managed within the context of broader flow management objectives.

7.4.5 De-siltation of Lakes

The Lakes present along the coastal areas may be desilted to ensure that it is filled in by the fresh rainwater.

CHAPTER 8: COST ESTIMATE

8.1 Preparation of cost estimate:

8.1.1 To work out the total cost estimate of the project in detail, the cost of various sub-heads shall first be estimated in a tabular form.

Format for Abstract of Cost Estimate

(Amount in Rs Cr.)
(Price level. year .....)

A	**DIRECT CHARGES**		**Remarks**
I	**I-WORKS**		
1	A-Preliminary		
2	B-Land		
3	C-Works		
4	K-Building		
5	M-Plantation		
6	O-Miscellaneous		
7	P-Maintenance		
8	R-Communication		
9	X-Environment and Ecology		
10	Y-Losses		
	I-WORKS		
II	Establishment		
III	T&P		
IV	Suspense		
V	Receipts and Recoveries (-)		
	TOTAL DIRECT CHARGES		
B	**INDIRECT CHARGES**		
(i)	Audit & Accounts charges		
	Total Cost including Direct and Indirect Charges (A+B)		

8.1.2 Cost estimate should be prepared on the basis of latest Schedule of rates of concerned State/UT.

8.1.3 Analysis of rates of non-schedule items should be worked out considering the cost of materials, carriage-handling-storing, labour, share cost of equipment involved in execution of work and profit and overhead charges over & above the prime cost of item of work so obtained.

The basic rates of material/hiring charges of equipments/Royalty charges etc. shall be adopted from the latest SoR of concerned state/UT exclusive of taxes and in case the rates are not available, then prevailing lowest market rate shall be adopted based on quotations.

The percentage provision towards profit/overhead/small T&P/water charges/carriage charges/loading-unloading to be considered in analysis of rates shall be adopted from the latest SOR

The GST shall be applied on total amount as per prevailing rates and shown separately in the estimate.

8.1.4 The wages of workers are periodically revised by the State under the statutory labour law. Daily wage rates, therefore, shall be taken as those prevalent in the State at the time of formulation of the project. The daily wages generally fixed by the states after computing wages for 30 days and distributing the same to 26 days. Therefore, provision of weekly rest shall accordingly be finalized. Other hidden charges as per applicable local / statutory labour law shall be provisioned.

8.1.5 For working out the use rates of machinery, the norms for life, depreciation, repair provision etc. should be adopted as per recommendation by the latest IS code 11590/ latest CWC Guide Book on use rate, hire charges and transfer value of equipment and spare parts. Price of various equipment preferably should be taken from SOR of concerned State if available; otherwise the same may be adopted on the basis of recent quotations/ price list of such equipment.

In case of specialized equipments like, barges/tug boats/spud barge for which use rate analysis is not available either in CWC guidelines or State SoR, various component of use rate like ownership cost/fuel consumption shall be judiciously determined based on similarly executed earlier works in nearby area.

The duty factor corresponding to light duty may be adopted for estimating fuel consumption of all marine equipments, irrespective of tide & other effects.

8.1.6 Provision for contingencies and work charged establishment should be considered up to 3% and 2% respectively of the item rates under the C-Works, K-Building and R-Communication sub heads only. These percentage provisions should not be considered on lump sum items and in case the submitted estimate is “contract estimate”.

The contingencies shall also not be considered where there is no scope of variation/unforeseen items like hydro-mechanical works, concrete structures (tetrapods) etc. The percentage provisions of 2% towards W/C establishment shall not be taken, in case provision of supervisory staff/ foremen has already been made in analysis of rate under cost of labour.

8.1.7 Quantity certificate regarding the correctness of quantities as per approved design and drawing should be provided by the project authority from the concerned Chief Engineer or equivalent rank.

8.2 Preparation of detailed estimates of Costs-I-Works: -The various items under this head and detailed sub heads for which estimates should be prepared are indicated below:

8.2.1 A-Preliminary: The provision under this head covers various investigations, surveys, Model tests, studies required for mandatory clearance etc. This shall be based on the actual cost likely to be incurred and shall be limited to 1 to 2% of the total cost of I-works. The cost of preparation of DPR may not exceed 1% of total cost of the project.

8.2.2 B-Land: The provisions under this head cover acquisition of land etc. The provision shall be made as per actual requirements.

8.2.3 C-Works: The provisions under this head cover the civil costs of the all coastal protection works and strengthening of existing works or any similar works etc. This shall be based on detailed cost estimate per km length for typical sections of protection works like sea wall etc.

A separate provision for quality assurance or third party quality inspection may be added under this head.

8.2.4 K-Building: The provision under this head covers the construction of temporary buildings for residential/ Non-residential and stores shed etc. during the construction period of the project. In addition to the cost of buildings, the provision for land development, fencing /boundary walls, security / observation booths, service connection such as water supply / sanitation drainage and electrification may be made as per norms fixed by the State Government. This should be based on the actual cost likely to be incurred and be limited to 2-3% of the total cost of I-works. The cost of store shed shall not be taken in case storage charges are included in material cost or rates are as FOR sites.

8.2.5 M-Plantation: The provisions under this head cover the requirement of plantation to augment the stability of coast. The provisions shall be made on lump sum basis keeping in view the experience of other projects or as per Environment Management Plan (EMP).

