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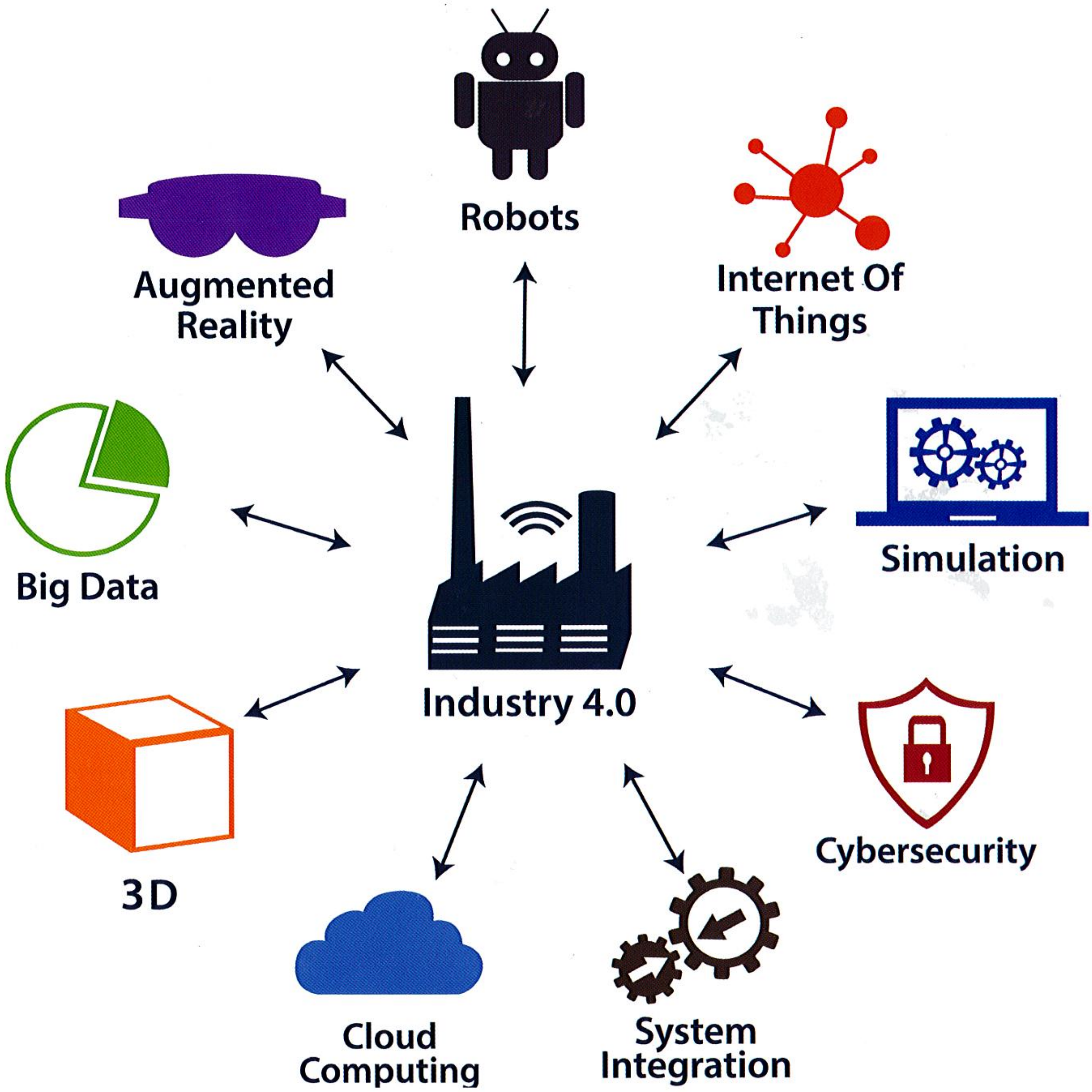

DIGITAL TECHNOLOGY PATHWAY

Risk Management for a Major Water Source Expansion Project

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Construction of a large scale water source expansion project is always exposed to some construction risks that can lead to delay and cost overruns. Commonly encountered risks and uncertainties include floods during construction, foundation conditions, variations in construction materials, weather conditions, environmental impacts etc. Risk management decisions made during the construction stage must evaluate the effects of the actions taken to mitigate the risks. Whatever is done to a dam during construction will have an impact on its future performance.

