National Centre for Coastal Research (NCCR)

Gap Analysis for Preparation of DPR for Kalpasar Dam

Inception Review

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List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ADB	Asian Development Bank
ALARP	As Low as Reasonably Practicable
ALS	Accidental Limit State
BIS	Bureau of Indian Standards
CAPEX	Capital Expenditure
CBIP	Central Board of Irrigation and Power
CFD	Computational Fluid Dynamics
CIfA	Chartered Institute of Archaeologists
CIFRI	Central Inland Fisheries Research Institute
CIRIA	Construction Industry Research and Information Association
CWC	Central Water Commission
DPR	Detailed Project Report
EIA	Environmental Impact Assessments
EPP	Emergency Preparedness Plan
ESIA	Environmental and Social Impact Assessment
EWS	Early Warning System
FAO	Food and Agriculture Organization
FEE	Functional Evaluation Earthquake
FHWA	Federal Highways Administration
FSL	Full Supply Level
GTS	Great Trigonometric Survey
HAT	Highest Astronomical Tide
ICOLD	International Commission on Large Dams
ICOMOS	International Council on Monuments and Sites
IFC	International Finance Corporation
GSDMA	Gujarat State Disaster Management Authority
IITM	Indian Institute of Technology Madras
InSAR	Interferometric Synthetic Aperture Radar
INTACH	Indian National Trust for Art and Cultural Heritage
IPCC	Intergovernmental Panel on Climate Change
LAT	Lowest Astronomical Tide
LiDAR	Light detection and ranging
M&E	Mechanical and Elec
MASL	Meters above sea level
MCE	Maximum Credible Earthquake
MCM	Million Cubic Meters

MDE	Maximum Design Earthquake
MHWN	Mean High Water Neaps
MHWS	Mean High Water Springs
MLWN	Mean Low Water Neaps
MLWS	Mean Low Water Springs
MSL	Mean Sea Level
NCCR	National Centre for Coastal Research
NCE	No Collapse Earthquake
NIOT	National Institute of Ocean Technology
NOAA	National Oceanic and Atmospheric Administration
Nr	Number
NWL	Normal Water Level
O&M	Operation and Maintenance
OBE	Operating Basis Earthquake
OPEX	Operational Expenditure
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PPP	Public Private Partnership
RAP	Resettlement Action Plan
RCP	Representative concentration pathways
RTE	Reservoir Triggered Earthquake
SCADA	Supervisory control and data acquisition
SDG	Sustainable Development Goals
SEE	Safety Evaluation Earthquake
SLS	Serviceability Limit State
SPS	Safeguard Policy Statements
ToR	Terms of Reference
ULS	Ultimate Limit State
UNESCO	The United Nations Educational, Scientific and Cultural Organization
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USEPA	U.S Environmental Protection Agency
US-FDSC	US Federal Dam Safety Commission
WB	World Bank

1 Introduction

The Consultant, Arup, teamed with HR Wallingford, UK, has been commissioned by the National Centre for Coastal Research (NCCR) on 14 June 2021 to perform a review of 31 completed studies on the Kalpasar project and undertake a gap analysis.

According to the contract the following are the expected deliverables:

1. Inception Report.
2. Draft Review Report that will comprise a review of the completed studies, provide comments and recommendations for development of the design, include actions to be taken for areas of concern as well as recommend further investigations and analyses to be carried out.
3. Final Review Report following receipt of a single consolidated set of comments from NCCR.

The NCCR shared the completed studies with Arup and HR Wallingford on 23 June 2021 and then three ongoing studies on 3 July 2021. A list of the reports received is presented in Appendix 1.

To better manage the review process, we have subdivided the tasks into the following components:

A) Dam Engineering.

B) Estuary Water Management & Quality.

C) Geotechnics/Geology and Seismology.

D) Marine & Estuary Environmental Review.

This is the Inception Report; the report comprises:

- Section 1: Introduction (this section).
- Section 2: The background to the project.
- Section 3: The methodology and design criteria against which the reviews will be carried out.
- Section 4: Selected initial comments and gaps on the reports reviewed.
- Section 5: Background to the risk based approach for undertaking the gap analysis.
- Section 6: Other issues.
- Section 7: Lessons learned on two similar projects, namely:
  - Saemangeum Tideland Project, South Korea.
  - Cardiff Bay project, UK.

2 Project description

2.1 Proposed project - Background

Government of Gujarat, India, proposes to construct a dam across the Gulf of Khambhat to create a freshwater reservoir by storing the run-off of 10,000 million cubic meter water from rivers Sabarmati, Mahi, Dhadhar and Narmada.

The location map of the proposed project is shown in Figure 2.1.

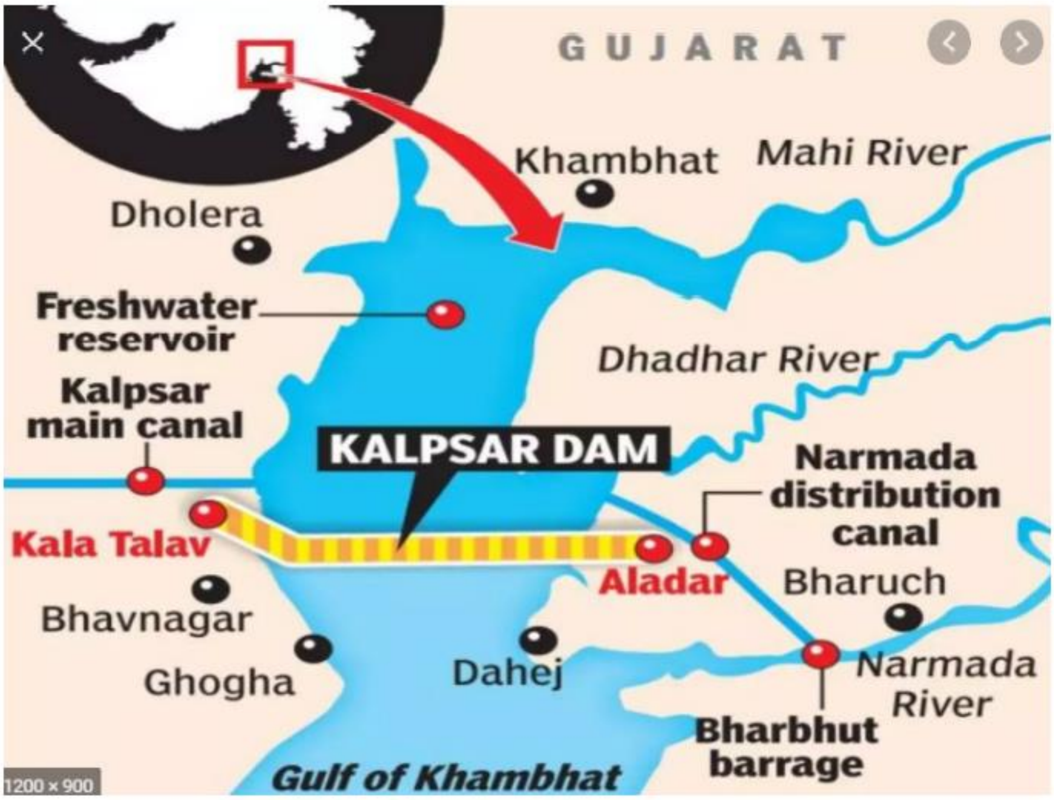


Figure 2.1: Geographical Location of Kalpasar Project

The Kalpasar project, known as the Gulf of Khambhat Development Project, involves the construction of around 30 km long dam across the Gulf. This will connect Bhavnagar and Dahej, through a transport corridor across the dam, which will reduce the distance between Saurashtra and Bharuch. The dam will also create a large freshwater lake by harnessing the excess waters of the Narmada through Narmada Diversion Canal, Mahi, Sabarmati and Dhadhar rivers. After decades of scientific and engineering investigations, the tentative layout of the proposed Kalpasar dam is shown in Figure 2.2.

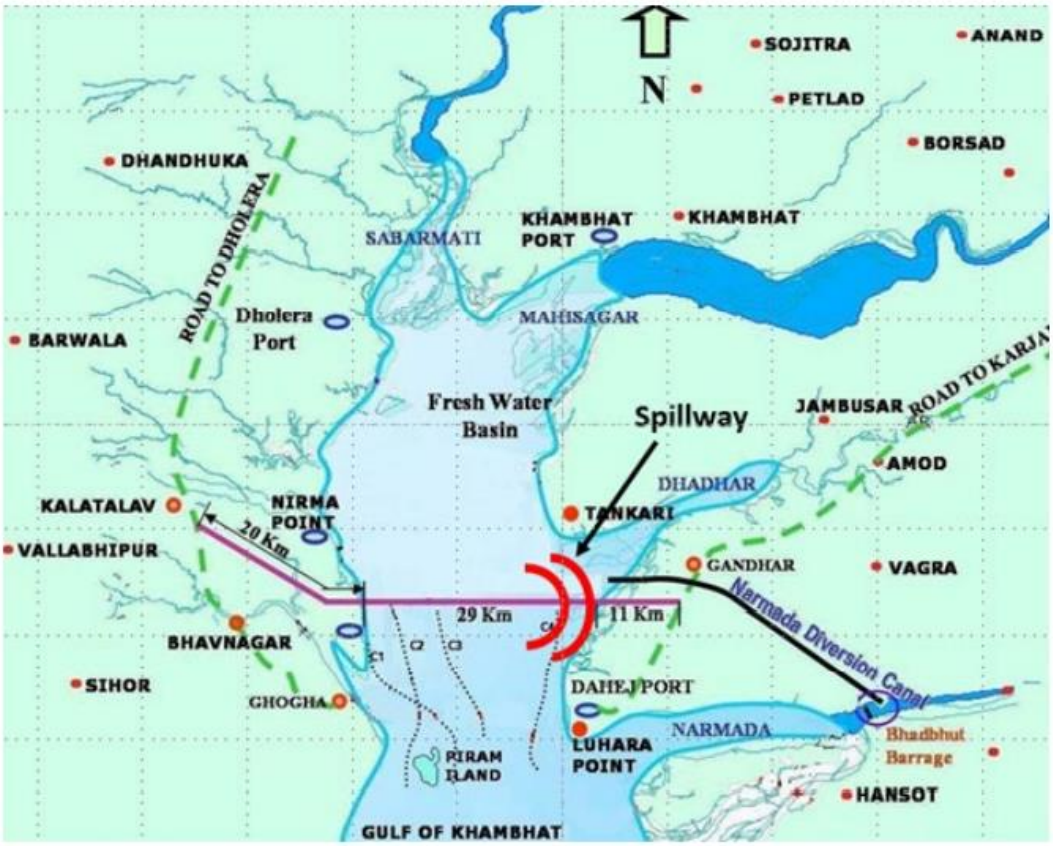


Figure 2.2 Location of Kalpasar Dam

The Kalpasar department has evolved a conceptual design based on geophysical, geotechnical, topography, bathymetry and oceanographic surveys conducted at the study area, feasibility studies by engaging various national, international agencies, consultants. A preliminary cross section of the dam is shown in Figure 2.3 below.

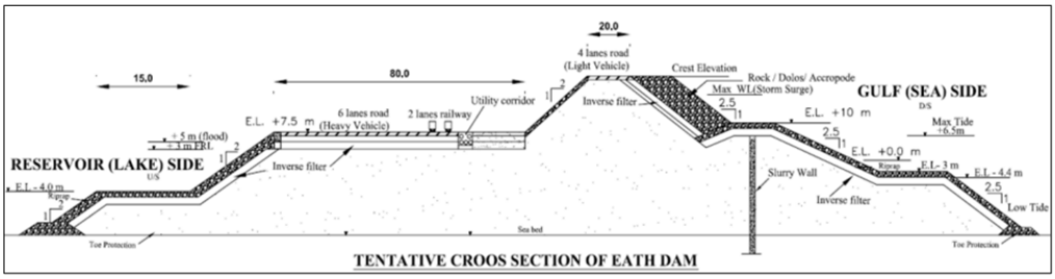


Figure 2.3 Preliminary proposed cross section of the dam

The Government of Gujarat has entrusted the preparation of Detailed Project Report (DPR) to NCCR. NCCR shall prepare the DPR based on studies carried out by various organizations and consultants in line with the Central Water Commission (CWC) guidelines (see reference 1). One of the major components of the DPR is the preparation of Detailed Design Report. NCCR commissioned services of a technically established institution for the preparation of the Detailed Design Report.

2.2 Background to current option selection

Report 30 "Synopsis of the environmental and socioeconomic aspects of the various studies related to Kalpasar project" (see Appendix 1) refers to various options considered. These are summarised in Chapters below.

2.2.1 Tidal power and freshwater

The Pre-feasibility Study on the Project considered three specific development alternatives as follows.

- Alternative 1: freshwater storage reservoir only.
- Alternative 2: combined freshwater storage and tidal power production.
- Alternative 3: tidal power production only.

Of these three alternatives, the project for combined use of freshwater storage and tidal power production (Alternative 2) was selected.

Similarly, three alignment alternatives for the construction of the dam were also considered. These were:

- Ghogha-Dahej (without Narmada inflow).
- Ghogha-Dahej-Hansot (including the mouth of Narmada river).
- Northern alignment at the latitude of Tankari point.

Of the three alignments, the alignment that includes the Narmada's mouth (Ghogha-Dahej-Hansot) was selected, as it was considered most favourable for tidal power production.

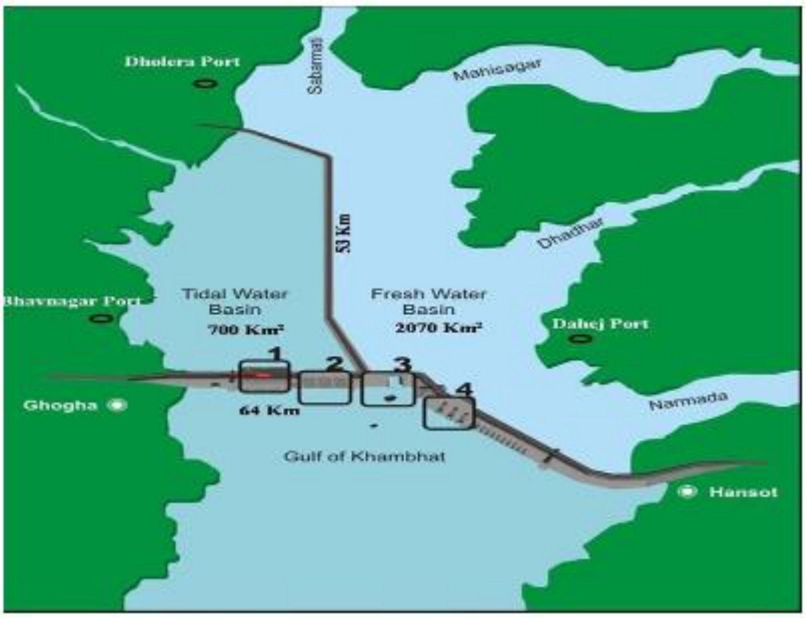


Figure 2.4 The first alternative with a tidal basin

The following summarises the key features of this alignment:

- A 62.9km long dam (28.9km Gulf closure and 34.0km Narmada closure) between Ghoga (west bank of the Gulf) and Hansot (mouth of Narmada estuary) through Luhara point south of Dahej (east bank of the Gulf).
- The crest elevation of the dam was to be GTS +13m.
- The dam would result in the creation of a freshwater reservoir area of 200km^2 and a single tidal basin area of 500km^2.
- It would also create a spillway at the Narmada mouth with 65 discharge openings and would have two ship locks: one in the tidal basin part and the other in the freshwater reservoir part.
- It would generate tidal power comprising 200 turbines and have sluices for a tidal basin area of 500km^2.
- The total cost was estimated at Rs. 19,253 crore, inclusive of direct, indirect and overhead costs.
- The development potential of the project was also considered, including the following:
    - Availability of 12,552 Mm^3 of water assuming that upstream utilisation would be 80 per cent.
    - Annual tidal power production of 12,000 GWh with an installed capacity of 5000MW.
    - Reclamation of 1,19,000 ha land area of which 71,000 ha to be for agriculture and additional 9,856 tonne freshwater for fishery production.
    - Reduction of transport and travel distance between Saurashtra and South Gujarat by about 200 km.
    - Port development by converting two work harbours, one each on west and east banks.

Specific Study Groups suggested several modifications. These included:

- An alternative concept of a double-basin system, which was included for consideration.
- An extended tidal basin area of 700 km^2 was adopted and the installed capacity was increased to 5,880MW with 12,130 GWh energy production annually from the project.
- A shortened Gulf closure dam, from 28.9km to 20.5km, to provide space for a tidal power block in the deep water section.
- A suggestion for the dam alignment at the Narmada river mouth was revised to accommodate flood flows and silt loads. According to the suggestions:
    1. The distance between the main dam and the Dahej bank of the Gulf should have a clear passage of not less than 5,000m.
    2. The clear distance between Luhara point and the proposed Narmada closure dam should not be less than 3,000m.

3. The Narmada spillway should be located in the existing main flow channel of the river.

4. The dam alignment for a single tidal basin scheme resulting from the above to have a total length of 64.16km, comprising the Gulf closure dam length of 20.46km and the Narmada river dam length of 43.7km.

5. The crest level of the dam, assessed at GTS +13m in the pre-feasibility study to be revised at +14.5m MSL.

The Specific Studies also revised the development potential of the project:

- Average annual freshwater availability of 12,248 Mm^3 between a water storage level of +5m MSL and -5m MSL in the reservoir (which was almost equal to the stated average yearly inflow volume of 12,317 Mm^3).
- Water utilisable for irrigation amounting to 5.461 Mm^3 (at 77 per cent dependability); irrigation to 10,54,500 ha, assuming gross water requirement of 0.55m and cropping intensity of 105.45 percent.
- Water supply for domestic use amounting to 900 Mm^3, and that for industrial use 500 Mm^3.
- Annual energy generation of 12,130 GWh for an installed capacity of 5,880MW (with 168 turbines and 200 sluices).
- Land reclamation of 1,19,00 ha between +6.5m MSL and +8m MSL.
- Freshwater fishery production.
- Facility of a 4-lane road on top of the dam, bringing a significant reduction in transport distance (about 200km) between the Saurashtra region and the east coast of Gujarat.
- Development of new ports downstream of the closure works, by converting work harbours on both flanks of the Gulf into permanent ports, while maintaining the status quo in respect of the existing Bhavnagar and Dahej ports falling inside the dam enclosed Gulf area.

