D1.1 Mission report Bhadra dam and reservoir Karnataka, India

Deltares in cooperation with iPresas, SkyGeo and Royal Eijkelkamp

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Keywords
Bhadra dam, dam safety, water reservoir, Operation & Maintenance, emergency response, PS-InSAR satellite imaging, online monitoring system, risk-informed dam safety management, FEWS forecasting.

Summary
The water reservoirs in India are of vital importance to the cities and urban areas. They provide water for irrigation of the land (food production), are used to generate electricity (water and energy) and offer protection against flooding (safety). Often, the dams are aging, but are also facing different circumstances than when designed, due to changes in land use, socio-economic developments and climate change. The goal of the DAMSAFE pilot project is to contribute to enhancing dam safety and water management in India by introducing innovative technologies that improve forecasting of dam and reservoir behaviour. This will contribute to optimization of water management, Operation and Maintenance (O&M) and emergency response.

The main stakeholders to the project in India are the Karnataka Water Resources Department (KaWRD) and the Central Water Commission (CWC) in New Delhi. The DAMSAFE consortium consists of Deltares (coordinator), Royal Eijkelkamp, SkyGeo and iPresas.

This document presents a summary report on activities and meetings in February 2017, including the inception meeting, a site visit to the Bhadra dam and a working session on dam failure mode identification. Next to that a monitoring system for the dam and reservoir is designed based on identified failure mechanism and goals of the project.

References
Partners for Water project proposal DAMSAFE: Enhancing Dam Safety and Water Management in Karnataka (India), dated 30-08-2016.

Disclaimer

Version	Date	Author	Initials	Review	Initials	Approval	Initials
02	May 2017	Mr. Ton Peters and others		Mr. Sanjay Giri		Mr. Leo Voogt	

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Contents

1 Introduction

The water reservoirs in India are of vital importance to the cities and urban areas. They provide water for irrigation of the land (food production), are used to generate electricity (water and energy) and offer protection against flooding (safety). Often, the dams are aging, but are also facing different circumstances than when designed, due to changes in land use, socio-economic developments and climate change. The overarching goal of the DAMSAFE pilot project is to contribute to enhancing dam safety and water management in India by introducing innovative technologies that improve forecasting of dam and reservoir behaviour. The project is funded by the Dutch Partners for Water program.

This overarching project goal is achieved by delivery of the following set of actions:

1. Application and demonstration of tools that forecast reservoir inflow and outflow, increasing reservoir performance and more controlled release of water in the environment.
2. Application and demonstration of innovative tools for assessment of the dam condition resulting in optimization of Operation and Maintenance (O&M).
3. Application and demonstration of innovative tools for rapid and risk based assessment of dam safety in order to provide information for emergency response.

The main stakeholders to the project in India are the Karnataka Water Resources Department (KaWRD) and the Central Water Commission (CWC) in New Delhi. The DAMSAFE consortium consists of Deltares (coordinator), Royal Eijkelkamp, SkyGeo and iPresas.

This document presents a summary report on activities and meetings conducted on 21-23 February 2017, including:

- 2017-02-21: Site visit to Bhadra dam, described in Section 2.
- 2017-02-22: Working session on dam failure mode identification, described in Section 3.
- 2017-02-23: Inception meeting, described in Section 4.

In addition, Section 5 describes aim and description of planned monitoring actions and requirements.

Prior to the site visits in Karnataka, the DAMSAFE project was presented and promoted at the Second National Dam Safety Conference, held on February 18 and 19 in Roorkee.

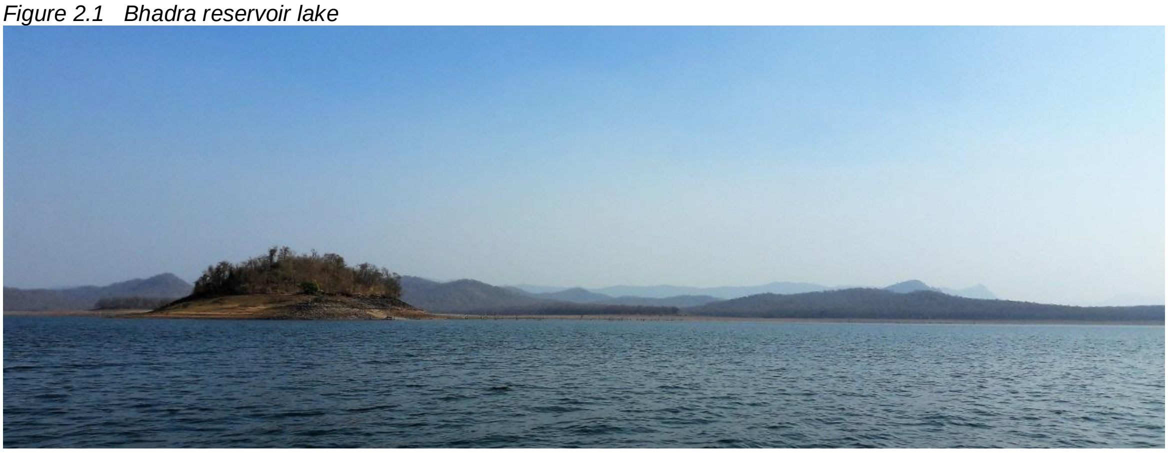
2 Site visit Bhadra dam and reservoir

2.1 Overview dam and reservoir

Dam location: Bhadra river
Purpose: Irrigation, water supply and hydropower generation
Construction year: 1962
Dam typology: Masonry/Earth/Concrete
Reservoir capacity: 2026 hm^3
Maximum dam height: 76.8 m
Spillway: 4 gates [1]

Bhadra Dam is constructed across Bhadra River near Lakkavalli village, Tarikere Taluk, Chikkamagalore District of Karnataka State at an elevation of 601.00 m above Mean Sea Level (MSL).

Figure 2.1 Bhadra reservoir lake



The construction of Bhadra dam was started in 1946-47 and completed in 1962-63. Bhadra dam-reservoir system is composed by a main dam (masonry dam) and 4 saddle dams. A masonry dam is constructed to the main valley in the river gorge portion with central spillway and 3 saddles have been banded up with earthen embankment.

Figure 2.2 Bhadra masonry dam with spillway

[1] Bhadra reservoir project, Technical note of Bhadra dam, Government of Karnataka, February 2017.

The maximum height of dam is 71.63 m above the lowest foundation level and 59.13 m from average river bed level. The central spillway has 83.3 meters length and having four vertical lift type gates of size 18.29 m x 7.62 m. The live storage is 63.03 Thousand Million Cubic Feet (TMC) , approximately 1785 Mm^3. It is a multi-purpose dam including hydropower with a capacity of 39.2 MW.