This article describes the risk management plan (RMP) formulated for the implementation of a major water source expansion project. The framework of the RMP and the related issues in its implementation are presented.

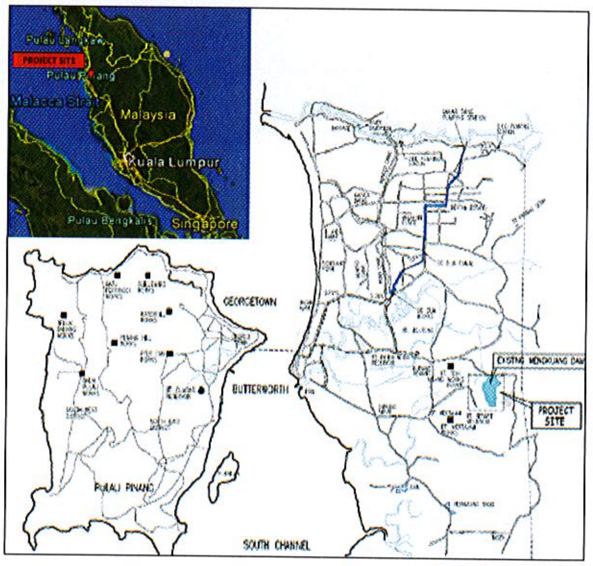

Figure 1 - Location Plan

The Expansion of Mengkuang Dam Project with a construction contract value of RM 607 million was awarded by KeTTHA (Ministry of Energy, Green Technology and Water) to China International Water & Electric Corp (M) Sdn Bhd in 2012. This major water source augmentation project increased the reservoir active storage from 22 to 73.5 million cubic metres (MCM) and the raw water supply capacity from 350 to 650 millions of litres per day (Mld). The water source is vital for the Sg. Dua Water Treatment Plant which provides over 80% of the potable water supply to the Penang state. The project is located in the State near Bukit Mertajam as shown in Figure 1.