2.2.2 Origin of alternative V - Dropping the option of tidal power generation

Consultant reviews of the past study reports (Reconnaissance Study, Pre-feasibility Study, Six Specific Studies, Investigations by NIOT, Observations of Expert Group of Geotechnical and Seismic Studies, views of subject-matter expert on tidal power production and industrialists' views on PPP route for project implementation) provided the following suggestions:

1. Combining a saline tidal basin with a freshwater reservoir would threaten freshwater sustainability in case of high salt leakage from the tidal basin.

2. The concrete structure of tidal power block is not a suitable option as it may lead to liquefaction of the foundation material and could induce earthquakes given the seismic nature of the Gulf.

3. It may be difficult to construct a tidal power block of sufficiently reliable design, given the complexity required, involving caissons weighing 60,000-100,000 tonnes. To date, there is no proper model.
4. The production cost of tidal energy is high, and the cyclical tidal energy produced in large quantities will be difficult to absorb into the regional power system since peak and off-peak demands, which vary, do not fit easily with tidal energy production.
5. The project cost gets greatly enhanced with the inclusion of a tidal power component which is around 64 percent of the total project cost; financial support will be difficult to obtain from public/private sources for this project.
6. The creation of a saline tidal basin on the Saurashtra side would aggravate salinity ingress onto land and ground water, besides cancelling the benefits of land recovery and development.

In view of these factors, the consultants recommended delinking the tidal power component from the proposed Gulf of Khambhat Development Project and focusing exclusively on construction of the freshwater reservoir project, alongside other compatible multiple uses (transport, port, township, agriculture, fishery and others).

2.2.3 Shifting of Dam Alignment

The Expert Group of Geotechnical and Seismic Studies headed by Dr. K. N. Mathur, Director General (Retd.), Geological Survey of India (GSI), reviewed the past studies /investigations, and inferred some crucial facts and notes. It noted that:

- The seabed substrata of over 500 m thickness chiefly consists of silty fine sands of very low bearing capacity.
- Conditions for laying foundations at the mouth of the Narmada river are poor. Several faults, which also make junctions, pass through the Ghogha-Hansot dam alignment zone, thus making the seabed stability highly prone to up–throw and down–throw along the fault lines.
- Existence of deep channels across the Ghogha–Hansot alignment was also noted with concern.

Taking cognizance of the above facts, and the likely interference with the commercial establishments at Dahej, the Expert Group recommended shifting the closure dam alignment by about 15 km northward along Kalatalav (Bhavnagar) and Aladar (Aladar) points. The Group also suggested that the tidal power component should be deferred, and only a freshwater storage dam considered, keeping the freshwater storage capacity almost intact as envisaged in case of the Ghogha–Hansot alignment.

Shri B. N. Navalawala, Advisor to Honourable Chief Minister and Chairman-EAG, held meetings in the months of March-April, 2008 with six prominent industry groups (Essar, GVK Power, L&T, Jai Prakash Associates, Hindustan Construction and Adani), seeking their view on implementing the Gulf of Khambhat

Development Project under PPP. All the industrialists expressed the view that tidal power would not be economically viable.

The proposed dam alignment, shown in Figure 2.5 below, involving the diversion of the Narmada water through a barrage-cum-canal, is the most feasible design, as it envisages keeping the Dahej port outside. With this project framework, they opined that the project could be taken up via the PPP route. They were emphatic in their insistence that there was no possibility of any PPP to suggest the Alignment I design involving tidal power.

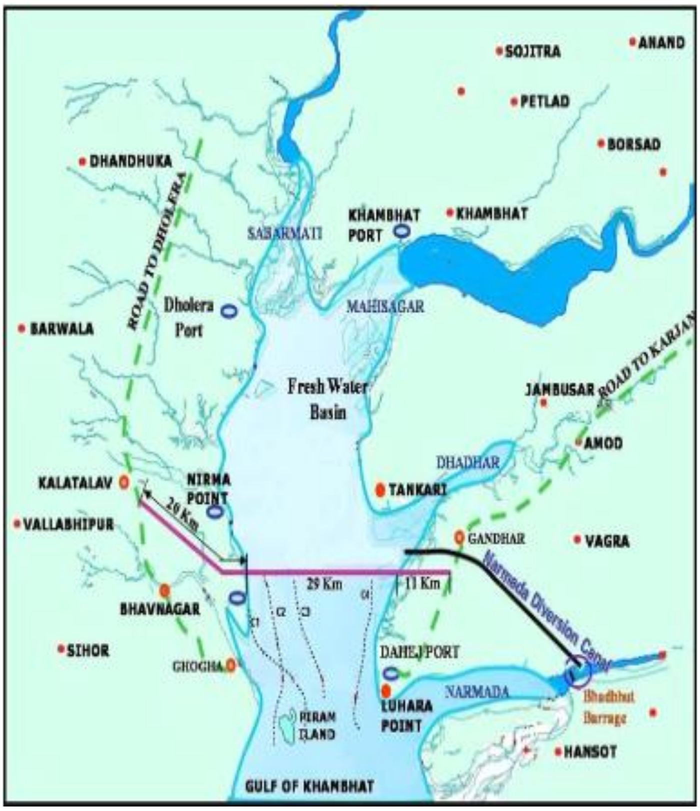


Figure 2.5 The proposed Kalpasar Dam

2.3 Objectives (concept design)

Given the various developments in options and alignments over many years, we would look to understand the proposed Kalpasar dam in terms of the various specific objectives. For example, what are the objectives for:

1. Freshwater Resource Impoundment.
2. Tidal exclusion barrage: including some beneficial use of zones presently occupied by the sea at times of High Water.
3. Rail and Road transportation link.

For each objective, we would expect to see an individual justification to satisfy the DPR requirements. We would then expect to judge the combination of objectives incrementally in terms of costs and benefits.

3 Proposed design criteria for the reports review – proposed alignment and cross section

This section discusses the methodology and the design criteria for review of the reports provided by the client presented in Appendix 1.

3.1 General

Generally, our review will follow the requirements of the national and the best international standards, such as:

- "The Guidelines for Preparation of Detailed Project Reports of Irrigation and Multipurpose Projects" (Government of India, Ministry of Water Resources),2010.
- International Levee's Handbook.
- Guidelines for Assessment and planning of Estuarine Barrages, HR Wallingford, 1999.
- BS 6349 Maritime structures.
- EurOtop Manual.
- Relevant International Commission on Large Dams (ICOLD) bulletins.
- USBR and USACE Dam Design Guidance.

For specific aspects of dam engineering design, the above documents will be complemented by specific design standards which are listed in sections below.

Note that in the interests of brevity, we have omitted the detailed referencing of standards and technical papers given in the text of the report, however we can provide that if required in due course.

3.2 A - Dam engineering

The dam engineering aspects expected to be covered by the design are described in this Section.

3.2.1 Dam design life

The service life of a well-designed, well-constructed and well-maintained and monitored dams are typically expected to be 100 years and for a major asset like Kalpasar dam the design life should be at least 100 years.

However, the life-span of hydromechanical steel structures, electromechanical equipment and control units is shorter than that of the main civil/structural components. All fixed, cast-in, or non-replaceable components should be capable of service for the full dam design life. Where mechanical and electrical components with a shorter design life are used the design must consider how they may be safely refurbished or replaced. Where a range of options for equipment with differing design life exists the whole life cycle cost should be assessed including differing maintenance and replacement/refurbishment intervals. The design life for replaceable M&E components should be at least 25 years.

Instruction manuals describing operation and maintenance should be provided for all equipment and included in the Operations and Maintenance Plan (O&M Plan).

It has to be recognized that there is a direct relationship between dam safety and its life-span, i.e., if the dam is unsafe its life-span has expired.

3.2.2 Dam hazard categorisation

The currently proposed dam geometry would classify as a large dam in accordance to ICOLD (Bulletin 157).

Whilst noting that Kalpasar is not a conventional dam, the risk of a dam breach should still be considered. The dam should be categorised based on its hazard potential using the approaches described in ICOLD Bulletin 82 and others with particular use of the USACE dam hazard classification. Whilst the area downstream of the dam is open estuary the proximity of coastal communities and therefore the risk of loss of life and property damage should be considered. In addition, the environmental and economic losses that would ensue including from loss of the dam's transport corridors and water supply should be considered. Therefore, it is considered that, pending a formal study, the dam hazard category is likely to be significant to high.

A dam breach assessment will be required, this will serve a number of purposes:

- To provide dam breach inundation mapping for development planning.
- To determine the consequences of a dam breach and therefore the selection of the reservoir design and safety check floods.
- For emergency planning and development of the Emergency Preparedness Plan (EPP).

The dam breach assessment should consider the potential for different types and location of failure for example due to piping or overtopping, at structures or highest part of the dam with different breach hydrographs being developed. Different methods should also be considered with the sensitivity to different events considered. Different flood events will need to be considered with, as a minimum a sunny day and extreme flood scenarios, additional flood events may need consideration when assessing incremental flood damages. In each case the flood extents should be plotted and the time of travel for the flood wave noted for settlements and other key locations. The approach to developing dam breach assessments should be is described in ICOLD bulletin 111 "Dam Break Flood Analysis". The flood wave routing model should consider different downstream water levels due to tidal variation.

The dam breach assessment will be used to inform an EPP, the draft plan should be developed for consultation with all relevant stakeholders including government ministries, local communities and emergency services. The EPP should be developed as set out in US Federal Dam Safety Commission Guide (US-FDSC Guide) and should be available, approved and tested before first impoundment of the reservoir.

Similarly, the risk of a sea breach at high surge tides should be considered along with the potential impact in the reservoir and reservoir rim.

The hazard categorisation of the dam informs the design of the dam including the safety check flood and seismic design criteria.

3.2.3 Design and safety check floods

An appropriate design and safety check flood should be determined based on the hazard of the dam. ICOLD Bulletin 82 defines the safety check and design floods as follows:

- Safety Check Flood: It is considered acceptable practise for the crest structure, waterway and energy dissipator to be on the verge of failure but to exhibit marginally safe performance characteristics for this flood condition.
- Design Flood: Strictly representing the inflow which must be discharged under normal conditions with a safety margin provided by the freeboard.

Selection of such floods varies between different organisational national standards and should be selected based on the dam hazard classification or consequences which would result from a dam failure. Two potential methods may be taken:

A ***prescriptive standards-based approach*** where a dam hazard category is assigned based on criteria such as dam height, stored volume, population at risk downstream and economic consequences. The design standards then dictate the design and safety check floods depending on the hazard. This approach is described in ICOLD Bulletins 82 and 125.

Alternatively, ***a risk-based approach*** may be taken where the incremental damages caused by failures in a range of events is considered along with a comparison of flood damages not resulting from a dam failure. This aims to achieve a risk that is As Low as Reasonably Practicable (ALARP).

One of the standards described in ICOLD Bulletin 125 should be followed which describes both approaches. The chosen method, design and safety check floods are to be agreed with the client.

3.2.4 Surveys

Topographical and bathymetric surveys will be required to inform the various studies and designs described throughout this report. These should be conducted and reported as described in “Guidelines for Preparation of Detailed Project Reports of Irrigation and Multipurpose Projects” (Government of India, Ministry of Water Resources). The survey of the dam site should be of sufficient detail to allow sufficient accuracy for detailed design. Surveys of the reservoir area will be required to verify bed level and morphology. The topography and bathymetry up and downstream of the dam will also be required to inform studies such as the dam breach analysis. Topographical data of the upstream catchment will be required to inform the hydrological studies, wide area surveys such as this are undertaken by remote sensing methods (typically LiDAR or InSAR).

All surveys should be carried out to a consistent level datum and coordinate system. Processing of survey results and any transformations of coordinate systems should be recorded in survey reports. Installation of survey monuments should be considered for reference during construction.

The topographical and bathymetric surveys are expected to be repeated multiple times to build up a picture of bed movement over time and the variation in bed morphology. Comparison with any older pre-existing surveys is also expected to be []

3.2.5 Hydrology and hydraulic modelling

Hydrological analysis of the catchment should be carried out according to the "Guidelines for Preparation of Detailed Project Reports of Irrigation and Multipurpose Projects" (Government of India, Ministry of Water Resources).

The hydrological methods described in the above guide as well as ICOLD Bulletin 170 "Flood Evaluation and Dam Safety" should be used to determine effective rainfall, peak flows from the catchments and flood hydrographs. A variety of methods should be applied and the sensitivity to different estimates considered with cognisance of the strengths and limitations of each method. A range of events of different return periods will be required including but not necessarily limited to the reservoir design flood, safety check flood and flood events required for the assessment of downstream flood risk, design of downstream river flood defences or flood risk of existing banks and defences. Given the nature of rainfall in the region, in which it's probably up to 90% of rainfall can fall during the monsoon months (June to September), it's important to consider the inflow data seasonally and not annually. This way, seasonal impounded volumes and higher water levels within the Gulf of Khambhat can be assessed and taken forward for design consideration. It is also anticipated that a range of storm events will need to be considered during different stages of construction to enable safe planning of the construction.

A selection of inflow hydrographs with different storm duration should be generated for the design and safety check of safety and reliability during exceptional flood events. These hydrographs should be routed through a numerical reservoir hydraulic routing model (such as HEC-RAS) to determine the critical storm duration that results in the highest reservoir Stillwater level and peak outflow with these values used for design. This should also consider the timing and operation of gates with the gate operating rules being consistent between flood study and operating procedure control philosophy. The risk of several gate failures should also be taken into account to provide resilience and redundancy in the overflow systems, especially in the event of any mechanical/electrical malfunction or non-availability. Conventionally some passive overflow capacity would be provided to allow time for gate operation and to provide a measure of safety against gate failure however this will need to be balanced against the risk of sea overtopping into the reservoir. The upstream flood storage capacity with the gates closed, and at times of high tide and under tidal surge conditions should be reviewed against the operating time for the gates and reliability.

A joint probability analysis should be performed considering combinations of fluvial and coastal storms.

A range of floods of differing return period should be modelled to consider the risk of flooding to people and property around the reservoir rim and to consider the gate operating philosophy accordingly. The standard of flood protection afforded should be agreed with the client and relevant authorities. Should the dam allow removal of exposure to tidal flooding development controls should be considered to mitigate the risk of new properties and people moving into that new potential zone at risk of flooding from the reservoir impoundment. This would also help mitigate the risk of flooding from a sea breach of the dam. Furthermore, the impact of the reservoir impoundment on the discharge of existing drainage should be considered.

- ICOLD Bulletin 170 "Flood Evaluation and Dam Safety".
- All Appropriate and Applicable United States Army Corps of Engineers (USACE) manuals including, but not limited to:
  - EM 1110-2-1619 Risk-based analysis for Flood Damage Reduction Studies.
  - EM 1110-2-1417 Flood-Runoff Analysis.

3.2.6 Water demand and supply reliability

The water demand flow requirements and required reliability of supply should be confirmed with the client and set as a project objective.

Hydrological analysis of the catchment should be carried out according to the Guidelines for Preparation of Detailed Project Reports of Irrigation and Multipurpose Projects" (Government of India, Ministry of Water Resources).

Using this guidance, a long duration inflow record should be used to simulate the reservoir operation. This should consider the supply demand flow and losses such as evaporation and leakage, overspills and sluiced flows to simulate the reservoir water level and availability of supply of time. This determined the reliability of the supply and allows the optimisation of the reservoir storage capacity. Periods of representative, high and low flows should be considered as sensitivity testing, with the effects of climate change also assessed.

This will also need careful consideration of the water quality and any measures needed to improve it. This is discussed in section 3.3.5.

3.2.7 Climate change impact

Climate change is already leading to changes in the intensity and frequency of events which can impact dam infrastructure, these impacts are anticipated to continue increasing and intensifying in future climate conditions. An understanding of potential climate change impacts is key to ensure that dam infrastructure is resilience to current and future climate impacts.

At the international level, there are a few limited examples of guidance and studies assessing climate change impact to dams. For example, in the UK there is specific guidance on the use of climate data to assess impacts to dams and reservoirs, and there are examples of academic literature addressing and suggesting approaches to estimate potential climate change impacts on dams. In addition, general guidance for designing climate resilient infrastructure is applicable to dams.

When assessing climate change impacts to infrastructure there are a set of key aspects to be considered in the analysis of climate change data. These are summarised below:

- Climate variable and characteristics: An understanding of key climate variables for the impact analysis (e.g., precipitation and temperature) and the relevant characteristics (e.g., occurrence of extreme events or seasonal pattern).
- Time period: The time period usually covered by climate models is 1950 to 2100. Climate change data should be analysed for the future period of interest in line with the design life of the infrastructure and key replacement or maintenance cycles.
- Scenarios: It is important to consider multiple (at least two) scenarios (representative concentration pathways (RCP) defined by the Intergovernmental Panel on Climate Change (IPCC). For example, RCP4.5 and RCP8.5.
- Climate model data and analysis: It is important to consider which is the most suitable data source for the specific impact analysis (e.g., global climate models from IPCC, regional climate models) and whether any additional processing or analysis is needed (e.g., statistical downscaling to obtain insight on change in extreme weather events at the local scale)
- Uncertainty: climate change projections are inherently uncertain, uncertainty in climate model outputs and scenarios should be assessed and represented.