Figure 2.3 Bhadra embankment dam

Figure 2.4 Downstream slope Bhadra masonry dam, river and hydro power unit

2.2 Technical feasibility DAMSAFE project

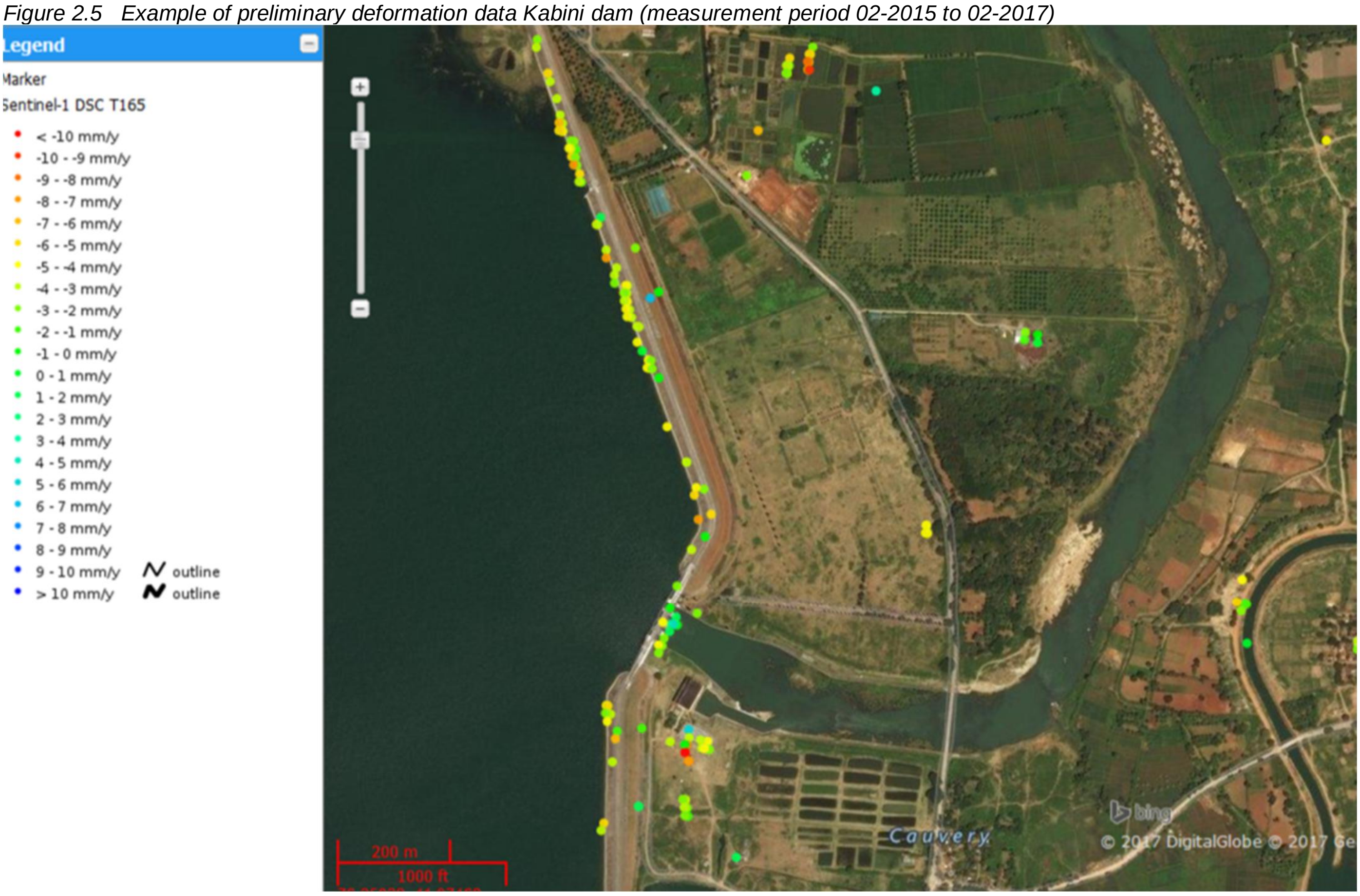
The starting points for implementation of innovative dam safety and water management solutions look promising for a number of reasons. First of all, as described in some of the other paragraphs as well, there is an explicit need for decision making information on the aging dam infrastructure that is under increased stress by changes to the local climate and the need for maximizing the benefit. Secondly, there is the awareness with the KaWRD counterparts that developing and maintaining decision making information requires data infrastructure and knowledge platform that is not yet readily available within KaWRD. Thirdly, KaWRD seems to be willing to allow the consortium (and especially Royal Eijkelkamp) to place necessary sensor and logging equipment near and inside the dam infrastructure. Last but not least, Bengaluru is one of India's IT hubs, meaning that capable human resources, focus and ambition to implement the fruits of the DAMSAFE project are widely available.

One of the challenging aspects of setting up infrastructure (whether its data infrastructure or physical infrastructure) in new environments is always to secure continuation, and follow through investments after initial efforts and investment.

The DAMSAFE pilot project at the Bhadra reservoir will be innovative in the sense that we will try to make the data flow and the analysis process robust and accessible. This means that terrestrial sensors (something KaWRD is already used to working with) will be combined with remote sensing data (free of charge supply is guaranteed by ESA) and the FEWS platform (a successful open community tool that is guaranteed to be around for the future). However it is expected that sufficient ESA remote sensing data will only be available at the end of this year.

Therefore, if we succeed in combining the different data sources in a cloud based environment, and train end users, then KaWRD will be well positioned to repeat and scale up the process for their entire portfolio of dams.

Figure 2.5 Example of preliminary deformation data Kabini dam (measurement period 02-2015 to 02-2017)



3 Dam safety risk assessment

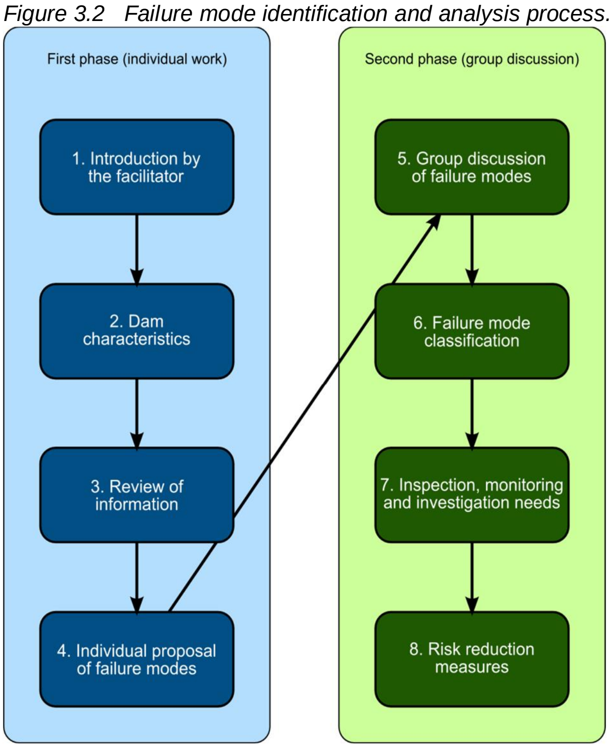
3.1 Summary of the working session

The working session on failure mode identification and analysis was held in Shimoga on February 22, 2017, including 39 participants.

Figure 3.1 Dam Safety Risk assessment session at the KaWRD district office in Shimoga

The session was structured based on the procedure for failure mode identification and analysis shown in Figure 3.2.

Figure 3.2 Failure mode identification and analysis process.



The aim of this working session was to review the current situation of the dam-reservoir system, to provide a preliminary assessment of dam performance and to identify potential failure mechanisms. With this information, the DAMSAFE consortium will work on defining the detailed sequence of events that may lead to dam failure.

3.2 Overview of collected information

Based on information contained in the technical note, the following aspects were presented and discussed during the session (quoting marks are used for text from references):

Concerning flood hazards:

- The differences between the dry and monsoon season is highlighted. “The rainfall in the catchment area generally starts from 1st week of June and it is very active generally during July, August and September months.”
- A gauge station is available at Balehonnur. “Reservoir operation schedule duly predicting the inflow in the reservoir based on gauged discharge at Balehonnur and also from the daily rainfall records of upstream rain gauge station in the catchment from 1st week of June.”
- An analysis of spillway capacity was conducted in 2014.
- A water pool level lower than FRL (Full Reservoir Level) is considered during monsoon season. “It is proposed to have 2.5 tmc (70 hm3) storage capacity as flood absorption below FRL during active monsoon so as to have safe and effective reservoirs operation schedule”.

Concerning seismic hazards:

- The dam is located in Zone 2 based on the Earthquake Zone Map for India. It is found, based on information available, that “seismic forces were not considered in the design”.