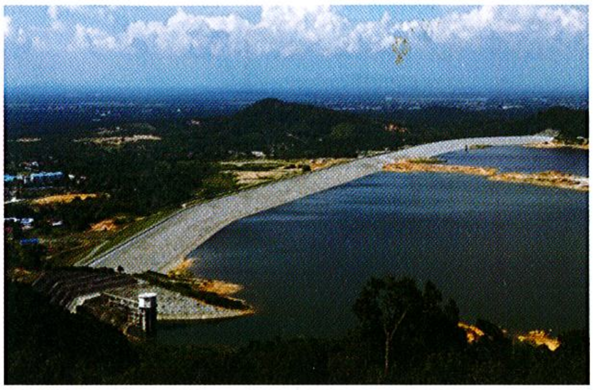

Figure 2 - Panoramic View of the Mengkuang Dam

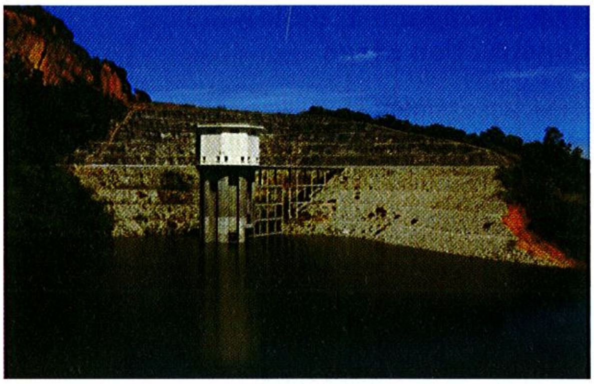

Figure 3 – A View of the Draw-off Tower

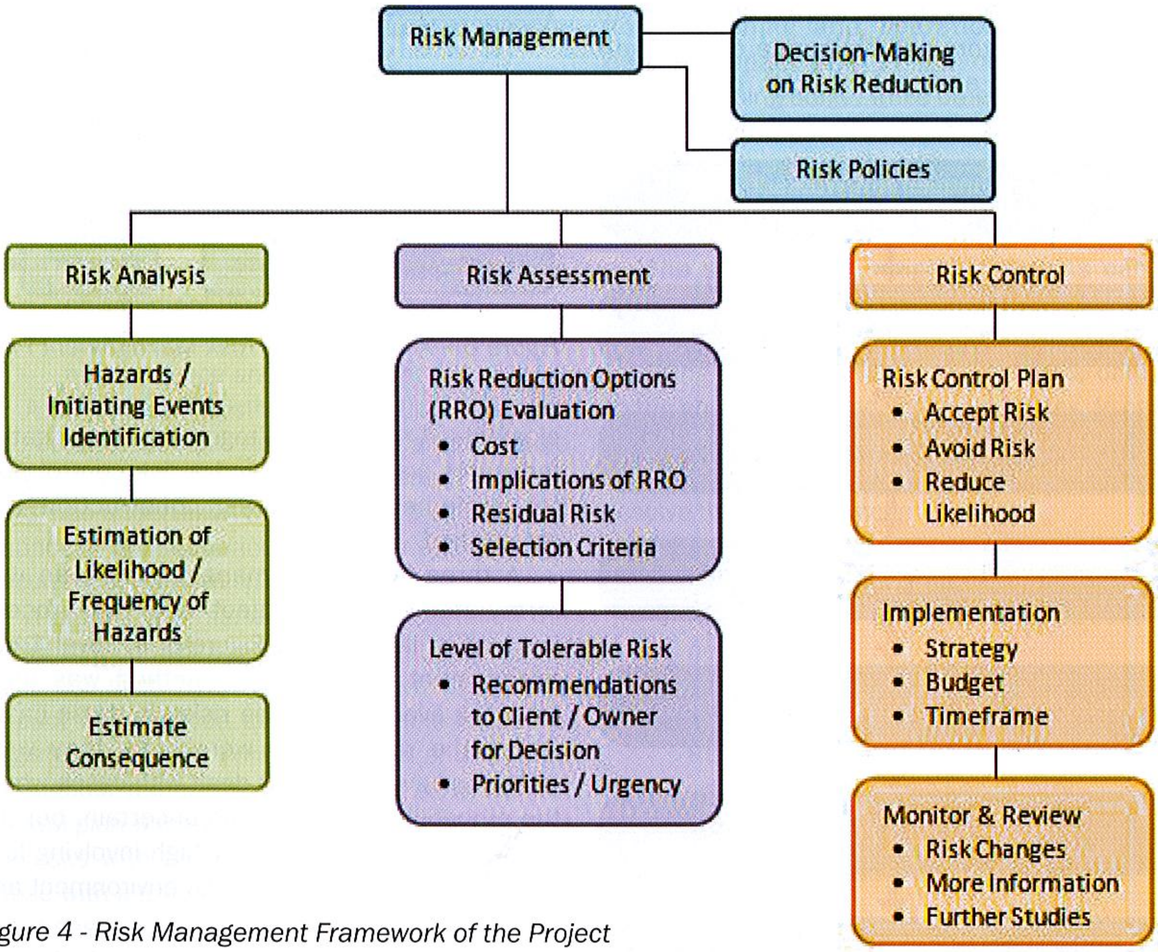

Figure 4 - Risk Management Framework of the Project

Key Features of Project

The original Mengkuang Dam was an earth-fill dam 31m high and about 1 km long completed in 1985. The 2012 project involved raising the original dam by 11m and constructing a new dam 45m high and about 2km long. The new dam is a zoned earth-fill dam. Figure 2 shows the new dam completed in July 2015. The draw-off tower of the new dam is shown in Figure 3.

Risk Management during the Construction Stage

A risk assessment study was conducted to assist in the decision-making process of determining what was the acceptable level of risk and which options provide the most suitable risk reduction measures. A risk management framework was established for the project, as shown in Figure 4. The process of risk management involved several phases, namely: risk identification, risk estimation, risk aversion and risk control.

The process involved in the implementation of the risk management plan developed for the construction stage of the project is depicted in Figure 5. Workshops were conducted to identify risk factors and deliberate on the likely consequences and risk ratings of the risk elements. A risk register, together with mitigation measures was created, and a risk control plan for implementation during construction was established.