8.2.6 O-Miscellaneous: The following provisions are to be kept in this Sub head:

(a) Capital cost of:

(i) Construction power infrastructure subject to prevailing site conditions or provision in SoR/AoR
(ii) Water supply, purification and distribution
(iii)Sewage disposal
(iv)Firefighting equipment

(b) Maintenance and service of:

(i) Electrification
(ii) Water supply, purification and distribution works
(iii) Sewage disposal and storm water drainage works
(iv) Security arrangements
(v) Firefighting equipment

(c) Other items:

(i) Contractor's All Risk Policy
(ii) Visits of dignitaries
(iii) Boundary pillars and stones, distance marks and bench marks
(iv) Misc petty items

8.2.7 P-Maintenance: Considering short duration of coastal work and major items to be executed under contract, the provision under this head may be kept with proper justification and should be limited to 0.5% of total cost of I-works less A-Preliminary, B-Land, O-Miscellaneous, M-Plantation, Q Special T&P and X-Environment & Ecology, Y-Losses on stocks and covers maintenance of all works during the construction period

8.2.8 R-Communication: The provisions under this head cover the construction of approach roads and quarry roads etc. shall be made subject to conditions that no facilities are available at site and provision towards construction and maintenance of road are not taken in Analysis of Rate (AoR) of item of works.

8.2.9 X-Environment and Ecology: The provisions under this head cover the items concerning environment and ecological impact due to coming of the project.

8.3 Sub head II-Establishment Charges: In case works to be executing departmentally, the provision for establishment charges should be kept 8 to 10 percent of I-works excluding B-land. No establishment Charges should be provided if works are to be executed on contract basis. In both case, certificate should be provided by the project authority from the concerned Chief Engineer or equivalent rank.

8.4 Sub head III-T&P: The provision under this sub head covers survey instruments, camp equipments, office equipments etc. A nominal provision of Rs 20-25 lakhs under this sub head may be adequate.

8.5 Sub-head IV-Suspense: Generally no provisions should be made under this sub-head unless necessary and well supported by facts and documentation.

8.6 Sub-head V-Receipt and Recovery: This head is meant to account for estimated recoveries by way of resale or transfer of temporary buildings & vehicles shall be accounted for under this sub head. The recoveries in account of temporary buildings may be taken at 15% of the construction cost of building.

8.7 Audit and Accounts Charges: The provision under this Sub head should be made @ 0.25% of I-Work.

8.8 Miscellaneous points:

8.8.1 Generally, these type of execution of protection works are of short duration and executed through contract and therefore

a) Escalation shall be provisioned based on indices only when completion period for contract work is beyond two years.
b) Nominal provisions under Q-Special T&P shall be provisioned with justifications
c) Y-Losses on stock shall not be taken, as insurance costs are separately provisioned.

8.8.2 Specification of various items mentioned in Bill of Quantities/Estimate shall be concurred by the Designers like size of crates in gabion wall/size of mesh/geo-textile/tetrapod/boulders/compaction factor of filler material in different zones of embankment/sand nourishment etc.

8.8.3 Performance evaluation of the projects would be done by agencies like IIM, IIT, NITs, WAPCOS, State WALMI or any other agency identified by the DoWR, RD & GR / State Govt. Both concurrent and post project performance evaluation should be carried out. Cost of Post project monitoring work should be limited to 2% of the total cost of the project which will be carried out for a period of 5 years after the completion of the project.

CHAPTER 9: BENEFIT COST RATIO

9.1 Methodology of Calculation

Benefit-Cost ratio for salinity ingress prevention schemes shall be calculated as follows or any other economic analysis method.

B. C. Ratio = Total annual damages/Total annual Cost

9.2 Total annual damages:

Total annual damages is to be worked out as follows,

(a) Average actual annual damages on the basis of past 10 years damage data duly certified by concerned authorities, i.e, Department of Drinking Water and Sanitation for loss in availability of drinking water, Revenue Department for land loss and Agriculture Department for loss of crops etc.

Average actual annual damage= Past annual damages/nos of years ---------- (a)

(b) Average anticipated annual damages shall be calculated for a period of economic life of project. While calculating the anticipated annual damages, extent of probable damages like cropped area, loss of availability of drinking water, land use, type of properties etc. shall be duly certified by the competent authority. The annual anticipated damages should be worked out by dividing the total value of the all type of properties, which is likely to be damaged in absence of the project by economic life of project.

Average anticipated annual damage= value of properties likely to be damaged/no of years (economic life of project). ----------(b).

Total annual damage= Average actual annual damage (a) + Average anticipated annual damage (b)

9.3 Total Annual Cost

The annual cost is to be worked out as follows,

i) Interest @ 10% of Capital Cost (Total estimated cost of scheme)
ii) Maintenance @ 5% of Capital Cost
jjj) Depreciation @ 2% of Capital Cost

Thus the annual cost will be 17 % of the total estimated cost of the scheme.