Figure 3.3. Earthquake Zone Map.

Regarding geology and foundation characteristics:

- There is uncertainty on foundation materials, as stated in the review analysis conducted in 2014. "Physical characteristics of the rock mass of the foundations rock should be determined by taking core samples on the downstream side of the dam."

Regarding abutments:

- A collapse of right bank guide wall occurred in 1991. "The Bhadra right bank left side guide wall was collapsed suddenly during 18.9.91 resulting in disruption of the irrigation to Bhadra right bank canal and its branch canals."
- After this event, saddle dam 4 was converted into a spillway. "After the collapsing of the tailrace training wall at the irrigation sluice of right bank canal during 1991, to save the standing crops and to ensure continuous irrigation, earthen dam at saddle No.4 on right bank was excavated and converted into a chute spillway and was constructed in its location to meet the emergent situation. The saddle No.4 on right bank is therefore not having earthen embankment now."

Regarding main dam stability:

- There is uncertainty on uplift pressures at dam foundation.
- "The dam stability of both over flow and non over flow dams have been analyzed for normal operating conditions with water level at Full reservoir Level (FRL) and with up lift force of 2/3 the water level at the upstream face reducing uniformly to "zero" at the downstream toe". This corresponds with the general assumption for defining uplift pressures without drainage system (triangular uplift pressure law).

Regarding main dam state:

- As stated in the technical note and observed during the site visit: "Seepage through the foundation drains in the gallery and quite excessive quantity of seepage is noted through the porous drain No. 5. It indicates that there is seepage through the masonry section of the dam which is also indicated by the downstream face wetting of the entire dam section and this should be monitored for taking remedial action."
- Based on outcomes from the safety review in 2014: "The dam masonry appears to have become pervious in the above reach through which the water is finding access from the reservoir as evidenced from the seepage and jetting appearing in the dam masonry and besides there is considerable lime leaching observed on the downstream face of the dam in the above reach as a result of which loss of strength of the masonry is apprehended. It is therefore necessary to determine permeability of the existing masonry".
- Grouting actions are currently in process.

Regarding saddle dams:

- An inspection of earthen dams at saddle dams 1 and 2 was conducted in 2002, and it was found that the sections adopted for earth dams appears were quite stable and well maintained.
- However, at Saddle No 2 slightly uneven settlements are observed on the upstream face. This settlement has been regularly monitored since last six years. Proposal for installing surface settlement gauges is included in the dam safety programme, but not yet implemented.
- The cause for the settlements on the left flank of the Saddle No. 1 is still unknown.

Regarding spillway and stilling basin at main dam:

- "Energy dissipating arrangements consists of a stilling basin of 320 feet (97.5 meter) in length at (-) 20 feet (at elevation 1952 feet). Beyond the stilling basin there is a tail channel." There is evidence of erosion at the river channel.

Regarding dam monitoring and surveillance:

- "Not much of instrumentation has been provided in the dam except seepage measurements in masonry dam, saddle dams" as stated in the Technical note.
- The water level at the reservoir is monitored.

Regarding emergency management:
- Development of an Emergency Action Plan is currently in progress under the DRIP project.

3.3 Results from preliminary evaluation

A preliminary assessment was conducted to indicate whether Bhadra dam is expected to meet established international good engineering practice. This action is the starting point for discussion about current dam situation and it is used to evaluate group understanding of the status of dam safety and justification of recommendations for decision-making.

Ratings were assigned for a list of assessment factors, including the following options:
"Is the dam in line with international standards on current dam safety practices?"
- **Yes**
- **Apparently**
- **Apparently not**
- **No**
- **Not applicable**

Analyzed factors are here included:
- Dam body stability
  - Central section
  - Spillway section
  - For seismic scenario
  - Left abutment
  - Right abutment
  - Abutment performance in case of sudden water lowering
- Dam body situation
  - Impermeabilization and leakage
  - Vegetation and external erosion
  - Filters and internal erosion
- Dam foundation
  - Resistance
  - Leakage
- Drainage system
- Outlet works
  - Discharge capacity of spillway
  - Current conditions of spillway channel and stilling basin
  - Spillway gates
  - Mechanical equipment of bottom outlet works
  - Mechanical equipment of water intakes
  - Electrical equipment
- Landslide stability of reservoir area
- Monitoring and equipment
  - Dam body
  - Dam foundation
- Emergency management and action planning

Figure 3.4 shows the summary of results from this assessment, conducted by participants directly related to Bhadra dam operation and experts on dam risk assessment from the DAMSAFE team.

Figure 3.4 Summary of results from preliminary assessment.

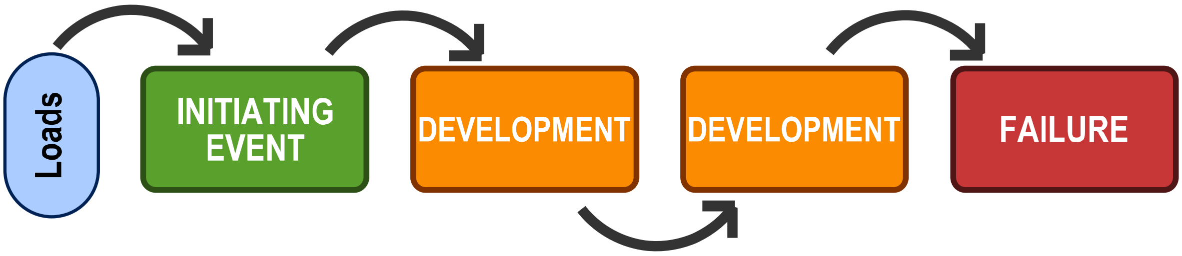
	Participant									
Is in line with international standards on current dam safety practices?	1	2	3	4	5	6	7	8	9	10
Dam body stability										
Central section										
Spillway section										
For seismic scenario										
Left abutment										
Right abutment										
Abutment performance in case of sudden water lowering										
Dam body situation										
Impermeabilization and leakage										
Vegetation and external erosion										
Filters and internal erosion										
Dam foundation										
Resistance										
Leakage										
Drainage system										
Outlet works										
Hydrologic capacity of spillway										
Current conditions of spillway channel and stilling basin										
Spillway gates										
Mechanical equipment of bottom outlet works										
Mechanical equipment of water intakes										
Electrical equipment										
Landslide stability of reservoir area										
Monitoring and equipment										
Dam body										
Dam foundation										
Emergency management and action planning										

Results show that there is significant variability on assessments regarding dam response in case of seismic scenario, internal erosion and leakage and, monitoring and equipment. These differences are mainly due to lack of information on dam-foundation characteristics, existing uplift pressures and state of dam body materials. Consequently, results reflect the need for reducing uncertainty on dam foundation and better characterizing dam response (loads, leakage and resistance).
From this preliminary evaluation, it may be concluded that spillway capacity seems to meet international standards, however more detailed analysis of flood routing for different inflow events would be desirable. The lack of knowledge and data on dam foundation and uplift pressures does not allow to draw conclusions regarding dam performance. Emergency management procedures are not yet established but an Emergency Action Plan is currently under development within the DRIP project.

3.4 Failure mode identification

A failure mode is a specific sequence of events that can lead to a dam failure. This sequence of events must be linked to a loading scenario and will have a logic sequence: starting with an initiating event, one or more events of failure progression and will end with a dam failure, as shown in *Figure 3.5*.

Figure 3.5 Failure mode scheme of events.



Based on results and conclusions from the working session conducted on February 22, 2017, the following potential failure modes are considered for Bhadra dam-reservoir system.

