QUEENSLAND WATER COMMISSION

DEPARTMENT OF NATURAL RESOURCES AND WATER

PROVISION OF CONTINGENCY STORAGE IN WIVENHOE & SOMERSET DAMS

SEQWATER
Wivenhoe, Somerset & North Pine Dams
Quality of water. Quality of life.

March 2007

Report No WS/OPS 011106

1. Executive Summary

This report has been prepared in conjunction with the Queensland Department of Natural Resources and Water (NRW) to investigate options to provide contingency storage as part of the South East Queensland Regional Water Supply Strategy (SEQRWSS). As part of these investigations it is proposed to look at options for the provision of an additional 200 to 600 GL of contingency storage in the Brisbane River catchment. The two options for this report are:-

- Raising Wivenhoe Dam Full Supply Level (FSL)
- Raising Somerset Dam FSL

These two options are being compared with other storage options in South East Queensland.

1.1 Scope of Work

This scope of work for this report includes the following options for the provision of the contingency storage:-

- Option W1 - Raise Wivenhoe Dam FSL by 2m to EL69.0
- Option W2 - Raise Wivenhoe Dam FSL by 4m to EL71.0
- Option W3 - Raise Wivenhoe Dam FSL by 8m to EL75.0
- Option S1 - Raise Somerset Dam FSL by 2m to EL101.0
- Option S2 - Raise Somerset Dam FSL by 4m to EL103.0
- Option S3 - Raise Somerset Dam FSL by 6m to EL105.0

This report provides:-

- Background data for each dam including risk profiles.
- A broad description of the works required to raise each dam to the nominated FSL.
- Feasibility cost estimates for each option.
- A preliminary assessment of the environmental and social impacts of each option.
- Risks and opportunities associated with each option.

The six options for the provision of contingency storage in Wivenhoe and Somerset Dams are presented in Table 1-1.

Table 1-1 - Summary of Raising Options

Wivenhoe Raising Options				
Option	**Raising (m)**	**Raised FSL (m)**	**Increase in Storage Capacity (ML)**	**Estimated Cost ($m)**
W1	**2**	**69**	**228,000**	**63**
W1A (Operational change)	**2**	**69**	**228,000**	**5 to 10**
W2	**4**	**71**	**481,000**	**138**
W3	**8**	**75**	**1,066,000**	**248**
Somerset Raising Options				
S1	**2**	**101**	**92,000**	**55**
S2	**4**	**103**	**202,000**	**70**
S3	**6**	**105**	**332,000**	**85**

It can be seen from the table that the most attractive option for the provision of contingency storage would be a 2m raising of Wivenhoe Dam as an operational change eliminating the need for expensive capital works. Intuitively, Wivenhoe would be the most logical option for contingency storage given the size of the catchment and the corresponding probability of capturing the additional flows.

The provision of contingency storage in Somerset will be difficult due to the upstream flooding issues associated with Kilcoy and land owners.

1.2 Flood Security Costs

Neither Wivenhoe nor Somerset currently satisfies the ANCOLD Guidelines on Acceptable Flood Capacity (2003). SEQWater is committed to an agreed program of works to allow the dams to comply with both ANCOLD and the Spillway Adequacy Guidelines (NRW 2005) in the timeframe specified by NRW. Given the assumptions for this study that the dams will be required to pass the current estimate of the PMF, a substantial portion of the costs to raise the FSL is associated with the long term works to increase flood security. It is arguable whether these costs should be included for the provision of contingency storage as SEQWater is likely to incur these costs in the future even if the storage is not raised. An attempt has been made to separate out the costs associated with the provision of additional storage from the costs required to upgrade the current dams. These costs are presented in Table 1-2.

Table 1-2 – Flood Security Costs

Wivenhoe Raising Options				
Option	**Increase in Storage Capacity (ML)**	**Direct Cost ($m_)**		**Total Estimated Cost ($m)***
		Raising FSL	**Flood Security**	
W1	**228,000**	**13**	**40**	**63**
W1A (Operational change)	**228,000**	**NA**	**5 – 10**	**5 to 10**
W2	**481,000**	**64**	**40**	**138**
W3	**1,066,000**	**151**	**40**	**248**
Somerset Raising Options				
S1	**92,000**	**1.5**	**24**	**55**
S2	**202,000**	**1.5**	**24**	**70**
S3	**332,000**	**1.5**	**24**	**85**

Note:

1. **The total costs include contingencies, design and construction supervision not included in the direct costs**
2. **The Wivenhoe flood security costs comprise the current estimated costs of the Stage 2 works. This work is required to be undertaken by SEQWater by 2035.**
3. **The works to raise the FSL at Somerset include gate seals, upgrading the crest, and upgrades to the controls. This work is constant for the three options as up to 6m additional storage could be held against the sector gates after upgrading.**
4. **The MFL for the Somerset Raising Options is similar for all three cases. Therefore, the post tensioning and downstream strengthening work are of a similar order of cost (at this level of assessment).**

For Wivenhoe it can be seen that the incremental cost associated with the small increase in the storage capacity is much less than the cost required to upgrade the dam to full PMF Capacity. For Somerset the cost of increasing the storage capacity is much less than the cost to upgrade to full PMF capacity in all cases.

1.3 Limitations

This report is intended to be a preliminary feasibility investigation for options to raise Wivenhoe or Somerset Dam. The investigations carried out for the report have focused on the engineering aspects of raising Wivenhoe and Somerset. There has been no attempt to quantify:-

- The potential impacts of the raising on the end of systems flows.
- The frequency and volumes of the storage to be held above FSL at either or both of the dams.

- The potential benefit of raising Wivenhoe or Somerset on the downstream flood impacts.

- Major environmental impacts.

- Impacts of the additional storage on the levels of service.

1.4 Flood Operational Procedures.

The proposed raising options investigated for Wivenhoe are capable of producing similar outflow hydrographs to the current configuration, thereby preserving the flood mitigation benefits downstream of the dam.

The proposed options for the raising of Somerset reduce the flood mitigation capacity of the storage for downstream stakeholders (impacts on the flood mitigation capacity of both Wivenhoe and Somerset) to limit the impacts of the raised storage levels on Kilcoy and upstream areas. These options would require a substantial revision of the flood operational procedures.

Option W1A has impacts on the flood capacity of the dam for events greater than the 1 in 1,000 AEP event. Given the rarity of this event it considered that this option has potential to be acceptable to the downstream stakeholders as a short term (10 to 15 years) option to capture additional storage in Wivenhoe.

It has been assumed that minor changes to the flood operational procedures and works to the downstream bridges may reduce the adverse impact of this operational change even further. It is proposed that this assumption be investigated further by SunWater, to provide a detailed assessment of the impacts of the raised storage on the downstream flood levels.

1.5 Wivenhoe Raisings.

The raising options W1, W2 and W3 considered involve:-

- Complex work in the spillway which could only proceed one bay at a time and probably only in the dry season months.

- The cost of such complex work with limited time windows is difficult to estimate with reasonable certainty.

Options W2 and W3 involve raising the embankments and a temporary relocation of the Brisbane Valley Highway causing major disruption to traffic. Less significant disruption would be caused to the Wivenhoe - Somerset Road. The indirect cost of these disruptions has not been estimated.

For Option W1A, the increase in downstream flooding is relatively minor but its acceptability would be dependent on consultation with stakeholders. A raising of Kholo Bridge and possibly of Burtons Bridge and Savages Crossing could be required to deal with possible concerns.

For Option W1A, the existing fuse plug will be triggered more frequently (existing 1:5,000 AEP flood). The frequency and consequences will need to be examined in further detail.

1.6 Somerset Raisings

Issues associated with the raising of Somerset include:-

- Flood Mitigation. Each of the options investigated for the raising of Somerset impact on the existing flood mitigation performance. This impact is greater as the proposed raising increases. This is due to constraints on the upstream flood levels imposed by Kilcoy and other upstream development.

- Equipment age. The gates and hoist equipment at Somerset Dam are of considerable age. There is some uncertainty whether it can be adapted as proposed.

- Dam condition. Cracking in a number of the dam monoliths and other stability concerns will be addressed concurrently with the raising proposals.

- Community opposition to the higher raising proposals is likely to be very strong.

- The indirect costs associated with the increased frequency of highway disruption have not been estimated.

1.7 Recommendations

It is recommended that:-

- Raising of the FSL level of Somerset Dam be rejected due to the impacts on the upstream population during flood events. Major flood events already result in inundation of the Kilcoy and surrounding private properties and infrastructure.

- The provision of contingency storage in Wivenhoe is investigated further. A 2m raising in the FSL could be achieved with minimal capital costs subject to addressing regulator and stakeholder issues.

- A detailed flood assessment is carried out to develop and asses changes to the flood manual to allow the storage of the additional 2m in Wivenhoe. The impact of the changes should be assessed for the full range of Annual Exceedance Probabilities and Storm Durations. This assessment should also link with the Brisbane River Flood Damages Assessment currently being carried out by Brisbane City Council.

- A detailed review of the structural adequacy of the various components of the dam is carried out to confirm the assumptions of this report. The review will provide design detail to refine the cost estimates and confirm the feasibility of the proposed increase in storage level.

- A program of consultation with the downstream stakeholders is carried out with the proposed changes to the flood manual once the assessment of flood events is completed.

- SEQWater be provided with the opportunity to instigate a public consultation process prior to the public release of options to raise the storage levels of Wivenhoe.

Table of Contents

Appendices

Tables

Figures

2. Glossary

Australian Height Datum (AHD)	*Mean sea level at the thirty tide gauges located around Australia*
Annual Exceedance Probability (AEP)	*The probability of a specified magnitude of a natural event being exceeded in any year.*
Dam Crest Flood	*The flood event which, when routed through the reservoir, results in a still water reservoir level at the lowest crest level of the dam.*
Design Flood Level (DFL)	*The peak level in a dam storage derived from routing the critical design flood event through the dam.*
Elevation Level (EL)	*The elevation relative to a specific datum point. For this report all elevation data is quoted in m AHD.*
Full Supply Level (FSL)	*The maximum normal operating water surface level of a reservoir when not affected by floods.*
Probable Maximum Precipitation (PMP)	*The theoretical greatest depth of precipitation for a given duration meteorologically possible for a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends.*
Probable Maximum Flood (PMF)	*The probable maximum flood is the flood resulting from the PMOP and, where applicable, snow melt, coupled with the worst flood producing catchment conditions than can be realistically expected in the prevailing catchment metrological conditions.*
Maximum Flood Level (MFL)	*The peak water level in a dam storage derived from routing the critical design flood event through the dam. May be the same as the DFL or used to denote a different water level if the dam has a flood capacity deficiency.*
Outlet Works	*The combination of intake structure, conduits, tunnels, flow controls and dissipation device to allow release of water from a dam.*
Right Abutment	*The right hand side abutment of a dam looking in the downstream direction*
Left Abutment	*The left hand side abutment of a dam looking in the downstream direction*
Probability	*The likelihood of a specific event or outcome.*
Revise Generalised Tropical Storm Method (GTSM-R)	*A generalised method for the estimation of extreme rainfall events (PMP's) in the northern parts of Australia.*
Reservoir	*An artificial lake, pond or basin for storage, regulation, control of water, silt, debris or other liquid or liquid borne material.*

3. Introduction

This report has been prepared in conjunction with the Queensland Department of Natural Resources and Water (NRW) to investigate options to provide contingency storage as part of the South East Queensland Regional Water Supply Strategy (SEQRWSS). As part of these investigations it is proposed to look at options for the provision of an additional 200 to 600 GL of contingency storage in the Brisbane River catchment. The two options for this report are:-

- Raising Wivenhoe Dam Full Supply Level (FSL)
- Raising Somerset Dam FSL

These two options are being compared with other storage options in South East Queensland.

3.1 Scope of Work

This scope of work for this report includes the following options for the provision of the contingency storage:-

- Option W1 - Raise Wivenhoe Dam FSL by 2m to EL69.0
- Option W2 - Raise Wivenhoe Dam FSL by 4m to EL71.0
- Option W3 - Raise Wivenhoe Dam FSL by 8m to EL75.0
- Option S1 - Raise Somerset Dam FSL by 2m to EL101.0
- Option S2 - Raise Somerset Dam FSL by 4m to EL103.0
- Option S3 - Raise Somerset Dam FSL by 6m to EL105.0

This report provides:-

- Background data for each dam including risk profiles.
- A broad description of the works required to raise each dam to the nominated FSL.
- Feasibility cost estimates for each option.
- A preliminary assessment of the environmental and social impacts of each option.
- Risks and opportunities associated with each option.

3.2 Assumptions

For the purposes of this study it has been assumed that the raised dam will be required to:

- Maintain the flood mitigation performance of the dam (for more frequent flood events up to the 1 in 500 Annual Exceedance Probability (AEP) flood event) provided by the current spillway facilities. Currently the flood manual for the operation of Wivenhoe and Somerset has four procedures. Procedure 4 marks the change from flood mitigation to ensuring the safety of the dam by passing the flood and occurs at approximately EL74. The intent of the manual is to be maintained for possible raising options. Any change to the manual intent will require extensive stakeholder consultation.

- Comply with the State's requirements on Acceptable Flood Capacity (AFC) for Dams. The Draft Guidelines on Acceptable Flood Capacity were issued by NRW (Dam Safety Regulator) in 2005 and are in the process of being finalised.

- Maintain the current release capability of the outlet works. The Dam is operated to release water supply discharges into the Brisbane River before being extracted by downstream customers. This requires an outlet capacity of approximately 1,500 ML/day.

4. Wivenhoe Dam General Information

4.1 Background

Wivenhoe Dam, as originally constructed, is a 56 m high, zoned earth and rock embankment with a concrete gravity spillway (crest level EL57), controlled by 5 radial gates, each 12.0m wide by 16.0 m high. Two saddle dam embankments are located on the left side of the reservoir. The Brisbane Valley Highway was relocated to pass over the dam.

The dam has four main functions by providing:

- A 1,165GL storage at full supply level (FSL EL67.0) providing water supply for Brisbane and surrounding areas;
- Flood mitigation in the Brisbane River with a dedicated flood storage volume of 1,450GL at a flood level of EL80.0;
- The lower pool for the Wivenhoe Pumped Storage Hydro-Electric power station which has a 500 MW generating capacity;
- A recreation area.

The dam was designed by the then Queensland Water Resources Commission. A design report was compiled by the then Department of Primary Industries for the South East Queensland Water Board (DPI, 1995). It was constructed by a series of contracts between 1977 and 1985, supervised by the Commission.

The dam has a HIGH hazard classification because of the significant development downstream in the Brisbane and Ipswich metropolitan areas, with the population at risk (PAR) numbering in the hundreds of thousands.

The first formal dam safety review was undertaken by Guthridge, Haskins & Davey Pty Ltd in 1997 (GHD, 1997). A concurrent review of the mechanical and electrical equipment was undertaken by HECEC Pty Ltd.

The original spillway capacity, with an Annual Exceedance Probability (AEP) of 1 in 22,000 for the Dam Crest Flood (DCF), was well below current standards for a high hazard dam. The Wivenhoe Alliance was formed by SEQWater to improve the flood security with a long-term goal of providing for the Maximum Probable Flood (PMF). Investigation studies concluded that a two-stage upgrade program outlined below would provide a cost-effective risk reduction program.

- **Stage 1 Upgrade Works**
  - Construction of a new secondary spillway on the right abutment that would enable the dam to handle an inflow flood with an AEP of 1 in 100,000 at a Maximum Flood Level (MFL) of EL80. This spillway is controlled by three fuse plug embankments;
  - Upgrading of the embankment crest to retain a MFL of EL80 with zero freeboard;
  - Upgrading of associated structures as appropriate, including protection of the main spillway gates and bridge and strengthening of the spillway gravity structure.
- **Stage 2 Upgrade Works**
  - Reconstruction of Saddle Dam 2 as a fuse plug spillway such that the dam can accommodate the PMF.

4.2 Flood Hydrology

The dam failure analysis report, WA (2005) summarises the storage and spillway discharge data, the PMF inflow data and downstream flood parameters for the following PMF scenarios:

- Original dam with dambreak
- The Stage 1 completed works with dambreak
- The proposed Stage 2 works without dambreak
- The proposed Stage 2 works with dambreak for comparison purposes.

The 36 hour PMP rainfall was found to produce the highest peak inflow and outflow at the dam. Details of the methodology used to derive the PMF hydrographs are described at WA (2004B).

The peak inflow for the PMF is 49,000 m3/s, which includes outflows from Somerset Dam. This was derived using the latest GTSM-R PMP rainfall depths and temporal patterns provided by BOM (2003). The PMF has a flood volume of 5,993,000 ML and the peak outflow discharge following Stage 2 construction is 37,400 m3/s.