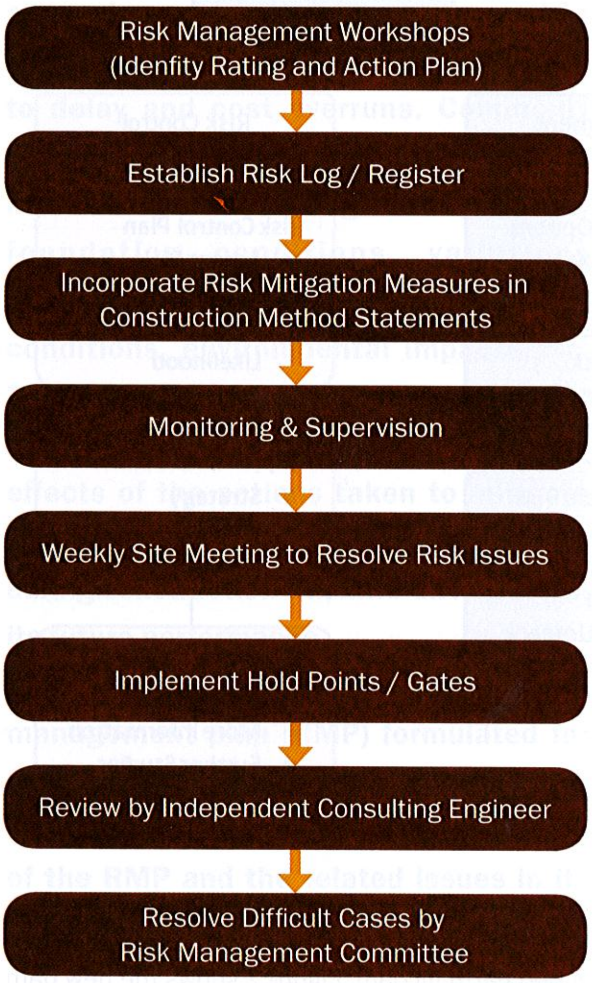

Figure 5 – Process in Implementation of Project Risk Management Plan

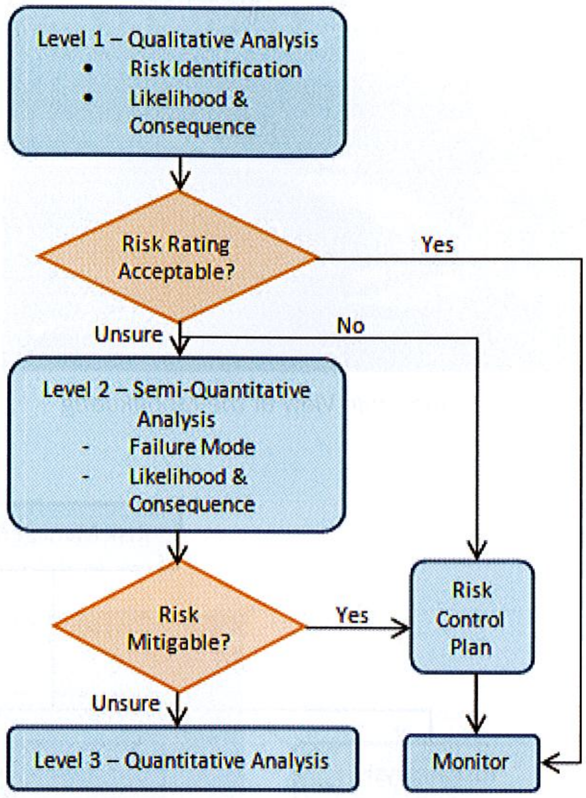

Figure 6 – A Three Tiered Risk Management Plan

A three-tiered risk management plan was formulated for the project and the process involved is illustrated in Figure 6. In Level 1 risk assessment, a qualitative method was used for quick evaluation of the risks. In those cases where the risk ratings were high, they were moved to Level 2. Level 3 dealt with cases where the probability of failure was uncertain, but the consequences could be very high involving loss of life, extensive damage to the environment and economic losses.