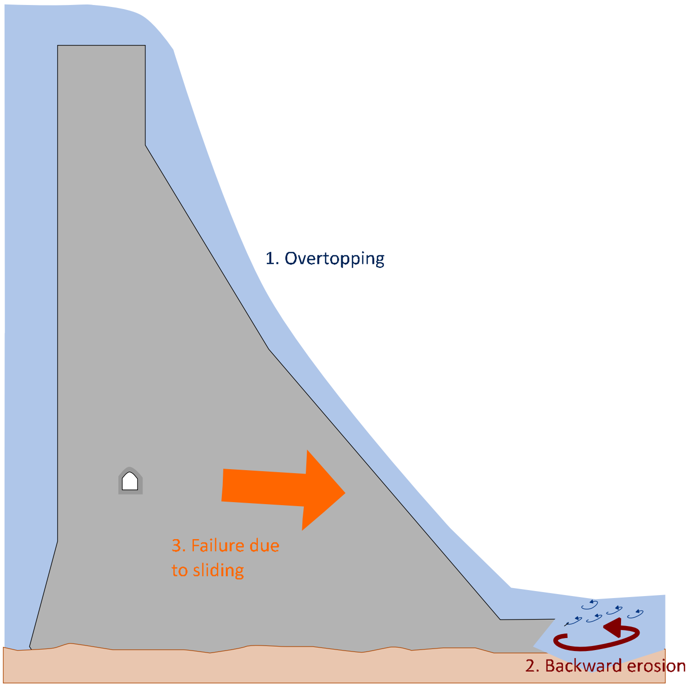
In future steps of the project, these failure modes will be further characterized, identifying key factors and providing a classification of failure modes for further incorporation into the dam risk model. The risk model architecture will include the sequence of identified events for each failure mode as shown in *Figure 3.5*.

Further information and data gathering will help on the detailed failure mode characterization for the Bhadra dam.

FM1. Overtopping [main dam]

Short description:

In a hydrologic scenario, due to a severe flood and/or inadequate spillway capacity and/or inability to open the gates of the spillways, adequate freeboard cannot be maintained and this can result in overtopping of the dam crest level. Flow over the crest washes out material in the dam toe and causes massive erosion that progresses leading to dam failure.

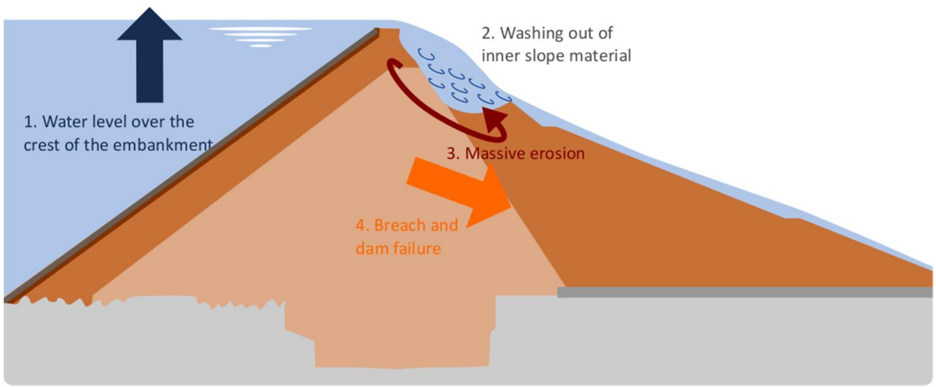


Simplified scheme for main dam

FM2. Overtopping [saddle dams]

Short description:

In a hydrologic scenario, due to a severe flood, the spillway at the main dam has insufficient hydraulic capacity to pass the flood event and maintain adequate freeboard and water level raises over saddle dams. Flow over the crest washes out material in the downstream slope of the embankment and causes massive erosion that progresses leading to slope instability, breach and dam failure.

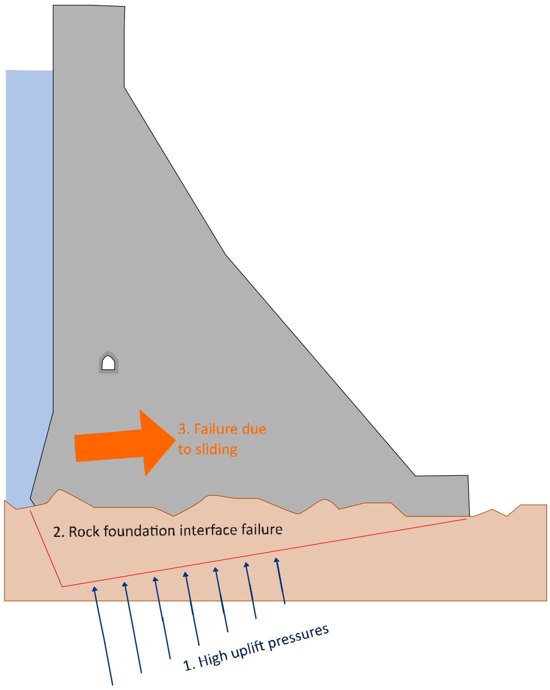


Simplified scheme for saddle dam nr.1

FM3. Sliding [main dam] (interface at rock foundation)

Short description:

In a normal or extreme hydrologic scenario, the combination of hydrostatic loads and uplift pressures produces a movement or deformation in dam foundation over a surface, resulting in loss of foundation strength.

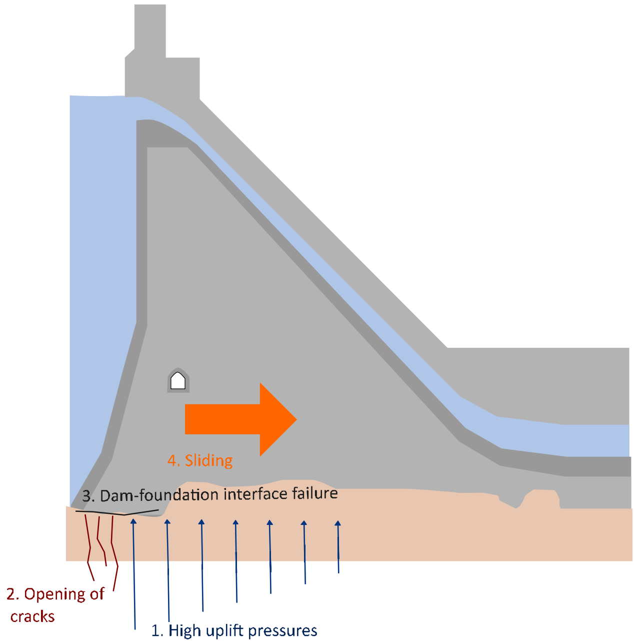


Simplified scheme for main dam

FM4. Sliding [main dam] (interface at dam-foundation contact).

Short description:

In a normal or extreme hydrologic scenario, there is an increase on hydraulic loads and uplift pressures (1) that produces a tensile crack (2) at the foot of the dam-foundation interface, and produces an increment in the hydraulic gradient at foundation joint close to the dam-foundation interface, this results in erosion in the foundation material (3) resulting in sliding of part of the dam body along a failure surface (4).

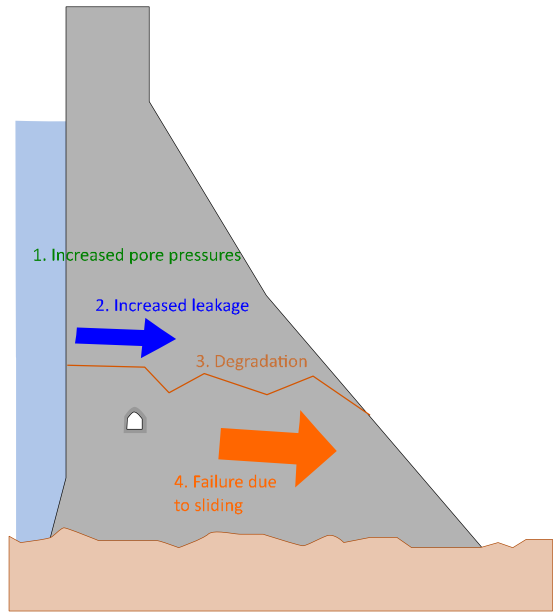


Simplified scheme for main dam (spillway section)

FM5. Sliding [main dam] (degradation of masonry material)

Short description:

In normal or extreme hydrologic scenario, pore-water pressures increase along with an increase of leakage through dam body, resulting in deterioration of masonry to an extent that affects stability and leads to dam failure.