4.3 Main Embankment

The Wivenhoe main embankment is located on the right hand side of the centrally placed spillway. The 1.2 km embankment is a 56 m high central clay core embankment with both upstream and downstream filters supported by outer shells of compacted sandstone with run of river gravel in the upper portion. The shoulder slopes are 2 horizontal to 1 vertical with a local steepening in the upper portion to 1.5 horizontal to 1 vertical. Riprap was provided on both upstream and downstream shoulders.

To the left of the spillway structure, the embankment has a sloping upstream core protected by both upstream and downstream filters and supported by a downstream shell of miscellaneous fill. Batter slopes are 3 horizontal to 1 vertical on the upstream face and 2 horizontal to 1 vertical on the downstream face. Riprap was provided on both upstream and downstream shoulders.

4.4 Saddle Dams

Two saddle dams close off low saddles on the left abutment of the dam. These are constructed from miscellaneous fill with some broad zoning of materials. They have a crest level at EL80 and have a maximum height of 10 m. The saddle dams only retain water during flood operation.

4.5 Foundation

A single line grout curtain, 15 m to 35m deep and an 8 m deep grout blanket was installed under the core of the main embankment and the sloping core of the left embankment. Water losses were generally low at depth but high water losses were noted as appearing to "coincide with poorly consolidated sandstone, which is a primary structural feature and is not the result of weathering" (DPI, 1995).

The foundation was cleaned off by removal of loose and shattered material and blasting with water - air jets. This was only done under the core and filter areas as the shoulders were founded on the alluvial materials. Foundation treatment generally comprised slush grout or mortar to seal fractures, fill irregularities and fill fissures. Dental concrete was used where the contact fill could not readily be compacted and to fill cavities and smooth abrupt vertical faces. Areas where the foundation was likely to weather rapidly were mortar treated immediately following clean up.

The contact clay (zone 1A) and filters (zone 2) were placed while the slush grout or mortar was still plastic. The contact clay was compacted with rubber tyred construction machinery.

4.6 Primary Spillway

The spillway is located in a low saddle between the two embankments and is controlled by 5 radial gates supported on a mass concrete ogee crest. The radial gates are 12m wide by 16m high and discharge via a flip bucket spillway to an unlined rock discharge channel.

The five 12m wide by 16m high radial gates in the Wivenhoe spillway structure are operated by hydraulic motor driven wire rope winches, one on each side of each gate. The power units (2) for the spillway gates and penstock gate are located in a winch room in the left abutment of the dam. Also located in the winch room is an auxiliary diesel operated hydraulic unit capable of operating the gates.

A left bank underground control complex in the dam comprises the winch room, water quality control room, main high voltage substation, main switchboard, fire control equipment, storeroom, diesel alternator set, and ventilation system.

A 79 tonne travelling gantry crane on the service bridge over the spillway structure serves to handle the bulkhead gate used for maintenance of the radial gates. A smaller gantry over the intake structure is used for handling the trash racks and water quality baulks.

4.7 Outlet Works

The following information on the Outlet Works is obtained from the DPI, 1995 report.

"The outlet works extend over 4 monoliths LH11 to LH14 with the entrances to the penstock and river outlet being in Monolith 11 and the regulating valves in Monolith 14. At the entrance to the outlet works in Monolith 11 a 3.6m diameter penstock with a large capacity intake was installed to provide for the future installation of a hydro power station. A 1.905m diameter river outlet was installed directly above the penstock so that one fixed wheel bulkhead gate could command either outlet (but not both outlets) to provide for emergency closure or dewatering" (DPI 1995).

In 2003, a 4.6MW mini hydro plant was constructed on the 3.6m diameter penstock. The GE turbine is utilised to generate electricity from the routine releases from the outlet works. The mini hydro is owned and operated by the Stanwell Corporation. The upper outlet, consisting of a 1.9m diameter pipe is controlled by a 1.5m diameter regulating valve. The regulating valve discharges into a stainless steel lined dispersion chamber. Additional off takes are provided for town water supplies.

"The inlet transition for both penstocks is steel lined because of the high 10m/s flow velocity in the pipes. The internal surfaces of the outlet pipes were coated with coal tar epoxy to a minimum thickness of 500 microns. This paint lining was refurbished in 2003.

A 4.1m wide by 5.25m high fixed wheel type emergency gate serves as a guard gate for the outlets through the dam (one 3.6m diameter penstock, and a 1.9m diameter outlet pipe).

Within the intake structure in the left abutment there is an arrangement of six baulks to allow selective withdrawal of water for quality control purposes" (DPI 1995).

4.8 Electrical Equipment

The electrical power system consists of the following major components:

- 11kV supply system and transformer
- Main switchboard
- Diesel generator
- Load bank
- Distribution boards
- UPS power supplies.

The diesel generator is a self contained skid mounted unit with a six cylinder Mitsubishi engine and a 330kVA Stamford generator providing a three phase 415 volt AC alternative power supply for the main dam distribution board. The rating of the engine is a nominal 250kW, with a continuous rating of 90% and a one hour rating of 110%.

The diesel is automatically started at a preset time delay after the mains power fails and the entire site load is automatically connected to the diesel a short time later. Upon the restoration of the mains power there is a short delay and the diesel is shut down and the load reverted to the mains supply. The instantaneous shutting down of the engine without any cooling down period is detrimental on the diesel and will shorten its service life.

To ensure that the diesel is not operated for prolonged periods of time on light load an automatic load bank has been provided. When the diesel load is below a preset level, the load is connected in one step and once the total loading has increased to another preset loading the load bank will be disconnected. Also the load bank is disabled when the 79 tonne gantry crane is operating form the diesel generator.

4.9 Supporting Services

There are several supporting services, which influence the safety of the asset and the operators and therefore indirectly compromise the gate operation. These services include:

- Fire detection
- Fire control and fighting
- Ventilation
- Security systems

- Communications
- Alarm systems
- Monitoring systems
- Access and material handling.

4.10 Stage 1 Upgrade Works

The Stage 1 upgrade works carried out by the Wivenhoe Alliance comprised:

- Construction of a secondary spillway in the right abutment. The excavation of the chute allowed for concrete works for a 3m high ogee crest, apron slabs, chute lining and divider walls to enable construction of three fuse plug embankments;
- Temporary diversion of the Brisbane Valley Highway and relocation of services to enable construction of a new road bridge across the new spillway;
- Upgrading of the existing crash barrier on the two main embankments to handle the new Maximum Flood Level (MFL) of EL80;
- Strengthening of the primary spillway with post-tensioned anchors to cater for the increased loading due to the raised flood level. Provision of a steel deflection baffle upstream of the radial gates to ensure the gates clear the flow profile for the raised MFL.
- Modifications to the saddle dams to prevent premature failure while ensuring they are overtopped prior to the main embankment.
- Associated works comprising spoil area, access roads, sediment and erosion controls, site facilities and landscaping.
- Refurbishment of the Visitors information Centre.

This Stage 1 upgrade changes the Dam Crest Flood (DCF) from a 1 in 22,000 AEP event to a 1 in 100,000 AEP flood event. The initial trigger level for the lowest of the fuse plug embankments is at EL76.2m (approximately the 1 in 6,000 AEP event).

4.11 Proposed Stage 2 Upgrade Works

Stage 2 works will involve the reconstruction of Saddle Dam 2 to incorporate a fully lined concrete chute spillway with a single fuse plug embankment. This 100 m wide spillway will provide full PMF protection with a conventional freeboard and will be triggered by the 1 in 50,000 AEP event. The concrete lining and flip bucket protects against erosion of the conglomerate foundation.

Under proposed State guidelines (NRW 2005) the Stage 2 spillway will be required to be in place by 2035 and will increase the flood capacity to cater for the PMF.

4.12 Geology

The following description of the site geology is taken from DPI, 1995 and GHD, 1997. Brief descriptions of the regional and rim geology are provided at GHD, 1995.

"The main dam is located wholly on the Helidon Sandstone (also known as the Wivenhoe Sandstone). The sandstone consists of quartz grains with minor dark chert fragments in a whitish kaolinitic matrix. Structurally, most of the rock foundation consisted of massive undulating layers of sandstone, sometimes cross bedded, which had dips between 2 and 10 degrees and strikes in the general ENE direction. Most of these units were separated by thin layers of shale, shale conglomerate or fine pebbly conglomerates containing minor amounts of fossilised plant material (coal).

An exception occurred on the right bank were up to 9 m of interbedded shales and fine sandstones were found. The sandstone unit above was fairly weathered and contained many thin layers of clay. A continuation of the shale / fine sandstone unit is thought to have been intersected on the left bank. This suggested that the unit was responsible for the incision of the river into the valley floor at the dam site and subsequent control of the alluvial deposition sequences upstream of the dam site.

Up to 20 m of alluvium / colluvium overburden was found to exist above the foundation rock." (DPI 1995)

4.13 Seismology

SEQWater has six monitoring stations throughout the three dam catchments (North Pine, Somerset and Wivenhoe) with seismometers, which measure seismic activity in x, y & z directions in real time. This data is transmitted via radio telemetry to the Wivenhoe Office where the information is analysed. Six accelerometers are installed, two at each dam, one at the crest and one at the base of each dam, to measure the actual dam movement during earthquakes.

A review of earthquakes and earthquake hazard in the Somerset Dam area, northwest of Brisbane was undertaken by Gibson (RMIT, 1995) using earthquake information published to December 1994. The study covers the area bounded by the Somerset and North Pine Dams and includes the Wivenhoe site.

No major earthquakes have occurred in the area since European settlement. The available data suggests the earthquake hazard in the area is above average for Queensland but below the average for eastern Australia.

The Report provides the annual exceedance probability (AEP) for peak ground accelerations as shown in Table 4-1

Table 4-1 - Earthquake Peak Ground Accelerations for the Wivenhoe, Somerset, North Pine Area

AEP	Peak Ground Acceleration
1 in 1	0.006 g
1 in 3	0.010 g
1 in 10	0.017 g
1 in 30	0.030 g
1 in 100	0.052 g
1 in 300	0.088 g
1 in 1,000	0.152 g
1 in 3,000	0.24 g
1 in 10,000	0.392 g
1 in 20,000	0.505 g

5. Raising Options for Wivenhoe Dam

To provide input into the provision of contingency storage in Wivenhoe Dam three different raising levels were selected:-

- Raise FSL by 2 m to EL69.0. This option (W1) provides a significant increase in storage, 228,000ML, for a relatively small capital cost (i.e. compared to a greenfield site) and could be achieved relatively simply. There is an additional opportunity to raise Wivenhoe FSL by 1 to 2m (which could be temporary) without the need to carry out extensive capital works. This is discussed as option W1A in Section 5.3.

- Raise FSL by 4 m to EL71.0. This option (W2) provides a mid point for the cost curve and marks a significant change in the scope of work required to satisfy the flood mitigation, flood security and operational requirements. This raising would provide an additional storage capacity of 481,000ML.

- Raise FSL by 8 m to EL75.0. This option (W3) was selected to provide an upper limit to the raising options and provide an additional 1,066,000ML of storage (effectively doubling the storage volume of Wivenhoe). This option would utilise the limit of land owned by SEQWater for the FSL storage. There would need to be compulsory acquisitions by Government of additional land impacted by flood operations up to at least the 1 in 500 AEP event. There is major capital works required to allow the dam to satisfy the flood mitigation and flood security criteria.

5.1 Summary Table

Key data for the proposed options is summarised in Table 5 - 1. The options are described in Sections 5.2, 5.3, 5.4, and 5.5

5.2 Option W1 - Raise Wivenhoe FSL 2m (EL69.0)

This option involves raising the storage level by 2m to EL69.0. This would provide and additional 228,000ML of contingency storage. The proposed scope of work for this option would involve:-

- Raising the fixed concrete ogee crest of the gated spillway by 1.5m to EL58.5 to preserve the air space controlled by the radial gate above FSL for flood mitigation.

Table 5 - 1 - Wivenhoe: Elevation data for Raising Options

Raising Option	Dam Structure				Secondary Spillway				Tertiary Spillway
	FSL	Dam Crest	Service Spillway	Top of Radial Gates	Ogee Crest[1]	Fuse Plug initiation			Fuse Plug initiation
						Bay 1	Bay 2	Bay 3	Single Bay
Current configuration	67	80	57	73	67	75.7	76.2	76.7	78.3 (100m wide)[2]
Option W1 - 2m permanent	69	80	58.5	Approx 74.5	67	76.7	77.2	77.7	78.5 (140m wide)
Option W1A - 2m temporary	69	80	57	73	67	75.7	76.2	76.7	78.3 (100m wide for FSL EL67) 78.3 (120m wide for FSL EL69)
Option W2 - 4m permanent	71	84	60	76	69	77.7	78.2	78.7	Not Required
Option W3 - 8m permanent	75	87.5	70	76[3]	73	81.7	82.2	82.7	Not Required

[1] Ogee crest level the same for both the Secondary and the Tertiary Spillways.

[2] Spillway not required to be finished until 2035 by the NRW Draft Guidelines on AFC

[3] Existing radial gates replaced with fuse gates

- Raising of the three fuse plug embankments in the secondary spillway by 1m to preserve the initiation level for the first embankment at approximately the 1 in 5,000 AEP flood event as per the current design constructed in 2004. The initial trigger for the lowest of these fuse plugs would then be EL76.7.

- Construction of the tertiary spillway proposed currently for Stage 2 of the Wivenhoe Flood Security Upgrade at Saddle Dam 2 with a single 140m wide fuse plug initiating at a level of EL78.5.

- Maintaining the current Maximum Design Flood Level (MDL) of EL80m adopted for the Stage 1 upgrade work to avoid any work along the crest of the existing dam.

Drawings of the works required for this option are presented in Appendix D.

5.2.1 Spillway Capacity

Under the Governments proposed guidelines on spillway adequacy, the spillway capacity to allow the dam to safely pass the 2003 estimate of the Probable Maximum Flood (PMF) is required by no later than 1 October 2035. The spillway layout and capacity are discussed in the following sections.

Radial Gated Service Spillway

The flood mitigation benefits obtained for more frequent flood events from Wivenhoe Dam are due to the freeboard against the radial gates above the nominated FSL. To preserve the current flood mitigation performance if the FSL were raised, the air space between FSL and the top of the radial gates will need to be maintained.

The simplest method to achieve this would be keep the existing radial gate arrangement and raise the fixed crest level with reinforced concrete from EL57 to EL58.5. The existing trunnion corbel, bearing and winches would be maintained in their current location.

The bottom gate seal would need to be raised and incorporated in the new concrete. The lower 1.5m of the gate slots would be filled with concrete and a new connection with the bottom gate seal fabricated and installed. Extensive anchoring would be required along the existing crest to secure the new concrete to the underlying original concrete.

The works required to raise the crest will involve the placement of reinforced concrete with grouted anchors at a regular spacing to ensure connectivity to the underlying crest concrete over the length of the crest to a suitable profile (assumed to mirror the current profile with a 1.5m topping layer for the development of costs). The control systems for the gates would also need to be modified.

Replacement of the radial gates was considered but requires major capital expenditure to fabricate and install new gates as well as modify the existing piers, trunnion corbel and anchoring. Due to the current design of the piers and trunnion anchoring it may not even be a possibility to install new radial gates to achieve the levels specified for this option. Drawings of the works required for this option are presented in Appendix D.

Raising of the fixed crests for the existing radial gated primary spillway will reduce the ultimate discharge capacity from 13,400 m^3/s to approximately 12,000m^3/s. This lost capacity could be replaced by the provision of an additional 20m of spillway crest length in the Stage 2 works proposed for Wivenhoe.

Secondary Fuse Plug Spillway

The Stage 1 works constructed for the Flood Security Upgrade of Wivenhoe in 2004 consisted of a three bay, 164m wide fuse plug spillway located at the right abutment of the dam. The first fuse plug embankment trigger level was set at EL75.7 (nominally the 1 in 6,000 AEP flood event) to protect the flood mitigation benefits of the storage and minimise the cost of the upgrade.

To preserve the design intent it is possible to raise each of the three fuse plug bays by 1m preserving this initiation AEP for the raised storage level. The divider wall between bay 1 and Bay 3 of the fuse plug would need to be raised by 0.2m which would be achieved using anchor bars and conventional concrete at limited cost. The Left Hand Side of the chute is protected by a concrete gravity wall. This would need to be raised by 0.5m to protect the main dam embankment. As the Maximum Flood Level (MFL) would remain at EL80.0 there would be no need to modify the bridge over the spillway, the ogee crest or the wall lining.