B.C Ratio should not be less than one for economic viability of a scheme**.**

CHAPTER 10: CONSTRUCTION PLAN & MAN POWER PLANNING

10.1 General: The construction planning for works envisaged in any works is a vital component for the timely completion of the works avoiding time and cost overrun. Construction Planning includes

(i) vulnerability/damage assessment,
(ii) Type of measures to be taken,
(iv) Design of structures, construction planning and preparation of DPR,
(v) Administrative approval of DPR and
(vi) Implementation of the works while keeping sufficient time for each activity. Time to accommodate unforeseen issues should also be kept in mind.

Implementation of works include invitation of tenders for various components, site survey, site clearance, etc, mobilization of resources like men, material at the site in pre-organized manner for various works.

10.2 Construction Planning: It is understood that construction planning is the key for in-time completion of any works. It is seen from the past experience that most of the projects are delayed in completion due to lack of proper construction planning.

For a proper completion of a project, the storage and installation of new innovative material for construction for project specific problem need to be executed under well trained guidance and accuracy. The planning for the same needs to be done considering all the situations like working season, monsoon season, land acquisition, site survey and clearance, procurement of materials etc. The Implementation of project may involve following steps.

10.2.1 Invitation of Tenders: Model tender documents for procurement of materials including geo-textile bags, geo-textile tubes, mattress, wire-mesh for various civil works including earth work, boulder work, etc. should be prepared and used immediately after administrative approval of the project.

10.2.2 Procurement of construction material: Construction materials, required frequently in large quantities including boulders, sand, geo-textile bags, geo-textile tubes, mattress, wire-mesh etc. should be procured well in advance to save time. Any additional quantity as per approved DPR may be procured concurrent to execution of works.

10.2.3 Storage of construction material at site: There should be proper space/shed for the storage of construction material. The storage space/shed should be such that, there is no risk of wear-n-tear and theft of the construction material till the works are over

10.2.4 Testing of the material: There should be arrangement of testing of the construction material before the start of the work. Provision for standard testing along with procedure of testing should be made a part of the tender document. All the construction material should possess qualifying standards before construction.

10.3 Construction Equipment/ Plan: Type and nos. of equipment deployed with justification, construction schedule, capacity, fuel consumption, BHP/FHP, twin/single motors etc. along with working cost shall be included. Detailed specifications and working cost of any special plant which is proposed to be employed for construction should be given.

10.4 Construction Material: Results of experiments, if any, bearing upon the suitability of construction materials proposed, types of materials, locations from which obtainable, borrow areas, quantity available, facilities for manufacture, distance of work from the source of manufacture,

nature of haul roads (whether in plains or hilly areas) should all be specified. Basic rates of steel and cement and other materials should also be given. A write up should be added indicating the quantities of key materials required for the project.

10.5 Communication: Average distance of carriage of heavy machinery, cement and steel etc. from the nearest rail head and communication facilities available for carriage of materials and suitability of existing roads and bridges for carriage of heavy plant and machinery should be described. Construction needs for new rail or road links should also be discussed.

10.6 Bar Chart and phasing of the project

10.6.1 Bar chart showing activities related with execution of the project should be appended with the DPR.

10.6.2 Phasing of the project comprising of physical progress along with financial progress should also be given in the DPR.

CHAPTER 11: ENVIRONMENTAL AND SOCIAL IMPACT ASSESSMENT

11.1 Environmental Monitoring Program

The primary aim of environmental monitoring program is to formulate a systematic, site- specific plan for monitoring the environmental parameters within the impact area, during and after commissioning of the project.

11.2 Environmental Impact Assessment (EIA)

The basic objective for Environmental Impact Assessment (EIA) is to predict environmental impact of projects, find ways and means to reduce adverse impacts and shape the projects to suit local environment. The design must be site-specific and based on a clear understanding of the coastal processes for the entire 'sediment cell', the long-term stability or instability of the entire cell and the ecological impacts therein. A comprehensive EIA based on long-term monitoring of the 'sediment cell' has been recommended.

The Ministry of Environment and Forests and climate Change (MoEF &CC) latest notification declaring the Coastal Stretches as Coastal Regulation Zone (CRZ) and regulating activities in the CRZ shall be kept in view.

An EIA report shall have to prepare which should provide clear information on the different environmental scenarios without the project, with the project and with the project alternatives. An Abstract of the EIA shall be appended with DPR.

11.3 Social Impact Assessment

Details of Social benefit, land acquisition and rehabilitation of affected areas/ people, if any may be appended with the DPR.

CHAPTER 12: MAPS AND DRAWINGS

12.1 Clear index map consisting of following in Arc-GIS/Autocad format on the basis of latest satellite imagery should be appended in the DPR.

12.1.1 Shorelines, rivers, creeks, High Tide Line, Low Tide Line, etc.in different colours should be marked in the index map.

12.1.2 Nearby G&D site along with its distance from the start of the project location may be given in the index map.

12.1.3 Nearby Executed works (green colour) and proposed works (Red colour) along with orientation, layout, etc. as well as benefitted area in yellow colour should be marked on the index map.

12.2 Following drawings should be appended in the DPR.

12.2.1 L-section of the river, creek in the area

12.2.2 X-section of the river, creek in the area

12.2.3 L-section and X-sections of the proposed works

12.2.4 Satellite/google images of the project site

CHAPTER 13: ANNEXURE & CERTIFICATES

Following annexure & certificates should be appended in the DPR.