Simplified scheme for main dam

FM6. Sliding failure in a seismic event [main dam].

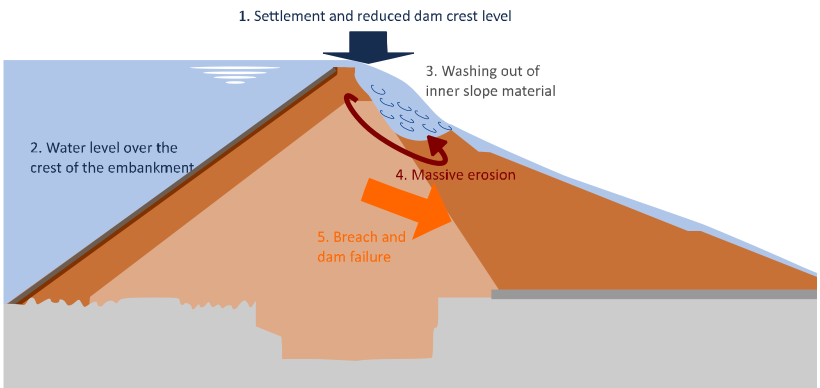
Short description:

In a seismic scenario, a combination of previous degradation of masonry material and a state of high uplift pressures with an earthquake that causes a ground motion with shaking, leads to a reduction of overall stability of the dam and dam failure.

FM7. Overtopping failure in a seismic event [saddle dams].

Short description:

In a seismic scenario, the earthquake causes a ground motion with shaking and cause settlement of embankment dams with reduced dam crest level, then resulting in uncontrolled flow over the dam crest, degradation of inner slope material, massive erosion and dam collapse.

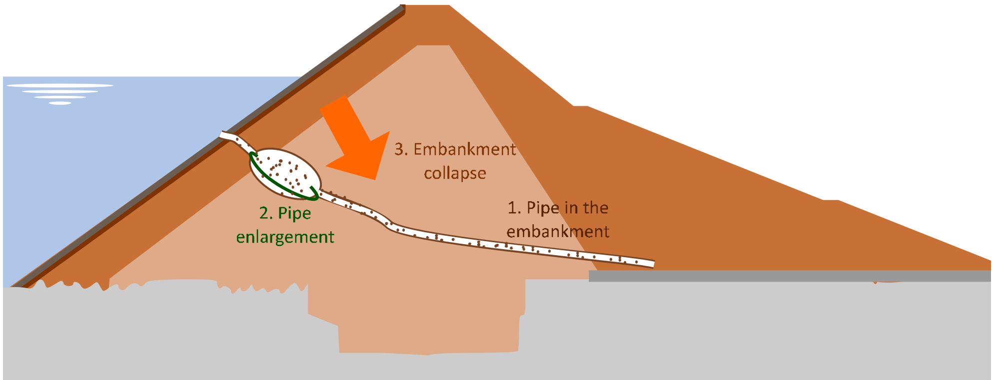


Simplified scheme for saddle dam nr.1

FM8. Failure due to internal erosion [saddle dams].

Short description:

In normal scenario during a period of high reservoir elevation, an increase in permeability and/or reduction in strength of the core occurs over time, then piping of the embankment core initiates at the foundation interface. Backward erosion occurs until a “pipe” (seepage path) forms through the core, not detected or ignored, reaching the upstream face below the reservoir level. Rapid erosion and enlargement of the pipe occurs and embankment dam collapse takes place.

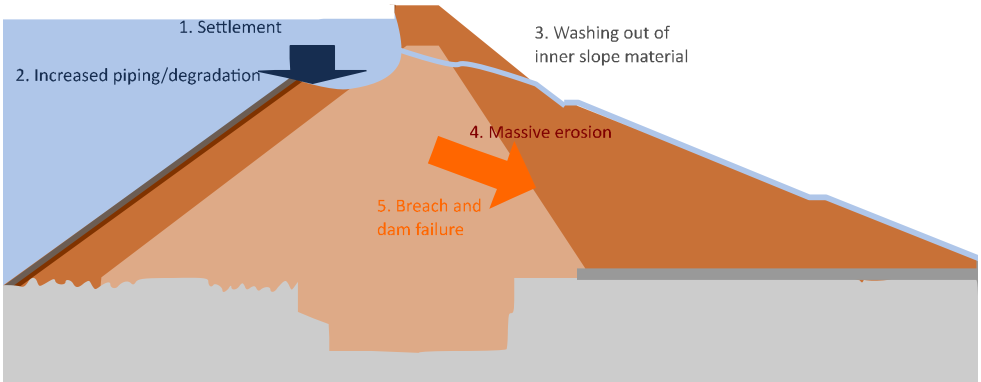


Simplified scheme for saddle dam nr.1

FM9. Failure due to settlement [saddle dams]

Short description:

During a period of high reservoir elevation, one or more slips occur within the embankment because design loads are exceeded or through deterioration of embankment-fill materials over time, resulting in settlement of the outside slope (upstream face) and increased degradation of core material and piping, resulting in degradation of inner slope and dam collapse.



Simplified scheme for saddle dam nr.1

FM10. Collapse of irrigation channel wall at right abutment [main dam]

Short description:

In a normal scenario, a collapse is produced at the irrigation channel located at the right abutment. Gates cannot be closed and water flows through wall breach, eroding right abutment and resulting in dam failure due to movements near the dam foundation close to right abutment.

4 Inception meeting

4.1 Introduction and goals

The inception meeting was organized at the Water Resources Department of Karnataka state in Bengaluru on 23-02-2017. The inception meeting was divided into morning and afternoon sessions. Among 32 participants in total, Indian participants are from the Karnataka Water Resources Department (KaWRD), including representation from district offices of the Bhahdra and Kabini dam, the Advanced Center for Integrated Water Resources Management (AC-IWRM) and Karnataka Engineering Research Station (KERS). The DAMSAFE consortium was represented by Deltares (coordinator) and the partners Royal Eijkelkamp Soil&Water, SkyGeo and iPresas.

The goals of the inception meeting are:
1 To get to know the main Indian participants / contacts on dam safety.
2 To collect current information, available data and reports related to Bhadra dam and reservoir including the hydrological and hydraulic studies, which have been carried out so far.
3 To introduce innovative technologies from the project consortium, which can help KaWRD and other Indian stakeholders to improve dam safety and water management.
4 To exchange knowledge and experiences on dam safety and water management.

4.2 Interactive sessions

In order to achieve the goals, several presentations were given in the morning session. Mr. Madhava from the KaWRD presented the current situation of Karnataka dams in general and zoomed into the Kabini dam with more detailed technical information. Mr. Ton Peters (consortium coordinator) then introduced the DAMSAFE project followed by presentations from each consortium partner on online monitoring instruments (Royal Eijkelkamp), satellite image on dam deformation (SkyGEO), dam safety risk assessment (iPresas) and integrated data management tool (FEWS) and reservoir optimization (Deltares). Participants showed great interests for further exploring each topic.