The following potential impacts should be considered as a minimum:

- Drought and extreme heat: The projected changes in mean precipitation, temperature and variability impact reservoir levels over time potentially leading to higher fluctuations in water levels and so changes in water supply availability.
- The future adequacy of flow capacity of spillway and outlet works for extreme floods and effect on dam freeboard against reservoir overspilling or wave overtopping.
- Sea level rise and increased tidal surge and effect on spillway and outlet performance.
- Sea level rise and increased tidal surge and effect on dam seepage and salinity.
- Sea level rise and increased tidal surge and effect on embankment and structure load conditions.
- Sea level rise and increased tidal surge and effect on dam freeboard and wave overtopping.

- Soil erosion: Soil erosion might be exacerbated under future climate conditions due to the increase and frequency of droughts and loss of vegetation. Potential to change reservoir sedimentation rate.
- Wind: Climate change projections on wind are highly uncertain. Nonetheless the potential for increase in strong winds due to a changing climate may need to be considered.
- Mass movement: An increase in extreme precipitation as well as the projected changes in seasonal precipitation patterns may lead to an increase in rainfall-induced landslides. This can impact on water quality, sedimentation, cause blockages of key structure and induce waves.

The whole life cost of the dam should be assessed considering the need for future climate change adaptations, either providing additional capacity where appropriate or allowing for ease of future modification with the decisions based on lowest whole life cost.

3.2.8 Dam body

3.2.8.1 Choice of dam type

The selection of the dam type should be based on the several factors including: geomorphology, geology, availability of material, geological and superficial deposits, the site specific seismicity and construction. The volume and depth of water requiring storage will also be an important factor. There are numerous types of dam which can be considered including embankment dams which can be homogeneous, heterogenous (zoned) and either earthfill or rockfill, or earthcore rockfill.

The following focuses on the form of dam currently proposed, though different forms of dam should be considered, potentially in different parts of the dam.

3.2.8.2 Proposed dam cross section

Referring to Primary Dam cross sections shown in Figure 2.3 (report 19 in Appendix 1), the currently proposed cross section for the Kalpasar dam is split into two main sections, both of a typical breakwater construction with a cement-bentonite cut off wall.

The gulf side has a core of rock/artificial block, with a slope of 1 in 1.5. The gulf side slope is stepped, with a 3.8m layer of 48t X-bloc armour, and a 2.4m layer of 12t x-bloc rock armour making up the toe. This section of the structure sits on a gabion mattress, intended to stabilise the seabed to allow subsequent construction.

The reservoir side uses a dredged material core, with a geo fabric layer protected by 60cm riprap. This side is also stepped, with a slope of 1 in 2.5. The road and railway sit on this section of the structure, which is separated from the gulf side by an 18m wide crest.

The dam incorporates spillway, sluice and includes corridors for a highway and railway. It will also require lock structures for access to upstream ports.

3.2.8.3 Key design considerations

The following key considerations need to be outlined and consistent throughout all documentation and reporting:

- Standard design units and reference datum.
- Design life for dam and for replaceable elements (see section 3.2.1).
- Geometry.
- Stability analysis.
- Seepage analysis.
- Topographical and bathymetric data.
- Metocean data for various return periods:
  - Significant wave height and period (reservoir-side and gulf-side).
  - Current data (including river outflow effects, variation with depth).
  - Wind speed & direction (monthly, seasonally, annually).
  - Temperature.
- Tidal data – Obtained from ESSO - Indian National Centre for Ocean Information Services or similar recognised body:
  - Highest astronomical tide (HAT).
  - Mean high water springs (MHWS).
  - Mean high water neaps (MHWN).
  - Mean sea level (MSL).
  - Mean low water neaps (MLWN).
  - Mean low water springs (MLWS).
  - Lowest astronomical tide (LAT).
- Water levels:
  - Highest combined tide + storm surge level.
  - Lowest combined tide and negative surge level.
  - Sea-level rise allowance due to global warming.
  - Reservoir water level range including Normal Water Level (NWL)/Full Supply Level (FSL), Peak Stillwater level (design and safety check), minimum level.
  - Gauge data for upstream catchments for upstream fluvial analysis.
  - Discharge rates for dams in the upper catchments.
- Design return periods need to be specified.
- The appropriate levels of risk should ultimately be decided by a combination of:
  - Industry standards (including those listed above) and national regulations.
  - Cost-benefit analysis to determine ALARP.
  - Acceptable degree of damage – balance of Capital Expenditure (CAPEX) with Operational Expenditure (OPEX) (including maintenance/repair and impact of downtime).

  - What funding agencies or insurance companies will accept.
- Materials:
  - Proposed material properties.
  - Source of material.

3.2.8.4 Geometry

The geometry of the dam will need to consider a wide range of design criteria, balancing the different design objectives and requirements.

The key parameters are:

- Crest width.
- Crest height.
- Road/rail vertical and horizontal alignments (see sections 3.2.13 and 0).
- Downstream (Dredged material) slope.
- Upstream (Rock core) slope.
- Rock/block armour layer thickness.
- Rock/block armour diameter.
- Settlement Allowance.
- Freeboard allowance (see 3.2.9).

The required crest width and width of the various berms will follow from stability analysis and ensuring any shallow failures do not jeopardise the safety of the dam but also operational requirements such as maintenance access. The width of the crest, berms and therefore overall dam footprint is expected to be heavily influenced by the width of the road and rail corridors. The width of the dam will also influence the seepage analysis where a narrower dam will be more prone to seepage and therefore the resulting risk of internal erosion and saline intrusion. This variation in seepage path length will also influence the appropriate choice of material with lower permeability material and more significant seepage cut-offs for narrower (and/or higher) dams.

The height of the dam will need to be sufficient to manage:

- The required reservoir water storage volume needed to meet the demand including any loss due to saline stratification and sediment dead storage.
- The modelled design and safety check flood rise, this is therefore related to the spillway design, gate operating philosophy and flood modelling.
- The freeboard allowance required to prevent reservoir wave overtopping.
- Operation requirements for the road and railway such as remaining operational (spray/overtopping) in specified return period events.
- Reservoir impoundment and reservoir rim flood risk.
- The tidal range and storm surge.

- The freeboard allowance required to limit wave overtopping from the sea.
- Allow for settlement of the dam whilst still maintaining all of the above.

The height of the dam also strongly influences the dam hazard categorisation, with higher dams generally resulting in greater consequences of failure and therefore posing a higher hazard.

3.2.8.5 Loading

Design return periods for the dam and structures need to be specified for ALS, ULS and SLS design scenarios. Examples of standards/code guidance:

- BS 6349-1:2000 ("Maritime structures – general criteria") suggests design events should be selected based on a cost optimisation exercise carried out for the life of the structure. It is clear that this can only be carried out with confidence if the degree of damage (and costs of repair – due to the repair itself and associated downtime) if the design event is exceeded is known.
- BS 6349-7:1991 ("Maritime structures – design and construction of breakwaters") recommends that stability is checked for conditions having a 5% probability of exceedance over the design life of the structure. This is interpreted as an Accidental Limit State (ALS) criterion.
- ISO 19901-1:2005 ("Requirements for offshore structures – metocean design and operating conditions") recommends the following return periods. The code does not define a specific design life, but we suggest that the return periods are considered in the context of a typical design life for offshore structures of 30~50 years.
  - ULS – 100 year ARI.
  - ALS – 1,000~10,000 year ARI.

Wave Loading

Wave loading on fixed structure elements (gates, sluices, locks) can be calculated using the Goda and Sainflou methodologies as described in the Coastal Engineering Manual 2011 for various design events.

Ship impact

All safety critical structures such as spillways, locks and sluices should be designed for dynamic forces arising from ship impact and impact of large debris. An assessment should be made of the likely type and size of ship and likely debris as well as the design impact velocity and deflection.

Methods for assessing the loading due to ship impact are given in EN 1991-1-7, Accidental Actions, or AASHTO Bridge Design Specifications.

3.2.8.6 Stability analysis

Guidance on design of embankment dams including slope stability is provided in USBR DS13 Embankment dams.

1 All global stability analysis for dams should consider, at least, the four key critical modes, which include, but are not limited to:
   a. End of Construction – Drained and undrained analysis performed, undrained properties for embankment materials for when wet cohesive materials are used for construction.
   b. Rapid Drawdown – Undrained analysis where water level is high for prolonged period and then lowers quickly, which represents conditions right after an extreme water event. Particularly applicable to upstream face of the dam and the reservoir rim.
   c. Steady State Seepage – Evaluation of steady state water level conditions, which represents the phreatic surface through the embankment during extreme water event. Submerged unit weights of soils beneath the phreatic surface should be used. Drained and undrained mechanical properties should both be used in the analysis.
   d. Earthquake – Evaluation of embankment stability when a seismic event occurs. For conditions where liquefiable soils are identified beneath the dam or appurtenant structures, the factor of safety against liquefaction versus depth should be assessed and the levels of liquefaction induced settlements. Seismic analysis will be carried out at full supply level for an Operating Basis Earthquake (OBE) and Safety Evaluation Earthquake (SEE).

2 Static and dynamic analysis of the dams should include:
   a. 2D finite element analysis to evaluate the seepage and hydraulic pressures developed in the foundation materials, in dam structure (if earth fill), and the hydrostatic pressures built up against all retention structures.
   b. Static 3D finite element analysis to evaluate total and effective stresses developed in the foundation materials and in the dam structural elements.
      i. Jointing and faulting of the basement rock should be explicitly modelled.
   c. Perform time-domain dynamic 2D finite element analysis incorporating drained, undrained, and coupled. Determine areas of transient and permanent deformation.
   d. Analysis of the soil-structure interaction for structures interfacing with foundation soils or rock should be performed.
   e. The modelling and analysis should determine the stresses and deformations occurring in the structural elements of the dam and appurtenant structures.

Load combinations and factors of safety should be adopted such as those in USBR DS13 Embankment Dams and Design of Small Dams.

The following loads should be considered as a minimum:

1. Dead loads – of the dam or appurtenant structures.
2. Water load (reservoir) – the peak reservoir water level shall be determined following the hydraulic design of the spillway. Associated pore water pressures.

3. Water load (tailwater).
4. Silt – confirmation is required of the anticipated siltation of the reservoir before an assessment of this load can begin.
5. Earth – weight and earth pressures.
6. Earthquake – two scenarios shall be considered: the OBE and SEE, as discussed above.
7. Surcharge loading from traffic.

An analysis of short-term settlement should be made to inform the phasing of the works and management of differential settlement between structures and earthworks. Long-term settlement should be carried out to ensure the minimum required dam crest level and height of any seepage cut-off is maintained throughout the design life of the dam.

3.2.8.7 Seepage analysis

Seepage analysis is critical for dams, especially in this situation of high tidal range on the seaward side. Some seepage is inevitable, and it will be necessary to ensure that seepage through the embankment and its foundations (or the foundations of concrete dams) is limited to safe levels. Excessively high seepage flows may cause internal erosion, washing out fine material leading to dam breaches. Excessive seepage can also cause flooding or other issues around the reservoir rim.

For embankment dams, a combination of measures are typically implemented to reduce the risk of such failures, impermeable barriers like dam cores and below dam cut-offs reduce seepage flows, filter layers are typically included downstream of fine grained materials such as dam cores to prevent the loss of fine material.

The grading of foundation materials and the seepage path length will depend on whether the foundation is vulnerable to internal erosion. Other protective measures include drainage blankets and rock toes for embankments.

Guidance on internal erosion is provided in ICOLD bulletin 164.

It is also noted that seepage analysis and the resulting design will be important for reducing saline intrusion.

3.2.8.8 Rock armour design

Failure methods to be designed for:

- Slope instability.
- Sliding of structure.
- Movement of rock cover.
- Migration of sub-layers.
- Piping.
- Liquefaction.

- Erosion of foreshore.

For each rock armour type (e.g., x-bloc, natural rock, riprap) the following information will need to be specified to calculate the above:

- Stone size and density.
- Permeability.
- Thickness of layers.
- Roughness.
- Water levels.
- Porewater pressure.
- Slope angle.
- Internal channel flow velocities.
- Wave heights and period.
- Earthquake data.

An appropriate level of damage will need to be specified for each return period and the design should be able to tolerate some damage without initiating progressive collapse.

CIRIA C683, “The Rock Manual” is a leading reference for the design and construction of armoured revetments. The US Army Corps of Engineers “Coastal Engineering Manual” is a suitable alternative. The “Rock Manual” also provides guidance applicable to design of rock armour as reservoir and channel scour protection.

3.2.8.9 Scour protection

Scour protection will normally be placed under the toe of a rubble-mound breakwater and extends seawards to the point where scour action is no longer a concern to mound stability.

The level of scour can be predicted using CFD analysis, or with physical model testing. Semi-empirical methods are available to select armour layer sizes and rules for grading of the filter and armour layer are given in CIRIA C742[1]. Numerous papers and books have been published on scour protection design, a leading reference being Whitehouse, “Scour at Marine Structures”.

Additional guidance on the design of scour protection for structures such as the spillways is provided in USACE and USBR design guides. The CIRIA “Rock Manual” and CIRIA Report 742 “Manual on scour at bridges and other hydraulic structures” also provides good guidance.

[1]CIRIA C742. Manual on scour at bridges and other hydraulic structures (2nd Edition) (2015)

3.2.9 Freeboard and overtopping

Overtopping of the dam both from the sea and reservoir will need to be assessed to ensure the design minimises the risk of damage to the dam.

The rate of safe overtopping tolerable to a dam will usually be extremely limited and based on the duration of the overtopping flow and velocity of the flow on the downstream face. The tolerable amount is therefore related to the geometry, materials and condition of the dam. Guidance on this is provided in CIRIA guides 116 and 742 as well as the EurOtop manual. Further guidance is provided in the Rock Manual, “The International Levee Handbook” and BS6349 “Maritime Works”.

The overflow capacity of the spillway must be sufficient to ensure that no overspilling of the dam occurs from the peak reservoir stillwater level in the design and safety check flood events. A freeboard should also be provided to ensure that effectively no wave overtopping occurs in a design event and only small wave overtopping flows occur in the safety check event, with such flows limited to that which can be safely tolerated without unsafe damage to the dam. Tolerable discharges in the safety check should be based on the resulting overtopping flow velocities and resulting scour risk as well as guidance such as the EurOtop Manual and UK Institution of Civil Engineers “Floods and Reservoirs Safety”.

In addition, limits should be placed on overtopping for the safety of operation of the highway and rail corridors as well as safe access of inspection, maintenance and emergency response. This should be based on limiting overtopping flows or spray to those safe for pedestrians and vehicles. The extreme floods under which the road and railway are closed to traffic should be agreed with the client and respective authorities.

There are no international standards determining operational limits for overtopping. In place of this, guidance such as provided in EurOtop[2] can be used to determine the allowable overtopping rate based on appropriate return periods. In order to do these key constraints will need to be identified such as:

- Safety of the dam.
- Protection of vehicles.
- Protection of railway.
- Pedestrian access during storms.
- Maintenance access during storms.
- Salinity of the reservoir.

The overtopping rate from the sea can be predicted using empirical methods identified in the guidance based on the cross section geometry and metocean data, or more accurate physical testing can be undertaken to minimise conservatism. For

[2] EurOtop: Manual on wave overtopping of sea defences and related structures, Second Edition (2018) [http://www.overtopping-manual.com/assets/downloads/EurOtop_II_2018_Final_version.pdf]

such a large structure, physical testing could result in significant savings despite the relatively large up-front costs.

Wave run-up on the reservoir side will be influenced by the dam geometry and materials, reservoir size and shape as well as wind speed and direction. Different combinations of reservoir stillwater level and wind velocity may occur. USBR Design Standard 13 Chapter 6 provides a suitable approach for determining minimum freeboard requirements on the reservoir side for embankment dams. Appropriate wind speeds of different return periods and direction will need to be determined based on local data. Allowable wave overtopping rates are typically higher for concrete dams (or structures), though erosion of the ground at the dam toe and risk of dam instability still requires consideration.

An additional consideration for embankment dams is that the peak stillwater level remains below any impermeable core or barrier within the dam with an allowance made for settlement and desiccation.

3.2.10 Sedimentation

3.2.10.1 Catchment sedimentation load

Potential sediment yields should be assessed using a combination of analytical methods based on soil types, flow conditions and comparison with similar dam sites. This assessment should then be verified through sampling undertaken at the dam sites at as wide a range of flow conditions and seasons as possible. An assessment of the proportion of silt deposited within the reservoir or passed downstream should be made using a relationship such as the Brune curve. Where high sediment flows are anticipated the risk of blockage and additional wear on structures, valves and other assets should be considered in the design. Methods for assessing sediment yields are described in ICOLD Bulletin 115.

3.2.10.2 Sediment management

A whole life cycle cost approach to sediment management should be taken as described in "Reservoir Conservation Volume 1: The RESCON Approach economic and engineering evaluation of alternative strategies for managing sedimentation in storage dams". Effectively balancing the cost of construction of sediment management facilities such as reservoir storage, silt traps, check weirs or sediment flushing against the cost of future silt removal operations. Methods for managing sediment are also described in ICOLD Bulletin 115.

Even where overall siltation rates can be stored within the reservoir without appreciable loss of storage over the design life the risk of localised deposits and blockage should be considered. To this effect, 2D or 3D numerical modelling or mobile bed physical should be deployed to determine the distribution of deposition within the reservoir and design mitigation measures.

It is also note that there is tidal movement of the estuary bed and this pattern of movement will be interrupted with a wide range of potential changes which should be considered in the design.

3.2.11 Dam access for inspection and maintenance

Access to the dam site is important both for construction and for ongoing surveillance and maintenance of the dam. Access roads for inspection and maintenance need to be accessible in a reservoir emergency and so need a good standard of protection from flooding and from other hazards such as rockfalls and landslides. The roads need designing with sufficient width and turning space for the largest vehicles envisaged as being needed during inspection, operation, maintenance, or emergency response. This could take the form of access of the main highway with turning areas to access dam infrastructure.

Vehicle bridges are therefore typically required over obstructions and structures such as the spillway.

3.2.12 Spillway structures

The dam will require one or more overflow spillways to safely convey the design and safety check floods. The proposed arrangements are unconventional in that all the overflows proposed will be restricted in an ability to discharge dependant on the height of the tide and any storm tide surge conditions which may be occurring when the dam is full from impounded water. We recommend that this is modelled and checked for ultimate safety and reliability.