13.1 Minutes of latest State TAC meeting in which the proposal was cleared

13.2 Clearance/No- objection certificate from the State Forest Department

13.3 Certificate regarding past damages from Revenue/Agriculture Department

13.4 Correctness of quantity certificate

13.5 Certificate that separate schemes are not being proposed/planned in the same region

13.6 Certificate of State Finance concurrence

13.7 Recent Site visit report by the regional office of CWC

13.8 Soft copy of the DPR in MS-word and MS-excel format in pen-drive/DVD

13.9 Power point presentation on the proposal

*** Mandatory clearances may be obtained as per the statute of their respective states.**

V. Procedure for Submission of Proposals by State Government

a. The scheme would be implemented generally by Flood Control/ Water Resources/ Irrigation/ Public Works Departments of the State Governments.
b. Managerial Inputs towards financial management, quality control, physical progress, timely completion of the works, etc. shall be the responsibility of the State Governments/ Implementing Agencies.
c. The general procedure(s) of techno-economic appraisal shall be followed for submission and appraisal of projects for getting central assistance.
d. CWC has launched the online platform e-PAMS (Project Appraisal Management System) for the submission and appraisal of the project. The DPRs for all projects shall be submitted by the State Govt/Project authority through the e-PAMS portal only, which will be examined by nodal office (i.e. Coastal Management Directorate, CWC, New Delhi) and will be forwarded to all the other concerned organization(s)/department(s) for further examination of the DPR.

Procedure for Submission, Appraisal and Acceptance for Central Assistance is as follows;

- Preparation of DPR as per CWC Guidelines for Salinity Ingress Management Projects.
- Submission of the Projects to field units of CWC after cleared by State TAC and other State/Central Agencies.
- Field units of CWC forward the DPR to Nodal office in CWC (HQ) for detailed examination after carrying out the preliminary investigation.
- The projects are examined by nodal and specialized units in CWC (HQ).
- However, if the project is externally assisted then the DPR is to be submitted to Deputy Secretary, EA, Department of Water Resources, River Development and Ganga Rejuvenation (DoWR, RD & GR), Ministry of Jal Shakti (MoJS). DoWR, RD & GR forwards the DPR to CWC (HQ) for detailed examination.
- After examination by nodal and specialized units and compliance by Project authority and all the Statutory clearances having submitted by the Project Authority, an appraisal note will be prepared and put up to Advisory Committee of Department of Water Resources, River Development and Ganga Rejuvenation for consideration of techno- economic viability.
- The advisory Committee accepts or rejects the Proposal and if found acceptable recommends the Proposal for investment clearance.
- Proposal for investment clearance is to be submitted by Projects Authorities to CWC.
- The proposal is examined with reference to check list and guidelines issues by DoWR, RD &GR. If it is found acceptable, it is forwarded to DoWR, RD &GR with recommendations.
- The Ministry then considers the same in the Committee for accord of Investment clearance. If found acceptable, investment clearance for the same is issued by Ministry.

VI. Inter-State Aspects

DPR should contain separate chapter on interstate/international aspects discussing details of the following important items and additional items, if any, as relevant to the project.

1. State/countries traversed by the river/Sea.
2. State/countries traversed by the Salinity control structures.
3. Distribution of catchment in states/countries and yields from the catchment of the state/country concerned.
4. Effect of the following on project & of the project on the following
   (a) Interstate/International agreement on sharing of waters, sharing the benefits and costs, acceptance of submergence in the upstream state(s)/ country(ies) etc., if any.
   (b) Interstate/International adjudication, if any.
   (c) Interstate/International aspect of territory, property, etc. coming under submergence, project affected people, rehabilitation, compensation, etc. Prior concurrence of other country(ies)/other State(s) where territory/property is affected by the project should be obtained and appended in the DPR.
   (d) Existing and sanctioned projects (to the extent the information on existing &sanctioned projects can be obtained with reasonable efforts)
   (e) Any other aspect of the project involving Interstate/International problems.
5. Existing riparian use, quantum of water presently utilised, commitments for ongoing projects, plans for future development, balance share of the state/country and proposed utilisation by this project. (Discuss relevant items both for upstream and downstream usages).
6. Whether operation and regulation of the project conform to the 'stipulation made in the Tribunal award/agreement and also the mechanism for such operation.
7. In case of addition/alterations for existing project involving submergence in other states and additional utilisation of water, concurrence of the concerned states is to be included.
8. Details regarding consumptive use of sea water in case of desalination plant.
9. While giving details of water diverted for cooling/drinking/industrial purpose, quantity diverted for such use shall correspond to gross requirement (not actually consumed) and accounting return flow into the river. Where there is tribunal decision, the details of water diverted for cooling/drinking/industrial purpose from the project, the gross quantity and also quantity for purpose of water use account in terms of tribunal decision shall be stated.
10. To take final decision whether a project fall in purview of inter-state aspect, State/UT Govt. may consult with concerned Directorates of CWC, New Delhi.