Level 1 Risk Assessment

A workshop was conducted to deliberate on approximately 50 identified risk factors. Various risk categories covering technical, environmental, legal, contractual and financial risks were evaluated. In the category of technical risk, risks were organised further according to their particular

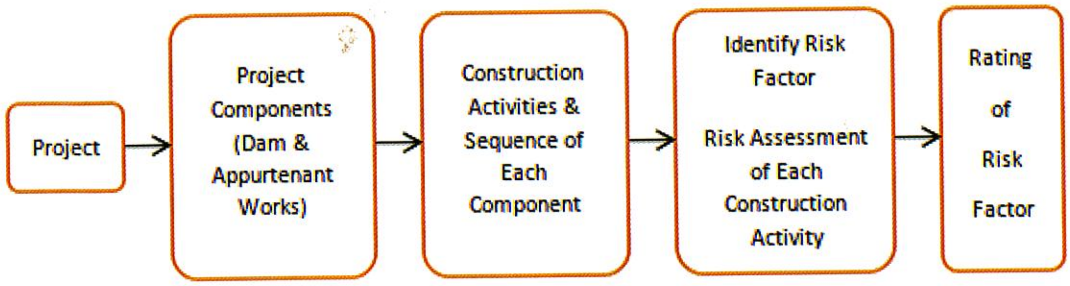

Figure 7 – Subdivision of Project into Components and Construction Activities in Risk Identification, Assessment and Rating of Risk Factors

nature or discipline such as hydrology, hydraulics, geology, geotechnical, structure, mechanical, electrical etc. The process performed in the risk analysis involved the following:

- Separating the project into its component parts and functions.
- Identifying the construction activity or influence that has potential to impact negatively the design, construction and operation of the project, a third party or the environment (illustrated in Figure 7).
- Analysing risks of each factor, its probability of occurrence and consequences.

A project risk register describing the risks and source of these risks and the parties responsible for them was drawn up. An assessment of these risks was undertaken by evaluating their potential impact or consequences and their likelihood of occurrence, from which a risk rating was derived.

A project risk management plan detailed the initial risk control action to reduce the rating of each risk such that the residual probability and impact was reduced to an acceptable level. The register was under continual review and revision throughout the construction stage. An initial risk control plan with mitigation measures was applied for risks with a medium to high rating, but for those with a low rating, monitoring was sufficient. In cases where the consequences or impact were high but the probability of occurrence was uncertain, a Level 2 risk analysis was undertaken.

Level 2 Risk Assessment

Altogether 13 risk factors were identified for Level 2 risk assessment as shown in Table 1; their locations are shown in Figure 8. A semi-quantitative risk analysis was conducted. Some risks constituted a threat throughout more than one stage of the project from design, construction, commissioning and operation. Some risks had an impact only at the construction and commissioning stage, while others had an impact on the future operational safety of the dam. The risk reduction measures (that would impact the future performance of the dam) to be adopted during the construction stage were identified.

The selection of mitigating options can be more difficult for cases where the probability of failure is low, but the consequences are very high involving potential loss of life, extensive damage to the environment and economic losses. In cases where the decision making process involved several parties a long lead time was required to resolve the issues concerned.

Three risk factors identified were determined to require Level 2 detailed analysis, as follows:

- Risk to the old dam due to construction of new dam.
- Risk to the old dam due to construction of dam raising works.
- Risk to pipes at left abutment of new dam adjacent to the Weng Lee Quarry.

Level 3 Risk Assessment on Failure of the Existing Dam

The existing dam was filled to its full supply level EL 43m at the time of construction of the project. During excavation for the foundation preparation works at the left abutment of the old dam, a concentrated leak was observed in an excavated trench about 100m away from the existing dam. The leak was coming from a thin porous layer of highly weathered granite as shown in Figure 9. The leakage through the existing dam abutment was