The control crest would remain at EL67.0 resulting in an inability to store water at the new FSL of EL69.0 until the fuse plug embankment was reconstructed.

Tertiary Fuse Plug Spillway

Stage 2 works are proposed to allow Wivenhoe Dam to pass the 2003 estimate of the PMF. The current proposal is to construct a 100m wide tertiary spillway through Saddle Dam 2. The spillway would be controlled by a single fuse plug embankment initiating at a 1 in 50,000 AEP flood event (EL78.3).

To preserve the design intent and pass the PMF for the raised FSL of EL69.0 would require the tertiary spillway width to be increased to 140m from the current proposal of 100m. The initiation level of the fuse plug embankment would be increased from 78.3 to 78.5 (approx 1 in 50,000 AEP event).

5.2.2 Existing Embankments

The Stage 1 flood upgrade works have been designed for the new MFL of EL80.0. Therefore no works are required to raise the embankments, bridges or Saddle Dams for the new FSL.

5.2.3 Key Data for a 2 metre Raising

Item	Proposed EL / Storage	Current EL / Storage
FSL	69m	67m
MFL	80m	80m
Dam Crest Level	80m	80m
Top of Radial Gate	74.5m	73m
Service Spillway Fixed Crest Level	58.5m	57m
Storage Vol FSL to Top of Gates	760GL	761GL
Secondary Spillway		
- Fuse Plug 1 Initiation	76.7m	75.7m
- Approx Initiation AEP	1 in 5,000	1 in 6,000
- Storage Volume FSL to Initiation Level	1122GL	1182GL
Planned Tertiary Spillway Stage 2		
- Crest Length	140m	100m
- Fuse Plug Initiation	78.5	78.3
- Approx Initiation AEP	1 in 50,000	1 in 50,000

5.2.4 Costs

Item	Cost	Comment
1. Raise the concrete ogee fixed crest of the existing service spillway by 1.5m in reinforced concrete	$8.7M for the five bays	This assumes anchoring, reinforcement, provision of access, steel work, mechanical system modifications, provision of access to the post tensioned anchors installed by the Alliance.
2. Construct the Stage 2 spillway to provide PMF capacity for the Dam	$27M	These works have been costed by the Wivenhoe Alliance.
3. Raise the secondary spillway fuse plug embankments, divider wall and the training wall	$2.5M	This assumes that the fuse plugs are all raised by 1m with works carried out on the downstream face of the embankments
4. Construction Supervision and Overheads (20%)	$7.6M	Contract Supervision and Constructors Overheads
5. Design and Approvals (15%)	$5.7M	Concept Design, Approvals and Detailed Design
7. Contingency (30%)	$11.5M	
Total	**$63.0M**	

A breakdown of the costs estimates is provided at Appendix C.

5.2.5 Inundation Area

The inundation area is presented in Appendix K. SEQWater owns land up to EL75m for operation of the dam during flood events. Currently, large parcels of this land are leased out to adjacent landholders to provide land management. Impacts from the raised storage levels would include:-

- Some reduction of land available to lease holders adjacent to the storage area. When the dam was constructed the landholders subject to resumption were granted favourable lease conditions. While the lease states that an increase in storage level is possible at the discretion of SEQWater there would need to be an early and comprehensive consultation program implemented.

- Loss of environmentally sensitive habitat (minor). There are areas around the storage listed as environmentally significant. The inundation of these areas may require the preparation of an EIS.

- Loss of access to private recreation areas at Billie's Bay and Hay's Landing currently leased from SEQWater. Substantial costs would be incurred to provide alternative access to these areas. This is not a considered a major issue as potentially the recreation areas could be closed after consultation.

- Slightly more frequent flooding of bridges on the Wivenhoe – Somerset Rd and significantly more frequent flooding of the A&PM Conroy Bridge.

5.3 Option W1A – Operational Change of Wivenhoe FSL

To satisfy the upgrading criteria (pass PMF and maintain flood mitigation capability as currently exists) it is necessary to incur significant capital expenditure. However, there is an opportunity to raise the FSL of Wivenhoe Dam without major capital works. Such a raising could provide temporary contingency storage until permanent works are undertaken. This would provide an additional storage of 228,000ML for the regional contingency storage for minimal cost.

5.3.1 Flood Mitigation Capacity

The possibility of increasing the FSL to EL71 was investigated by SEQWater previously in a draft report on the raising of Wivenhoe prepared for discussion with NRW. While this additional storage did not have a major impact on the flood discharges for extreme flood events (events greater than the 1 in 10,000 AEP event) it did have implications for the operation of Wivenhoe and Somerset for more frequent flood events (floods smaller than the 1 in 500 AEP event). This impact (increased discharges) is summarised in a report by SunWater presented in Appendix E. Key outcomes from the SunWater investigations was that the 4m raising of the storage compromised the ability of the Flood Operations Centre to manage small flood events without the initiation of a fuse plug.

As this previous work identified that flood mitigation would be compromised by a 4m raising of the storage without modifying the spillways, significant modification works are proposed for Options W2. The proposed scope of work is presented in Section 5.4.

The flood operation group of SunWater was subsequently engaged during this investigation of contingency storage options to assess the impact of increasing the Wivenhoe FSL to EL69.0 on the more frequent flood events. This report is presented in Appendix F. This assumes that there are no modifications to the existing primary and secondary spillways. The assessment looked at the impact of the raised storage level on the 1 in 100, 1 in 200 and 1 in 500 AEP events. A summary of the results of these investigations is presented in Table 5-2.

It can be seen from the table that the increase in the FSL of 2m has very limited effect on the 1 in 100, 1 in 200 and 1 in 500 AEP events in terms of the peak flow at the Moggill Gauge. These results suggest that 1 to 2m raising of the storage would not compromise the ability of the Senior Flood Operations Engineer to manage a large flood event up to and above the 1 in 500 AEP event. As a short term measure to provide contingency storage it would therefore appear feasible to allow the storage of Wivenhoe to be held at EL

69.0m (2m above the FSL of EL67.0) following a flood event without compromising the flood mitigation ability of the dam for follow up events up to and above the 1 in 500 AEP event.

Subject to a detailed review of the structural adequacy of all elements of the dam, this could be achieved with almost no capital expenditure and minimal impact on flood mitigation and the flood capacity of the dam. Alternatively, a 2 metre raising of Wivenhoe's FSL could become permanent if the Stage 2 spillway (which is required by 2035) were widened to 120 metres

5.3.2 Flood Risk

Holding the storage at EL69 after a flood event presents a small increase in risk due to:-

- Increasing discharges for a limited range of events (from the 1 in 1,000 AEP event to the 1 in 5,000 AEP event) to try and limit fuse plug initiation.
- Increasing the likelihood of initiating a fuse plug embankment from an AEP of 1 in 5,000 to an AEP of approximately 1 in 4,000.
- Increasing the AEP of the Dam Crest Flood from 1 in 100,000 to approximately 1 in 95,000 (peak inflow of approximately 41,000m^3/s instead of 42,600m^3/s). Note: Under the states Proposed Guidelines on Acceptable Flood Capacity, Wivenhoe Dam would be required to have full PMF capacity by 2035.

It should be noted that the additional storage volume of 228,000ML could be used within 10 months therefore limiting exposure to the increased risk. However, the impact of concurrent flood events and joint probability with storage levels would need to be assessed in more detail to quantify risk. It should be noted that historical precedence has shown follow up events occurring in the same season as major flood events.

Table 5-2 - Comparison of Wivenhoe Somerset Flood Operations Results

Design Flood Event Centered over Wivenhoe Dam

Peak Values

Flood Event	Wivenhoe FSL	Wivenhoe Dam			Somerset Dam			River Flows				Fuse Plug Init.
		Elevation (m AHD)	Inflow (m3/s)	Outflow (m3/s)	Elevation (m AHD)	Inflow (m3/s)	Outflow (m3/s)	O'Reillys (m3/s)	Lowood (m3/s)	Bremer (m3/s)	Moggill (m3/s)	
Feb 1999	67	72.836	6862	1552	105.021	3766	1265	132	1553	424	1629	*No*
	71	74.766	6862	3494	104.804	3766	1645	132	3621	424	3943	*No*
	Increase (m or %)	1.930	0	125	-0.217	0	30	0	133	0	142	
Jan 1974	67	74.123	5019	3930	105.871	3456	1716	3260	6074	4241	6312	*No*
	71	74.425	5019	6643	105.595	3463	1490	3260	9001	4241	9562	*No*
	Increase (m or %)	0.302	0	69	-0.276	0	-13	0	48	0	51	
Feb 1893	67	75.161	9085	9695	107.370	4602	4363	3089	11337	1845	11403	*No*
	71	75.555	9085	10385	107.075	4602	3494	3089	11992	1845	12105	*No*
	Increase (m or %)	0.394	0	7	-0.295	0	-20	0	6	0	6	
WD Q100	67	73.094	5397	2392	103.165	1964	541	1921	2853	1349	3608	*No*
	69	74.501	5397	2503	103.165	1964	541	1921	2958	1349	3645	*No*
48hr	71	na	na	na	na	na	Na	na	na	na	na	*na*
ARR(87)	Increase (m or %)	1.407	0	5	0.000	0	0	0	4	0	1	
WD Q200	67	73.377	8433	2863	103.535	2377	615	1334	2974	1069	3197	*No*
	69	74.825	8433	3013	103.555	2377	614	1334	3116	1069	3164	*No*
48hr	71	74.820	8433	6037	102.963	2377	946	1334	7332	1069	7684	*No*
GTSMR	Increase (m or %)	1.448	0	5	0.020	0	0	0	5	0	-1	
WD Q500	67	74.219	10543	4452	104.337	2930	968	1886	5922	1487	6193	*No*
	69	75.645	10543	4545	104.362	2930	980	1886	5862	1487	6123	*No*
48hr	71	75.664	10543	7649	104.462	2930	1188	1886	9311	1487	9694	*No*
GTSMR	Increase (m or %)	1.426	0	2	0.025	0	1	0	-1	0	-1	

5.3.3 Risk Reduction

There are opportunities to reduce exposure to this minor increase in flood risk such as:-

- Utilising early releases from the storage to take advantage of the flood warning system. Modification of the flood procedures could be made in conjunction with minor capital works to allow discharges to be ramped up earlier.

- Making the use of the additional stored water a priority within the region to draw down the storage quicker.

Early releases

A flood alert system was developed by NRW during the mid 1990's to provide accurate forecasting of the size of flood events and necessary gate operations to optimise the flood management from both Wivenhoe and Somerset Dams. This system was tested during a major flood event in 1999 and proved to be an accurate tool to predict flood levels and releases. The alert system is maintained by SEQWater and provides real time data to a flood operations centre in Brisbane.

This system will provide up to 18 hours advance warning during a flood event which allows the implementation of an early release strategy to lower the storage of Wivenhoe in the event of an imminent flood.

Currently the ability to release significant volumes of water from Wivenhoe Dam is limited by low level bridges across the Brisbane River at Kholo, Savages Crossing and Burton's Bridge. Savage's Crossing is cut by a flow of around 130m^3/s, Burtons Bridge at 430m^3/s and Kholo Bridge at 550m^3/s. If these bridge's were raised to allow a discharge of 1,200 to 1,500 m^3/s to be released without submerging them, then the opportunity for early releases becomes more attractive. The Brisbane River Flood Damages Study currently being carried out by Brisbane Water has also identified that these discharges would be non damaging.

A flow of 1,500m^3/s equates to a release of 97,000ML in the 18 hour warning time available to the Flood Operations Centre (approximately half of the additional storage held) thereby significantly reducing the flood risk.

The ability to provide early releases is conditional upon concurrent flows in Lockyer Creek and the Bremer River and should be investigated further. It is estimated that for a capital expenditure of $5M the three bridges could be raised to provide flood immunity up to a flow of 1,500m^3/s. Note: The proposed raising of Mt Crosby Weir would require a raising of Kholo Bridge.

Use Additional Storage

A simple method to further reduce the risk associated with this option is to use the additional storage as quickly as possible. With the proposed water grid for South East Queensland being constructed and the operational flexibility it will provide, there is an opportunity to use the additional storage across the region to increase the rate of draw down for Wivenhoe Dam. Additional work is required to assess the rate of draw down possible but it is conceivable that the 228,000ML of additional storage could be used within 9 months.

5.4 Option W2 - Raise Wivenhoe FSL 4m (EL71.0)

This option involves raising the storage level by 4m to EL71m. This would provide and additional 481,000ML of contingency storage. The proposed scope of work for this option would involve:-

- Increasing the Maximum Flood Level from EL80m to EL83.4m to maintain the flood mitigation benefits of the storage.
- Existing Spillway
  - Raising of the fixed crest spillway from EL57 to EL60m and raising the existing spillway radial gates so that the top of the spillway gates is at EL76m. Alternatively the radial gates could be abandoned and a new uncontrolled spillway crest constructed at an EL 71m. Undershot gates could be provided through the fixed crest to reinstate the flood mitigation capacity. This would allow the new crest to replicate the outflow hydrographs for the 1 in 100 and 1 in 200 and 1 in 500 AEP flood events.
  - Raising the service bridge deck and the Brisbane Valley Highway bridge across the existing spillway up to EL82m, above the flow surface.
  - Raising and strengthening the upstream training walls and rockfill bunds.
- Secondary Spillway
  - Reconstruct a new ogee crest upstream of the existing spillway crest to EL69m and raise the fuse plugs by 2m each to maintain the initiation levels. Other spillway configurations are possible to avoid the loss of storage but this option appeared to be considerable cheaper by avoiding the need for a tertiary spillway.
  - Raising the bridge over the secondary spillway by 2.5m to EL 82.8 to lift the underside of the bridge beams above the flow surface.

- Raise and post tension the divider walls and the entrance training walls for the spillway chute.

- Raise both Saddle Dams to EL84m

- Existing Dam Crest

  - Raising the crest of the dam by placing fill on the downstream face of the embankments to achieve a new crest level at EL84m

  - Reconstructing the Cormorant Bay entrance.

- Raising the bridges for the Brisbane Valley Highway away from the dam to EL82m and the bridges on the Wivenhoe - Somerset Road.

Drawings of the works required for this option are presented in Appendix D.

5.4.1 Spillway Capacity

The spillway capacity is required to allow the dam to safely pass the 2003 estimate of the Probable Maximum Flood (PMF) by October 2035. Spillway layout and capacity are discussed in the following sections.

Radial Gated Service Spillway

The flood mitigation benefits obtained for more frequent flood events from Wivenhoe Dam are due to the freeboard against the radial gates above the nominated FSL. To preserve the current flood mitigation performance if the FSL is raised, then an equivalent flood storage volume is required. This is not achievable with the current radial gates if the storage is raised to EL71m as the rate of opening for the gates during a flood event would be controlled by the rise in water level. This limitation is due to the need to avoid overtopping the radial gates as the storage rises. The current gates have 6m of storage rise available before overtopping providing the operational flexibility for flood mitigation. Raising the FSL to RL 71 without modifying the spillways does not provide the flood control centre adequate flexibility to manage the more frequent events.

To provide the required flexibility for flood mitigation it would be necessary to raise the current gates and the fixed crest level from EL57.0 to EL60.0. The proposed construction sequence would involve:-

- Drilling through the concrete pier to insert the necessary stress bars required for the gate loads. Installation and stressing of the bars.

- Construction of a new corbel and trunnion bearing support, winch ledge and modification to the hydraulic controls for the gate.

- Construction of a new upstream pier end to allow the upstream end of the pier to be post tensioned.

- Dewatering of one spillway bay at a time using the bulkhead gate.

- Disconnecting the radial gate from the trunnion bearing and raising the gate clear of the spillway crest to facilitate access to the crest.

- Placement of the concrete and anchoring on the existing spillway crest including new gate sill and cutting new gate slots for the side seals on the gate.

- Lifting the gate and connecting it to the new trunnion bearing support.

- Relocation and connection of the winch motors including modification to the hydraulic control lines. The hydraulic lines would need to be moved from the service bridge deck to another location to facilitate the raising of the service bridge.

- Raising of the service bridge deck and removal of the baffle plate from under the bridge. The baffle plate may be raised and re-used.

- Raising of the road bridge across the existing spillway to maintain the Brisbane Valley Highway across the dam.

The upstream training walls would need to be raised. This would be achieved through the use of anchor bars to join the raised concrete to the existing wall. The walls would then be post tensioned to cater for the increased load from the raised flood level.

Limited works would be required for the dissipator as the discharges from the spillway would be similar to the current design discharges.