VII. Monitoring and Evaluation

a. The State Governments shall undertake regular maintenance of works and even during execution of works.

b. The groundwater scenario of the pre-project and post-project period should be monitored at an appropriate interval of space and time (Core Zone & Buffer Zone). Observation wells (existing wells or purpose built piezometers) may be established such a way to represent the sea water intruded area, fresh water area and peripheral areas of the sea water – fresh water interface to study the shifting of the interface over space and time. If existing wells are established as observation wells the well inventory details including the aquifer zones tapped should be collected.

c. Water level and water quality are to be monitored continuously starting from the pre-project period and shifting of the interface may be deciphered to evaluate the efficacy of the structures constructed under the project. The water quality parameters to be monitored like EC, Chloride, bicarbonate, isotope analysis etc and monitoring frequency are to be specified in the DPR.

d. Cost of Post-construction monitoring work may be limited to 2% of the total cost of the project which will be carried out for a period of 5 years after the completion of the project.

e. Monitoring of the schemes will be carried out by the Central Water Commission (CWC) and Ganga Flood Control Commission (GFCC) in their respective jurisdiction and as envisaged under the respective schemes/ Programme.

f. As required, the Department of Space/ NRSA would be associated in monitoring of physical progress of the schemes through Remote Sensing Techniques.

g. The above central organizations would play an active role at formulation stage of the proposals by the state governments in their respective jurisdiction and provide necessary guidance in preparation/ submission of the proposals in time for appraisal and release of central assistance.

h. The monitoring teams (of CWC/ GFCC) would monitor the physical and financial progress of the schemes. They would conduct sample checks on the quality of construction materials like bricks, stones, geo-textiles, compaction of soil, etc. and quality of works in general during the field visits. The samples taken/ witnessed at site by the teams would be got tested for quality checks and results thereof would be reflected in the monitoring reports.

i. Release of central assistance would be recommended by Department of Water Resources, River Development and Ganga rejuvenation under Ministry of Jal Shakti, GOI to the Ministry of Finance based on the recommendations of CWC/GFCC submitted in the prescribed formats as envisaged in the respective Schemes/ Programme.

j. Performance evaluation of the completed works would be done by agencies like IIM, IIT, NITs, WAPCOS or any other agency identified by the Department of Water Resources, RD & GR under Ministry of Jal Shakti.

k. The suggestions by an Expert Committee on Performance evaluation of the completed works shall be taken into account to fix performance benchmarks for the structures to be constructed.

VIII. Completion Report

On completion of works / projects, the State Governments shall, in respect of each work / project, submit a completion report along with a consolidated Utilisation Statement giving a brief account of works approved, works actually carried out, Total expenditure on the project, Centre Share released (with reference number of release order), Central Share utilized (giving details of UCs submitted), State Share spent and reasons for delay, if any.

Annexure-I

Composition of the Committee constituted for preparation of Guidelines for preparing DPR & New scheme for Salinity Ingress Management Projects and setting up of National Centre for Scientific Study of Salinity Ingress in Delta Region

1.	**Chief Engineer (P&D), CWC, New Delhi**	**Chairman**
2.	Member (Technology Transfer & Water Quality), CGWB or his representative	Member
3.	Chief Engineer (S.G.) & Additional Secretary, Narmada Water Resources, Water Supply & Kalpasar Department, Govt. of Gujarat/his representative	Member
4.	Director(Hydrology-Central),CWC, New Delhi	Member
5.	Director(BCD-NW&S),CWC, New Delhi	Member
6.	Director(Embankment-South), CWC, New Delhi	Member
7.	Scientist 'E' /Head dealing with Coastal Engineering in CWPRS, Pune	Member
8.	Dr. Anupama Sharma, Scientist E, NIH, Roorkee	Member
9.	Director, Beach Erosion Dte, CWC, Kochi	Member
10.	Director (Coastal Management Dte.), CWC, New Delhi	Member- Secretary

Identification of Key Persons/ divisions for preparation of various Chapters/ Section of the Guidelines

Chapter No.	Name	Organisation/ Department
I	Background	Coastal Management Dte, CWC, New Delhi & Beach Erosion Dte, CWC, Kochi
II.	Scope of the Scheme	
III.	Affected Zones of Salinity Ingress	
IV.	Content of DPR	
1.	Introduction	Coastal Management Dte, CWC, New Delhi & Beach Erosion Dte, CWC, Kochi
2.	Salient Features	
3.	Executive Summary	
4.	Hydrology	Hydrology (Central), CWC, New Delhi & NIH, Roorkee
5.	Hydro-Geology	**CGWB**
6.	Survey & Field Investigation	**CWPRS, Pune**
7.	Design of Works	• Salinity Control Structure: – Embankment (NW&S), CWC, New Delhi, BCD (NW&S), CWC, New Delhi, Govt. of Gujarat and CWPRS, Pune. • Recharge Techniques: – CGWB & NIH, Roorkee. • Management Techniques – NIH, Roorkee & CGWB
8.	Coast Estimate	Coastal Management Dte, CWC, New Delhi & Beach Erosion Dte, CWC Kochi
9.	Benefit Cost Ratio	
10.	Construction Plan and Man Power Planning	
11.	Environmental & Social Impact Assessment	
12.	Maps and Drawings	
13.	Annexure & Certificates	
V.	Procedure for Submission of Proposals by State Government	Coastal Management Dte, CWC, New Delhi & Beach Erosion Dte, CWC Kochi
VI.	Inter-State Aspect	
VII.	Monitoring and Evaluation	
VIII.	Completion Report	

Annexure-II

List of Indian Standard Codes and Specification mentioned in the Guidelines.