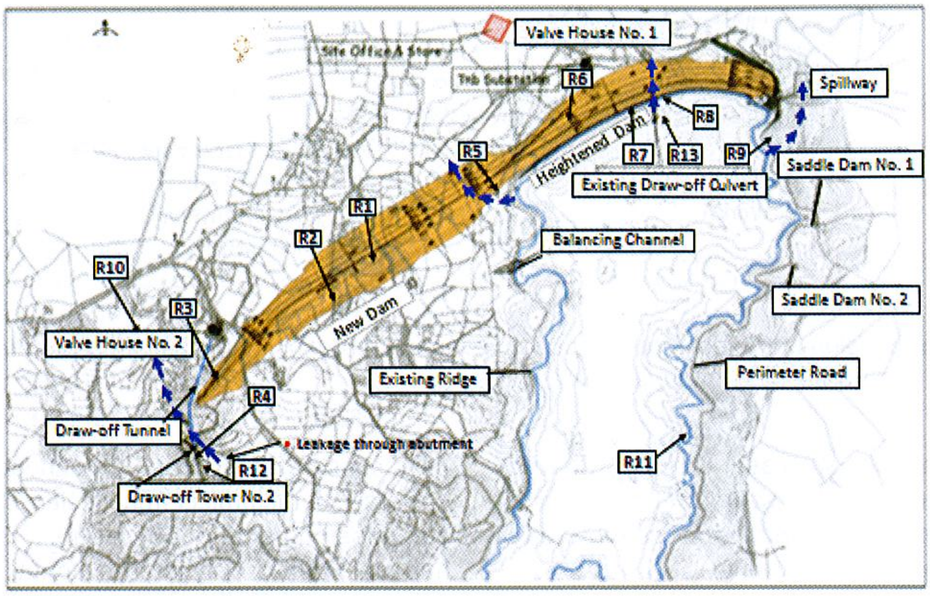

Figure 8 - Locations of Identified Risk Factors for Level 2 Risk Assessment

Table 1 – Risk Factors Identified for Level 2 Risk Assessment

R1	Piping at old river course due to arching effect at the filled embankment Ch400.	R7	Risk of collapse of the existing dam during trenching for the construction of a plastic concrete cut off wall.
R2	Excessive settlement resulting in cracks at the dam embankment due to thermally altered granite at the dam foundation Ch350 to ch950m.	R8	Piping through the clay core of the dam embankment due to a low stress zone along draw off culvert.
R3	Piping at the left abutment might lead to blow out at Weng Lee Quarry face due to layer of whitish thermally altered granite.	R9	Slope instability at the inlet channel of the spillway.
R4	Cut slope instability at draw off tower No.2.	R10	Impact of rock blasting at the Weng Lee Quarry on the integrity of plastic concrete walls and the grout curtain of dam.
R5	Ch.1750 Piping through the left abutment at the existing dam due to layer of a porous weathered granite.	R11	Slope instability of hills at the reservoir rim during the operational stage.
R6	Piping of the existing dam during construction of raising existing dam due to excavation at the toe of dam.	R12	Instability of the Tunnel Inlet Portal during construction.
		R13	Instability of the Access Bridge to the Draw-off Tower No 1.

hydraulically connected to the existing reservoir. This observation prompted the need to critically assess the safety of the existing dam due to the construction of the project.

Purpose of Level 3 Risk Assessment

A quantitative risk assessment was conducted to determine whether the do-nothing option was acceptable and if not, whether lowering the reservoir water level would reduce the probability of breaching the dam to an acceptable level and how it would compare with the option of soil improvement works or the option of controlling the construction activities near the existing dam. The process involved in Level 3 risk assessment is shown in Figure 10.

Risk Identification

The study was not aimed at assessing the overall probability of failure of the existing dam under all possible causative events. Thus, the following types of specific events were not included: events which cause a slip of the upstream shoulder of dam such as rapid draw down, floods which cause overtopping of dam; and earthquakes which cause cracks, liquefaction or slip failure of the dam. The

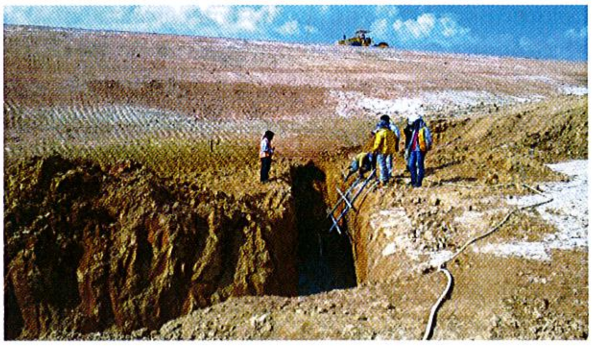

Figure 9 - Concentrated Leak at left abutment of existing dam

risks associated with the above events would be similar for all the options assessed and the risks would not affect the overall risk comparisons. In so far as the reservoir water level was concerned, floods need not be considered as a separate causative event as the dam has adequate freeboard, has an ungated spillway and the flood risk is similar to all options.