The maximum design discharge from the spillway would remain at around 13,000m^3/s

Constraints

A major constraint for this work would be the need to maintain at least four gates fully operational for the duration of the works. It is unlikely that works could be carried out during the wet season so the construction works would need to be programmed for the 6 months during the dry season. It is anticipated that this work would require three dry seasons to complete resulting in significant cost penalties.

Secondary Fuse Plug Spillway

The Stage 1 works constructed for the Flood Security Upgrade of Wivenhoe in 2004 consisted of a three bay, 164m wide fuse plug spillway located at the right abutment of the dam. The first fuse plug embankment trigger level was set at EL75.7m (nominally the 1 in 5,000 AEP flood event) to protect the flood mitigation benefits of the storage and minimise the cost of the upgrade.

To preserve the flood mitigation benefits for more frequent events it will be necessary to raise the three fuse plug embankment initiation levels by 2.0m. This will preserve the initiation AEP at approximately 1 in 5,000.

Flood routing the PMF through the storage including the fuse plug embankments has identified the possibility of improving the flood security of the dam by changing the initiation levels to EL77.7, EL78.2 and EL78.7 and leaving the fixed crest level for the secondary spillway at EL69m. The loss of storage and the changed initiation levels would provide full PMF capacity with a maximum flood level of EL83.4m.

The incremental increases in downstream flood levels for the initiation of each fuse plug embankment need to be determined to asses the acceptability of this proposal. A major change in downstream flood levels (>1m) immediately following initiation of the fuse plug embankments would be unacceptable.

Tertiary Fuse Plug Spillway

The proposed Stage 2 works would not be required as the proposed modifications to the existing spillways would provide full PMF capacity.

5.4.2 Existing Embankments

The new adopted flood level of EL83.4 would require all of the embankments to be raised. Preliminary stability analysis has shown that raising the crest of the dam using a wave wall is not an option. Therefore it is proposed that the dam crest would be raised using placement of fill on the downstream face of the dam.

The proposed construction sequence would involve:-

- Diversion of the Brisbane Valley Highway off the existing crest.
- Stripping and stockpiling the downstream rip rap facing on the embankment.
- Extending the filter blanket on the downstream side of the core and providing an equivalent drainage system under the new downstream material.
- Placement of sandstone fill borrowed from adjacent land (potentially the spoil material from the Stage 1 works)
- Exposure of the clay core and downstream filters once the embankment has reached the height of the existing crest.

- Raising the height of the existing clay core and extending the upstream and downstream filters in the upper 5m of the raised embankment.

- Reinstating the road pavements and the upstream wave wall.

Constraints

There would be major disruption to the Brisbane Valley Highway traffic. An alternative route downstream of the dam would be required for the duration of the raising works for the embankment and the bridges. This would have significant social and environmental impacts on the downstream communities.

5.4.3 Key Data for a 4 metre Raising

Item	Propose EL / Storage	Current EL / Storage
FSL	71m	67m
MFL	83.4m	80m
Dam Crest Level	84m	80m
Top of Radial Gate	76m	73m
Service Spillway Fixed Crest Level	60m	57m
Storage Vol FSL to Top of Gates	748GL	761GL
Secondary Spillway (fixed crest at EL69) - Fuse Plug 1 Initiation - Approx Initiation AEP - Storage Volume FSL to Initiation Level	 77.7m 1 in 5,000 1044GL	 75.7m 1 in 6,000 1182GL
Tertiary Spillway Stage 2 - Crest Length - Fuse Plug Initiation - Approx Initiation AEP	 NA NA NA	 100m 78.3 1 in 50,000

5.4.4 Costs

Item	Cost	Comment
1. Raise the Embankment Crest	$24.3M	This includes filters, rip rap and bulk fill borrowed from the Stage 1 spoil.
2. Raise the existing Spillway Bridges	$4.7M	This assumes modification to the piers, abutments, concrete works, reinforcement, bearings, deck and roadway.
3 Raise radial gates and modify the concrete crest	$28.2M for the five bays	This assumes anchoring, reinforcement, provision of access, steel work, mechanical systems modifications, provision of access to the post tensioned anchors, post tensioning, gate modifications.
4. Raise the Saddle Dams	$2M	This assumes that the embankment dam remain as zones earthfill.
5. Raise the auxiliary spillway crest and the fuse plug embankments	$14.2M	This assumes that the training walls and raised, new ogee crest is constructed, fuse plug embankments are raised, divider walls are raised and post tensioned.
6. Raise the auxiliary spillway bridge	$2.5M	This includes strengthening the piers, additional anchoring, new headstocks, jacking the bridge beams and raising the abutments.
7. Somerset Dam Works	$2.5M	Modify power station and outlet works
8. Road and Bridge Works	$8.5M	Includes diversion of 14km of road and works to raise three small bridges.
9. Construction Supervision and Overheads (20%)	$15.7M	Contract Supervision and Constructors Overheads (does not include the road and bridge works away from the dam)
10. Design and Approvals (15%)	$11.8M	Concept Design, Approvals and Detailed Design (does not include the road and bridge works away from the dam)
11. Contingency (30%)	$23.5M	(does not include the road and bridge works away from the dam)
Total	**$138M**	

Note: Approximately $30M in savings is realised by the elimination of the Stage 2 works currently proposed

A breakdown of the costs estimates is provided at Appendix C.

5.4.5 Inundation Area

The inundation area for this option is presented in Appendix K. SEQWater owns land up to the EL75.0 contour due to the operation of the dam for flood mitigation. Currently large parcels of this land are leased out to adjacent landholders to provide land management. Impacts from the raised storage levels (not included in the cost estimate) would include:-

- Significant reduction of land available to lease holders.
- Loss of environmentally sensitive habitat (significant) including land at Mt Esk Pocket.
- Loss of recreation areas at Somerset Dam, O'Shea crossing, Captains Flat, Lumley Hill and Cormorant Bay.
- Loss of private recreation areas (Billie's Bay and Hay's Landing).
- Impacts on Somerset Dam outlet works and power station (costs incurred as the cone valves and power station would be inundated).
- Diversion of road required along the Wivenhoe Somerset Road (approximately 14km).
- Tarong Power Station off take would require modification.
- Minor reduction in the generating capacity at the Wivenhoe Pumped Storage Power Station.

5.5 Option W3 - Raise Wivenhoe FSL 8m (EL75.0)

This option involves raising the storage level by 8m to EL75.0. This would provide and additional 1,066,000ML of contingency storage, almost doubling the storage of Wivenhoe Dam. The proposed scope of work for this option would involve:-

- Increasing the Maximum Flood Level from EL80.0 to EL85.0 to maintain the flood mitigation benefits of the storage as well as supply the contingency storage.
- Existing Spillway
    - Removing the radial gates, raising the fixed crest to EL70 in reinforced and mass concrete and installing 6m high concrete fuse gates on the spillway crest.
    - Raising the service bridge and the bridge for the Brisbane Valley Highway across the existing spillway up to EL85.0.

- Raising and strengthening the upstream training walls and rockfill bunds.

- Existing Dam Crest
    - Raising the crest of the dam by placing fill on the downstream face of the embankments to achieve a new crest level at EL87.5.
    - Reconstruct Cormorant Bay entrance.
- Raise both Saddle Dams to EL87.5
- Secondary Spillway
    - Reconstruct a new ogee crest upstream of the existing spillway crest to EL of 73.0 and raise the fuse plug embankments by 6m each to maintain the initiation levels.
    - Raising the bridge over the spillway by 5m.
    - Raise and post tension the divider walls.
- Raising the bridges for the Brisbane Valley Highway and the Wivenhoe – Somerset Road up to EL85.0.

Drawings of the works required for this option are presented in Appendix D.

5.5.1 Spillway Capacity

The spillway capacity is required to be adequate to allow the dam to safely pass the 2003 estimate of the Probable Maximum Flood (PMF). Spillway layout and capacity are discussed in the following sections.

Radial Gated Service Spillway

It is not feasible to alter the radial gates in the existing spillway to cater for such a large raising of the FSL. The most cost effective alternative would be to abandon the existing spillway radial gates and utilise concrete fuse gates on the raised crest to provide the required spillway capacity. This does not provide as much control over flood events but would still provide significant protection to the downstream areas for the full range of flood events investigated.

The upstream training walls would need to be raised. This would be achieved through the use of anchor bars to join the raised concrete to the existing wall. The walls would then be post tensioned to cater for the increased load from the raised flood level.

Limited works would be required for the dissipator as the discharges from the spillway would be similar to the current design discharges.

The maximum design discharge from the existing spillway would be reduced to around 7,700m^3/s.

Constraints

A major constraint for this option again would be the opportunity to work in only one bay at a time for the duration of the works.

The spillway works would need to be programmed after raising the embankment to avoid increasing the risk of failure during an extreme flood event.

Secondary Fuse Plug Spillway

The Stage 1 works constructed for the Flood Security Upgrade of Wivenhoe in 2004 consisted of a three bay, 164m wide fuse plug spillway located at the right abutment of the dam. The first fuse plug embankment trigger level was set at EL75.7 (nominally the 1 in 5,000 AEP flood event) to protect the flood mitigation benefits of the storage and minimise the cost of the upgrade.

To preserve the flood mitigation benefits of Wivenhoe Dam, it has been assumed that the secondary spillway would have the crest level raised to EL73.0 by building a much larger crest structure upstream of the existing spillway. The fuse plug embankment downstream of the new crest would need to be raised to EL81.7 for the first trigger level. This equates to approximately the 1 in 5,000 AEP event. The new MFL for this spillway configuration would be EL87.0.

Other works for the spillway would include:-

- raising of the spillway bridge by 6m.
- raising of the divider walls using post tensioning and reinforced concrete entrance walls.

Tertiary Fuse Plug Spillway

The proposed Stage 2 works would not be required as the existing spillways as modified would provide full PMF capacity.

5.5.2 Existing Embankments

The new adopted flood level of EL87.0 would require all of the embankments to be raised. Preliminary stability analysis has shown that raising the crest of the dam using downstream stabilising fill is the only viable option. Therefore it is proposed that the dam crest would be raised using placement of fill on the downstream face of the dam.

Main Embankments

The proposed construction sequence would involve:-

- Diversion of the Brisbane Valley Highway off the existing crest.
- Stripping and stockpiling the downstream rip rap facing on the embankment.
- Extending the filter blanket on the downstream side of the core and providing an equivalent drainage system under the new downstream material.
- Placement of sandstone fill borrowed from adjacent land (potentially the spoil material from the Stage 1 works)
- Exposure of the clay core and downstream filters once the embankment has reached the height of the existing crest.
- Raising the height of the clay core and the filters to the new embankment height as the final 8m of raised embankment is constructed.
- Reinstating the road pavements and the upstream wave wall.

Saddle Dams

Saddle Dam 1 and 2 are zoned earthfill embankments constructed in saddles on the left abutment area of the dam. Currently these embankments do not store water at the FSL of EL67.0. Raising the FSL to EL75 .0 would result in up to 6m of permanent storage against these embankments.

Given this permanent storage it is considered necessary to install filters within the embankment to minimise the risk of piping. Therefore the raising of the Saddle Dams to EL87.5 would include:-

- Stripping material from the downstream face and toe area.
- Placement of a two stage blanket filter across the embankment footprint downstream of the clay fill core.
- Raising the embankment in locally borrowed earthfill and extending the filter up to the new embankment crest.
- Extending the upstream rip rap and filter to the new crest level.

Coominya Saddle

There is a low saddle 8km along the Brisbane Valley Highway, near the turn off to Coominya, travelling toward Esk from Wivenhoe Dam which has a natural surface level at EL85.0. For the proposed MFL there would need to be a low level embankment constructed (maximum height of 3m to prevent flood flows from leaving the storage basin and discharging into the Lockyer Valley. This embankment would consist of a homogenous earthfill embankment with 1 (v) to 2 (h) slopes and a 5m crest width.

5.5.3 Key Data for an 8 metre Raising

Item	Propose EL / Storage	Current EL / Storage
FSL	75m	67m
MFL	87.0m	80m
Dam Crest Level	87.5m	80m
Top of Radial Gate	76m (6m high Fuse Gates)	73m
Service Spillway Fixed Crest Level	70m	57m
Storage Vol FSL to Top of Gates	164GL	761GL
Secondary Spillway (fixed crest at EL73) - Fuse Plug 1 Initiation - Approx Initiation AEP - Storage Volume FSL to Initiation Level	 81.7m 1 in 5,000 1218GL	 75.7m 1 in 6,000 1182GL
Tertiary Spillway Stage 2 - Crest Length - Fuse Plug Initiation - Approx Initiation AEP	 NA NA NA	 100m 78.3 1 in 50,000

5.5.4 Costs

Item	Cost	Comment
1. Raise the Embankment Crest	$32.7M	This includes filters, rip rap and bulk fill borrowed from the Stage 1 spoil.
2. Raise the existing Spillway Bridges	$5.2M	This assumes modification to the piers, abutments, concrete works, reinforcement, bearings, deck and roadway.
3. Raise the spillway crest, training walls, remove gates and install fuse gates	$46.7M	This assumes anchoring, reinforcement, provision of access, steel work, provision of access to the post tensioned anchors, post tensioning, fuse gates
4. Raise the Saddle Dams	$3.2M	This assumes that the embankment dam remain as zones earthfill.
5. New Saddle Dam at Coominya	$0.9M	Zoned earthfill embankment
6. Raise the auxiliary spillway crest and the fuse plug embankments	$26.5M	This assumes that the training walls and raised, new ogee crest is constructed, fuse plug embankments are raised, divider walls are raised and post tensioned.
7. Raise the auxiliary spillway bridge	$5M	This includes strengthening the piers, additional anchoring, new headstocks, jacking the bridge beams and raising the abutments.
8. Upgrade Somerset Dam outlet works and power station	$15M	Works are required to upgrade the outlets as the FDC Valves and the power station would be 5m below the water surface. The modifications would include new valves and valve chambers.
9. Road and Bridge Works	$25M	Includes diversion of 40km of road and works to six bridges.
10. Construction Supervision and Overheads (20%)	$27M	Contract Supervision and Constructors Overheads (does not include the road and bridge works away from the dam)
11. Design and Approvals (15%)	$20.2M	Concept Design, Approvals and Detailed Design (does not include the road and bridge works away from the dam)
12. Contingency (30%)	$40.5M	(does not include the road and bridge works away from the dam)
Total	**$248M**	

Note: Approximately $30M in savings is realised by the elimination of the Stage 2 works currently proposed

5.5.5 Inundation Area

The inundation area for this option is presented in Appendix K. SEQWater owns land up the EL75.0 due to the operation of the dam for flood mitigation. Currently large parcels of this land are leased out to adjacent landholders to provide land management. Impacts from the raised storage levels would include (not included in costs):-

- Inundation of private land during any flood event. May require the resumption of land by Government (SEQWater does not have any ability to compulsorily acquire land) and major potential for community opposition.
- Loss of environmentally sensitive habitat (high significance) including land at Mt Esk Pocket.
- Loss of recreations areas at Somerset Dam, O'Shea crossing, Captains Flat, Lumley Hill and Cormorant Bay.
- Loss of private recreation areas (Billie's Bay and Hay's Landing).
- Upgrading of the Somerset Dam outlet works and power as raised level would flood both. New outlet works would be required and major structural modifications required for the power station.
- Diversion of the Wivenhoe - Somerset Road (approximately 40km) including bridge replacement.
- The Tarong Power Station off take would need to be raised.
- Relocation of residential houses in the Wivenhoe Storage area (three houses are built close to EL 75m.
- Minor reduction in the generating capacity of the Wivenhoe Pumped Storage Power Station.

Flood Impacts

Relatively frequent flood events would impact on key infrastructure including:-

- Land holder residences (up to 50 houses would be impacted).
- The Wivenhoe Pumped Storage Power Station at Wivenhoe owned by Tarong. Additional work would be required to reduce flood risk (the floor level of the generator room is at EL 78m).
- The Brisbane Valley Highway would be cut at several locations for longer durations during flood events.

6. Somerset Dam General Information

6.1 Background

Somerset Dam is a 47m high concrete gravity dam on the Stanley River upstream of Wivenhoe Dam. It is a dual purpose dam providing water supply to Brisbane and adjacent Local Authorities and flood mitigation benefits for the Brisbane and Ipswich areas. A general arrangement of the dam is shown at Figure 2. A dam data sheet is provided at Appendix G.

Water is released as required from Somerset Dam to supplement Wivenhoe Dam which in turn supplements the natural flow of the Brisbane River and maintains an adequate supply of water to the Mt Crosby pumping station, 132 kilometres downstream from Somerset Dam.