Different requirements would apply in each case for example with greater freeboard requirements applied to the design flood than the safety check. The overarching definition of design and safety check floods described earlier means that a spillway must comfortably pass the design flood with the spillway and dam remaining safe with an additional margin of safety remaining available. In a safety check flood some damage may occur to the spillway and dam but this must not threaten the safety of the dam.

Numerous forms of spillway may be possible to suit the form of dam and hydraulic requirements. The form and design of spillways is discussed in ICOLD Bulletins 58 and 172.

The location of spillways is also important with the resulting risk of a failure of the dam being considered, both due to design flow exceedance and due to defects or structural failures with the structure or it's interface with the dam or ground. Risks such as seepage from or around the spillway or structural failure should be considered. The preference is therefore typically for spillways located off the dam or at its abutment, though this is not always achievable.

The design of the spillway should typically ignore any flow through outlet works (saline flushing) where smaller pipes, valves and screens are likely to be blocked, the spillway therefore carries the full design and safety check outflows.

Spillway options include gated or uncontrolled spillways. Gated spillways require expensive mechanical and electrical components and require additional specialist maintenance and operation but can allow greater flows in a given length of structure without losing water at low flows. Determining a safe operating plan also requires careful consideration, balancing operator response times, rate of flood rise and balancing reservoir safety with downstream flood risk and water supply conservation. Passive spillways, without gates or other operating systems are therefore usually preferred where feasible. The relative cost-benefits of an active and passive system should be considered.

As highlighted earlier, the design of the spillways should consider the tidal range downstream which may limit the discharge head through submergence and/or limit the time where the reservoir level is higher, and the structure may discharge. The variation in load cases and reverses in direction of loading of structure and gate along with cyclical loading effects will also need considering.

The crest level of the spillway will be set based on the required storage capacity within the reservoir to meet the required demand with the necessary reliability. In events exceeding the Full Supply Level (FSL) the reservoir spillway would discharge to ensure safety of the dam.

For structures of this size, it would be expected that the performance of the spillway be demonstrated through a sufficiently detailed physical or Computational Fluid Dynamics (CFD) model, ideally both to allow the benefits and inaccuracies of each to be complemented.

The spillway structure should be design in accordance with USBR DS14-3 “Appurtenant Structures for Dams (Spillways and outlet works) Design Standard” and USACE “Hydraulic Design of Spillways” (EM 1110-2-1603) and USBR “Hydraulic Design of Stilling Basins and Energy Dissipators” or similar agreed national or international guidance.

It will be necessary to demonstrate the discharge performance of the spillway from zero to slightly greater than the safety check flood and to plot a rating curve of this performance. This rating curve should inform the routing analysis of floods through the reservoir described elsewhere, with the spillway design safely passing the outflow. The approach must be designed to not restrict the performance of the spillway and to provide approach velocities low enough to minimise scour risk. The risk of debris blockage and impact damage to the structure should be considered in the design. The effects of any bridge piers and abutment geometry should be considered. Freeboard to bridge crossings of the spillway and the safe passage of large debris will be important.

It will be necessary to determine the flow velocity and depth profile along the length of the chute. Phenomena such as air bulking and cavitation will need consideration along with an assessment of uplift/plucking pressures, hydrostatic and hydrodynamic effects. The spillway chutes must be of a robust, none-erodible material and it is anticipated that the spillways will be predominantly reinforced concrete. Spillways should be straight or with very gradual changes in direction and where any changes in direction occur these are carefully analysed with consideration of the risk of super-elevation and cross-waves. Spillways should be of constant gradient or with gradual changes with consideration of flow separation and changes in pressure.

At the base of each spillway a terminal structure such as a stilling basin or apron will be required to ensure that energy from the chute flow is dissipated, and flows discharged at safe velocities with the outlet protected from scour. There are a wide variety of designs including flip buckets and baffled or unbaffled basins. The approach and different forms of terminal structures are described in USBR "Design of Small Dams" and "Hydraulic Design of Stilling Basins and Energy Dissipators". These guides provide design guidance on standard forms of structure based on model testing, other forms and variations are possible but may require additional model verification. In order to correctly design these terminal structures and determine the outlet conditions a range of downstream tidal conditions should be considered.

Freeboard within the spillway should be provided using the approach described in USBR Design of Small Dams or similar agreed with the client for both the approach, chute and stilling basin.

The structural detailing of spillways is important both to safely carry the required floods but also so as to manage risks with the interface with the dam or foundation. In particular the structure should be detailed to prevent seepage between the spillway and its foundation and to ensure the watertightness of the structure. Movement joints are a particular area requiring careful attention to ensure sufficient flexibility again movement and watertightness. Guidance on detailing is provided in USBR guides "Design of Small Dams" and "DS14-3 Appurtenant Structures for dams". These references also provide guidance on the appropriate structural design considerations such as load cases. Settlement of the structures and in particular differential settlement is also likely to be an important consideration, for example between bridge, spillway and dam. Boat and large debris impact loads on the structure should also be considered as well as dynamic loads on spillways and gates.

Particular technical guides:

- United States Department of the Interior – Bureau of Reclamation DS14 Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standard.
- All Appropriate and Applicable United States Army Corps of Engineers (USACE) manuals including, but not limited to:
  - EM 1110-2-1619 Risk-based analysis for Flood Damage Reduction Studies.
  - EM 1110-2-1417 Flood-Runoff Analysis.
  - EM 1110-2-1603 Hydraulic Design of Spillways.
- ER1105-2-101 USACE Risk Assessment for Flood Risk Management Studies.
- United States Department of the Interior – Bureau of Reclamation Hydraulic Design of Stilling Basins and Energy Dissipators.

3.2.13 Highway design

The design of the highway will require a thorough design to Indian road standards. The design should consider the horizontal and vertical alignment required as well as the influence this has over the dam geometry. The depth of road construction will need coordinating with the wider freeboard and other dam height constraints. The maximum speed and requirements for refuges and breakdown plans will influence the dam geometry. Provision for pedestrian and cycle access should be considered.

The requirement for demarcation from pedestrians, cycle and railway and boundaries fencing and parapets will require definition.

The designs including the overtopping design criteria limits (and flood events under which the road may close, and any associated prediction and warning processes) should be agreed with the client and approval authority.

The design standards for road drainage will also require agreement, measures to reduce the risk of pollution runoff into the reservoir should also be considered. The relevant design standards and coats, safety criteria and stopping points will also require agreement. The routing of utilities will need care to avoid penetrating the watertight elements and to ensure important utilities are adequately protected.

The highway loading criteria (ULS, SLS, ALS) will need to be developed as well as combinations with other loads. Differential settlement of the railway particularly between on and off dam sections, between dam and bridge structures.

3.2.14 Railway design

The design of the railway and rail corridor will need to conform to Indian Rail standards. The design should consider the horizontal and vertical alignment required as well as the influence this has over the dam geometry. The depth of rail ballast will need coordinating with the wider freeboard and other dam height constraints. The operational and maximum speeds and signalling requirements require agreement with client and approval authority.

The requirement for a rail safety corridor demarcation from pedestrians and highway and boundaries fencing and parapets will require definition.

The designs including the overtopping design criteria limits (includingflood and seismic events under which the railway operations may need to follow prescribed monitoring/safe shut-down protocols) should be agreed with the client and approval authority.

The design standards for rail drainage will also require agreement, measures to reduce the risk of pollution runoff into the reservoir should also be considered. The routing of utilities will need care to avoid penetrating the watertight elements and to ensure important utilities are adequately protected. The relevant design standards and coats, safety criteria and stopping points will also require agreement.

The railway loading criteria (ULS, SLS, ALS) will need to be developed as well as combinations with other loads. Differential settlement of the railway particularly between on and off dam sections, between dam and bridge structures will need to be considered.

3.2.15 Access requirements for fishing/shipping

A study will be required on the type, size and volume of shipping along with the routes followed, with particular reference to the proposed new ports of Dholera and Khambhat within the freshwater reservoir. This will inform the need for and design of navigable canals and locks including the number, length and width of locks, their positioning and the type of lock gate and lock structures proposed.

It is also likely that designs will need to be approved by CIFRI, Central Inland Fisheries Research Institute, the Indian Regulator, with suitable conditions that will encourage both upstream and downstream movement of fish and aquatic species between the saline estuary waters and the freshwater impoundment.

3.2.16 Mechanical equipment

Gates are required on the spillways to dispose of floods, flush out sedimentation and remove saline water.

The design of the spillways has 65 radial gates of 17 x 17m (Techno economic feasibility report Kalpasar).

Current designs show that each spillway will have a set of two gates: an upstream gate for regulating spillway flow and a gate on the downstream for preventing sea water entering into the freshwater reservoir during high tides.

Alternative designs for spillway gates were considered (Khatsuria, 2018):

Alt layout I: 105 vertical lift gates across a 2,311m span. Each vertical lift gate being 18m wide, 7.5m tall.

Alt layout II: 95 vertical lift gates across a 2,068m span. Each vertical lift gate being 18m wide, 5m tall.

For the removal of saline water, sluices or pumps are intended to be used.

Option 1 – Sluice gates: 9no gates at 16m.

Option 2 – pumping: Utilisation of freshwater pumps to initially remove saline water. Estimated to be 1-2 years (20-25% of reservoir live capacity, 10,000 million m^3). The vision is to utilised wind energy to provide power for the pumping operations (Haskoning, 1998).

The selection of appropriate options (e.g., pumping vs sluices) and appropriate gate choices should be reviewed in an option selection exercise.

Where either gates or pumping is utilised to remove the saline water at lower levels, careful consideration needs to be given to sedimentation and the impacts this will have upon the operation and longevity of the equipment.

The reservoir water level and inflow will require monitoring to inform gate and sluice operation and flood warnings and emergency response. Such monitoring will also inform water resource planning. Similarly, sea levels will need to be monitored to inform gate and sluice operation and to provide warning in case of emergency.

All gate options will require instrumentation to be integrated into a SCADA system for control and health and condition monitoring. Due to the criticality of the system, the security of it will need to be considered. As well as security of access and control the reliability of the system should be considered. Redundancy of power and operation of safety critical systems such as spillway gates will be required. Control systems will need to link to early warning and flood warning systems.

Standards applicable to gates and mechanical equipment:

- Structural design basis EN 1990 Eurocode Basis of structural design.
- Loads and other actions EN 1991 Eurocode 1: Actions on Structures, Parts 1–7: General actions—Accidental actions.
- Steel structures, design general EN 1993-1-1 Eurocode 3: Design of Steel Structures, Part 1-1: Gen. rules and rules for buildings.
- DIN 19704-1 – Hydraulic Steel Structures - Part 1: Criteria for design and calculation.
- DIN 19704-2 – Hydraulic Steel Structures - Part 2: Design and Manufacturing.
- DIN 19704-3 – Hydraulic Steel Structures - Part 3: Electrical Equipment.
- BS EN 10204 – Metallic Products. Types of Inspection Documents.
- IS 4622 - Indian Standard RECOMMENDATIONS FOR STRUCTURAL DESIGN OF FIXED-WHEEL GATES.
- IS 5620 - Indian Standard Recommendations for Structural Design Criteria for Low Head Slide Gate.
- IS 9349 – Indian Standard RECOMMENDATIONS FOR STRUCTURAL DESIGN OF MEDIUM AND HIGH HEAD SLIDE GATES.
- ETL 1110-2-584 - US Army Corps of Engineers® DESIGN OF HYDRAULIC STEEL STRUCTURES.
- EM 1110-2-3105 - US Army Corps of Engineers® Mechanical and Electrical Design of Pump Stations.
- ISO/IEC TR 27019: Information technology - Security techniques - Information security management guidelines based on ISO/IEC 27002 for process control systems specific to the energy utility industry.

3.2.17 Construction Sequence and Methods

The construction methods and sequencing will require careful consideration considering the risk of:

- Flooding during construction and risk of breach.
- Flow velocities during closure of works and risk of scour.
- Sediment flow entrapment and deposition.
- Variation in bed level due to tidal movement and longer term trends.
- Weather disruption to the works.
- Safe access to the works and emergency egress.
- Sourcing and movement of materials.
- Seismic stability, taking due account of a potentially long construction period.

3.2.18 Instrumentation Plan

ICOLD bulletin 61 describes 4 important purposes for instrumentation of a dam:

1. To indicate the evolution of conditions during construction so that the validity of certain criteria can be confirmed before the project is commissioned.
2. To indicate the evolution of conditions during and following first filling of the reservoir so that performance can be evaluated with respect to that assumed in the development of the criteria.
3. To indicate the evolution of undesirable conditions throughout the life of the dam so that remedial measures may be undertaken to avoid deterioration of its security.
4. To record experience for the improvement of the design of future dams.

A programme of instrument readings, combined with inspections and periodic evaluation reports throughout the life of the dam, will serve to confirm that the security criteria of the design remain valid or that steps should be taken to restore the dam and its foundation to acceptable levels of security (ICOLD 61).

The design of the instrumentation would need to be developed based on the dam section design and site conditions. Typically monitoring should include:

- Reservoir water level monitoring and recording.
- Seepage and leakage monitoring- such as with v-notch weirs for flow monitoring and inspection of flow.
- Water pressure in (embankment) dams and in foundations (all dams).
- Deformation monitoring such as crest settlement and displacement or for deformation of slopes.
- Seismic monitoring/ strong motion detectors.

ICOLD Bulletins 60, 68, 87, 118, 138, 158 and 180 further describe the objectives and forms of monitoring for dams as part of an overall package of surveillance. Consideration should also be given to automating elements of the instrumentation and monitoring, particular in remote sites as described in ICOLD Bulletin 118, though this should be seen as a supplement to visual inspections rather than a replacement.

3.2.19 Operations and Maintenance Manual

The United States Bureau of Reclamation (USBR) guide for preparation of Operation and Maintenance (O&M) manual and procedures for dams should be used as a framework to develop a site-specific document. There should be one primary controlled document with the complete, accurate, and current operating instructions for the reservoir and its appurtenant structures. The purpose is to ensure adherence to approved operating procedures over long periods of time and during changes in operating personnel.

The O&M manual and gate operating philosophy shall also address procedure for sediment management, as discussed.

The document extends beyond the everyday operations to procedures required in an emergency situation, for example, where the dam is at risk of an uncontrolled release of the reservoir water. The USBR guide breaks down the operation and maintenance into the following chapters:

- General Information - administration of the dam, reservoir or power facility.
- Electrical, Mechanical & Structural - detailed descriptions and instructions for operating, maintaining and examining the structures and equipment.
- Structural Behaviour Instrumentation - extent of installed instrumentation, monitoring and maintenance requirements.
- Reservoir Operations - detailed instructions and information on all aspects of reservoir operation.
- Power Facility Operations - detailed instructions and information on all aspects of power operation.
- Appendices - drawings, logs, maps, photographs, charts, copies of selected supporting documents.

Alternative guidance is provided in ICOLD Bulletin 154- Dam safety management: Operational phase of the dam life cycle.

The design should feature access tracks and roads as needed to ensure timely access to the dam for the purposes of ongoing monitoring, surveillance, maintenance and operation.

Surveillance and monitoring is important through the life-cycle of the dam; however, additional significance should be taken during the first filling of the reservoir. Regular surveillance observations of the dam and reservoir should be undertaken by suitable trained personnel. The frequency of the visits can be related to the hazard posed by the dam.

It is usual international practice to employ the ‘four eyes’ principle, with the first pair of eyes belonging to the owner or dam operator and the second pair to an independent body, for example supervisory authority or boards of experts (ICOLD 167 Regulation of Dam Safety: An overview of current practice worldwide). ICOLD 180 Dam Surveillance – lessons learnt from case histories provides worldwide examples of surveillance and why it is important. A monitoring regime should be established to take measurements or readings relevant to the type of dam. Analysing the measurable parameters can suggest the acceptable performance of the dam or indicating deviation from expected behaviours, prompting more detailed surveillance or monitoring and/or interventions to protect the safety of the dam. Instrumentation forms one part of the surveillance package and is described in more detail in Section **Error! Reference source not found.**.

3.2.20 Emergency Preparedness Plan

An outlined EPP is typically prepared prior to construction and agreed with relevant stakeholders. A typical content of an EPP, based on the recommendations by the US Federal Dam Safety Commission, is given below.

1. Introduction and objective of the EPP.
2. Description of the scheme.
3. Emergency detection/failure modes.
4. Notification Flowchart.
5. Alarm Levels and Organisation of Warning.
6. General Responsibilities under the EPP.
7. Notification Procedures and response matrix.
8. Early Warning System (EWS).
9. Mitigation Activities.
10. Organisation of evacuation.
11. Approval, maintenance, exercise and correction of EPP.
12. Appendix (dam break analysis, inundation maps etc).

The notification flowchart, Section 4 of the EPP, shall list all stakeholders and shall show clearly, for each level of emergency, who is to be notified, and who is responsible for notifying which owner representative(s) and/or public official(s), and in what priority. The notification flowchart shall include individual names and position titles, office and home telephone numbers, and alternate contacts and means of communication.

The alarm levels and organisation of warning (Section 5 of the EPP) shall include the following alarm levels:

- Minor deficiencies – Level 1: mobilise personnel and equipment to deal with minor deficiencies.
- Serious deficiencies- Level 2– Local public officials have to be informed to be prepared for action if the situation gets worse.
- Very serious deficiencies- Level 3 – as for Level 2.
- Alarming deficiencies – Level 4 – Special Mobile Force, police and local public to be alarmed; radio broadcasting to be interrupted to warn the population; the population to be evacuated.

Section 6 describes general responsibilities under the EPP. It typically describes:

- Operators’ duties in implementing the EPP.
- The person(s) authorised to notify local officials should be predetermined & clearly set forth in the EPP.

- Gives pointers on how to communicate the emergency situation to those who need to be contacted.
- Describes predetermined remedial action to delay or mitigate the severity of failure.
- EPP should be co-ordinated with high enough levels of management to ensure full awareness of capabilities.
- Describes specific actions operators are to take after implementing the EPP.