The afternoon session is on discussion and the main contribution from the Indian side is from the KERS, which has conducted the latest hydrological study of most Karnataka reservoir catchments. The institute has expressed its willingness to share the monitoring data and hydrological models under the confirmation of KaWRD. The institute has both HEC-HMS and HEC-RAS models for reservoir catchments and rivers, but during the discussion session, the institute demonstrated their own hydrological model which is made in Excel. The reason of making such an excel model is to make every hydrological process transparent to the modellers and end-users, so that they can feel more confident about the model results. During discussion, KaWRD confirmed that the pilot case will be Bhadra reservoir. But the institute has not finished the hydrological study of this reservoir catchment yet. The institute stated that a HEC-HMS model for Bhadra reservoir catchment will be available at the end of week 9 (5 March 2017) and would be possible to share with us. However, we have not received it so far.

Figure 4.1 Inception meeting at the KaWRD head office in Bengaluru


During the discussion session, all participants went through the information table (see Appendix), which was sent to KaWRD earlier, and it was filled by them. The table stated the information completeness. With the information gathered during the site visit to Bhadra dam and the morning session of the inception meeting, the project consortium confirmed the status of the information table ('available', 'partly available' and 'not available' yet). Both iPresas and Royal Eijkelkamp asked for support from KaWRD over relevant data and permission of instrument installation, and KaWRD agreed on those points. It was stated that Royal Eijkelkamp was going to install instruments in Bhadra catchments in May or June 2017.

The inception meeting finished with a great success. People got to know each other. The project consortium got to know more about dams / reservoirs managed by KaWRD and their management. More importantly, the innovative technologies were promoted and discussed, and as a result, it was agreed to set-up an interesting pilot case with application of these technologies with strong support from both state and local organizations. At the end of the meeting, more became clear about data availability and completeness. Further effort is required to collect all necessary missing information.

The project consortium agreed to send a list of missing data to KaWRD and KaWRD agreed to provide those data if they have them at their disposal. In response to this agreement a memo was sent on 19 March 2017. The memo, presented in annex A, gives a status of requested documents, reports, data and models. At the moment of issuing this report a major part of the information has still to be provided.

5 Online monitoring system

5.1 Aim of the online monitoring system

To achieve the three main project goals (section 1), not only measurement data from the online monitoring system is required, but also other measurements and sources of information would be necessary. For each goal, the questions that need to be answered by the online monitoring system can be outlined as follows:

- **Q1** The first goal is <u>forecasting and optimization of the water reservoir performance.</u> For that purpose the online monitoring system needs to give answers to the following questions: (i) what are the weather conditions (especially rainfall and evaporation) in the catchment area and the reservoir? (ii) what is the amount of water flowing into the reservoir, and (iii) what is the amount of water flowing out of the reservoir through spillways, intakes and channels as well as water loss through evaporation?

- **Q2** The second goal is to <u>optimize Operation and Maintenance (O&M).</u> The information needed for this purpose is provided not only by the online (in-situ) monitoring system, but also from visual inspections, reports of repair and maintenance, etc. Another important source of information will be the data of dam and saddle deformation, derived from PS-InSAR satellite measurements that will be provided by SkyGeo later in the project. The in-situ measurements will need to provide answers to the following question: How much water is flowing through the drainage systems of the dams related to the water levels in the reservoir?

- **Q3** The third goal to provide information for early warning (e.g. <u>alarm) and emergency response</u>. The in-situ measurements will need to provide answers to the following questions: (i) how intense is rainfall in the catchment area?, (ii) what are the water levels in the reservoir compared to the crest of the dam (*overtopping risk*)?, (iii) how much water is flowing through the drainage system of the dams and is this water containing sediments (*internal erosion risk*)?, (iv) what are the water pressures inside the embankment dams (*failure risk*)?, and (v) what are the water pressures below the masonry dam (*uplift/sliding risk*)?

5.2 Measurement instruments and locations

Based on the monitoring questions Q1…Q3 and Failure Mechanism FM1 … FM9 a monitoring system has been designed. Table 5.1 indicates the type and amount of instrumentation foreseen. In figure 5.1 the location of the instruments is presented.

Table 5.1 Overview instrumentation online monitoring station

Code of instrument	Measurement type, no. of instruments	Goal	Related FM	Selected instrument type	Installation method	Approx. depth
WS1…WS3	Weather Stations, 3 stations	Q1, Q3	FM1, FM2 (at mid and long term)	Weather station complete, GDT-M SDI12, solar panel, battery	Manual mounting on a mast	Ground level
SL1...SL7	Surface water Level measurements, 7 sensors	Q1, Q3	FM1, FM2, FM7	Diver, GDT-M SDI-12 modem (+ 1 meteo)	In plastic tubing and in an existing manhole at the dam	5 – 10 m
VD1	V-notch Drainage, saddle dam, 1 sensor	Q2, Q3	FM8, FM9	Diver, GDT-S Prime	In existing measurement station	Ground level
VD2	V-notch Drainage, gallery, 1 sensor	Q2, Q3	FM5	Diver, GDT-S prime	In existing measurement station	In gallery
SA1...SA3	Water pressures in the saddle dams 1 cross section with 3 sensors	Q3	FM8, FM9	Diver, GDT-S prime	In monitoring wells to be constructed	5 – 10 m
SB1...SB3	Water pressures in the saddle dams, 1 cross section with 3 sensors	Q3	FM8, FM9	Diver, GDT-S prime	In monitoring wells to be constructed	5 – 10 m
WA1…WA2	Water pressures under the Masonry dam, 1 cross sections with 2 sensors	Q3	FM3, FM4, FM6	Diver, GDT-S prime	In a hole to be drilled in the dam foundation	In the dam foundation
WB1…WB2	Water pressures under the Masonry dam, 1 cross sections with 2 sensors	Q3	FM1, FM2, FM3, FM4, FM5, FM8, FM9	Diver, GDT-S prime	In a hole to be drilled in the dam foundation	In the dam foundation
OS1…OS4	Opening position of the spillway 1…4	Q1, Q3	FM1, FM2 (at mid and long term)	Manual locally by the dam operator[1]	Not applicable	Not applicable

[1] In order to determine the outflow of water through the spillways, the position of the spillway compared to the water reservoir level needs to be monitored. This is performed locally by the dam operator and registered manually in the log book of the online monitoring system. Eijkelkamp will explain this in a training session.