The plans of the dam are in imperial units. The level conversion that applies to these plans is:

$$AHD\ (m) = EL(ft) \times 0.3048 - 0.124m$$

6.2 Concrete Dam and Spillway

6.2.1 General

The 47m high concrete gravity dam has a central gated overflow spillway, controlled by 8 radial gates and 8 low level sluice gates. Full Supply Level (FSL) is at EL99.00, some 1.45 m below the spillway fixed crest and the gates are used only for flood control purposes. There are 4 low-level outlets through the abutment units and a pipeline leading to the power station downstream of the dam on the right hand side abutment. Water is released as required from Somerset Dam to supplement Wivenhoe Dam.

There are 7 mass concrete abutment units on each side of the central spillway structure supporting a road bridge at EL112.34. The abutment units are constructed with an open overflow section below the bridge at EL107.46. Flood flows passing through these openings flow down the back face of the dam and impact on an unprotected rock foundation, before flowing laterally towards the central spillway channel.

The concrete dam is a conventional mass concrete construction with upstream slopes of 0.05H:1V and downstream slopes of 0.7H:1V in the central overflow section and 0.75H:1V in the abutment units. There is an abrupt “change of slope” above FSL in the abutment units that provides a constant width of nominally 4.3 m in the top section. This “change of slope” discontinuity provides a critical section for dam stability due to the applied flood loads (indicated by the results of previous stability assessments).

6.2.2 Galleries

There are a number of galleries within the dam and there is some inconsistency in nomenclature in the surveillance data. The following terminology is used throughout this Report:

- The Foundation Gallery is located at EL60 and is normally half full of water;
- The Lower Gallery is located at EL66.0;
- The Upper Gallery is located at EL88.9;
- Gate Inspection Chambers for the sluice gates are located within the central portion of the dam near the level of the Upper Gallery.

Concrete cracking has occurred at the Upper Gallery providing the second critical section for dam stability. The cracking has the potential to induce full hydrostatic loads within the dam section impacting on stability. There is considerable horizontal cracking exposed in the gallery walls, presumably from temperature and shrinkage effects. The main cracks are located on the downstream side of the gallery wall, one about 0.4 m above floor level and the other 1.6 m to 1.8 m above floor level. The latter crack extends for most of the length of the gallery and appears to be at the same level as a construction joint in the downstream face of the dam. Cracks can also be seen extending to the downstream face in the two access adits at each end of the dam.

Horizontal hairline cracking can also be seen in the upstream gallery wall and in the stairways to the lower gallery. In one spillway monolith the crack emerges in the upstream face of the gate shaft and there has been long term leakage. There is no indication of leakage elsewhere in the Upper Gallery.

Investigation work by SMEC included horizontally drilled holes into the downstream gallery wall. There was some difficulty in following the cracks with horizontal holes as the cracks deviated around 50 mm along the drilled length. The surface of the cracks was irregular and rough. Drilling water returned along the crack for 0.5m either side of the borehole collar.

The drilling showed the cracks were open for at least 1 to 2 m from the downstream face of the gallery. At some distance from the gallery, they reduce to hairline cracks that appear to extend to the downstream face, as seen in the access adits.

A number of consultants have reviewed the stability of Somerset Dam. Both Commerce (2005) and GHD (2000) assumed that a crack exists across the full width and length of the monolith blocks and if the dam was subjected to unprecedented water levels, the upstream cracks could develop significant uplift pressures. SKM (2000) took the view that continuous cracking was a conservative assumption but accepted it for stability analyses.

It is not known whether cracking exists above or below the gallery. Cracks that emerge in the gallery walls will be drained by the gallery and are not necessarily a significant stability problem. If similar cracks exist above or below the gallery, these become a plane of weakness with uplift relieved only by the internal drains. Russo (1996) mentions cracking has been observed at EL95.3 and EL97.2.

Cracks have also been observed in the central pier area between the gate units L and M. Inspections and investigatory drilling, SMEC (2004), concluded that these cracks were due to thermal effects and were not significant in terms of adequacy of the dam.

6.3 Staged Construction

The construction of the township and dam began in 1935, but, work was suspended in 1942 due to the war. Work resumed on the construction of the dam in 1948. In 1953, the last structural concrete was placed and the hydro-electric power station on the right abutment of the dam was commissioned.

6.4 Foundation

Recent geological investigation studies (SMEC 2004) recorded the foundations to be generally slightly weathered and assessed visually to be of very high strength and high durability, showing no signs of significant degradation or weathering upon exposure. The dam was excavated into high strength, tight rock and while erosion of near surface materials below the dam could be expected under low to medium flows, the rock mass was tight at depth and was judged to have a high resistance to erosion.

6.5 Spillway Gates and Hoists

6.5.1 General

The dam has twenty-one controlled outlets, eight of which are radial gates (sector gates) installed on the top of the spillway. The remaining thirteen are conduits or sluice-ways through the bottom of the dam wall. One of the conduits supplies a small power station, four connect to fixed cone dispersion valves and the eight sluice-ways constitute the main outlet regulating capacity.

6.5.2 Radial (Sector) Gates

The eight radial gates are each 7m high by 8m long (23ft high by 26ft long), and are installed above full supply level and therefore can only be used to delay the passing of a flood peak that exceeds full supply level. While they do not normally come into operation during minor floods, they have been considered in this study because they could be employed in a major flood event. The gates are counterbalanced so that the hoist does not have to lift the full weight of the gate.

6.5.3 Sluice Gates

The eight main sluice gates are each 3.7m high by 2.4m wide (12ft by 8ft). The gates are not counterbalanced, and are hoisted by two ropes, each rope being reeved into a four-part system. The sluice tunnels are protected by similar roller gates which are 2.7m high and 2.7m wide (9ft by 9ft) with hoists essentially identical to the main sluice gate hoists, the differences relating to the rope drums.

6.5.4 Radial Gate Winches

Each winch unit comprises a six-pole electric motor close-coupled to a worm reduction gear set. The output of the worm reduction passes through three sets of spur gears, the last spur gear being bolted to the rope drum. The rope is attached directly to the centre of the gate without any intermediate pulleys, while the counterweight is attached to both ends of the gate. An electric thrustor brake operates on the motor-coupling drum. A parking brake is operated by a hand wheel applying a band brake to a drum mounted on the last spur gear drive shaft. To improve level of control and safety, the bank brakes of the drums could be spring applied with actuator and/or manual release when the hoist is operational. This is less significant for the sector gates than the sluice gates, but could be significant if a severe event failure involved loss of a counterweight. There is a connection point on the winch for attachment of a petrol engine to provide emergency power if the electrical system fails.

6.5.5 Sluice Gate Winches

Each winch unit comprises a six-pole electric motor close-coupled to a worm reduction gear set. The output of the worm reduction passes through two sets of spur gears, the last spur gear being bolted to the rope drum. The rope drum is a double drum with two ropes attached. Each rope is reeved through pulleys to create a four-fall rope system connected to an equalising beam on the top of the gate. An electric thrustor brake operates on the motor to worm pinion coupling. A band brake is hand wheel applied to a drum bolted to the rope drum for added security. If there was a component failure within the hoist during operation, the thrustor brake would be ineffective. Higher than desirable gate closure rate could result, depending on the failure point in the drive. To increase safety the band brakes of the drums could be spring applied with actuator and/or manual release when the hoist is operational. There is a connection point on the hoist unit for attachment of a petrol engine to provide emergency power if the electrical system fails.

6.5.6 Brakes

In both hoists the power operated brakes are mounted at the high-speed, low torque end of the drive train. This is often done to minimise the size of the brake. In the case of gate hoists it is not necessarily the best location. If a component in the drive train fails then the gate is liable to drop uncontrolled, unless an operator is immediately available to operate the emergency brake. Alternatively, if the brake tends to drag it can apply sufficient torque to prevent the hoist operating. Both situations are undesirable, with the latter bearing more on the risk of a gate not opening when required to assist in flood releases. Modern practice is to have the main brake as close to the final drive as is practicable, on or close to the rope drum. In the case of both the sector and sluice gate winches this is where the manual emergency brake is located.

6.6 Geology

6.6.1 General

The following assessment of geological conditions at Somerset Dam has been taken from SMEC (2004).

6.6.2 Topography

The dam is oriented northwest-southeast across the Stanley River in a valley section that flows south-west. Natural valley slopes average 25 degrees. The valley sides are wooded with frequent rock outcrops.

6.6.3 Geology

Available Information

The geology of the damsite, as indicated by the regional maps, a map of the immediate area by C.W. Ball and comments included in the SKM and SEQWater reports consists of volcanic and igneous rocks of Triassic Age. These rocks include fine-grained andesite lavas that were intruded by medium to coarse-grained diorite and granite with a later intrusion of fine-grained felsite dykes.

Ball's map indicates a complex distribution of these rock types - presumably exposed during the excavation of the dam foundation in the 1930s and now obscured by the dam structure.

Information on site investigations before construction is restricted to several cross sections with logs of test holes and shafts which identify the depth to "jointed rock" and "hard rock". No rock names are included.

The description of excavation conditions during construction are limited to comments included in the SKM and SEQWater reports that describe the removal of jointed rock and the control of excavation by the presence of joints.

Several joint sets were identified. There is no mention of the presence of low strength rock substance.

Investigations during 1999-2000 and reported in the SEQWater report included the drilling of several holes through the dam into the foundations for the installation of piezometers. The foundation core recovered from these holes was extremely high strength andesite.

Observations During Site Visit by SMEC 2004

"Rock is extensively exposed on the sides of the Stanley River and several outcrops were observed in the riverbed downstream of the dam. In the immediate area of the dam, near the downstream toe, the cliff line formed by the foundation excavation is distinct on the left bank and partly obscured by landscaping on the right bank. Both areas have large outcrops of rock. See photographs 3.1 to 3.3 show rock outcrops on the abutments in SMEC (2004).

The rock substances observed in the outcrops are fine-grained andesite and medium grained diorite. Both rock types are assessed to have a very high strength. The contacts between the two rock types are intrusive with no apparent loss of strength near the contact observed. No felsite dykes were observed during the site visit.

The dominant feature of the rock outcrops near the dam, which is also apparent in other outcrops on the valley sides and riverbed, is the presence of well developed jointing. These joints appear to be concentrated in three sets - one near vertical set striking approximately north-south, another near vertical set striking east-west and a third set dipping at about 10 degrees to the west-south-west into the right abutment.

Initial observation indicates that the vertical joints are smooth, often tight with a spacing that ranges from about 0.5m to about 3m. Observed joint continuity is less than 10m on the right bank but the cliff on the left bank appears to be controlled by a near vertical joint that is about 50m long. The low angle joints are irregular and rough with an apparent continuity on some surfaces of at least 20m" (SMEC 2004).

6.6.4 Engineering Geological Assessment

The data on site conditions before and during construction is limited but is supported by the observations made during the site visit. The dam is apparently underlain by a rock mass composed of several volcanic and igneous rock types. All contacts between these rock types are intrusive and therefore should not represent areas of rock mass weakness. The rock substance strength in all rock types is very high.

The feature that governs the engineering properties of the rock mass in the foundations is the rock mass defects and in particular the jointing. The control of excavation by jointing is mentioned in the construction reports and is obvious in outcrops near the downstream toe.

As is common, near the natural ground surface there is some opening of the joint surfaces due to stress relief and weathering. The foundation excavation during dam construction appears to have been taken below these open joints. This is indicated by the downstream exposures and the core recovered from the recent drilling.

The concerns raised about foundation conditions has speculated that the rock downstream of the dam toe in the non-overflow sections may be eroded to the extent that the stability of the dam structure may be affected.

Features that are relevant include:

- the very high substance strength of the rock;
- the presence of a topographic high of significant height downstream (about 10m high on the left bank);
- the characteristics of the joints in the area - location, orientation, spacing, continuity, surface shape, surface condition, opening, infilling; and
- the level of the existing excavation - apparently below the level of open joints.

It appears unlikely that the rock substance could be eroded by flood overflow water from the reservoir. High velocity water flow could attack the joints and remove detached blocks. The amount of material that could be displaced would depend on the duration of any overflow and the characteristics of the rock mass defects - the joints.

Based on the available information a preliminary assessment is that flood overtopping could remove some material from the rock outcrops near the downstream toe but the extent of this material removal is unlikely to extend into the dam foundation.

This assessment could be confirmed by a limited amount of additional site investigation.

6.7 Seismology

Refer to Section 4.13.

7. Raising Options for Somerset Dam

Currently the storage at Somerset Dam has a FSL at EL99 and a storage volume of approximately 380,000ML. To provide input into the provision of contingency storage in Somerset Dam three different raising levels were selected:-

- Raise FSL by 2 m to EL101.0. This option provides a significant increase in storage of 92,000ML above the current storage of 380,000ML for a relatively small capital cost (i.e. compared to a greenfield site development) and could be achieved relatively simply.

- Raise FSL by 4 m to EL103.0. This option provides a mid point for the cost curve. Upstream impacts start to become a key issue for this option. This raising would provide an additional storage capacity of 202,000ML.

- Raise FSL by 6 m to EL105.0. This option, selected to provide an upper limit to the raising options, provides an additional 332,000ML (effectively doubling the storage volume of Somerset). At this level, houses upstream of the dam are inundated and would require relocation and Kilcoy is isolated without extensive road works.

SMEC were engaged to investigate the works required to raise the FSL to the above levels. Their report is presented in Appendix J.

7.1 Scope of Works

The proposed scope of works required for all options would include:-

- Modifying the radial gates and hoist to allow them to be removed from the flow for the PMF. This work is required even without raising the storage.

- Provision of side seals, bottom seals, side guide rollers, roller paths for the radial gates to allow them to be used to retain water.

- Post tensioning of the dam for the flood load cases.

- Upgrading of the spillway dissipator.

There would be a nominal increase in MFL for the 2m raising. The 4m and 6m raisings would increase the MFL by 1.5m and 2.5m to EL113.5m and EL 114.5m respectively

The 4m and 6m raisings would also include:-

- Road diversion and bridge upgrades for the Daguilar Highway at Mary Smokes Creek
- Relocation of picnic facilities and public recreation areas.
- Relocation of the water supply intake and treatment plant for Kilcoy.

The 6m raising would require relocation of low lying houses in Kilcoy

7.1 Spillway Capacity

Increasing the FSL would negatively impact on the MFL and the flood discharge capacity of Somerset Dam. The spillway consists of 8 sluice gates, 4 regulators and eight overflow spillway bays with sector gates (not used to control flow). There is also the potential for the concrete abutments to be overtopped once the storage level exceeds EL107.46. Extensive works are required to strengthen the existing spillway to cater for the PMF. Refer to the SMEC report.

7.2 Key Data for the Raisings

Item	Current Storage	FSL Raised 2m	FSL Raised 4m	FSL Raised 6m
FSL (EL m)	99	101	103	105
MFL (EL m)	112	Approx 112	Approx 113.5	Approx 114.5
Dam Deck Level (EL m)	112.34	112.34	113.0	114.0
Top of Non Overflow Crest (abutments) (EL m)	107.46	107.46	107.46	107.46
Top of Sector Gates (EL m)	107.46	107.46	107.46	107.46
Service Spillway Fixed Crest Level (EL m)	100.46	100.46	100.46	100.46
Storage Vol FSL to Top of Gates	520GL	428GL	318GL	188GL

7.3 Estimated Costs

The estimated cost of physically raising the FSL of Somerset Dam for all options is $55M. Refer to the SMEC report for a break down of the costs.

For the 4m and 6m raisings additional costs of $15M and $30m respectively will be required for the highway diversion, relocation of recreation facilities and relocation of property at Kilcoy.

For the 6m raising additional costs will include the purchase and relocation of low lying houses at Kilcoy and surrounding areas. An allowance of $50M has been estimated but has not been included in the direct costs.

7.4 Inundation Area

The areas of inundation are presented in Appendix K. Impacts from all raisings of the storage level include:-

- Loss of environmentally sensitive habitat. While the loss is of generally minor significance it becomes major for the 6m increase in FSL.
- Some loss of picnic areas and recreational facilities at the Spit and Kirkleigh.

The 4m increase in FSL causes inundation of the Daguilar Highway at Mary Smokes Creek resulting in the need to relocate the Highway and the 6m increase extends the inundation into Kilcoy.

The 6m increase also inundates low lying houses in Kilcoy

7.5 Flood Impacts

- All options to raise the dam will cause more frequent inundation of private land during flood events with potential for community opposition.
- Kilcoy, which is impacted when water levels reach EL102.5m, will be flooded more frequently. For the 2m and 4m increases in FSL the AEP of flooding Kilcoy will be 1:20 and 1:5 respectively. If the dam is raised 8m Kilcoy will be impacted by any flood event.
- For all increases there is a loss of flood storage volume and an increase in the discharges to Wivenhoe Dam. For the 2m increase the impacts are minor. However, the loss of storage is significant for the 4m and 6m increases with a resulting moderate impact on the performance of the Wivenhoe /Somerset system.
- More frequent disruption to the major roads surrounding Kilcoy including the Daguilar Highway. The impacts are progressively more severe as the raising level is increased.