3.2.21 Land Acquisition and Social Impacts

Within this part of the design, concerning the land and buildings acquisition, the buildings and land that will be covered by the construction and operation impact zone shall be identified and classified, and the costs of temporary and permanent acquisition shall be estimated.

The unit prices of acquisition shall be adopted based on current market data.

Within this part of the design, it is required to:

- Analyse the existing ownership structure.
- Define the land classification and use.
- Define the land areas to be acquired.
- Define the costs of permanent and temporary acquisition.

Access and temporary occupancy sites must be obtained by means of a valid legal instrument that provides legal certainty for both the affected party and the contractor.

In the case of economic loss, there must be compensation from the party who caused the damage.

Consideration should be given to the most suitable way of releasing the areas. In that sense, all possible forms of release should have been ruled out and land acquisition should be left as the last option. If resettlement is considered, prior and necessary activities that will need to be carried out must be taken into account. The standards based on the best international practice are given in Section 3.5.3 of this report.

3.2.22 Archaeological Impacts

3.2.22.1 Introduction

India has high regard and respect for its internationally important heritage, also its former and present cultures/religions. This all relates to both tangible and intangible historical resources and attributes. The national and state activities, creating museums, conserving monuments, preserving ruins, retrofitting historic buildings and presenting archaeologically excavated sites, is planned to dramatically increase as India is further rapidly transformed. Increasingly, archaeology is of general interest, and with public participation, for an informed society and for discovering, celebrating and sharing the achievements of India's past. The assets can provide stability at times of change. The assets are fundamental to future 'place-making'.

It is however important to note that archaeological remains, known or awaiting discovery, are finite and irreplaceable if destroyed. Remains, generally regarded as having a society ownership, are important as one can learn from the past, are essential for defining and contributing to culture, and for present status/well-being of society and community. Importantly, remains provide a tool for supporting quality development and can be a way to measure SDGs successes and failures.

A scheme of the scale of Kalpasar Barrage with large scale temporary and permanent construction, and then with onward management and development, will, with certainty, discover and impact on cultural heritage remains, potentially spanning Prehistoric to Industrial times. Remains could be of international and national cultural value, but more likely of regional and local value.

For this reason, Culture and Cultural Heritage are legitimate concerns and must be addressed, so satisfying national to local requirements and international expectations. There is a need for the scheme to:

- Abide by laws, directives and best practice.
- Learn from the past, thus potentially avoiding mistakes.
- Mitigate adverse effects on cultural heritage assets and making the results public.
- Preserve whenever possible archaeological sites in-situ.
- Integrate protection of the man-made historic landscape attributes with natural ecological - environment needs.
- Minimise design and construction disruptions resulting from dealing with archaeological remains that cannot be avoided.
- Be efficient, cost effective and non-disruptive.

In achieving these needs there would be significant support to cultural and recreational tourism; tourism is one of the stated benefits of the project. It will also be useful for education and local enjoyment / employment. The enhanced status of the scheme and of participating parties would be the result.

3.2.22.2 Assessment of project reports

A brief review of a large number of documents provided (see Appendix 1) shows that the Cultural Heritage of the scheme variously comprising the dam site, the water body, and the rim hinterland supporting temporary works and new infrastructure, has not been considered. No references have been found that would suggest it has been scoped out as a subject not relevant to the scheme proposals.

One document providing a, 'Synopsis of Various Environmental and Socio-Economic Studies' (document #30) contains two short texts, hinting at there being a heritage:

- Chapter 9.6 Cultural and Aesthetic Sites Content – Lothal Indus Valley Site, p148.
- Chapter 12.1 Heritage Related Sites – Piram Island, p241.

3.2.22.3 Immediate suggestions

Arup considered there is an urgent need to comprehensively address cultural heritage related to the Kalpasar Barrage, firstly as a catch-up related to what has been achieved for a large number of other technical topics. These studies do not directly or indirectly reference archaeology and heritage, though the subject matters have a related background and relevancy.

The catch-up would improve the scheme and general support it being more viable and acceptable. The cultural heritage assets may be found on the seabed in deep and shallow water regimes, buried within the tidal foreshore, throughout the surrounding rural hinterland and in urban centres.

The archaeological and cultural study process should address:

1. Relevant National and Regional Laws and Directives and show how they will be abided by or will need exemption.
2. International best practice.
    - UNESCO and ICOMOS Charters and Conventions.
    - Methods and standards of ASI and of the State.
    - INTACH policies and its mission.
    - Chartered Institute of Archaeologists (CIfA) Standards (from UK as a good and respected example that may be useful to utilise).
3. An archaeological-cultural heritage baseline addressing assets and related historic landscape/environment. This would require background research and consultation, then integrated with extensive fieldwork. The resources would typically be defined by:
    - Type and age.
    - Location and context.
    - Extent.
    - Land use.
    - Cultural value and afforded legal protection – single and group values.
    - Burial preservation regimes.
4. Vulnerability of the sites and assets.
    - Asset robustness.
5. Asset locations related to development, and/or loss from the Hazards - the impacts and adverse effects.
    - Temporary works at scheme sites.
    - Temporary undertakings not at scheme sites.
    - Construction works at dam and other related sites.

- Onward changes to environment.
- Onward management and asset protection.
- Societal development schemes resulting from the scheme.

6. Risks Assessment.

- Consequences resulting from damage or destruction.
- Cumulative and strategic risks.
- Acceptability of residual risks if there is protection and/or mitigation.

7. Mitigation options – a grey scale of interventions – done according to a research and implementation agenda:

- Do nothing.
- Location and evaluation of sites and historic landscape by a range of methods.
- Watching brief.
- Strip and mapping.
- Archaeological excavations.
- In situ preservation/reburial.
- Change of development scheme.

8. Strategy for promotion of Cultural Heritage – giving direct and indirect added value

- Analysis of fieldwork findings.
- Functional preservation and display of sites and artefacts considering what can be achieved at the dam scheme and at distance.
- Use for education.
- Cultural tourism – local to international.
- Community engagement.
- Publications and other social media outputs.

9. Integration of archaeological skills within the dam development planning and implementation team and its undertakings

- Employment of archaeological consultant.
- Employment of archaeological contractor.
- Stakeholder engagement.
- Use of an external reviewer.

3.2.22.4 Long term support to design and execution

The above recommended for a baseline study and field research agenda would set a suitable and rigorous strategy for addressing tangible cultural heritage during the advanced design stage, then during the scheme's construction implementation. Alternatively, the subject could be comprehensively addressed by achieving a Heritage Impact Assessment, as now commonly done for sites being promoted for inscription as a World Heritage Site, the methodology now being more widely promoted internationally for sites of national, regional and local values.

With appropriate engagement of archaeological professionals' and processes it is considered unlikely that significant changes would be needed for the scheme's engineering, while highly significant added-value would be ensured outline.

Given the history and importance of sea trading, fishing, use of mangroves, salt production, agriculture and of urban life-styles around the estuary, a case can be made for looking at the impacts and negative/positive effects to the intangible cultural heritage of the region, supporting socio economic considerations and well-being.

3.3 B - Estuary water management and quality

3.3.1 Introduction

We have considered the estuary water management in terms of tidal and fluvial flood risk in relation to the proposed Kalpasar dam. The hydrology and hydraulic modelling of the fluvial catchment is discussed in section 3.2.4; this section concentrates on the flood risk impacts.

We have also considered the requirements for the quality of the proposed water supply. Issues related to the volume of water supply are discussed in section 3.2.5.

3.3.2 Tidal flood risk

It is expected that there will be tidal model built to leading standards that will assess existing conditions to form an appropriate baseline scenario. It should also include provisions for projected sea level rise with an appropriate consideration of the IPCC RCPs.

The tidal model should have been adapted to include the proposed Kalpasar Dam scheme to assess the tidal impact on the scheme. This should cover

- Extreme tidal surges, sea level rise and a consideration of RCPs and a strategy for management/adaptation considered for both the protection of the dam and the surrounding area.
- Dam breach scenarios – land side and sea side – should be considered to assess the impact on the reservoir, and coastline upstream and downstream of the dam.
- Identifying potential overtopping of the dam.
- The underlying tidal modelling and the maximum tidal levels observed, with a consideration for climate change and sea level rise should have been consulted when assessing the levels of the dam and the associated infrastructure within.

3.3.3 Fluvial flood risk

It is understood that the upstream fluvial flow estimates have been derived with consideration of the catchments shown in Figure 3.1 below. This consists of an ultimate upstream dam release flow (where applicable) and gauge readings used to derive unit hydrographs for gauged basins and average dimensionless unit hydrographs for ungauged basins to understand basin runoff.

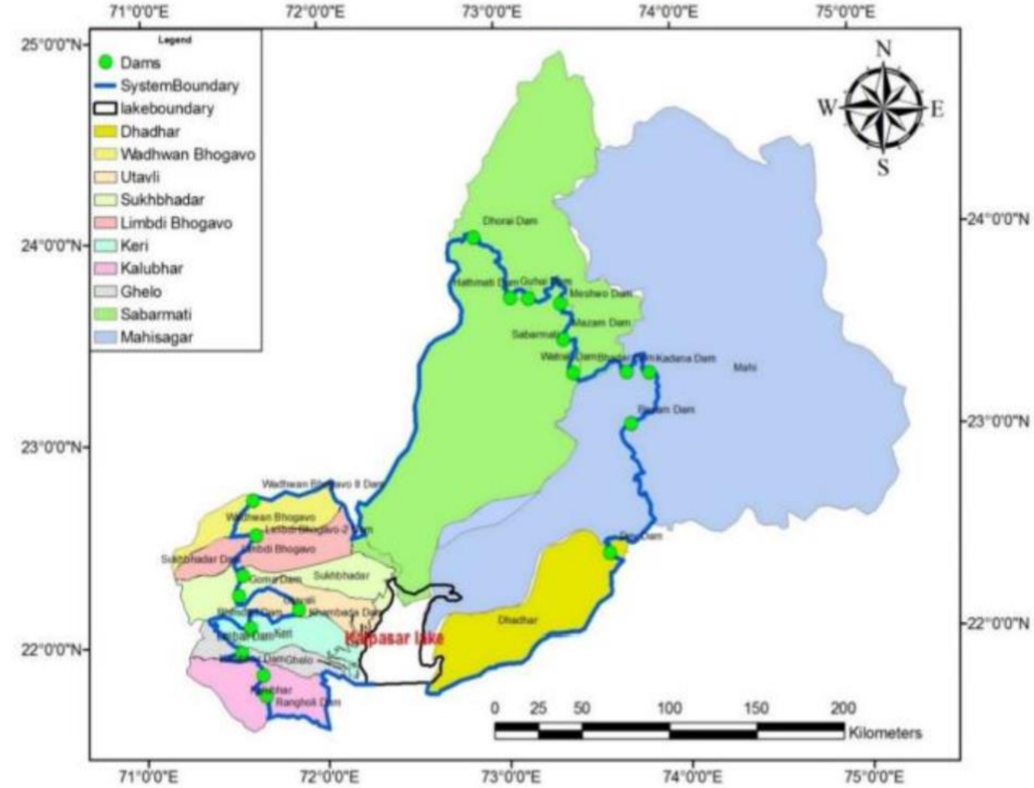


Figure 3.1 Project catchment map

In order to have accurately represented the runoff from the upper catchments and to understand the fluvial flood risk and thus the supply to the Kalpasar reservoir, the following studies should have been completed and will be the subject of Arup's ultimate gap analysis review:

- The hydraulic analysis of all upstream catchments should have been completed to known Indian standards or to international standards such as USACE EM 1110-2-1317 Flood-Runoff Analysis and cover a range of return periods that also include an allowance for climate change – with uplifts added to reflect best practice in the region.
- This hydraulic analysis should have included the most up to date, available catchment descriptors that cover the hydraulic characteristics of the land represented.
- The hydraulic analysis should have considered the seasonal nature of the study area and perform separate analyses for the dryer season and the monsoon season.
- Seasonal discharge flow rates from upstream dams should have been obtained from the relevant authority.
- Gauged data should have been used to determine flows in all watercourses where available. Best practice in the region should be applied to generate unit hydrographs.
- To understand the hydraulic nature in the region a 2d model should have been created (or used if one exists) to, as a minimum, cover the upstream fluvial

extents that are tidally influenced. This analysis should have been completed using best available practice and standards from the region.

- The hydraulic model should utilise the most up to date survey and topography available for the river channels and floodplains.
- This model should have been linked to existing tidal models to understand the downstream influence of the tide on the whole catchment and understand the residual flood extents and ramifications of removing this tidal influence. Has a joint probability analysis been performed to assess a wort case scenario of a maximum fluvial stage coinciding with a maximum tidal stage?
- Calibration against known events should have been completed for confidence in the unit hydrographs derived. This will enable confidence in a baseline hydraulic representation of the area that represents an existing fluvial and tidal regime.

Once the baseline, existing model has been confirmed, the following should likely have been completed:

- To understand the upstream fluvial impact of removing the tidal influence and implementing the Kalpasar Dam scheme. A further study should have been performed, using the baseline fluvial model, to remove the varying tidal downstream boundary with a (presumed) lower, static boundary to represent the reservoir. This will have allowed for an understanding into the impact of different levels/flow regimes further upstream into the catchment and would have ultimately informed socio-economic and environmental studies.
- How has the flood risk to the to the reclaimed land, due to the lower level on the reservoir side, been assessed for both surges due to monsoon flooding and potential breech scenarios of the Kalpasar Dam? Existing plans suggest these areas will be developed; how will future developments be protected from flood risk?
- Were the derived flows and/or the hydraulic model used in the derivation of the dam levels and was climate change and sea level rise been considered?

3.3.4 Catchment Water Management (quality/supply)

The following are standards, guidelines and local regulations that may be applicable to surface water and groundwater quality:

International standards and guidelines

- World Health Organisation, Guidelines for drinking water quality, Fourth edition incorporating the first addendum.
- FAO irrigation and drainage paper 29 Rev 1, Water quality for agriculture.
- EU Directives relating to the quality of water intended for human consumption (80/778/EEC) and Council Directive 98/83/EC.
- USEPA standard — National Primary Drinking Water Standard. EPA 816-F-02-013.

National standards. bills and guidelines

- Indian Standard for Drinking Water as per BIS specifications (IS 10500-2012) (second revision).
- Manual on Water Supply and Treatment, third edition, Ministry of Urban Development, New Delhi.
- Central Water Commission tolerance limits for inland surface waters for the various classes of water use.
- Surface Water Quality Standards (ISI-IS 2296-1982).
- Model Bill to regulate and control the development and management of ground water, 2005.
- The Water (Prevention and Control of Pollution) Amendment Bill by Ministry of Water Resources (2012).
- IS 11624 (1986): Guidelines for the quality of irrigation water [FAD 17: Farm Irrigation and Drainage Systems].
- IS 4251 (1967): Quality tolerances for water for processed food industry [FAD 25: Drinking Water].

3.4 C - Geotechnics/seismicity

3.4.1 Geotechnics

3.4.1.1 Ground investigation, dam site and construction materials

The preliminary ground investigation undertaken by COMACOE (reported April 2021) for the Gulf of Khambay Development Project (Kalpasar) Government of Gujurat provides valuable information regarding the likely conditions along the line of the favoured alignment (Alternate -5). This comprises some 49 locations across the 51km section investigated so the locations are very widely spaced. Within the entirely marine section the spacing between investigation locations is between 1400m and 5500m so there is currently no detailed understanding of the ground conditions beneath the proposed dam alignment, and it is recognised that additional phases of investigation will be required to inform the developing design process. To put the current level of information into context, if we assume eventually a spacing between investigation point of say 100m would apply, then at this stage we have between about 10% to 15% of the information needed to support detailed design.

The report by COMACOE is divided into 7 Zones but appears to be missing all of the borehole and insitu test data (Appendix B and C have information from a different zone) from Zone 1. We would note that IITM's assessment of the data reduces this to 6 Zones so we would suggest that a clear referencing system needs to be put in place to avoid confusion.

One aspect of the COMACOE investigation that does not appear to have been commented on by other is the apparent high to very high carbonate content of many of the underlying soils. These results need some clarification as it is not clear whether this is expected in this area as it does not appear to have been noted by published information for the geology of the area. However, if confirmed, this may have a positive effect in relation to liquefaction potential (see Seismic Assessment Section). It is also noted that the liquefaction assessment assumes Seismic Hazard Zone IV which may be an early stage assessment using a very conservative zonation (as identified by others also eg IITM). A site specific seismic hazard assessment will be required to inform the developing design (see Seismic Assessment Section).

It is clear from the ‘as built' levels of investigation locations in the COMACOE investigation that the bed of the inner as well as the outer gulf is a very active environment with constantly changing levels and differences over a few years of up to 30m appear to be a characteristic result from successive bathymetry and borehole location surveys. This means that geotechnical investigation of the soils within 30m of mean sea level provides only a ‘snapshot in time'. Sand ridge and bar migration will result in variable bed level, density and strength development in the shallow foundation soils until construction is complete. The proposed earthfill dam will have a potentially huge volume of material below MSL. This means that the normally simple calculation of dam material volumes is going to be difficult to predict with certainty, due to the shifting nature of the seafloor. Consequently, dam construction cost and programme are going to unpredictable. Further study of this aspect is likely to be required.

Reference is provided of other (perhaps minor?) investigations having been undertaken in the area for the project (e.g., NIOT 2012 and also by Haskoning) but at this point we have not had access to that data. IITM have noted however that the findings of the recent investigations are generally consistent with the previous information. The seafloor morphology has been quite extensively studied (see for example *The morphology and evolution of tidal sand bodies in the macrotidal Gulf of Khambhat, western India* Sourav Saha Stuart D. Burley, Santanu Banerjee, Anupam Ghosh and Pratul K. Saraswati , *Marine and Petroleum Geology Volume 77, November 2016,* Pages 714-730) and a thorough desk study is recommended in order to place the geotechnical data into a coherent soil model that recognises the transience of the gulf bed levels along the dam alignment.