Figure 5.1 Overview Bhadra reservoir and instrument locations

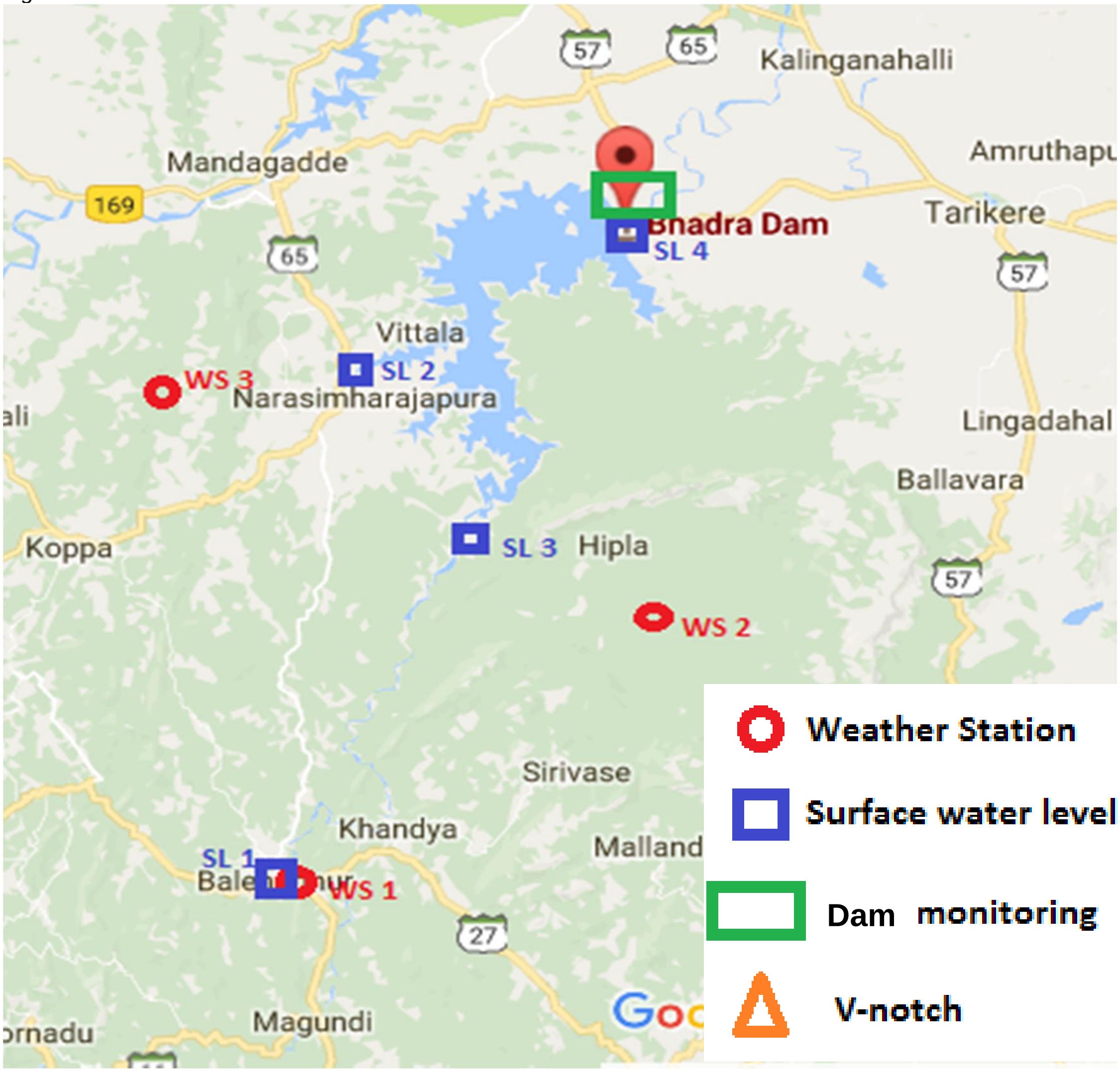
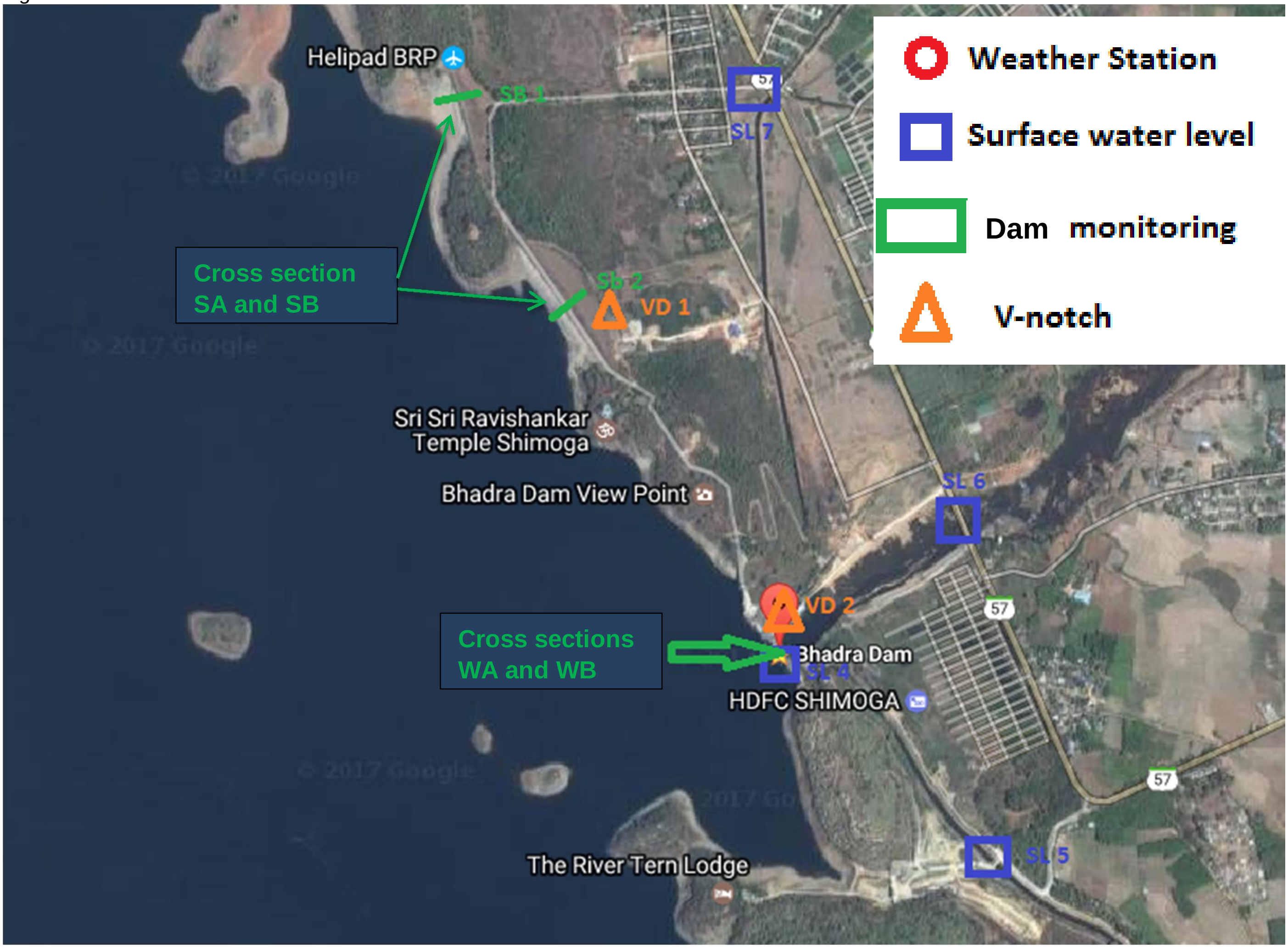


Figure 5.2 Overview dam site and instrument locations



5.3 Requested support from KaWRD

Prior to the start of the installation of the online monitoring system the following support is requested from KaWRD:

- Approval of this monitoring plan.
- All permits and approval of land owners to install the instruments at the indicated locations.
- Photos of all measurement locations, at least 3 per location.
- 1 contact person for the total monitoring network. He has to cooperate and coordinate everything from Bhadra dam side.
- All rating curves necessary to calculate water flow in and out of the reservoir at the locations of surface water level measurements.
- Preparing the location for installation of the weather stations WS1…WS3. This means investigating the situation to find a suitable and safe location. This location should be flat and cleared from obstacles (bushes, trees) over a radius of 20 meter and fulfil other requirements for accurate weather measurements. On this location a 1.5 meter high mast will be installed by Eijkelkamp. Specification of location requirements and mast will be provided by Eijkelkamp.
- During the site visit it appeared that the station for V-notch measurements are out of order. This would need maintenance and repair prior installation of sensors VD1 and VD2.

- Regarding the locations where the river is entering the reservoir (SL1…SL3)
  - Investigate the location and access route
  - Find a spot where to install the equipment, using an existing concrete wall or pillar (if available) or prepare and construct a new point of attachment. Specification of requirements will be provided by Eijkelkamp.
- Drilling of 4 holes into the dam foundation of the masonry dam (WA1, WA2, WB1, WB2). The best place could be inside the drainage gallery at 100m from the entrance. These boreholes needs to be drilled until under the concrete material. Position to be determined.
- Determine the position and height to reference level (by precise surveying) of the location for the measurement of surface water levels (SL1…SL7) and all water pressures SA1...SA3, SB1...SB3, WA1…WA2 and WB1…WB2.