8. Discussion

Seven options for the provision of contingency storage in Wivenhoe and Somerset Dams have been investigated by SEQWater for the South East Queensland Water Supply Strategy. These options are presented in Table 8-1.

Table 8-1 - Summary of Raising Options

Option	Raising (m)	Raised FSL (m)	Increase in Storage Capacity (ML)	Estimated Cost ($m)
Wivenhoe Raising Options				
W1	2	69	228,000	63
W1A (Operational change)	2	69	228,000	5 to 10
W2	4	71	481,000	138
W3	8	75	1,066,000	248
Somerset Raising Options				
S1	2	101	92,000	55
S2	4	103	202,000	70
S3	6	105	332,000	85

It can be seen from the table that the most attractive option for the provision of contingency storage would be a 2m raising of Wivenhoe Dam as an operational change eliminating the need for expensive capital works. Intuitively, Wivenhoe would be the most logical option for contingency given the size of the catchment and the corresponding probability of capturing the additional contingency storage.

The provision of a significant volume of contingency storage in Somerset will be difficult due to the upstream flooding issues associated with Kilcoy and land owners.

8.1 Flood Security Costs

Neither Wivenhoe nor Somerset currently satisfies the State's Guidelines on Acceptable Flood Capacity (2005). Given the assumptions for this study that the dams will be required to pass the current estimate of the PMF, a substantial portion of the costs to raise the FSL is tied up in the works to increase flood security. It is arguable as to whether these costs should be included for the provision of contingency storage as SEQWater is likely to incur these costs even if the storage is not raised. An attempt has been made to separate out the additional costs associated with the provision of additional storage from the likely costs required to upgrade the current dams. These are presented in Table 8-2.

Table 8-2 – Flood Security Costs

Option	Increase in Storage Capacity (ML)	Raising of FSL Direct Costs ($m)	Flood Security Direct Costs ($m)	Total Estimated Cost ($m)*
Wivenhoe Raising Options				
W1	228,000	13	40	63
W1A (Operational change)	228,000	NA	5 to 10	5 to 10
W2	481,000	64	40	138
W3	1,066,000	151	40	248
Somerset Raising Options				
S1	92,000	1.5	24	55
S2	202,000	1.5	24	70
S3	332,000	1.5	24	85

Note:

1. **The total costs include contingencies, design and construction supervision not included in the direct costs**
2. **The Wivenhoe flood security costs comprise the current estimated costs of the Stage 2 works. This work is required to be undertaken by SEQWater by 2035.**
3. **The works to raise the FSL at Somerset include gate seals, upgrading the crest, and upgrades to the controls. This work is constant for the three options as up to 6m additional storage could be held against the sector gates after upgrading.**
4. **The MFL for the Somerset Raising Options is similar for all three cases. Therefore, the post tensioning and downstream strengthening work are of a similar order of cost (at this level of assessment).**

It can be seen that the incremental costs associated with the small increase in the FSL are much less than the costs required to upgrade the dam to full PMF Capacity.

8.2 Potential benefits.

There has not been as yet, any attempt made to assess the likely benefits of any of the options by for example, assessing the frequency and volumes of storage likely to be held above the existing FSL's at either or both of the dams. Additional water in storage, available only at intervals, could provide an improvement in levels of service but this would need to be quantified before proceeding further with any of the high cost options.

8.3 Flood operational procedures.

The down stream flood impact results presented for the Wivenhoe W1B option are based on minor variations to the operational procedures defined in the existing approved Flood Operations Manual. Whether the impacts and these variations are acceptable will need to be agreed with the regulator and downstream stakeholders.

SunWater, consultants for this work, have reported that other variations to the operational procedures warrant consideration based on this recent work.

8.4 Wivenhoe Raisings.

- Options W1, W2 and W3 each involve complex work in the spillway which could only proceed one bay at a time and probably only in the dry season months.

- The cost of such complex work with very difficult access is difficult to estimate with reasonable certainty.

- Options W2 and W3 involve raising the embankments and therefore an at least temporary relocation of the Brisbane Valley Highway. Less significant disruption would be caused to the Wivenhoe Somerset Road. The cost of these disruptions has not been estimated.

- For Option W1A, the increase in downstream flooding appear to be relatively minor but its acceptability would be dependent on consultation with stakeholders. A raising of at least Kholo Bridge and possibly of Burtons Bridge and Savages Crossing could be required to deal with possible concerns.

- For Option W1A, the existing fuse plug will be triggered somewhat more frequently (existing 1:5,000 AEP flood). The frequency and consequences will need to be examined.

8.5 Somerset Raisings

- Each of the options assumes that the dams existing flood mitigation performance does not need to be maintained. Possible impacts have not been examined.

- The gates and hoist equipment at Somerset Dam are of considerable age. There is some uncertainty whether it can be adapted as proposed.

- Cracking in a number of the dam monoliths and other stability concerns could be addressed concurrently with the raising proposals.

- Community opposition to the higher raising proposals is likely to be very strong.

- Highway dislocation costs have not been estimated.

9. Recommendations

It is recommended that:-

- The provision of contingency storage in Wivenhoe Dam is investigated further. A 2m raising in the FSL could be achieved with minimal capital costs subject to addressing regulator and stakeholder issues.

- A detailed assessment is carried out to develop and asses changes to the flood manual to allow the storage of the additional 2m in Wivenhoe. The impact of the changes should be assessed for the full range of Annual Exceedance Probabilities and Storm durations. This assessment should also link with the Brisbane River Flood Damages Assessment currently being carried out by Brisbane City Council.

- A detailed review of the structural adequacy of the various components of the dam is carried out to confirm the assumptions of this report. This review will provide more design detail to refine the cost estimates and confirm the feasibility of the proposed increase in storage level.

- A program of consultation with the downstream stakeholders is carried out with the proposed changes to the flood manual once the assessment of flood events is completed.

- Raising of the FSL level of Somerset Dam be discounted due to the impacts on the upstream population during flood events. Major flood events will already result in inundation of the Kilcoy and surrounding private properties and infrastructure.

- SEQWater be provided with the opportunity to instigate a public consultation process prior to the public release of options to raise the storage levels of Wivenhoe.

10. References

ANCOLD, 2000A	Guidelines on Selection of Acceptable Flood Capacity for Dams; prepared by the Australian National Committee on Large Dams, March 2000
ANCOLD, 2000B	Guidelines on the Assessment of the Consequences of Dam Failure; prepared by the Australian National Committee on Large Dams, May 2000
Commerce, 2003	Somerset Dam Annual Inspection Report, prepared by Department of Commerce, 9 December 2003
Commerce, 2004	Somerset & North Pine Dam, Dam Safety Review; prepared by Department of Commerce, December 2004
Commerce, 2005	Somerset Dam, Stability of Abutment Monoliths; prepared by Department of Commerce, May 2005
GHD, 1995	Safety Review of Somerset Dam, prepared by GHD Pty Ltd, September 1995.
GHD, 2000	Safety Review of Somerset Dam, prepared by GHD Pty Ltd, September 2000. This Report is based on GHD, 1995 but includes geotechnical work completed in following years upgrades the Report to take into account the comments made at Russo (1996).
GHD, 2002	Somerset Dam Annual Inspection Report, prepared by GHD for inspection on 4 September 2002
GHD, 2004	Somerset Dam Annual Inspection Report, prepared by GHD, 28 October 2004
NRW, 2005	Draft Guidelines on Acceptable Flood Capacity for Dams, October 2005
RMIT, 1995	Review of Seismicity, Somerset Dam and North Pine Dam; prepared by the Seismology Research centre at RMIT University, March 1995.
Russo, 1996	1996 GHD Somerset Dam Safety Review, Comments by R. Russo, prepared by R. Russo, August 1996
SEQWater, 2005	The Dam Safety Management Program for Wivenhoe, Somerset, North Pine Dams; prepared by SEQWater, March 2005

SKM, 2000	Preliminary Risk Assessment for Wivenhoe, Somerset and North Pine Dams; prepared by Sinclair Knight Merz in conjunction with Hydro Consulting, Hydro Electric Corporation, 2004
SMEC, 2004	Somerset Dam – Detailed Risk Assessment Stage 2; prepared by SMEC Australia Pty Ltd, March 2004
WA, 2004A	Somerset Dam – Maximum Flood Level Estimates for Various Gate Operation Scenarios; prepared by Wivenhoe Alliance, February 2004.
WA, 2004B	Design Discharges and Downstream Impacts of the Wivenhoe Dam Upgrade; prepared by Wivenhoe Alliance 2004.
WA, 2004C	Wivenhoe Dam Spillway, Augmentation Works: Review and Updating of Risk Assessment, prepared by Wivenhoe Alliance 2004.
WA, 2005	Dam Failure Analysis of Wivenhoe Dam; prepared by Wivenhoe Alliance, Q1091, WIV-RP-HD-006, 2005