The development by the project of a Geodatabase appears to be exactly what is needed to provide an overview of the information available. It is recommended that once that information is available, a ground model based on all the available information is prepared and provided for the project teams use in the design going forward.

Currently it is envisaged that the dam structure will be constructed largely of rock fill and sands (potentially dredged) but there are no further details of the sources of such material, the means of transport to site or of the environmental impact of such activities. It is understood that such work is to be instructed shortly but at this point we have no further information. Alternative construction methods for part of the structure may well be appropriate, for example the use caissons of known geometry that can be floated out and ballasted into position on a seafloor prepared by suction dredger or similar. Such options could significantly reduce the quantity of mass fill required and will no doubt be considered as the design develops.

Further details of the developing geotechnical design will need to be reviewed as information becomes available. It is apparent that some preliminary work is underway including in the following areas:

- Development of a geological model for the site.
- Assessment of geohazards.
- Seismic engineering including liquefaction assessment.
- Soil structure interaction aspects.
- Study of construction options.

3.4.1.2 Reservoir Basin

Rim Stability/ Landslides

The potential for mass movement hazard needs to be assessed in relation to the reservoir basin. Risks of mass movements in the reservoir rim area must be evaluated and mitigation measures may be needed. The stability and structural integrity of the reservoir rim upstream of the structure must be evaluated for all potential loading conditions whether hydrologic, earthquake, or other hazards, man-made or natural. Reservoir rim instability may lead to poor water quality, blockage of channels and structures and waves which may threaten reservoir users and the dam structure.

Basin Leakage

Basin leakage during impoundment occurs when infiltration of reservoir water is occurring through the surrounding and underlying soils, which is problematic if seepage occurs beneath the dam retention structures and can cause other erosional issues for the reservoir area. The permeability, hydraulic conductivity, and porosity of the soils supporting the reservoir volume should be evaluated. Erosion potential and corrosivity of the foundation soils should be evaluated.

3.4.1.3 Relevant Codes

International Codes relevant to the proposal in addition to the existing Indian Standards would include the following:

Dam Design

- International Levee Handbook CIRIA 731.
- United States Department of the Interior – Bureau of Reclamation Design of Small Dams.
- United States Department of the Interior – Bureau of Reclamation Design of Gravity Dams.

- United States Department of the Interior – Bureau of Reclamation DS13 Embankment Dams.
- United States Department of the Interior – Bureau of Reclamation DS14 Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standard.
- AASHTO LRFD Bridge Design Specifications.
- AASHTO LRFD Bridge Construction Specifications.
- ICOLD Bulletins.
- Federal Highway Administration (FHWA) Manuals, Guidelines and Circulars including but not limited to:
  - FHWA, Geotechnical Engineering Circular No. 5 - Evaluation of Soil and Rock Properties, FHWA-IF-02-034.
  - FHWA, Subsurface Investigations – Geotechnical Site Characterization, FHWA-NHI-01-031
- All Appropriate and Applicable USACE manuals including, but not limited to:
  - EM 1110-1-1804 Geotechnical Investigations.
  - EM 1110-1-1904 Settlement Analysis.
  - EM 1110-1-1905 Bearing Capacity of Soils.
  - EM 1110-2-1902 Slope Stability.
  - EM 1110-2-1908 Instrumentation of Embankment Dams and Levees.
  - EM 1110-2-1913 Design & Construction of Levees.
  - EM 1110-2-2100 Stability Analysis of Concrete Structures.
  - EM 1110-2-2302 Construction with Large Stone.
  - EM 1110-2-2502 Retaining and Flood Walls.
  - EM 1110-2-2503 Design of Sheet Pile Cellular Structures Cofferdams & Retaining Structures.
  - EM 1110-2-2504 Design of Sheet Pile Walls.

Earthworks in general

- EN 16907-1 Earthworks — Part 1: Principles and general rules.
- EN 16907-2 Earthworks — Part 2: Classification of materials.
- EN 16907-3 Earthworks — Part 3: Construction procedures.
- EN 16907-4 Earthworks — Part 4: Soil treatment with lime and/or hydraulic binders.
- EN 16907-5 Earthworks — Part 5: Quality control.
- EN 16907-6 Earthworks — Part 6: Land reclamation earthworks using dredged hydraulic fill (this document).
- EN 16907-7 Earthworks — Part 7: Hydraulic placement of extractive waste.

Further work will need to be undertaken to develop the applicable codes based on the agreed classification of the structure.

3.4.2 Seismic Engineering including liquefaction assessment

3.4.2.1 Introduction

The Indian subcontinent is a region that is prone to earthquakes. According to the NOAA Significant Earthquake database, more than 100,000 lives were lost to earthquakes in India, Nepal and Pakistan during the last three decades.

The Gujarat region lies about 300 to 400km from the plate boundary between the Indian and Eurasian plates. Despite this it is one of the most active intraplate regions of the world resulting in nine major earthquakes during the past 200 years. The most recent event was the 2001 Bhuj earthquake. The earthquake killed 20,005 people, injured another 166,836 and destroyed nearly 339,000 buildings resulting in a direct loss of US$2,623million.

The proposed site of the Kalpasar dam lies about 200km from the most active region in Gujarat, but it would still be subject to ground shaking due to both larger distant and smaller local events.

This note reviews the local and international seismic design codes and proposes seismic design criteria for the design of the Kalpasar dam.

3.4.2.2 Seismic considerations

When considering the design of a major multifunctional infrastructure element the following considerations needs to be addressed from a seismic design perspective.

The Kalpasar dam is a major piece of infrastructure that sits outside normal building design codes (e.g., IS 1893). As currently conceived, the Kalpasar dam has three principal functions:

- As a dam to impound freshwater.
- As a coastal barrage to prevent coastal flooding.
- As a transport corridor for both road and railways.

Potential failure modes and consequences include:

- Excessive settlement leading to loss of railway function.
- Local slope instability leading to local loss of the transport corridor.
- Total collapse leading to inundation of coastal communities downstream.

The potential seismic hazards which should be considered include:

- Seismic ground shaking including soil and topographic amplification.
- Surface fault rupture.
- Liquefaction of foundation soils.
- Dam reservoir seiches
- Tsunami

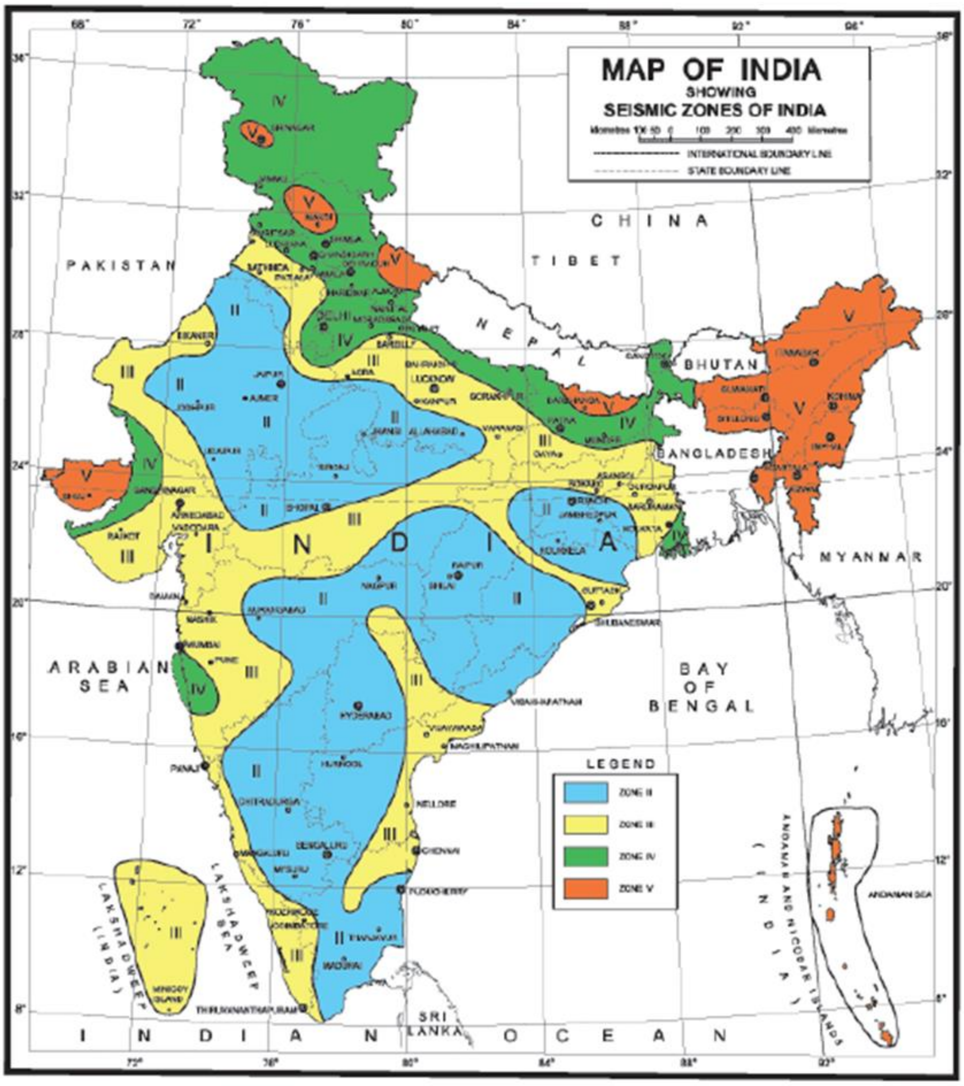
3.4.2.3 Indian Design Codes and Guides

The following bullets present the local design codes relevant for seismic design of embankments and small to moderate dams in India.

- IS 1893 (2016) Criteria for Earthquake Resistant Design of Structures. Bureau of Indian Standards
  - Part 1 refers to general provisions and buildings.
  - Figure divides India into four seismic zones, labelled from Zone II to Zone V. The site is in seismic zone III. This equates to a seismic acceleration coefficient Z of 0.16.
  - The ground motion definition in IS 1893 is referred to as the Maximum Considered Earthquake (MCE) but is not related to a specific return period.
  - Part 5 refers to dams and embankments, but it is not yet written. A draft is given in IITK-GSDMA (2007).
- IITK-GSDMA (2007) Guidelines for Seismic Design of Earth Dams and Embankments
  - Clause 1.1 states the provisions of these guidelines are applicable to earth embankments and small to intermediate size earth and rockfill fill dams as classified in Indian code IS 11223-1985.
  - Clauses 1.3 and 6.1 states the seismic coefficient should be taken from IS 1893 or a site-specific seismic hazard assessment. This should be carried out for projects in active fault zones.
  - The commentary to Clause 1.3 states for the design of intermediate dams or embankments and dams and embankments whose failure entails unacceptable level of risk, a two-tier seismic design approach is usually adopted so that:

    a) The dam or embankment remains operational following an earthquake that has a reasonable probability of occurrence during the service life of the facility with distress of a minor nature, and

    b) The dam or embankment does not collapse following an earthquake that has a small probability or occurrence during the life of the facility.
- IS 11223 (1985) Guidelines for Fixing Spillway Capacity. Bureau of Indian Standards.
  - Clause 3.1.2 classifies a large dam as one that has a gross storage of more than 60 million m3 or a hydraulic head greater than 30m.
  - No seismic provisions are given in IS 11223.



Based upon Survey of India Political map printed in 2002.

Figure 3.2 - Seismic Zones of India (IS 1893-1, 2016)

3.4.2.4 International Design Codes and Guidelines

For the design of large dams, the International Commission on large Dams (ICOLD) sets out guidelines on all aspects of siting, design and construction. India is one of the member countries. The in country committee is INCOLD, which is hosted by the Central Board of Irrigation and Power (CBIP).

- The principal guideline is ICOLD 148 (2016) Selecting Seismic Parameters for Large Dams - Guidelines (revision of Bulletin 72). International Commission for Large Dams.
- This defines a large dam as one that is one more than 15m high or one between 10 and 15m high satisfying one of the following criteria:

  a) more than 500m long.

  b) reservoir capacity exceeding 1Mm3.

c) Spillway capacity exceeding 2000m3/s.

- A site-specific seismic hazard assessment is typically required to develop the seismic parameters that will be required for seismic design or performance assessment of a dam.
- Two levels of earthquake are defined for the design of the dam, namely:

  a) The SEE is the level of shaking for which damage can be accepted but for which there should be no uncontrolled release of water from the reservoir. It is the maximum level of ground motion for which the dam should be designed or analysed. Where there is a risk of significant loss of life a ground motion with a very long return period, for example 10,000years should be considered.

  b) The OBE is that level of shaking for which there should be no or insignificant damage to the dam and appurtenant structures. A minimum return period of 145 years (i.e., a 50 % probability of not being exceeded in 100 years) is often chosen.

- Other seismic criteria should also be considered.

  a) Reservoir Triggered Earthquakes (RTE) – This is due to the impounding of water behind the dam which changes the in stress within the ground causing earthquakes. (N.B. The 1967 Koyna Dam earthquake is thought to have been an RTE).

  b) Construction Earthquake – For critical constructions stages and temporary structures such as cofferdams, retaining structures etc. it is also necessary to check the earthquake safety.

  c) Appurtenant Structures which are not safety critical the earthquake ground motion should have a return period equal to that specified in the seismic building codes.

For the design of transport infrastructure such as tunnels or bridges, there are various international design codes, for example AASHTO (2016) or Eurocode 8 (2004). These provide requirements which are broadly similar to the requirements in IS 1893. However, when dealing with a major structure or system, for example a major suspension bridge (e.g., Osman Gazi Bridge in Turkey or Stonecutters Bridge in Hong Kong) or a high speed railway network (e.g., California High Speed Rail in the USA or HS2 in the UK), a multi-level set of seismic criteria are often prescribed. This is due to the economic and social considerations of the project.

An example of typical multi-level seismic performance criteria (Foged et al, 2015) are given below:

- Functional Evaluation Earthquake (FEE) – The structure shall have no damage and traffic shall have immediate access. The earthquake return period is 150 years.
- Safety Evaluation Earthquake (SEE) – The structure may sustain repairable damage and traffic shall have limited access. The earthquake return period is 1000 years.

- No Collapse Earthquake (NCE) – The structure shall not collapse and there shall be no casualties. The earthquake return period is 2475 years.

3.4.2.5 Proposed Seismic Design Criteria

Due to the scale and multi-function nature of the Kalpasar Dam it is important that an appropriate set of design criteria are developed to ensure the safe and economic performance of the structure following an earthquake. Based on the review of local and international design codes provided above it is clear that local design standards need to be enhanced based on best international practice. The following set of seismic criteria are proposed.

Table 3.1 – Proposed Seismic Criteria

Design Level	Return Period (years)	Annual Probability in Design Life	Performance Criteria
OBE	145	50%	No loss of life Elastic structural response and no structural damage. Acceptable crest settlements (less than 50mm). No liquefaction within the dam or the foundations. No derailment, trains able to safely brake from the maximum design speed to a safe stop. Immediate emergency access available. Resumption of all operations within a few hours. Safe performance in aftershocks.
FEE	950	10%	No loss of life Inelastic structural response permitted. Repairable damage can be sustained (e.g., crest settlement of 500mm). No liquefaction within the dam or the foundations. Immediate emergency access available. Resumption of all operations after several weeks.
SEE	10,000	1%	No loss of life. No collapse of the dam or any safety critical appurtenant structure. No uncontrolled release of water from the reservoir. No liquefaction within the dam or the foundations. Large permanent offsets permitted. These may require extensive repairs or complete rebuild before operations may resume.

As recommended by ICOLD 148 seismic criteria should also be defined for the construction phase of the project. Table 3.2 presents the proposed criteria assuming a maximum 5 year construction period for the dam.

Table 3.2 - Construction Period Seismic Criteria

Construction Period (years)	Annual Probability	Return Period (years)	Performance Criteria	
5	10%	47	Continued Construction	Elastic performance
5	1%	497	No Collapse	Prevent catastrophic failure No loss of life

3.4.2.6 Recommendations

To define these seismic design criteria a site-specific probabilistic seismic hazard assessment should be carried out to best international practice.

3.5 D – Environmental Risk

3.5.1 Introduction

The work will consider best practice Environmental and Social Impact Assessment (ESIA) and will therefore consider environmental risks, alongside social risks insofar as they are considered by best practice Environmental Impact Assessments (EIA). For the purpose of this report, these considerations are referred to as ESIA, EIA or environmental risks collectively.

The review will focus on a gap analysis of risks associated with typical environmental assessment topic areas and will focus on the interaction of these risks with the overall project business case. The gap analysis will therefore assess whether the main environmental risks from the project are being appropriately considered and managed as the project is developed, supporting a robust project business case.

The analysis will also consider whether the environmental impact studies conducted to date (or currently underway where information has been made available) have provided or will provide the required evidence or quality of assessment in accordance with national and international standards and good practice.

The consideration of environmental risks will provide two deliverables:

1. A review of the technical coverage by the EIA studies of each environmental topic area; feeding into.
2. A commentary of project compliance with international standards and identification of any gaps for further development of studies or assessment needed to support the project's development.

Both deliverables will be high-level in nature, focusing on the key issues. It is envisaged that whilst there may be gaps in the published / historic reports, some of these will be addressed by the ESIA work currently underway. Therefore, it will be essential to the gap analysis that written information on the scope and nature of environmental and social impact assessment currently under development is made available by the ESIA project team at the beginning of the review. The gap analysis for environmental and social risks will focus on the interaction of these risks with the overall project business case.

3.5.2 A review of technical coverage of environmental risks

National and international requirements

The principal national standard for EIA is the EIA Notification, 20063, under the Environment (Protection) Rules, 19864. Major projects require prior environmental clearance at the prefeasibility stage, and then a full EIA for the final project. The content of the prior environmental clearance is provided in Appendix II of the EIA notification, and the required structure of an EIA in India is outlined in Appendix III. The gap analysis will therefore consider whether the adopted processes and scope of the EIA (if provided by the ESIA team) for the Kalpasar Barrage addresses the requirements of the EIA Notification.