Sl.No.	BIS Codes	Description
1.	IS 5477 (Part-I,II,III&IV)	Methods for fixing the capacities of Reservoirs
2.	IS 11223	Guidelines for fixing Spillway Capacity
3.	IS 13094:1992	Selection of ground improvement techniques for foundation in weak soils
4.	IS 6966-1:1989 (R 2005)	Hydraulic Design of Barrages and Weirs.
5.	IS 4997:1968 (R 2004)	Criteria for design of hydraulic jump type stilling basins with horizontal and sloping apron
6.	IS 456:2000	Design of Plain and Reinforced Concrete Structures (General)
7.	IS 457:1957 (R 2005)	Code of Practice for General Construction of Plain and Reinforced Concrete for Dams and Other Massive Structures
8.	IS 12169:1987	Design Criteria for Small Embankment Dams
9.	IS 8237:1885	Pitching of Stone
10.	IS 1893:2002 (Part-I)	Seismic Coefficient
11.	IS 12094	Guidelines for planning and design of River Embankments (Levees)
12.	IS 8835:1978	Guidelines of Planning and design of drainage works
13.	IS 8535:1978	Guidelines of Planning and design of surface drains
14.	IS 11130	Criteria for Structural design of Barrages and Weirs
15.	IS 11150	Construction of Concrete Barrages
16.	IS 1892:1979	Code of Practice of Subsurface Investigation for Foundation
17.	IS 11590:1995	Guidelines for working out unit rate cost of the construction equipment used for river valley projects
19.	IS 2720	Indian Standards on methods of test for soils
20.	IS 14262:1995	Planning & Design of Revetments
21.	IS 6955:2008	Subsurface Exploration for Earth and Rock fill Dam
22.	IS 15662:2006	Geological Exploration for Gravity Dams and Overflow Structures
23.	IS 6065:1985 (R2004)	Recommendations For the Preparation of Geological and Geotechnical Maps for River Valley Projects
24.	IS 8835:1978	Guidelines for planning and design of surface drains
25.	IS 6531:1994	Criteria for Design of Canal Head Regulators

Annexure-III

Success Story-(1) Reclamation of Salinity Ingress in Coastal Area of Gujarat State under Rashtriya Krishi Vikas Yojana (RKVY) Year 2015-16

The Success story is categorized under agriculture in the area of soil & water conservation. The soil is the great connector of lives the source and destination of all. It is the healer and restorer, without proper care for it we can have no life. Majority poor people lives in areas of saline soil.

Problem of the Area:

The major problems in coastal areas are –

- Land is highly saline.
- Land subjects to the influence of tidal waves and periodical inundation by tidal water.
- Shallow water table enriched with salts contributes to increase soil salinity during winter and summer months.
- Heavy rainfall resulting in waterlogged condition during kharif season.
- Poor surface and sub-surface drainage condition.
- Lack of good quality of irrigation water and acute salinity during rabi season.
- Limited introduction of high investment technology.

The Story is about farmers who are facing the problems of salinity ingress in sea area of coastal zone of Gujarat State. Farmers of area like Bharuch, Bhavnagar, Morbi, Surendranagar, Devbhumi Dwarka etc., face problems of high salinity in soil. 15 coastal districts have been selected for reclamation, considering the severity of salinity problem & demand of farmers as well as of villagers of coastal zone. Considering sizable area affected by coastal salinity and need for its checking this special project has been proposed for the year 2015-16.

This is a special project for reclamation of problematic area and bringing it under cultivation. A total area of 12,100 ha in 15 coastal districts has been selected for reclamation, considering the severity of problem and demand of farmers as well as of villagers for this project Village community participated in this project.

Main components carried out in the project is (1) Salinity Prevention Structures (2) Recharging Structure and (3) Soil Management aspect.

Ingress of sea water in arable and non-arable land in coastal area is checked by salinity prevention structure and Recharging structure. The salinity affected land will be reclaimed by soil management aspect.

Objective / Aims of the project:

The project was started with the objectives as below:

- To check the seawater intrusion and ingress by salinity ingress prevention structures.
- To increase the rainwater recharge potential of the area by constructing recharge structures and field bunding.
- To improve the condition of soils by proper soil salinity management techniques.
- To improve the ground water quality of the area.
- To increase the irrigation potential of the area.
- To increase the productivity of agricultural crops in the area.
- Making rehabilitation of the highly saline waste land.

- To improve the socio economic condition of the population of the project area by casual employment to laborers and checking their migration and increasing use of natural resources.

Key Result:

All the farmers and village panchayats covered under coastal salinity project are benefited due to prevention of salinity affected barren land ingress project under cultivation. Productivity of land as well as agriculture production also increased. A Total of 4437 ha area was treated under this project whereby 90 farm ponds, 132 Sim talawadis, 41 Water Harvesting Structures, 1,11,002 Running Meter Reclamation bund, 27 Percolation Tanks & 6 Village ponds were constructed. So that with Impounding / Recharging 3.00 lakh Cubic Meter water, useful for supplementary Irrigation for 1216.20 ha area of Land.