Initiating Events

A plausible initiating causative event would be piping due to excavation at the abutment and the downstream toe of the existing dam. A potential

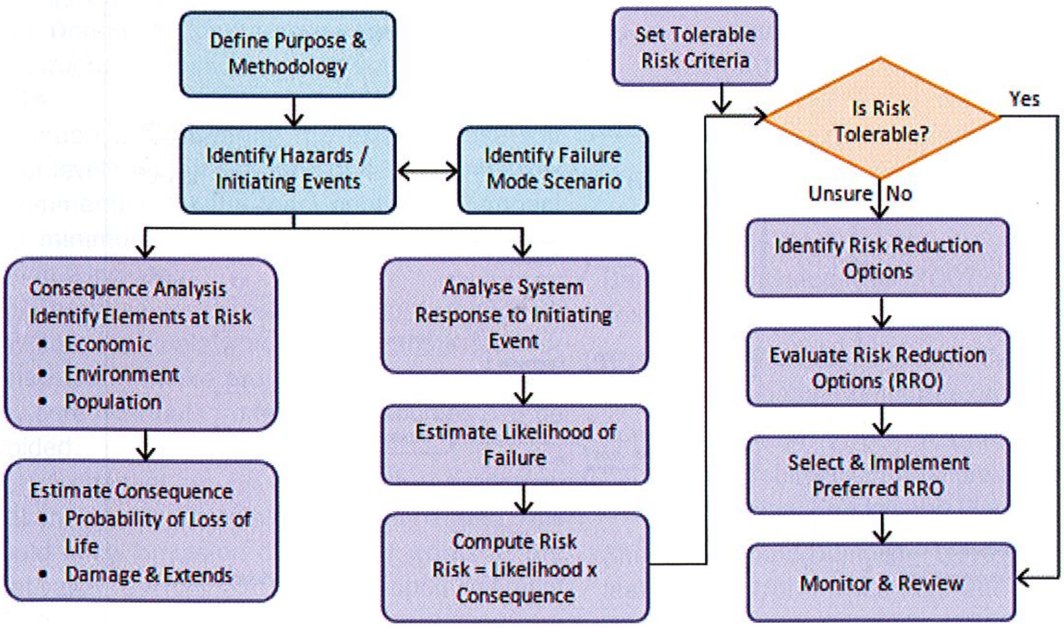

Figure 10 – Process in Level 3 Risk Assessment

failure model related to internal erosion at the abutment soils was considered likely to occur during foundation excavations at the left abutment of the existing dam.

Assessing Whether Erosion Will Initiate

The hydraulic shear stresses (HST) in the leakage conduit were computed based on the Wan and Fell method (2004). The reservoir level assumed leakage conduit dimensions and location relative to the reservoir surface were taken into consideration so the hydraulic gradient could be determined.

The HST computed was compared to the critical shear stress (CST), at which erosion of the soil in the abutment will initiate. CST was estimated based on results by *Wan and Fell (2002)* who developed a method to estimate critical shear stress using laboratory test results of the Hole Erosion Test. Piping analysis using an analytical method was faced with uncertainty on factors such as the hydraulic gradient, permeability, variability of materials and their properties and erodibility of materials. A probabilistic risk assessment was considered more appropriate to assist in the decision making process to address the issue of the safety of the existing dam due to construction works.

Postulated Breach Mechanism and Event Tree Construction

An internal erosion failure mechanism might result from progressive sloughing and unravelling of the downstream abutment slope as a result of flows undercutting and eroding of the abutment, until the reservoir is breached at which point rapid erosion of the abutment soils is likely to cause instability in the embankment and eventually creating a breach to the dam.

If internal erosion and piping failure modes were to occur, it would be difficult to detect during rainy days and at night. The failure modes could be well developed and in progress by the time they were detected. Once the abutment to the reservoir was breached, rapid enlargement and complete loss of the reservoir filled with 22 MCM of water could occur. Also, even if the breach was detected, there are uncertainties on the evacuation efficiency. Figure 11 shows the Event Tree constructed based on the postulated failure mechanism.