It is understood that the EIA Notification requirements are subject to revision, following the publication of the draft 2020 EIA Notification5. This may lead to changes to the requirements of the Environmental and Social Impact Assessment (ESIA) process. Confirmation will be sought from the ESIA project team at the outset that future likely revisions to the EIA notification will be addressed by the ESIA team delivering the EIA and a recommendation made to embed any changes into the proposed EIA approach for the Kalpasar project.

A project of this scale may require the resettlement of directly or economically displaced people. The Rehabilitation and Resettlement Bill 2007, provides for benefits and compensation to people displaced by land acquisition purchases or any other involuntary displacement. The technical review will therefore consider whether resettlement issues have been adequately considered and how they are being managed. This will include requesting inputs from the project ESIA team at the study outset.

The technical review will also consider whether any relevant international legislation, including those transposed into national law, are applicable considerations for the assessment of environmental risk. For example, considering whether there are any internationally recognised sites of nature conservation and the requirements for their protection.

Review of existing and planned assessments of environmental risk

The development and operation of the Kalpasar barrage will have the potential to have a considerable impact on the existing estuarine environment and beyond. It is essential therefore that all major environmental impacts and costs are taken into account and that alternative options that may satisfy the project aims are fully considered.

[3] http://www.environmentwb.gov.in/pdf/EIA%20Notification,%202006.pdf
[4] https://parivesh.nic.in/writereaddata/ENV/THE%20ENVIRONMENT.pdf
[5] http://environmentclearance.nic.in/writereaddata/Draft_EIA_2020.pdf

The review and gap analysis will consider whether the existing assessment materials and planned EIA encompass the major risks posed by an estuarine barrage. Examples of the likely main issues can be found in the HR Wallingford publication 'Guidelines for the Assessment and Planning of Estuarine Barrages' (Burt and Rees, 2001). However, the issues and assessment of environmental impacts for the Kalpasar project will need to be grounded in the local and regional environmental conditions at Kalpasar. These are expected to include:

- Effects on river and estuary hydrodynamics, morphology and flood risk.
- Biodiversity effects from the footprint of the barrage structures, the water impoundment and water level and quality changes inside and outside the barrage.
- Climate implications from resource usage and energy consumption during construction and operation, as well as the potential to be affected by, and/or act in combination with, climatic changes associated with climate change (e.g., extreme weather events).
- Direct and indirect displacement of people within and outside the barrage area.
- The practicality and effectiveness of measures to mitigate and compensate for adverse physical, natural and human effects.

The World Bank and ADB also provides general and sector-specific guidance on assessing the environmental risks associated with major infrastructure projects. Whilst there is no specific guide for barrage or dams, there is related guidance provided by the EBRD 6 and by the International Hydropower Association 7, which will be considered by the review. These technical guidance documents will also be used as background guidance for conducting the gap analysis to identify any areas to strengthen the environmental assessment.

The principal national standard for EIA is the EIA Notification, 2006 8, under the Environment (Protection) Rules, 1986. The required structure of an EIA in India is outlined in Appendix III of the EIA Notification. The gap analysis will therefore consider whether the adopted processes and scope of the EIA for the Kalpasar Barrage addresses the requirements of the EIA Notification.

Output of the review

Gap Analysis

The gap analysis will be delivered through a systematic high-level review of available materials by industry experts using the topic headings within Appendix II of the EIA Notification against the following criteria:

- **Baseline & Evidence** - Is there a robust baseline and future-baseline understanding, including sufficient evidence to make an assessment of environmental risk?

[6] https://www.ebrd.com/documents/environment/pdf-guidance-note-hydropower.pdf
[7] https://assets-global.website-files.com/5f749e4b9399c80b5e421384/60b122c9e6fb91bd42ced28e_Hydropower%20HtG%20E%26S%20268x190%20160421.pdf

- **Scoping** - Have the issues considered in the EIA studies been scoped appropriately?
- **Analysis** - Has the impact analysis been conducted objectively using appropriate tools and standards?
- **Mitigation & Compensation** - Are there comprehensive plans in place to mitigate and compensate for adverse effects?
- **Residual Risk** - What environmental impacts remain unresolved?

It is anticipated that the analysis could be presented in the form of a matrix, with supporting commentary, an example of this is provided below. This table will adopt the checklist of EIA topic headings adopted within Appendix II of the EIA Notification.

Criteria	EIA Notification Topic (examples)			
	Land Environment	Water Environment	Vegetation	Fauna
Baseline & Evidence				
Scoping				
Analysis				
Mitigation & Compensation				
Residual Risk				

Figure 1 – Indicative example of a matrix-based presentation of the gap analysis

The output of the analysis is anticipated to be presented as a Red-Amber-Green risk identification system will be adopted, with a short accompanying commentary. The environmental risk levels are defined as follows:

- Red – Major gap or high risk to project consenting
- Amber - Significant gap or medium risk to project consenting
- Green – Minor gap or low risk to project consenting

Final presentation of the output will be confirmed following comments on the Inception Report and the analysis itself.

Recommendations
The review will also provide any recommendations following the gap analysis on how gaps and/or key risks / issues identified in the analysis can be addressed.

3.5.3 Commentary on compliance with international standards and good practice

International Standards and best practice

The World Bank and its associated institutions such as the IFC have Environmental and Social Standards that aim to ensure that the people and the environment are protected from potential adverse impacts of major infrastructure projects. Regardless of whether the Kalpasar project will require international investment, these policies provide a widely accepted template for including environmental and social considerations into project design and implementation.

The World Bank Environmental and Social Standards[9] therefore provide a comprehensive mechanism for addressing environmental and social issues in in project design, implementation and operation, and they provide a framework for consultation with communities and for public disclosure. Examples of these requirements include conducting environmental and social impact assessments, consulting with affected communities about potential project impacts, and restoring the livelihoods of displaced people.

The Asian Development Bank (ADB) also has an equivalent Safeguard Policy Statement (SPS) that builds upon its previous safeguard policies on the environment, involuntary resettlement and indigenous peoples, and brings them into one single policy that enhances consistency and coherence, and more comprehensively addresses environmental and social impacts and risks.

The SPS [10] aims to promote sustainability of project outcomes by protecting the environment and people from a project's potential adverse impacts by avoiding adverse impacts of projects on the environment and affected people, where possible; minimising, mitigating, and/or compensating for adverse project impacts on the environment and affected people when avoidance is not possible; and helping borrowers to strengthen their safeguard systems and develop the capacity to manage environmental and social risks.

Output of the review

Gap Analysis

There are similarities in overall approach between World Bank Group and ADB policies. However, being focussed on the Asian region including India, the ADB policies are considered the more appropriate for use in a gap analysis for the Kalpasar Project.

The gap analysis will therefore consider the extent to which the following policies (and their supporting principles) are addressed:

1) ADB Environmental Safeguards Objectives: To ensure the environmental soundness and sustainability of projects and to support the integration of environmental considerations into the project decision-making process.
2) ADB Involuntary Resettlement Safeguards Objectives: To avoid involuntary resettlement wherever possible; to minimize involuntary resettlement by exploring project and design alternatives; to enhance, or at least restore, the livelihoods of all displaced persons in real terms relative to pre-project levels; and to improve the standards of living of the displaced poor and other vulnerable groups.
3) ADB Indigenous Peoples Safeguards Objectives: To design and implement projects in a way that fosters full respect for Indigenous Peoples' identity, dignity, human rights, livelihood systems, and cultural uniqueness as defined by the Indigenous Peoples themselves so that they (i) receive

[9] https://www.worldbank.org/en/projects-operations/environmental-and-social-framework/brief/environmental-and-social-standards
[10] https://www.adb.org/documents/safeguard-policy-statement?ref=site/safeguards/main

culturally appropriate social and economic benefits, (ii) do not suffer adverse impacts as a result of projects, and (iii) can participate actively in projects that affect them.

The output of this analysis / review will be a high-level commentary based upon professional experience, with recommendations for further work. It will not represent a full due diligence assessment.

Recommendations
Where the analysis suggests the policies / principles are not likely to be fully met, the review will provide recommendations of the actions required to ensure that they are met.

4 Initial design findings review

This Section provides initial comments on the reports reviewed and highlights some "gaps" initially identified.

The reports supplied will be reviewed against the design criteria noted in Section 3 of this report and the findings will be presented in the final Review Report.

4.1 General comment on project potential, complexity and safety

This is an exciting but sophisticated and complex project which promises lasting social and economic gains for the people Gujarat and the rest of India.

One of our first observations is that the proposed Kalpasar Dam, with a primary purpose of freshwater supply, is somewhat novel and unique in its location, within the Gulf of Khambhat, in close proximity to open sea. This brings additional hydraulic loading conditions from the tidal waters, which need specific consideration in relation to the proposed operation and usage, alongside the more traditional dam safety considerations of impounding freshwater.

In our reviews, we will be looking at the three basic uses of the Kalpasar Dam as proposed:

3. A tidal exclusion barrier
4. A freshwater reservoir
5. A transport crossing

Each of these uses interact, and influence the design to satisfy the others. For example, firstly as a tidal exclusion barrier, the Kalpasar dam creates space and opportunity for freshwater impoundment within the estuary. However, in turn this means that any dam spillway to discharge the freshwater PMF is not able to operate at all times of the tidal cycle; there will be times when the spillway cannot discharge to seawards.

The tidal exclusion barrier also allows new development of beneficial land use in zones previously occupied by saline water at times of high tides. However, with tidal water levels regularly exceeding the upstream reservoir levels, and in extreme tides, the PMF upstream levels, to allow the spillway to be low enough to discharge requires the installation of gates. Should the gates fail in an open position, or even breach, a tidal surge upstream would occur under extreme tidal levels. The consequences of such a tidal surge would be increased with new developments at lower levels on land that was previously within the tidal flood plain. With future sea level rise, the risk of this and potential consequences increase. This situation could be managed with a passive emergency spillway set at an extreme tidal level, yet in doing so this would be far in excess of the desired freshwater PMF level, creating concerns in other areas.

With the stated primary use of the Kalpasar dam being to provide freshwater supply, the contamination from saline intrusion is of course a concern. Should the dam overtop, or gates fail, this will occur. However, we would want to analyse the water contamination (and supply interruption) separately from the safety concerns from tidal inundation of low lying areas. Raising the crest of the dam to reduce the frequency of tidal overtopping, or virtually eliminate the possibility, also raises the latent hazard of a tidal breach through the gates, however unlikely this may be considered.

Similarly, the transport crossing will bring certain safety criteria in regard to flooding and allowable overtopping. We would expect to see a balanced assessment of operational targets (% availability of the transport links), against costs of raising, allowable overtopping and losses in transport benefits. As part of this, we would expect the option of emergency road and rail closures to be considered, instead of rain=sing to reduce overtopping.

We therefore urge that a due diligence study is conducted following our initial gap analysis and in particular that this diligence review investigates the structural stability and ultimate integrity of the dam as a prime safety consideration and under extremes of adverse hydraulic and hydrological loading in a number of tidal, fluvial, transport and combined scenarios.

4.2 A - Dam engineering

4.2.1 Morphology of the site

It is clear that the site area comprises tens of metres of loose interbedded sands and silts, that shift around year on year due to the morphological drivers of tidal currents, waves, river inputs and littoral transport. The water depth varies from 2m to around 30m+.

This explains why there are multiple ‘Tentative’ cross-sections of the dam with Bed levels varying from 0m MSL to -30m MSL. The crest of the dam is roughly +14.5m MSL. Thus, the proposed earthfill dam is going to have a potentially huge volume of material below MSL. It means that the normally simple calculation of dam material volumes is going to be difficult to predict with certainty, due to the shifting nature of the seafloor. Consequently, dam construction cost and programme are going to unpredictable.

It appears to be no coherent study of seafloor morphology or a study of material volumes, sources of that material, alternative means of creating a dam with a crest at +14.5m MSL (a possible solution would be to use caissons of known geometry that can be floated out and ballasted into position on a seafloor prepared by suction dredger or similar).

The scope of the recent COMACOE investigation shows the predicted mudline/seafloor levels that are taken from the earlier Bathymetric survey of 2011, which in turn refers to the extreme bed level changes in certain locations since an earlier survey of 2004.

It is recommended that a detailed seafloor morphology assessment is carried out and then input to the wider Environmental reports because at the moment those reports seem to treat the seafloor as an essentially stable entity, which it evidently is not.

4.2.2 Design Life

The dam typical section schematics provided show a number of components which may have limited design life incompatible with a major dam.

A geosynthetic mattress is noted as a potential option to be explored for the filter layer between rock and sand fill. The risks of gaps during construction (gaps at laps, tearing) generally mean that granular filters are preferred. Selection of any geotextiles will also need to demonstrate the required design life.

A gabion mattress is included at the base of the sea side rock berm, the design life of gabions is typically considered to be around 30years as damage to the corrosion coating can lead to rapid corrosion and loss of integrity.

4.2.3 Embankment Cross Section

Has it been considered to place the 6 lane road and 2 lane railway lines on a viaduct on the crest of the dam; this would reduce the cross section of the dam.

4.2.4 Spillway structures and gates redundancy

The dam will require one or more overflow spillways to safely convey the design and safety check floods. The proposed arrangements are unconventional in that all the overflows proposed will be restricted in an ability to discharge dependant on the height of the tide and any storm tide surge conditions which may be occurring when the dam is full from impounded water. We recommend that this is modelled and checked for ultimate safety and reliability.

Also, no redundancy of spillway gates has been considered for discharging the maximum flood; this is considered unsafe.

4.2.5 Mixing of saline and freshwater

There is a risk of saline and freshwater mixing via:

- infiltration through the embankment

-dam foundations

- reservoir rim

-navigation lock?

- the Narmada diversion channel

All of these cases should be analysed, and mitigation measures proposed.

4.2.6 Supply Reliability

A 50% water availability dependability rate is referenced in recent presentations. This is considered to be low. The projects water supply objectives should be confirmed. It would be good to understand the climate change projections (if any undertaken).

4.2.1 Archaeological Impacts

A brief review of a large number of documents provided (see Appendix 1) shows that the Cultural Heritage of the scheme variously comprising the dam site, the water body, and the rim hinterland supporting temporary works and new infrastructure, has not been considered. This needs to be considered.

4.3 B - Estuary water management and quality

Areas that we would like to focus during the gap analysis phase are:

- Completeness and granularity of baseline water availability and water demand (municipal, agricultural and industrial) datasets (e.g. seasonal variability)
- Future projections of water availability and water supply including analysis of the impact of climate change on contributing rivers
- Projections of water demand (urban, agricultural and industrial) based on future land use, urbanisation and economic growth scenarios
- Baseline information and datasets of diffuse and point source pollution and current impact assessment
- Impact assessment of future water pollution loads based on future land use, urbanisation and economic growth scenarios and consideration of pollution mitigation strategies
- Current sediment transport management and future strategy

4.4 C - Geotechnics/seismicity

4.4.1 Geotechnics

In terms of geotechnical information the gaps identified are as follows and may well overlap with other discipline requirements:

- An overarching Desk Study is required to bring together all the available information regarding the existing ground conditions and to identify ground issues and risks. The development of the Geodatabase should facilitate this
- A study of seafloor morphology /scour study to understand how the seabed changes with time. This may well include on site monitoring work.

- Based on the desk study a conceptual ground model/geological model should be prepared so that the various findings to date can be collated and interpreted
- As the design stages develop there will quickly become a need for more detailed ground investigation. This is likely to be undertaken in stages and the very hostile environment of much of the alignment means that significant forward planning will be required to facilitate this work and is likely to include:
    - Line of route geophysics to characterise
    - CPTU/SCPT to provide detail (CPT and Seismic cone)
    - Boreholes for correlation with the above indirect methods
- A preliminary sources study should be undertaken to identify sources of material for use in construction.
- A study of alternative construction options should be undertaken and compared to the currently identified method of mass filling.
- A site specific seismic hazard assessment is required (noted that deterministic and probabilistic hazard assessments - DSHA and PSHA - ongoing by NGRI)
- A Design Basis Report should be established at the earliest opportunity and agreed by all stakeholders to inform all designers going forward. We note that development of this has now been initiated.

4.4.2 Seismic Engineering including liquefaction assessment

No site-specific seismic hazard assessment has been carried out to define the design criteria.

No assessment of the reservoir seiches has been undertaken.

5 Risk based approach for undertaking the gap analysis

It has been pointed out in our previous initial presentation that we will apply a risk based approach when undertaking the gap analysis. An example of a Risk Matrix is shown in Table 5.1 below.

In doing this we will look at the whole lifecycle of the project and ensure that issues which may come up during construction and operation can be addressed upfront, with appropriate mitigation measures

Table 5.1 Example of Risk Matrix for a dam Project in Peru

• Topic	• Comments	• Risk	• Risk Mitigation
Hydrology			
• Climate Change • Design Floods	• No specific information related to climate change was found in the design in relation to the dam assessment • 1 in 10,000 year event (estimated from the Rainfall-Runoff approach) used for sizing of the reservoir/dam proposed Fam is a 'Large Dam', Potential Risk Cat A	• High Engineering • High Financial, construction and engineering	• Climate change allowance must be taken into consideration for flood assessment in the dam design. The rainfall distribution used for hydrological and hydraulic modelling should be increased by a factor defined in the chosen Representative Concentration Pathway (RCP).
			• Climate change uplift on peak flows

			not considered. See comment above
Sedimentation			
• Dead Storage Allowance	• Not assessed in the design	• High Operation & Maintenance	• Needs to be stated as it could affect the storage and useful life of the structure.
Geotechnics/Geology		•	•
• Faulting	• Information Not Given in the design report	• Moderate, Financial, construction and engineering	• Mapping of regional and local faulting will be needed for seismicity, but also for mitigation of localized faults that can be a source of reservoir induced seismicity and require mitigation

We propose to undertake a Gap/ Risk workshop in week 13 of our assignment to discuss the Risk identified and proposed mitigation measures.