11. Figures

Figure 1 - Wivenhoe Dam General Arrangement

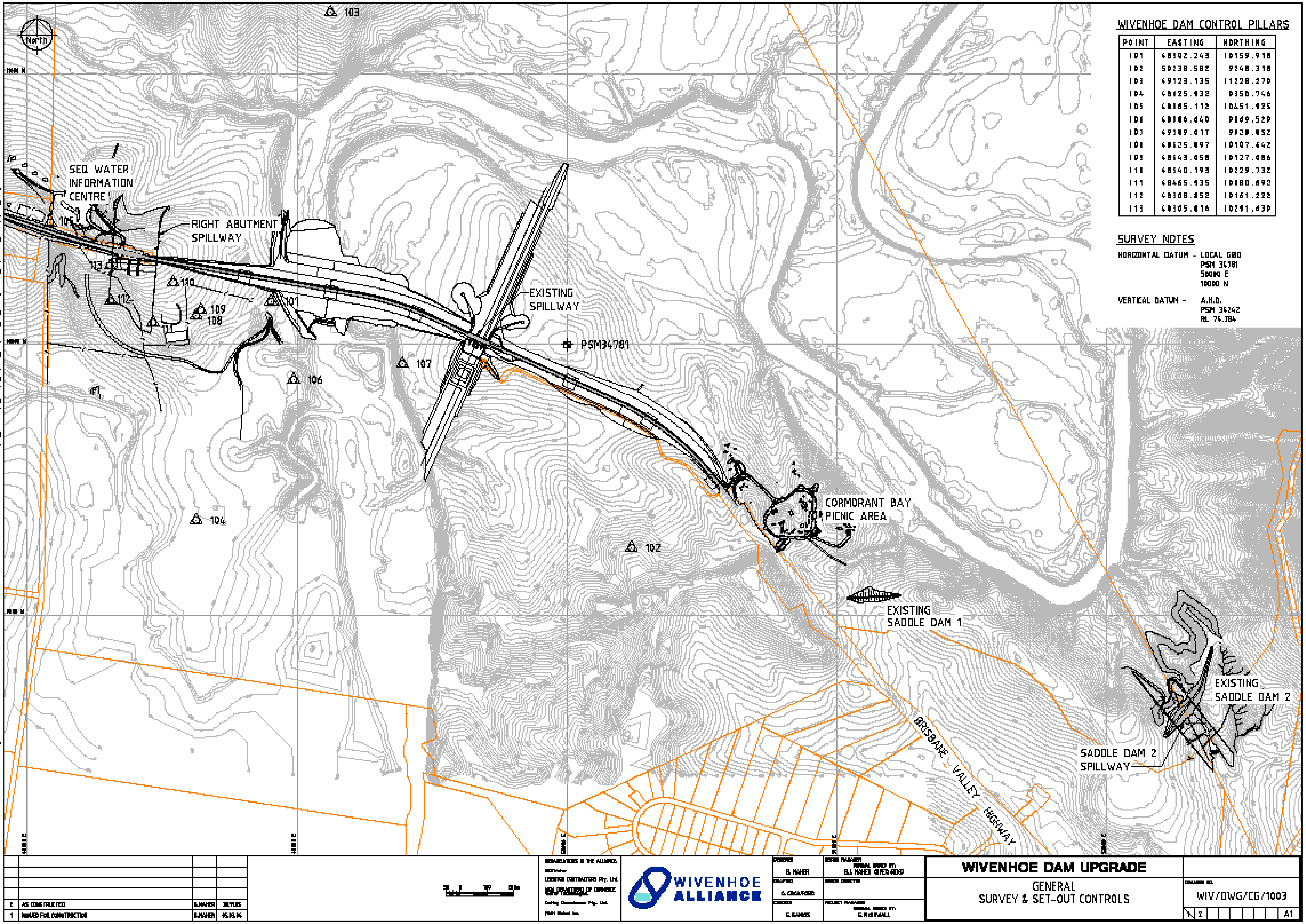


Figure 2 - Somerset Dam General Arrangement

Figure 3 - ANCOLD Total Societal Risk Assessment – from Wivenhoe Alliance, 2004

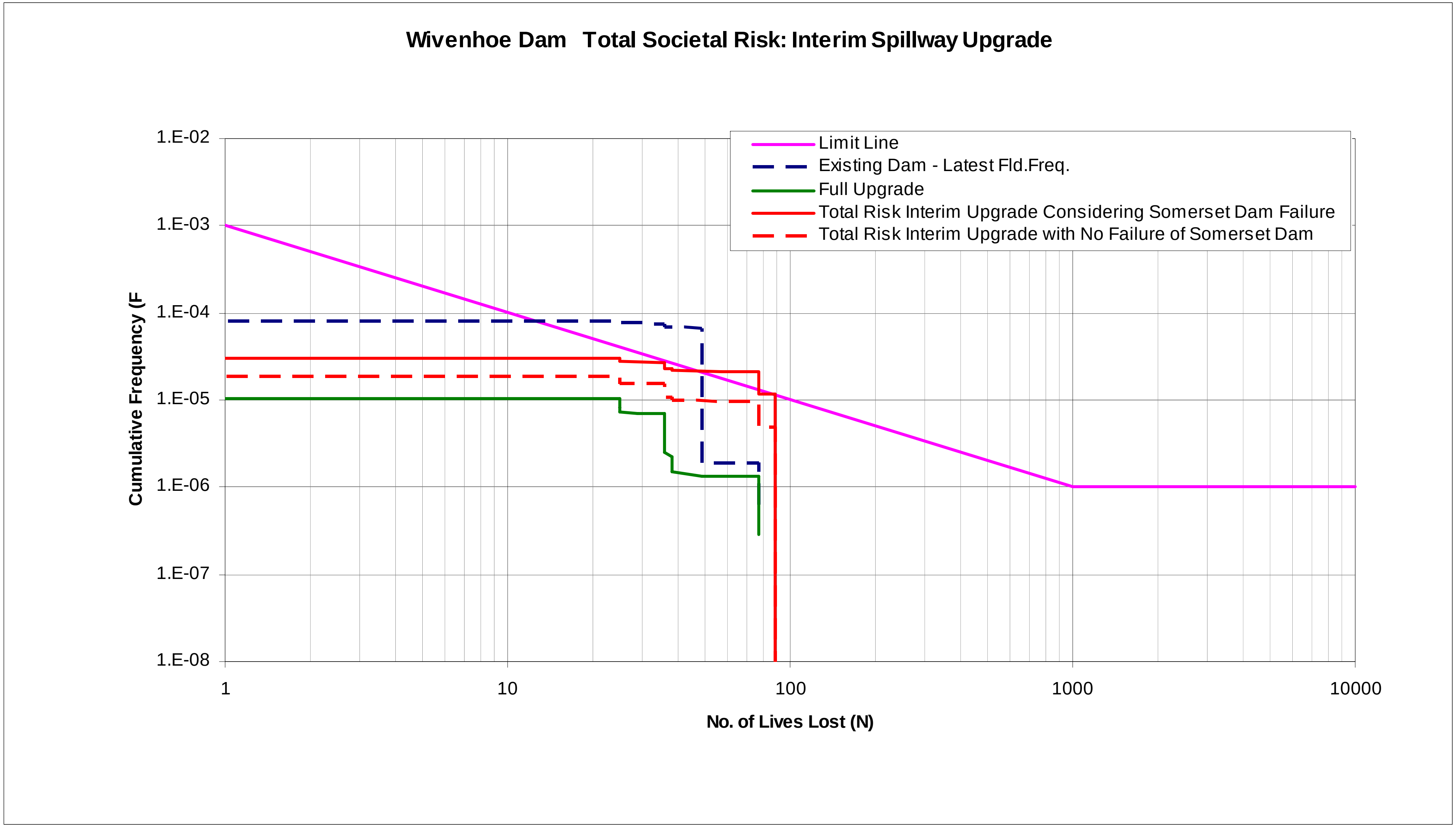
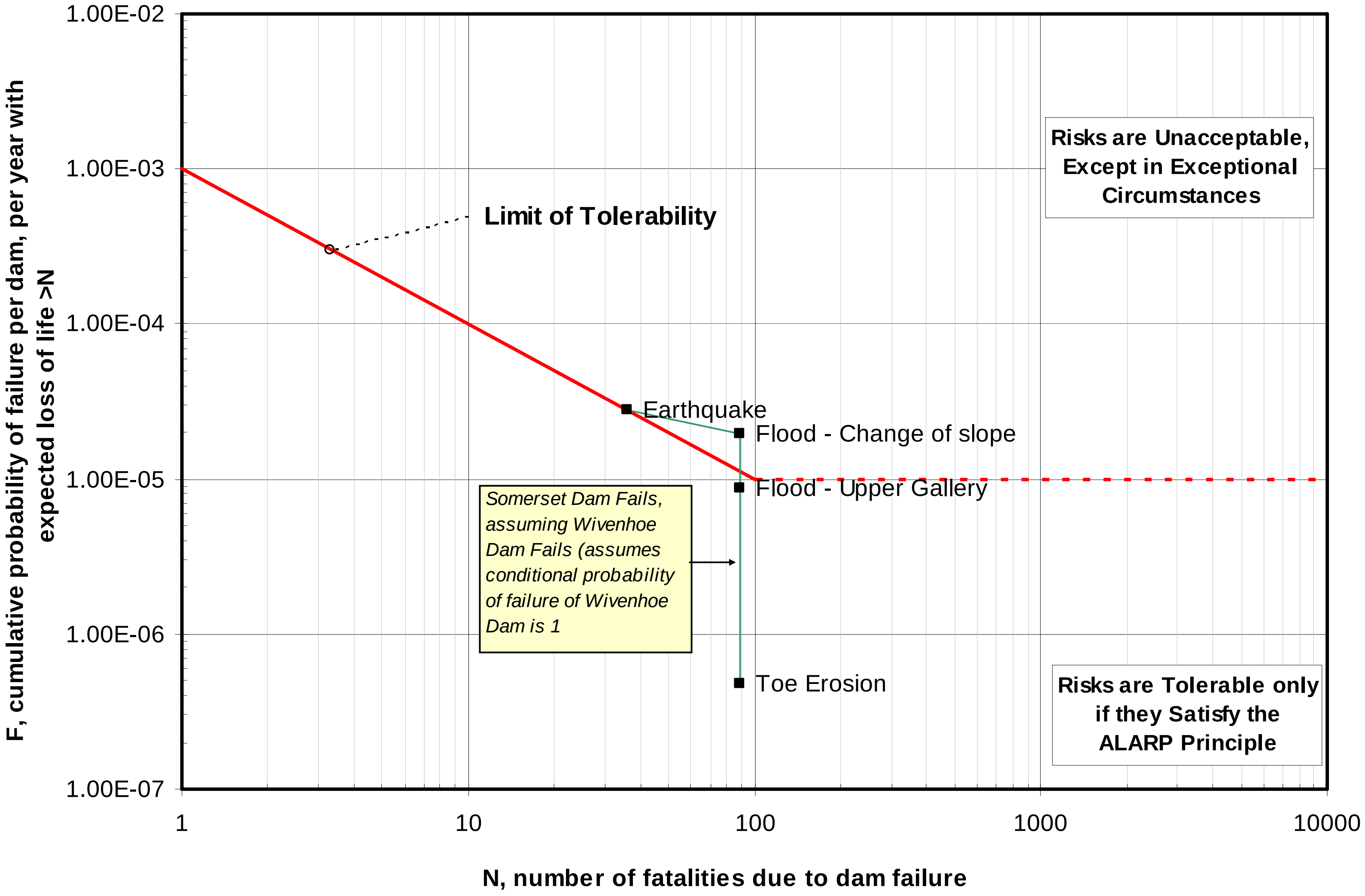


Figure 4 - ANCOLD Incremental Societal Risk Assessment – from Wivenhoe Alliance, 2004

Figure 5 - ANCOLD Societal Risk Assessment – from SMEC, 2004



Appendix 5.1 ANCOLD Societal Risk Guidelines: Existing Dams

Figure 6 - ANCOLD Total Societal Risk Assessment, – from Wivenhoe Alliance, 2004

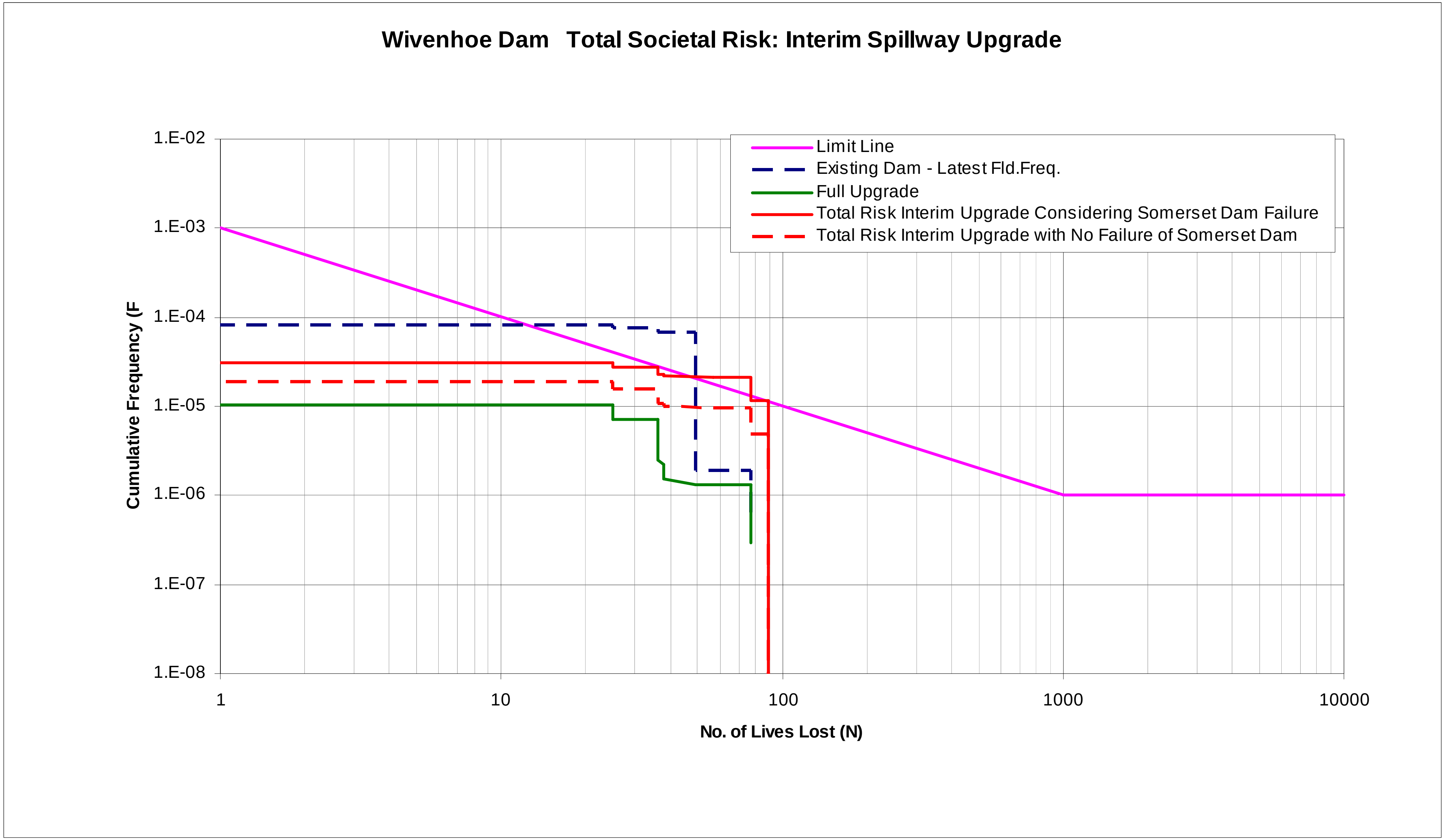
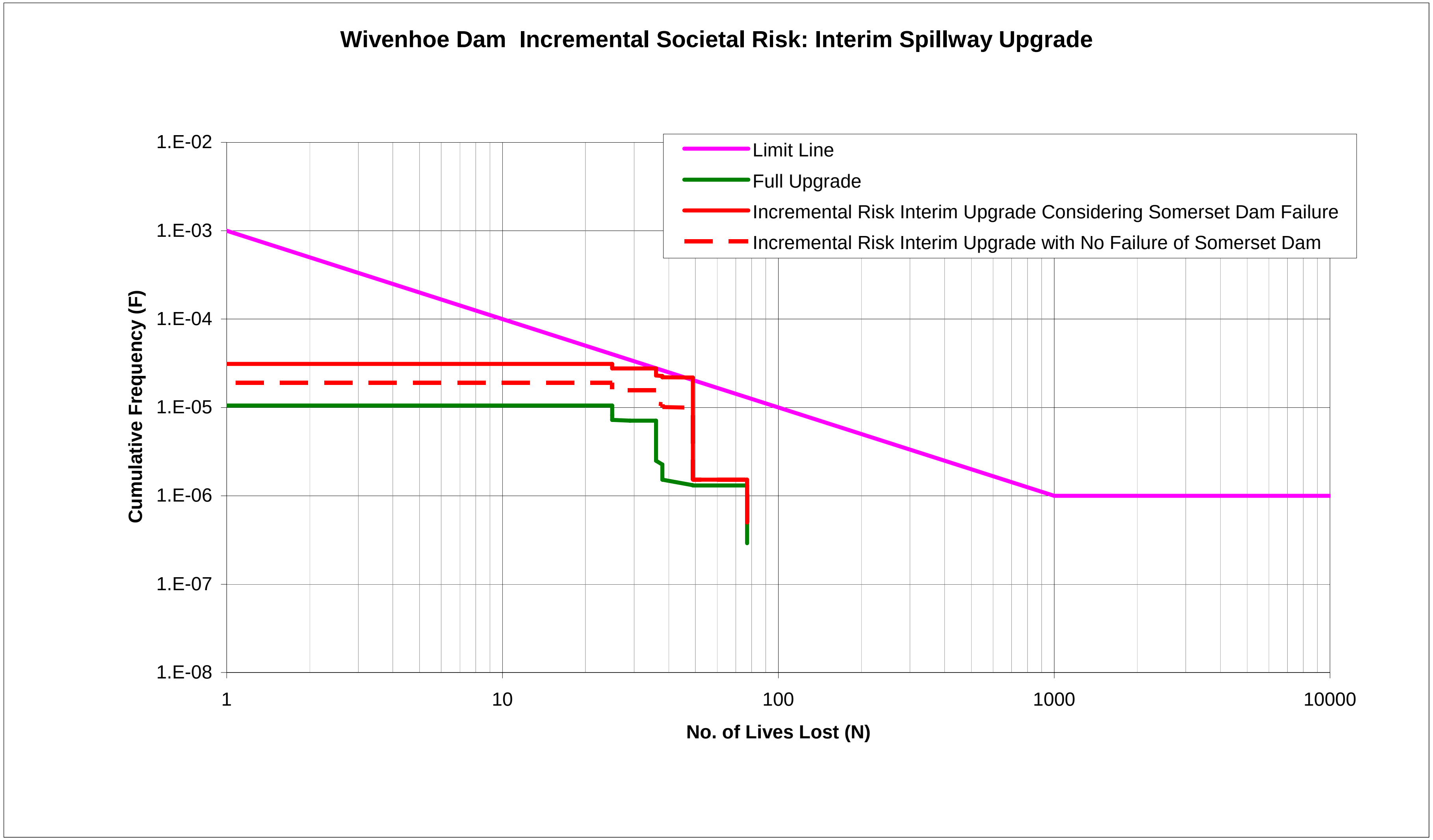


Figure 7 - ANCOLD Total Societal Risk Assessment, – from Wivenhoe Alliance, 2004



Appendix A. Wivenhoe Dam Description and Pertinent Data

Reservoir

Full Supply level (FSL)	EL67.0
Storage (at FSL)	1,150,000 ML
Reservoir Surface Area (at FSL)	10,820 ha

Dam

Type	Zoned earth and rockfill dam with a concrete gravity spillway section and two earthfill saddle dams.
Crest Level	EL79.15m excluding the wave wall

Main Dam

Type	Earth and rockfill dam
Crest Level	EL79.15
Wave Wall	EL79.7m (top of wall)
Dam length (including spillway section)	2260m
Dam height (maximum above downstream toe)	53m
Right embankment	Central core embankment
Left embankment	Sloping core embankment

Saddle Dam 1

Type	Earthfill embankment
Crest Level	EL80.0m
Crest width	4.0m
Upstream slope	3H:1V
Downstream slope	2.5H:1V
Embankment height (maximum)	11m
Embankment Length	160m

Saddle Dam 2

Type	Earthfill embankment.
Crest Level	EL80m
Crest width	4.0m
Upstream slope	3H:1V

Downstream slope	2.5H:1V
Embankment height (maximum)	6m
Embankment Length	225m

Outlet Works – Water Supply Intake

Variable level draw off facility	
Penstocks	2
Penstock diameters	1.9m & 3.6m

Outlet Works – Regulators

Number of regulators	2
Type and size of regulators	1.5 m diameter fixed cone dispersion valve 4.5MW power station owned by Stanwell Corporation
Level of centreline of regulators	EL31.5

Service Spillway

Type	Gated, concrete gravity section with flip bucket and flanking retaining walls.
Number of radial gates	5
Size of each gate	12.0m wide x 16.5m high
Top of gates when closed	EL73.0
Top of bridge deck	EL79.15
Spillway width (excluding piers)	60.0m
Unlined stilling basin invert	EL17.0
Peak water level as a result of PMF	Embankment overtopped
Imminent Failure Flood (IFF)	1 in 100,000 AEP event
Maximum flood level (IFF)	EL80.0
Peak discharge (IFF)	13,000m3/s

Secondary Spillway

Type	Ogee crest spillway with limited concrete lining controlled by fuse plug embankments
Number of Fuse Plug Embankments	3
Size of each Fuse Plug Embankment	Bay 1 (centre) 34m wide Bay 2 (LHS) 64m wide Bay 3 (RHS) 65m wide
Initiation Levels	Bay 1 (centre) EL75.7 Bay 2 (LHS) EL76.2 Bay 3 (RHS) EL76.7
Height of Ogee Crest	3m
Spillway width (excluding piers)	159m

Chute Floor Downstream	EL64.0
PMF Peak water level	Embankment overtopped
Imminent Failure Flood (IFF)	1 in 100,000 AEP event
Maximum flood level (IFF)	EL80
Peak discharge (IFF)	14,900m3/s

Appendix B. Wivenhoe Dam Risk Assessment, Failure Modes and Consequence Assessments

Risk Assessment Studies

A number of studies have been undertaken in recent years relating to various aspects of Wivenhoe and Somerset Dams. Somerset Dam is relevant in relation to the possibility of a cascade failure of the two dams. These include:

- A preliminary risk assessment of Wivenhoe, Somerset and North Pine Dams by SKM, reported at SKM (2000);
- A detailed risk assessment for Somerset Dam by SMEC;
- A review and updating of the Wivenhoe risk assessment report by the Wivenhoe Alliance, WA (2004C).
- Two short studies for Somerset Dam by Commerce, Commerce (2004 and 2005). These were based on a hydrology study by WRM Water and Environment, WRM (October 2004). It is understood that this Report has been revised and these revisions need to be incorporated in to the Commerce conclusions.

Failure Modes

Wivenhoe Dam, following the completion of the Stage 1 Upgrade works, is designed to handle a 1 in 100,000 flood event centred on the Wivenhoe catchment, assuming that Somerset Dam does not fail. A cascade failure would only result from a major flood event. Wivenhoe reservoir has sufficient capacity to store the normal Somerset storage without initiating the secondary spillway fuse plug.

The impact of a Somerset Dam failure on Wivenhoe Dam was detailed at Commerce (2004). The dominant risk associated with Somerset Dam is structural failure of the non-overflow units at the change in slope during a major flood event. Stability studies indicated, with some reservations over the cracking in the upper gallery, that the dam would satisfy normal stability criteria for the 1 in 100,000 AEP flood event centred on the Somerset catchment.