Impacts:

- Salinity ingress in project area reduced.
- Quality of Soil in project area improved.
- Migration of villagers were checked.
- Additional area came under Rabi crops.
- Area came under cash crop like Cotton and Pulses from traditional crops like Jowar and Bajara.
- Annual income of farmers increased.

Department: Gujarat State Land Development Corporation Ltd.
(Government of Gujarat Undertaking)
(Sources:http://rkvy.nic.in/static/NewSucessStory.aspx)

Success Story-(2) Kharland scheme in Maharashtra

The Khar lands that occur along the sea coast and creeks are unfit for cultivation mainly due to salinity. The sea water enters through the creeks during high tides and submerges large areas of cultivable land. These periodical inundations render the land progressively saline and in time make it completely unfit for growing any crop. The Khar lands in Maharashtra do not have any other source of irrigation and cultivation in the area is possible only in Kharif season

Remedial Measures

The state of Maharashtra established Kharland Board in 1948 for Kharland development works.The Government of Maharashtra later dissolved the Kharland Board and started taking up the works of construction and maintenance of Kharland Development by enforcing the Maharashtra Kharland Development Act-1979. The Schemes proposed have been implemented by Kharland Development Circle. Government of Maharashtra developed the Master Plan of Kharland Development Schemes in 1981-82 and planned to reclaim 49120 hectares of Kharland through 575 Kharland Schemes along creeks and sub-creeks.

Construction of Kharland Bunds: Through construction of embankments along the banks of creeks, the tidal waters are restricted from entering into and submerging the agricultural lands. The flood water from upland area is allowed to go into the sea through the cross drainage works constructed in the embankments. One way gates are provided to the cross drainage works in order to restrict the saline water from the sea to enter into the agricultural lands.

Benefits of the remedial measures

The following benefits are accrued from the remedial measures adopted by Maharashtra.

Environmental Aspects

- Prevention of salinity ingress occurring through creeks.
- Freshwater recharge
- Stoppage of saline water from entering into adjoining fresh water drains.
- Ecological balance maintained by enriching area under mangrove vegetation on creek side.
- Creation of better environment for fish breeding on creek side in mangrove area.
- The embankments also restrict the coastline erosion due to tidal surges.

Socio-Economic Benefits

- Help poor farmers with small land holdings to take paddy crop on the protected areas including fruits, vegetables and other useful crops.

- By improving agriculture system, yield of paddy can be increased; increase in employment avenues and economic status.
- Having provided necessary support and confidence in staying at their native places, by means of protection through the saline embankments, migration of local population to other places in search of better livelihood is minimized.
- To protect the villages near coastal area from floods, cyclone, tidal surges.
- To protect the people near the coastal areas from the effects of Tsunamis and Cyclones.
- To protect the property of the people from the effects of Tsunamis and Cyclones.
- To protect the drinking water from salinity ingress.
- To provide emergency exit at the time of Tsunamis and Cyclones.

Annexure-IV

SALINITY INTRUSION MANAGEMENT – INTERNATIONAL EXPERIENCES

The wetlands have been manipulated for different purposes since time immemorial. For instance, in Europe, the use of dikes and tide gates to convert estuarine wetlands into agricultural lands and to allow urban development on low-lying coastal zones began in the seventh century and was common practice by the eleventh and twelfth centuries. This type of land conversion has occurred in other continents as well and is the single greatest reason for the destruction of wetlands worldwide. Along the coast of northwestern North America during the past two hundred years, dikes and levees have been built to drain tidal wetlands, both to convert them into agricultural land and to protect flood-prone areas.

Coastal areas all over the world have been affected adversely by the problem of salinity ingress. Saline water intrusion has affected surface water as well as ground water resources. In the case of surface water, intrusion may be detectable and accordingly situation may be improved by adopting suitable protection measure; but in the case of ground water salination, the monitoring as well as protection measures are not so straightforward.

- **Salinity Intrusion Management in Coastal regions of North America**

In the continent of North America, this problem persists in coastal regions with different degree of extent at different places. The variable hydrologic characteristics and the different history of ground water withdrawals have contributed to the different patterns of salinity intrusion in the continent.

In North America, numerous engineering and regulatory approaches have been adopted to counter the problem of ground water salination. Most common approach is to reduce the rate of pumping in the coastal areas or to move the location of withdrawal wells further inland. Reductions in coastal withdrawals allow groundwater levels to recover from their stressed levels, and fresh groundwater to displace the intruded saltwater. The successful implementation of such practices can be seen in Central New Jersey.

On the Atlantic Coast in southeastern Florida, artificial recharge technique is extensively used. Artificial recharge can be accomplished through injection wells or by infiltration of freshwater at land surface; and, thus created network of injection wells filled with fresh water acts as a hydraulic barrier to saltwater intrusion.

In addition to these conventional methods, some innovative approaches are also used. ASR (Aquifer Storage Recovery) systems have been developed, which store additional imported water during wet years and extract the additional groundwater during dry periods to fulfill the demand of fresh water. These systems are developed in New Jersey, Virginia, South Carolina, Florida and California. Desalination systems, which use reverse osmosis membrane to remove salts from the water, are being used at some places, viz. City of Cape May, New Jersey etc, in North America. Desalinated water is further blended with the fresh water, and hence, increasing the fresh water availability in the region.