6 Other Issues

This Section presents discussion on other issues, such as:

- Review of transport connections and impacts on design standards
- Social impact
- Cost/benefit assessment
- Climate assessment – (Carbon, climate impacts)
- SDGs

6.1 DPR Benefit Cost requirements

The DPR requires the calculation of the benefit cost ratio, financial return and internal rate of return for the project. However, it also requires this to be broken down into the various multi purpose uses of the project. In this case the main uses would be irrigation, flood control, transportation and possibly fisheries.

We would expect to see each use of the project assessed separately and sufficiently to inform this analysis.

6.1.1 Assessment of Wider Benefits

To assist and enhance the DPR, and to support funding applications, we would look for the assessment and valuation (where possible) of wider benefits (e.g. social, human, financial) associated with the creation of a multipurpose dam and associated transport infrastructure. Assessment should also include negative benefits (e.g. environmental) as required.

6.2 Transport cost benefit analysis

We note that a significant traffic study has been carried out to evaluate the benefits and costs of the transport crossing. We summarise some observations and recommendations below, which we will revisit in our gap analysis.

6.2.1 Benefits

Within the traffic study, the benefits were assessed by monetising traffic forecasts and resulting benefits from cutting the travel time through provision of the transport crossing. The following benefits were monetised:

- Vehicle operation costs (VOC) benefits
- Value of time (VOT) benefits
- Carbon credits

The benefits would be realised through a toll across the barrage which by law can reclaim a certain percentage of the benefits; several scenarios have been assessed ranging from 50% to 75% of benefits reclaimed.

The following additional benefits were not monetised:

- Reduction of congestion and improvement of speeds on existing road network
- Reduction in accidents
- Reduction in Air and Noise pollution load

Induced traffic from increases in regional GDP due to the barrage were included in some traffic forecast scenarios. Forecasts were done up to 40 years into the future. The remaining operational life of the barrage after 40years was not considered

6.2.2 Costs

The costs included capital construction estimates, assuming a 5 year construction duration after completion of the dam, with a 20% spend each year to completion. Transport forecasts were projected 40 years into the future and capacity requirements checked against the proposed 8 lanes. However, no projections or checks on capacity past 40years were reported.

The capital costs included are for the road surfacing only on top of the existing dam. This most likely underestimates the costs since the dam cross section and crest height will have to be increased due to safety requirements for the road; these costs were not included.

Similarly the O&M costs include for maintenance of the road surface and operation of the toll plaza only; no provision is made for the maintenance of the dam in terms of transport links.

6.2.3 Summary

The transport crossing has been assessed in terms of economic costs and benefits over a 40 year horizon, discounted back to give an Expected Investment Rate of Return (EIRR), which at the time of analysis needed to be 12% to pass the Government of India and World Bank criteria for investment. The 2013 study, with a price base of 2010, concluded that the transport crossing is a viable investment with the lowest EIRR of all scenarios tested being 59.84%. However, the costs include only for road surfacing and not for construction of a dam suitable for a transport crossing; this will underestimate the costs and the EIRR as stated is unlikely to reflect the true transport crossing EIRR.

6.2.4 Recommendations

We would recommend the various success criteria for the dam are defined separately and the costs to satisfy each estimated separately:

1. Freshwater Resource Impoundment – how much would it cost to provide the required supply of freshwater, with adequate risk based protection against salt water ingress from various pathways (seepage and overtopping)
2. Tidal exclusion barrage – how much would it cost to provide tidal surge protection to existing tidal flood risk areas and those zones presently

occupied by the sea at times of High Water which may be re-developed and re-settled.

3. Rail and Road transportation link: How much would it cost to provide a dam with a suitable cross section and foundation to support the transport links and provide the required levels in terms of safety considerations

We would then recommend that each is evaluated for the benefits of successfully delivering those criteria and that the cost benefit of each, and incrementally in combination, for providing those criteria, is assessed to provide costs and benefits that can be considered in line with DPR guidance. The gap analysis will confirm if this has been done.

6.2.5 Carbon Assessment of Transport Crossing

- The assessment only considers the carbon avoided from reduced distance travelled by traffic
- The embedded carbon in constructing the dam and road infrastructure is not considered
- This will be assessed in the Environmental gap analysis

7 Summary on lessons learnt on some previous projects

7.1 Cardiff Bay Barrage: Design, Construction and Operation - Lessons Learnt

The Cardiff Bay Barrage, in Wales (U.K.), completed in 2000, is comparable to the proposed Kalpasar Dam despite being a much smaller project. Key features, shown in Figure 7.1 below, include:

- Construction in a very high tidal range (over 14m, 3rd highest in world)
- Soft foundations
- Creation of a large freshwater lagoon, previously a saline tidal bay
- Significant environmental impacts
- Providing flood protection benefits
- Providing access for navigation and for road access along the barrage

Figure 7.1 Cardiff Bay Barrage

Lessons were learnt relating to all stages of the project, including planning and design, procurement, construction, and operation and maintenance. During the planning and design stages careful attention was given to all stages of the project, and this forward planning was the key to minimising unforeseen issues.

One of the HR Wallingford review team was the manager of the Cardiff design team throughout the design and construction of the Cardiff Barrage, and HR Wallingford carried out over twenty design studies examining the hydraulic, sedimentation, water quality and construction aspects of the barrage.

The design team included experienced designers of both dams and maritime works, and the combined skills of these two disciplines proved invaluable in designing a dam to be constructed in challenging maritime conditions.

The constructability of all components of the barrage, and the overall sequence of construction, were key aspects of the design process.

Topics at Cardiff of particular relevance include the following:

7.1.1 Planning

- Identifying objectives
- Assessment of flood protection benefits (e.g. cyclone surges, fluvial flooding, sea level rise) provided by the project
- Provision of facilities for navigation through the barrage including locks and associated harbours at lock complexes
- Provision of transport routes along the length of the barrage
- Fish access requirements
- Renewable energy options
- Provision of public access to this mega-project where appropriate

7.1.2 Design Issues

- Impacts on water quality within and without the impounded area, during and after construction
- Transition from salt water to fresh in impounded areas
- Impacts of saline penetration from navigation locks into freshwater impoundment
- Impacts on water levels within the impounded area and implications for upstream flooding
- Impacts on groundwater levels on land near water areas previously tidal
- Sedimentation rates during construction and within impounded areas
- Fish access requirements including fish passes permitting passage at all stages of the tide, and seasonal constraints on construction processes to allow fish migration
- Sluice systems to manage flood risk and exclude sea water

- Fail-safe designs of operating systems, and back-up systems, particularly to ensure that discharge sluices can always be opened in the event of high river flows
- Use of float-in structures (caissons) and construction within cofferdams to minimise exposure to marine risks
- Comprehensive site investigations to minimise risk of unforeseen conditions (including associated cost and schedule impacts) during construction
- Optimised embankment design allowing for minimised removal of soft underlying foundation materials, optimum use of available construction materials, phased construction to allow for consolidation of foundations, and avoidance of erosion due to waves and currents at all stages of construction (including erosion due to tidal inflows and outflows prior to dam closure). Design of the closure method and associated scour protection works was a fundamental part of the dam design, requiring specialised hydraulic studies.
- Impacts of siltation during construction, including on foundations of float-in caissons, and after completion
- Integrated engineering and architecture to give public access to this mega-project
- Interactive communication with stakeholders on environmental topics throughout planning, design, construction and operation
- Impacts of climate change including sea level rise and peak fluvial flows

7.1.3 Procurement

- Maximising communication between designers and contractors before finalising design
- Freezing the design before starting construction, to minimise cost increases.
- Selecting experienced organisations to construct the barrage. (Selection of subcontractors can be as important as selection of main contractors.)
- Construction
- During the four-year construction period, it was important to:
- Plan construction methods to minimise exposure to risks
- Obtain the required large quantities of construction materials from sources that minimise adverse impacts of extraction and of transport to the project site
- Minimise environmental and social impacts of the construction process
- Keep stakeholders informed of operations and issues

7.1.4 Operation

Finally, during the operation and maintenance of the barrage it is essential to have:

- Adequate staffing
- Comprehensive spare parts policy (consumables and provision for breakages)
- Rigorous adherence to planned testing and maintenance schedule
- Maintenance of planned environmental monitoring.
- Effective two-way communication with the public and all stakeholders.

The Barrage has been maintaining an impounded bay for twenty years, and during that period it has produced the expected flood control benefits as well as providing an attractive waterside environment that has encouraged substantial redevelopment of the extensive waterfront of the City of Cardiff.

7.2 Saemangeum Tideland Project - Lessons Learnt

7.2.1 Introduction

Following the world food crisis in the 1970s and the poor harvest of the 1980s the Korean Government developed plans for large scale tideland reclamation and impoundment project.

The west coast of the Korean peninsular displays a frequently indented shoreline with a gently sloping sea bottom. The tidal range reaches approximately 6 m in spring tide at the Saemangeum site. These favourable geographic and hydraulic conditions permitted the Korean Government to initiate several tideland reclamation projects along the coastline. The Korean Agricultural and Rural Infrastructure Corporation (KARICO) and the Ministry of Agriculture and Forestry (MAF) of the Republic of Korea launched a large-scale tideland reclamation project, the so-called Saemangeum Project, in 1991.

The Project site is located at the mid-west coast of Korean peninsula, approximately 200 km south from Seoul. The Project covers a total area of 401 km^2 which, after the completion of the internal structures, will be composed of 283 km^2 of reclaimed tidal flats and a desalinated reservoir of area 118 km^2. The major sea dikes required to enclose this huge area of the Saemangeum estuary also include two drainage sluices and navigation locks.

The watersheds of the Saemangeum reservoir total 3,319 km^2 and contain the basins of two major rivers, which flow into the reservoir, meandering through the plains. Water depths along the sea dikes vary from 4 m to 27 m below MSL (Mean Sea Level). Deep tidal channels have developed at three regions with a thickness of fine sand deposits on the seabed reaching to 20 to 30 m.

Some of the major engineering works that formed part of the project include the following:

a) Sea dikes, total length: 33.0 km, crest elevation:8.5 – 11.0 m above MSL, typical height: 22.0 m, bottom width: 290.0 m at typical section

b) Reservoir, storage capacity: 535.million m^3, available storage: 355 million m^3, water surface area at normal water level: 96.7 km^2

c) Drainage sluices, 2 sets (one set of 10 and one of 8) of 30m x 15m radial gate type sluices, combined total maximum discharge ~16,000 m^3/s

d) Navigation locks

e) Fishway

A schematic of the completed project, with all the project elements within the impoundment complete, is shown in Figures 7.2 and 7.3. below. Figure 7.4 shows one of the radial sluice gates used.

Figure 7.2. Schematic of Saemangeum project

Figure 7.3. Project location

Figure 7.4. Garyeok Sluice gate constructed on island, 50x30m

7.2.2 Areas of investigation

HR Wallingford became involved in the early 2000s. In 2000 following pressure from environmental groups, the project was halted, and various discussions were had. Out of this moratorium various actions were detailed, including an assessment of the long-term morphological impact. At the time of commencing ours work, there were three gaps in the dike. These were to be replaced by two sluices on completion. The most northerly gap (Gap Number 3) was closed in July 2003. Dike construction works were completed about 90% by length at the end of 2004. It was planned that the other two gaps will be closed by 2006. The project was eventually completed in 2010.

The studies undertaken included

- Undertake hydrodynamic and morphological modelling for morphological impact of the project, with a variety of gaps closed.
- Review of hydrodynamic modelling and method used for predicting currents in the gap during the dike closure
- Physical modelling of flows through the gap during closure, identification of local current acceleration and bed material mobility
- Review of scour predictions
- Review of adequacy of rock/gabions for: Bed protection, Sill, Progressing closure bunds
- Timing of closure works in 2006
- Review of construction programme
- Risk analysis for closure operation
- Review of risk of piping and leakage through completed dike

7.2.3 Lessons learnt with relevance for Kalpasar

1) Substantial morphological change can be expected during and following the closure operation. The design of the ends of the gaps needs be take account of this.
2) Misalignment of the closure gap with the flow through it can result in additional scour and morphological effects.
3) Enhanced forces from local flow acceleration and turbulence generation in the narrowing gap need to be modelled carefully (3D computational model or physical modelling) to avoid additional scour at the edge of scour protection and the risk of undermining the protection.
4) The use of a mix of rock and rock filled gabions was a reasonable approach however some concerns were raised to make sure gabions were constructed well (stones not loose in gabions’ nets).
5) A full risk analysis for failure of the constructed sill in the gap and the end of the dike itself is a key activity in considering the closure process. This risk assessment requires consideration of all foreseeable failure mechanisms.
6) An issue of water leakage through the bed protection layer (which has been in the gap) after final closure has been completed was identified and a strategy to minimise this was developed.

8 Next Steps

Following acceptance of this Inception Report by NCCR, we will undertake the full review of the gap analysis.

Appendix 1

The following table shows the reports for studies complete, ongoing and to be carried out. It highlights whether these have been received yet at the time of this review.

No.	Package Name	Status	Received	Included in the original 38 Reports
1	Techno Economical Feasibility Report Including Haskoning Report	Complete	Yes	Yes
2	Conceptual and Structure Plan and Preparation of Base Map of Kalpasar Project Area	Complete	Yes	Yes
3	Legal Opinion	Complete	Yes	Yes
4	Topography Survey 0 to 10 m contour along peripheral area of reservoir.	Complete	Yes	Yes
5	Bathymetry Survey for entire GoK	Complete	Yes	Yes
6	Traffic_Assesment_Study_GoK	Complete	Yes	Yes
7	Geo physical survey for revised dam corridor 2010 & 2014	Complete	Yes	Yes
8	Water Sampling and Water Quality Monitoring Program	Complete	Yes	Yes
9	Estimation of PMF, Design flood including determining spillway capacities	Complete	Yes	Yes
10	Groundwater conditions in Kalpasar Command area in Saurashtra	Complete	Yes	Yes
11	Water availability study for Kalpasar project main report	Complete	Yes	Yes
12	Vetting of Water Availability Studies for Gulf of Khambhat Development Project (Kalpasar)	Complete	Yes	Yes
13	Study on sea-level changes, global warming and regional climate	Complete	Yes	Yes
14	Impact of Kalpasar Project on the existing and Proposed Ports	Complete	Yes	Yes
15	Impact of Tsunami	Complete	Yes	Yes
16	Impact of Storm surges, wind waves and seiches	Complete	Yes	Yes
17	Design of spillway report 2018	Complete	Yes	Yes
18	Primary and alternate locations of Spillway 2 DT 2014	Complete	Yes	Yes
19	Primary Dam cross sections were finalized during3 DT 2015	Complete	Yes	Yes
20	Hydrodynamic and sediment model studies and related measurements	Complete	Yes	Yes
21	Fisheries Study	Complete	Yes	Yes

22	Study of taluka-wise Irrigation planning and Agro-economic impact of Kalpasar project in coastal areas of Saurashtra region	Complete	Yes	Yes
23	A study on positive irrigation impact of Kalpasar reservoir project in Saurashtra region of Saurashtra	Complete	Yes	Yes
24	A study of agronomical constraints in agriculture in the command area of semi-arid and arid region of Saurashtra	Complete	Yes	Yes
25	Irrigation facilities	Complete	Yes	Yes
26	Assessment of Baseline Environmental quality and social status of Kalpasar Project	Complete	Yes	Yes
27	Present Status of Salt Pans and Assessment of Social, Economic and Environmental Impact of the Kalpasar Reservoir Project	Complete	Yes	Yes
28	Impact on mangroves consequential to creation of Kalpasar reservoir and mitigation strategy	Complete	Yes	Yes
29	Scope of Work for EIA & SIA Studies	Complete	Yes	Yes
30	Synopsis of the environmental and socioeconomic aspects of the various studies related to Kalpasar project	Complete	Yes	Yes
31	Reclaimable land plan GIS data base	Complete	No	Yes
	Renewable Energy	Complete	Yes	No
	Reference_Report_CWC_Guidelines_for_Preparation_of_DPR_for_Irrigation_And_Multipurpose_Projects	Complete	Yes	No
	Reference_Report_Six Speific Studies Kalpasar	Complete	Yes	No
1	Establishment & Monitoring of Seismological Observatories	Ongoing	No	Yes
2	Geotechnical Investigation and Survey along Dam Alignment	Ongoing	Yes	Yes
3	Water Quality Monitoring and diversion effluent studies	Ongoing	Yes	Yes
4	Desk wave flume studies for design c/s	Ongoing	Yes	Yes
5	Physical model study break water alignment.	Ongoing	No	Yes
6	Mathematical model studies for wave tranquility	Ongoing	No	Yes
7	Hydraulic model studies	Ongoing	No	Yes

1	Design of Dam, spillway, sluices, gates, breakwater structures and any other allied structures, stability of dam.	To be completed	No	No
2	Foundation compressibility studies for estimating the extra quantities of dam construction materials	To be completed	No	No
3	Detailed Construction Material Survey and transport facilities	To be completed	No	No
4	Survey investigation and design of Narmada Diversion Canal	To be completed	No	No
5	Survey investigation and design of Irrigation Canal, Pumping Stations & Allied Structures	To be completed	No	No
6	Detailed Studies on Wind Solar Power Plant	To be completed	No	No
7	Existing proposed Drinking Water supply scheme	To be completed	No	No
8	Existing proposed Industrial Water supply scheme discuss Kalpasar	To be completed	No	No
9	Hydrological, Meteorological & Hydro Geological	To be completed	No	No
10	Arrangements for offtake of reservoir water (by canals/ lift schemes) locations, capacities and main canal alignments	To be completed	No	No
11	Closure Techniques for construction of dam	To be completed	No	No
12	Inundation area on downstream of Kalpasar dam and Effect on sub soil water table in the adjoining area particularly downstream of the dam	To be completed	No	No
13	EIA/SIA study	To be completed	No	No
14	Flood Control	To be completed	No	No
15	CRZ Clearance proposal	To be completed	No	No