<u>During the installation</u> of the monitoring system the following support is requested from KaWRD:

- Local transport (car and boat), including personnel to drive it.
- Safe and suitable storage capacity for equipment near the site.
- Board and lodging of our installation team near the site.
- Personnel to assist during installation of the instruments and cabling, depending on activities 1 to 2 persons, including installation tools (drill, shovel, plugs, nuts, etc.)
- Drilling of 6 holes in the saddle dams and installation of PVC water observation wells. Locations on the crest and slopes. At each cross section 3 wells need to be installed. Specification of requirements and depth will be provided by Eijkelkamp.

For the <u>duration of the monitoring period</u> the following support is requested from KaWRD:

- Periodic (3 monthly) inspection and maintenance of the measurement locations so correct measurements can be done. Note all the maintenance aspect in the logbook of the webportal.
- Change batteries when necessary (the web portal will give a message when batteries have to be replaced)
- Calibration of sensors every three months.
- Logging events.

At the end of the project the monitoring system is handed over to KaWRD.

ANNEX A: MEMO on requested information dated 19 march 2017

Project: **DAMSAFE**
WP: **2**
Title: List of required information of Bhadra dam and reservoir system

Author: **iPresas and Deltares**
Date: **March 19, 2017 (updated version)**

KEY INFORMATION FOR RESERVOIR FORECASTING

1. Existing meteorological data, if data is online, including station names (Ids if applicable) and coordinates.
2. Existing hydrological data, if data is online, including station names (Ids if applicable) and coordinates.
3. GIS map layers for the three sub-catchments of Bhadra reservoir.
4. Hydrological models (HEC-HMS) for the three sub-catchments of Bhadra reservoir (available from KIRS).
5. Digital river characteristics (cross-sectional shapes, roughness coefficients, etc.). If KaWRD or KIRS has a model for Bhadra River, it is also a valuable input which can be integrated in to the forecasting system.
6. The amount of inflows to the two irrigation canals.
7. Confirmation whether there is an inflow to the Bhadra reservoir indicated in Figure 1.

Figure 1. Bhadra reservoir map.

KEY INFORMATION FOR DAM RISK ANALYSIS

Based on results and conclusions from the working session conducted on February 22, 2017, and the inception meeting on February 23, the following information is considered of high interest to conduct the dam risk analysis and assessment for Bhadra dam.

Key information is highlighted in green.

Type of information	Availability	Comments from DAMSAFE team
Technical note on Bhadra dam	Yes	Delivered during site visit and meetings (hard and soft copy)
PPT presentation on Bhadra dam	Yes	Delivered during site visit and meetings (hard and soft copy)
Dam design, including outlet works and drawings	Yes, on paper good	Delivered during site visit and meetings (soft copy) Missing: 1) Top view drawing on location cross section saddle 1-4. 2) Composition core / geotechnical properties drainage systems of saddle dams
Hydrologic studies river catchment	Yes, on paper good	1) Still required, it would be of high importance to have statistical analysis of flood events into the reservoir at disposal to estimate loading scenarios (to link inflow hydrograph and return period of the corresponding rainfall event at the upstream river catchment) 2) Report and spread sheets from PMF analysis will be also useful if available. 3) Provide available hydro data and hydrological model (HEC-HMS and HEC-RAS) of Bhadra reservoir catchment. Still required, if available.
Rainfall studies		Statistical analysis of rainfall events of upstream basin (already developed for Kabini, not yet for Bhadra; if not available for Bhadra, reports from Kabini are also useful) Still required, if available.
Flood routing analysis	Not defined	Still required, if available
Hydraulic studies in downstream areas, inundation maps	Yes, on paper good	Still required, it would be of high importance to have the hydraulic modelling and consequence analysis (if available) in downstream areas to incorporate input data on potential consequences into the risk model (e.g. flood maps in GIS format, dam break model) Preliminary results obtained within DRIP project might be included as input data to

		the dam risk model.
Periodic Inspection reports	Yes, on paper good	Delivered during site visit and meetings in hard copy *Soft copy would be desirable.*
Reports on maintenance and repair works	Yes, on paper good	Delivered during site visit and meetings in hard copy *Soft copy would be desirable.* *Historical data of measures taken in the last 5 years*
Operation rules in normal situation	Yes, on paper good	Available
Emergency management procedures	No under preparation	It would be of interest to receive **preliminary results from hydraulic modeling and the hydraulic model if possible**, even if the EAP is not yet fully developed
Emergency management procedures before EAP		Current procedures in case of emergency (still required)
Inventory of downstream settlements, infrastructure, land use	No under preparation	It would be of interest to receive preliminary results from analysis of downstream infrastructure and population, even if the EAP is not yet fully developed
Register of reservoir water levels	Yes	It would be of great help to receive soft copy of water level records (historical data)
Dam project	-	Original project document from dam design and construction if available
Structural analysis	-	Structural analyses if available
Questions related to the design and installation of the monitoring system	1) How much is the discharge at the main inflow? 2) How much is the discharge at the outflow at the dam side (main spill gates, irrigation and hydropower channel)? 3) Are there other inflow points with considerable discharge? 4) What is the precipitation at the three different catchment areas? 5) What is the evapotranspiration in these catchment areas? 6) What is the evaporation of the lake, take in account the water level/surface? 7) What is the hydrological situation in the earth dams; seepage, turbidity, water level/slope? Main inflow 8) Is a rating curve available? 9) Pictures of the existing level measuring point Sub inflow 10) Are there any sub inflows except the main inflow with considerable discharge?	

	11) What data do you have of these inflows? Gauge station Balehonnur 12) What data is available of this gauge station 13) Pictures of the situation 14) Possibilities to mount sensors, modems and meteo station 15) Is 110/220 Volts available? Meteo station sub-catchment 16) Ideally, one station will be situated in game reserve (ideal). Is this possible? 17) What are the locations of the existing precipitation gauge stations and reliability of data Outflow 18) Are rating curves available of irrigation- and hydropower channel available? 19) Any data available of opening distance of spillways? Earth dams 20) If water pressure inside dams has to be measured: installation of monitoring wells with profile description. Can this be arranged by KaWRD, do they have equipment and skilled people?

Dam	Year Completed	Dam design and reservoir			Maintenance		Operation & Emergency		
		Dam design, including outlet works and drawings	Hydrologic studies river catchment	Hydraulic studies in downstream areas, inundation maps	Periodic Inspection reports?	Reports on maintenance and repair works	Operation rules in normal situation?	Emergency management procedures	Inventory of downstream settlements, infrastructure, land use
Bhadra	1965	Yes on paper good	Yes pdf good	No under preparation	Yes on paper good	Yes on paper good	Yes on paper good	No under preparation	No under preparation

Table 2.

Dam	Year Completed	Topography mapping dam + catchment area including reservoir + downstream area	Digital Elevation Model (DEM)?	Geotechnical subsoil model of the dam area, results of soil investigation	Describe the type of measurement systems available, e.g. register of reservoir water levels	Describe the number of measurement stations, including frequency of readings, (e.g. 1 per hour, 1 per day, 1 per week etc.) and period	PS-InSAR data quality and availability[5]
Bhadra	1965	No To be obtained from Survey of India	No 0.5mx0.5m grid DEMS available in NRSA Hyderabad on payment basis	No	Yes From inception to till date available pdf good	Yes Per day measurement available 1974-2016	No To be obtained from NRSA on payment basis