Multi-component strategy in the State of Georgia, USA*

'In response to the saltwater contamination and related water-supply issues, the State of Georgia has developed a comprehensive plan to stabilize or halt saltwater intrusion into the Upper Florida aquifer (Georgia Environmental Protection Division 2006). The basis of the plan is the establishment of three management sub-regions within the state's coastal zones, with each sub-region having a varying degree of vulnerability to saltwater intrusion. Within the area closest to Hilton Head Island, the plan includes restricting withdrawals from the Upper Floridan aquifer to 2004 pumping rates and eventually reducing withdrawal rates within the area by 2.2×10−1m3/s (5 Mgal/day). The plan also encourages blending of groundwater and surface-water sources to meet increased demands within this area. In the Brunswick area, the plan prohibits new wells within the area of saltwater contamination and management of existing withdrawals to avoid further expansion of the saltwater plume. The plan also calls for the implementation of water-conservation, water-efficiency, and water-reuse strategies within the entire coastal zone of the state, and continued monitoring of groundwater levels, chloride concentrations, and streamflow within the coastal zone to determine how the hydrologic system responds to management actions.

* Paul M. Barlow & Eric G. Reichard, Saltwater intrusion in coastal regions of North America, Hydrogeology Journal · February 2010.

- **Israel's Experiment in Desalination**

Israel, with a coastline length of around 270 km, is leading in the world to combat the fresh groundwater shortage crisis using advanced technologies. Israel's water demand outstrips available water from conventional resources that are provided by the natural replenishment. Tremendous pressure on fresh water supply forced the Israel government to choose a different water management plan.

Sea water and the coastal / mountain aquifers being the main source of supply of water, Israel has achieved a sustainable water consumption level, providing for all the water needs of the country via innovations that have involved overcoming extensive engineering, biological and logistical challenges. Instead of using various measures for preventing salt water intrusion in ground water, they focused instead on the desalination of the salt water to meet their fresh water demand. In fact, they have adopted a multistage approach to fight salinity in the country, and have simultaneously used various approaches to avoid salinisation and its negative effects, such as reduction of salt in supplied water, reduction of salts added during domestic and industrial use of water, proper water resource management such as release of part of water resources to sea, first-flush release etc, proper drainage system, soil conditioning, pioneering work in drilling, exceptionally deep wells, reaching 1500 meters and pump settings as high as 500 meters, etc.

Driven by necessity, Israel is learning to squeeze more out of a drop of water than any country on Earth, and subsequently, Israeli researchers have pioneered new techniques in drip irrigation, such as moisture sensitive automated drip irrigation directly to plant roots, and development of new crop strains that provide 10 times higher yield with the same amount of water. They have developed resilient well systems for African villages and biological digesters than can halve the water usage of most homes. They have developed a nationwide water conveyance system to deliver water

throughout the country from the natural reserve in the north. Almost all the domestic waste water is being treated and reused for irrigation in the agriculture sector.

Israel experimented with seawater desalination almost 50 years ago, building a pilot plant on the Tel Aviv beach. More recently, the world's largest seawater reverse osmosis plant was commissioned at Hadera in 2009. Three large scale seawater desalination plants and some smaller brackish water desalination facilities desalinating brackish water from ground water wells rather than sea water provide about 320 MCM of Israel's potable water requirements to all sectors. This volume is approximately 42% of the country's domestic water requirement.

Israel's water management approach has been supported by a vigorous R&D programme, which has been responsible for close to 250 water technology companies in Israel. Worldwide, Israeli companies have installed more than 350 desalination plants in nearly 40 countries, which is a testament to the country's leadership in this field. Israel now fulfils around half of its domestic water demand from desalination, and that has helped to turn one of the world's driest countries into the region which has more water than it needs.

Annexure-V

Important Field Parameters and Frequency of Data Collection

Parameters	Depth (m)	Frequency	Remarks
Current in sea	Near-shore approx .10 m water depth	30 minutes	21 days data collection over the vertical each during pre-monsoon and post monsoon seasons.
Tide	Near-shore approx .10 m water depth	30 Minutes	-
Riverine Data	Near-shore approx .10 m water depth	Thrice a day (during high tide, low tide and mid tide), twice in a month (once during the Spring Tide & once during Neap Tide), once during Pre-Monsoon, twice during the Monsoon and once again during post-Monsoon	Location of the data collection site should be close to the inlet so that the tidal influence on river should be taken care of in the data collection activity .
Rainfall /Wind/ Relative Humidity	NA	15-30 Minute	4 sensors -Wind (Speed and direction), Temperature, Humidity and Rainfall .
Beach Profile	NA	Monthly	For a very long straight stretch of a beach, it should be taken for 1 km with transact spacing at 100m .For a stretch with some significant coastal features, the transact spacing should be varied accordingly . In such cases, for a stretch of less than 1 km, transact spacing should be kept as 100m, for 1 to 5 km stretch, it should be kept as 500 m and for a stretch of more than 5 km it should be kept as 1 km.
Bathymetry	Upto 10 m water depth	Once during Pre-Monsoon & Once during Post-Monsoon	-
Shoreline	NA	Monthly	-

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