Probabilistic Risk Analysis

The assigned conditional probabilities for each event tree were based on a method proposed by *Fell, R et al*, in 2008. In the event tree, the

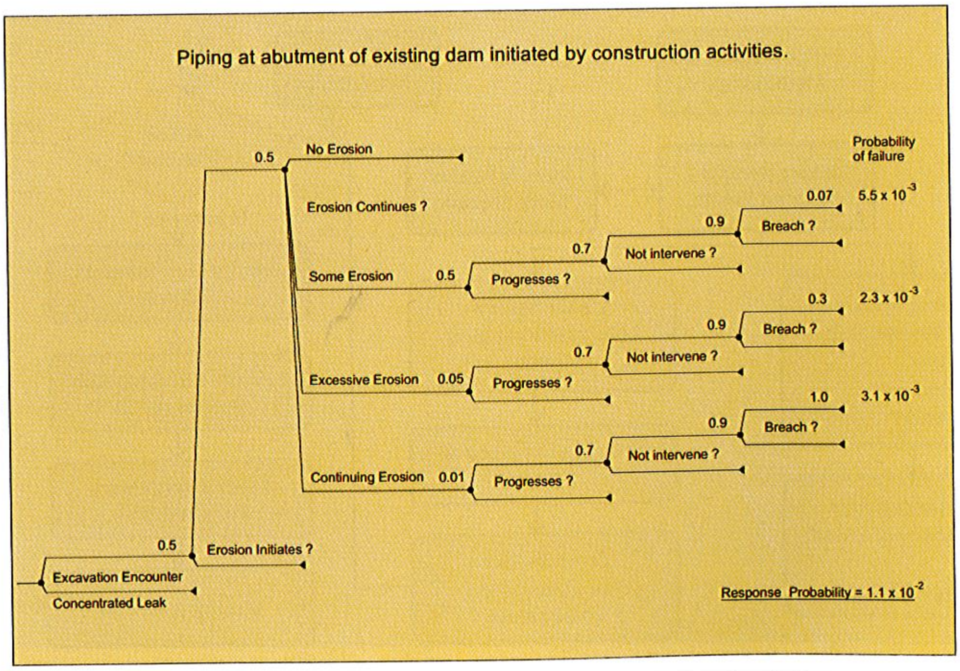

Figure 11 – Event Tree for Postulated Failure Modes

aggregate conditional probability of dam failure along each failure path is calculated. The summation of the probabilities of failure of all paths gives the probability of dam failure. The issue of piping is complex, and judgement coupled with analytical method is required as a guide for this type of risk analysis.

Consequences

Consequences include potential loss of life, economic loss, environmental and social damages. The inundation maps prepared from the dam break simulations were used to estimate the population at risks and the properties in the flood plain. The consequences due to the dam failure would be catastrophic.

The risk management plan followed the guidelines of the Canadian Dam Association on the principle that the risk should be as low as reasonably practicable (ALARP) and the maximum level of societal risk for life safety should be less than 10^{-3} /year for loss of one life that was not explicitly foreseen and identified in advance of the failure; a higher risk is considered unacceptable.

Risk Reduction Measures – Options Evaluation

Options evaluated include: Option 1 - Do-nothing, Option 2 - Lowering the reservoir water level, Option 3 - Construction control and Option 4 - Structural measures using soil improvement works.

Option 2 – Lowering the existing reservoir water level from an elevation of 43m to 34m was recommended for the least contractual impact and minimum cost involved. Other merits of Option 2 included:

- The ridge contains large amount of suitable clay core materials which can be abstracted for construction of the project. The need to import clay core materials from external sources can be avoided.

- A channel can be cut through the ridge so that the two reservoirs can be connected. This would allow omission of draw off works at the right valley reservoir and extensive optimisation of design for raising the existing dam.

However, Option 2 involved reducing the amount of water stored in the reservoir from 22 MCM to 10 MCM which had a serious impact on the security of the water supply system of Penang State. The potential risk was not acceptable to the Penang Government unless an alternative water source as a back-up could be provided. Beris Dam water source from Kedah state was identified as a suitable back up source. However, charges on raw water release from Beris Dam was imposed by the Kedah Government. The issue was resolved through a process of negotiation amongst the Federal Ministry (KeTTHA), the Penang and Kedah State Governments.

Conclusions

1. Construction of a large scale water source development project is always exposed to some construction risks and uncertainties that can lead to delay and cost overruns. Risk management should be applied throughout the construction period to minimise risk and to achieve the best outcomes for the project.
2. Risk assessment can provide a basis for decision making in the selection of mitigation measures required to reduce risk to an acceptable level.
3. A three-level risk assessment management plan involving Level 1 qualitative assessment, Level 2 semi quantitative assessment and Level 3 quantitative assessment is a practical approach to deal with a wide range of risk factors with different likelihood of occurrence and severity of consequences. ■

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