On this basis it is argued (Commerce, 2005), that any upgrade to Somerset Dam should attract the same degree of urgency as Stage 2 Wivenhoe works and should be examined at that time.

It is noted that there was a later revision of the hydrological studies, WRM (2005). The relevance of this update to the above comments is unclear.

Consequences of Failure for Wivenhoe Dam

Loss of Life Assessments

SKM (2000) provided loss of life estimates for both day and night failures of Wivenhoe Dam for a variety of load cases. SMEC (2004) has used the SKM data for total loss of life at night and adopted the following loss of life figures for the risk assessment:

- IFF Failure (Main Embankment) 89
- Earthquake 36
- Normal Operating Condition 77

Financial Loss Assessments

SKM (2000) has assessed the financial consequences associated with the failure of Wivenhoe Dam under three broad categories; third party damages, SEQWater direct damages and SEQWater loss of revenue. A major failure of Wivenhoe Dam was valued at $12B to $25B.

Environmental & Intangible Consequences

The SKM (2000) study included an assessment of environmental and intangible consequences. SKM assessed the incremental environmental consequences for Wivenhoe Dam as low while the incremental intangible consequences were assessed as high. It concluded that:

"These environmental and intangible consequences were far outweighed by the significant life loss and financial consequences for this portfolio. As such they did not play a significant role in the development of the risk reduction strategy."

Risk Analysis

The original risk analysis for Wivenhoe Dam was developed by SKM and is reported at SKM, 2000.

WA (2004C) reviews the risk to life presented by Wivenhoe Dam in both its existing state and after flood security upgrading works. It is an extension of the risk assessment undertaken by SKM (2000) and starts with a review of the earlier risk analysis of Wivenhoe Dam. It then considers the effect of the latest (2003) flood hydrology on the dam's risk profile.

The Wivenhoe Alliance further revised this work to incorporate the risks associated with a Somerset failure. The FN Charts for total loss of life are shown at Figure 3 and indicate that:

- The original Wivenhoe Dam plots well above the ANCOLD Limit Line;
- The Stage 1 Upgrade for Wivenhoe brings the risk below the ANCOLD Limit Line provided Somerset does not fail;
- If allowance is included for risks associated with a Somerset Dam Failure, the plot rises just above the Limit Line;
- The Stage 2 Upgrade brings the risk well below the Limit Line.

The total risk to Wivenhoe Dam as a stand-alone construction following the Stage 1 Upgrade works is assessed at $0.84*10^{-5}$. Introducing the risks associated with a Somerset failure increases these risks by a factor of 2,4 to $2.0*10^{-5}$.

The risk to life matrix (F-N Chart) using the incremental loss of life figures is reproduced at Figure 4. This shows the Wivenhoe risks plotting below the ANCOLD Limit Line.

The report recommended that due to its relatively simplistic nature and the way in which judgement was used (in conjunction with deterministic analysis) to estimate conditional probabilities, the risk analysis should not be used to determine the satisfaction of ANCOLD risk criteria in an absolute sense.

However, the risk analysis was useful in comparing the relative risk presented by various states of the dam (existing dam, fully and partially upgraded dam, various levels of radial gate upgrading). It further recommended that consideration be given to further, slightly more rigorous risk analysis. However, the decision for doing this analysis should not be made until the final option is determined and the dambreak studies completed and the consequences re-assessed.

Limitations of Risk Studies

The Wivenhoe Alliance study is a modification of the SKM study and as such is a Preliminary Risk Assessment. If the risk profile is a concern, a detailed risk analysis should be carried out, that includes a detailed assessment of the consequences, particularly loss of life. Previous consequence studies are dated and there has been considerable development in the Brisbane River study since the previous assessment.

Hazard Category

The Dam Safety Management Plan, SEQWater (2005) at Section 6.1 states "The Corporation's dams are classified under the ANCOLD classification guidelines as HIGH hazard because of the significant consequences of a dam failure".

The basis for this classification is outlined at GHD, 1997 and is based on:

- The significant development downstream in the Brisbane and Ipswich metropolitan areas, with the population at risk (PAR) numbering in the tens of thousands.

- The extensive residential and commercial development in the Brisbane along the river banks;

- The investment in infrastructure including key road and rail bridges.

The classification was based on an early version of ANCOLD, 2000B. The current Guideline has a more extensive classification system and it is recommended that the Hazard Classification be reviewed using the current Guideline.

It is anticipated that Wivenhoe Dam would be classified as Extreme Hazard.

Conclusions

The risk assessments for Wivenhoe Dam are Preliminary Assessments only. If the risk profile is a concern, a detailed risk analysis should be carried out, that includes a detailed assessment of the consequences, particular loss of life. Previous consequence studies are dated and there has been considerable development in the Brisbane River since the previous assessment.

Appendix C. Cost Estimates for Raising Wivenhoe Dam

Appendix D. Wivenhoe Dam Drawings

Appendix E. SunWater Assessment of Raised FSL (EL71) on Flood Operations

Appendix F. SunWater Assessment of Raised FSL (EL 69) on Flood Operations

Appendix G. Somerset Dam Pertinent Data

Reservoir

Full Supply level (FSL)	EL98.93
Storage (at FSL)	369,000 ML
Reservoir Surface Area (at FSL)	4,400 ha

Dam

Type	Concrete gravity dam
Crest Level	
bridge deck level	EL112.34m
non-overflow crest level	EL107.46m
spillway crest level	EL100.45m
Dam height (maximum)	58m
Embankment Length	308m

Outlet Works - Regulators

Number of regulators	4
Type and size of regulators	2.3 m diameter fixed cone dispersion valves
Level of centreline of regulators	EL69.97
Discharge capacity of each regulator with reservoir at FSL	79m3/s

Spillway

Type	Gated spillway with stilling basin and flanking retaining walls.
Number of radial gates	8
Size of each gate	7.9m wide x 7.0m high
Top of gates when closed	EL107.46

Sluice Gates

Type	Caterpillar type gates
Number of radial gates	8
Size of each gate	2.44m wide x 3.66m high
Invert level of sluice entrance	EL71.2

Stilling Basin

Concrete basin length	58.2m
Top of stilling basin training walls	EL73.02
Basin invert level	EL60.83

Baffle height	3.0m

Flood Flows

Peak water level as a result of PMF	
all gates open	EL110.4m
one gate out of service	EL110.7m
Maximum discharge as a result of PMF	
all gates open	8140 m3/s
one gate out of service	7950 m3/s

Power Station

Generating capacity	4MW

Appendix H.
Somerset Dam Risk Assessment, Failure Modes and Consequence Assessments

Risk Assessment Studies

A number of studies have been undertaken in recent years relating to various aspects of Somerset Dam. These include:

- A preliminary risk assessment of Wivenhoe, Somerset and North Pine Dams by SKM, reported at SKM, 2000;
- A dam safety review of Somerset Dam by GHD, reported at GHD, 2000;
- A detailed risk assessment for Somerset Dam by SMEC. This risk assessment was undertaken in two stages. The initial stage entailed a review of information and identification of deficiencies. Stage 2 provided a detailed assessment of the likelihood of failure of the identified deficiencies. This work is reported at SMEC, 2004.
- This study included an assessment of the reliability of the spillway gates.
- A short review of dam safety issues, based on the above Reports was carried out by Commerce in December 2004 and is reported at Commerce, 2004:
- Further stability assessments of abutment monoliths were carried out by Commerce and are reported at Commerce, 2005.
- The above Commerce Reports were based on a hydrology study by WRM Water and Environment, WRM (October 2004). This Report has been revised (WRM, September 2005) but these revisions have not been incorporated in to the Commerce, 2005 conclusions.

Failure Modes

The following is taken mainly for Commerce (2004) but includes information from all sources referenced above, particularly SMEC (2004).

The detailed risk analysis for Somerset Dam, SMEC (2004), identified three basic failure modes:

- Erosion of the downstream toe due to flood discharges passing through the open sections of the dam abutments and impacting on the foundation at the downstream toe of the dam;
- Structural failure of the dam under extreme water load. The dam was considered stable at the foundation interface for the PMF (albeit approaching the limit of its stability) but liable to failure at two higher locations for smaller flood events;
  - At the change of slope in the back face of the non-overflow sections;
  - At the Upper Gallery.
- Structural failure of the dam under earthquake.

The results obtained from the event tree analyses are summarised at **Table** 11-1. Structural failure of the non-overflow units at the change in slope of the back face was the dominant failure mechanism followed by failure at the Upper Gallery. Gate reliability was assessed and included in the event trees and had a significant effect on the results.

Table 11-1 - **Result of Event Tree Analyses**

Failure Mode	Probability of Failure (/year)
Failure at Change of Slope under Flood	110*10-7
Failure at Upper Gallery; under Flood	80*10-7
Failure under Earthquake	80*10-7
Failure due to Toe Erosion	5*10-7
Total for Somerset Dam	275*10-7

Reference SMEC (2004)

Failure due to toe erosion at the toe of the dam was not considered to be a major factor. The foundation was assessed as a hard strong andesite with jointing the major defect. While erosion of the surface rock is expected under low to medium flows, the rock mass was judged to be "tighter" at depth and have a high resistance to erosion that is unlikely to lead to dam failure.

Moderate earthquake events are likely to cause distress at the change of slope, but as this is above Full Supply Level, it had no impact on the risk analysis. Stability analyses, GHD (2000), indicate the dam is unstable at the Upper Gallery for the Maximum Design Earthquake.

Structural Investigation Studies

The critical flood levels adopted for the risk analysis were:

- EL109.7 for the Change of Slope failure;
- EL110.0 for the Upper Gallery failure.

These levels adopted by SMEC (2004) were based on separate stability analyses by GHD (2000) and SKM (2000). SMEC (2004) noted that "the results from the two analyses are at odds" and that "the reasons for the differences are not apparent". In addition, the Report in Appendix 3.6 extracts from DPI (1994) quotes a Ben Russo conclusion that differs from both of these studies.

> ***"Russo also recommends that to ensure the survival of the two portions of two non-overflow monoliths above EL100.0 , the reservoir should not exceed EL111.7 . He adds that the structural integrity of the spillway gates(if used) would have to be checked for the loads such a reservoir level would impose."***

The variations in these three stability assessments cover a range that could have a significant impact on the event trees developed by SMEC and on the overall risk assessment. The differences are presumably due to different assumptions for uplift and for the extent of cracking in the concrete at the Upper Gallery.

Commerce reviewed the stability assessments and concluded that stability criteria were satisfied for:

- Storage levels up to EL111.0 at the change of slope;
- Storage levels up to EL110.9 at the Upper Gallery;

However, if extensive cracking exists above or below the gallery. The dam just satisfies stability criteria for a storage at EL109.7.

Hydrological studies (WRM, 2004) assess the storage level for flood with an AEP if 1 in 100,000 at EL109.75. The above studies indicate that the dam would satisfy normal stability criteria at this level, although there would be little margin if cracked concrete exists above or below the Upper Gallery.

This conclusion needs to be reviewed following the revised hydrology study at WRM, 2005.

Impact of a Somerset Dam Failure on Wivenhoe Dam

The impact of a Somerset Dam failure on Wivenhoe Dam was detailed at Commerce (2004) and summarised below.

The consequences of failure of Somerset Dam are largely dependent on whether it can cause a cascade failure of Wivenhoe Dam. Wivenhoe Dam, with Stage 1 Upgrade works now completed, is designed to handle a 1 in 100,000 flood event centred on the Wivenhoe catchment, assuming that Somerset Dam does not fail.

Somerset Dam, on the basis of its known condition, satisfies stability criteria for a storage level of EL109.75 and will safely handle the 1 in 100,000 AEP flood event. This in turn ensures that the Stage 1 upgrade works for Wivenhoe Dam are not compromised by any Somerset Dam deficiencies.

On this basis upgrade work at Somerset Dam, if required at all, would reasonably attract the same degree of urgency as Stage 2 Wivenhoe works. It is recommended that any upgrading of Somerset Dam be considered at the time that Stage 2 Wivenhoe works are assessed.

Commerce, 2005 raises several issues in relation to the above:

- Cracking observed in the Upper Gallery walls may also exist above or below the Gallery. While such cracked concrete would just satisfy stability criteria for a storage level of EL109.75, stability reduces rapidly for higher storage levels and failure could occur at EL110.1. It was recommended that some exploratory drilling be carried out to determine whether such cracks do exist. A similar recommendation was made in GHD (2000);

- The WIVOPS flood operation program at one time required that the Somerset spillway gates be lowered if Wivenhoe Dam is in danger of being overtopped. This is a difficult procedure that would raise a number of operational and safety issues and require a review of the stability conclusions given above.

- Stability analyses assume that the gallery systems are not flooded by water overtopping the abutment monoliths. The dam layout should be reviewed to ensure this is the case and waterproof doors installed where necessary.

Consequences of Failure for Somerset Dam

Loss of Life Assessments

If Somerset Dam fails without causing a cascade failure of Wivenhoe Dam, the consequences are limited to the area between the two dams.

The SKM (2000) Report predicted no loss of life would occur from a Somerset failure for the following reasons.

- The small population at risk for flood failures;
- Adequate warning times for flood failure;
- The location of the population at risk above peak flood levels caused by normal operational failure.

If failure of Somerset causes a cascade failure of Wivenhoe Dam, then the loss of life figures are substantially increased. This could only occur during an extreme flood event as Wivenhoe reservoir has sufficient capacity to store the normal Somerset storage without initiating the secondary spillway fuse plug.

SKM (2000) provided loss of life estimates for both day and night failures of Wivenhoe Dam for a variety of load cases. SMEC (2004) has used the SKM data for total loss of life at night and adopted the following loss of life figures for the risk assessment:

- IFF Failure (Main Embankment) 89
- Earthquake 36
- Normal Operating Condition 77

Financial Loss Assessments

SKM (2000) has assessed the financial consequences associated with the failure of Somerset Dam under three broad categories; third party damages, SEQWater direct damages and SEQWater loss of revenue. A major failure of Somerset Dam, involving failure of the spillway gates and partial failure of the abutment units was valued at $20M, with $18M of this classed as SEQWater direct damages.

SMEC (2004) quote a far higher cost of $200M to repair Somerset, including environmental impacts.

These estimates depend heavily on the type of failure and extent of the damage. Failure of several abutment units at the change of slope would incur a relatively low repair cost, while major damage to the gated spillway would involve substantially higher repair costs. No detailed estimates are available but the SKM (2000) estimates appear low, particularly as they involve spillway gate failure.

Similarly, a major flood failure of Wivenhoe Dam is estimated at $12B to $25B by SKM (2000).

Environmental & Intangible Consequences

The SKM (2000) study included an assessment of environmental and intangible consequences. SKM assessed the incremental environmental consequences for both Somerset and Wivenhoe dams as low. The incremental intangible consequences were also assessed as low for Somerset although high for Wivenhoe. It concluded that:

> ***"These environmental and intangible consequences were far outweighed by the significant life loss and financial consequences for this portfolio. As such they did not play a significant role in the development of the risk reduction strategy."***

Risk Analysis

No Failure of Wivenhoe Dam

SMEC, 2004 notes that for zero loss of life, the ANCOLD life safety criteria do not apply.

The ANCOLD fallback criteria however, would require either PMF security for an "Extreme Category" or PMPDF security for a "High A Category." Somerset Dam does not satisfy PMF and is unlikely to satisfy PMPDF. This reflects the overall importance of the dam to SEQWater.

SMEC, 2004 also notes that the risk of failure could be reduced by around 3 orders of magnitude by:

- Installation of anchors to increase the structural adequacy at the upper gallery and change of slope;
- Construction of a concrete slab/cutoff at the toe of the dam to protect against erosion and undermining.

The above works have not been costed, SKM nominated costs between $1M and $2M (now dated) and SMEC "judged that costs are likely to be higher, but still in the millions of dollars range".

SMEC noted that the cost of anchors could be justified, even if consequential failure of Wivenhoe did not occur. The value of erosion protection was more difficult to justify and that ":it would need to be determined whether its cost is grossly disproportionate to the improvement gained".

Upgrading of Somerset Dam, as a stand alone structure is an ALARP issue under the ANCOLD Guidelines. As noted by SMEC, SEQWater needs to determine their acceptable level of risk in order to assess the need for risk reduction measures.

Cascade Failure of Wivenhoe Dam

The FN Chart produced by SMEC, 2004 is shown at Figure 5, and is based on the risk assessment of Somerset Dam with the assumption of a conditional probability of failure of Wivenhoe Dam of 1.0. This Report did not assess the likelihood of a failure of Somerset Dam resulting in a failure of Wivenhoe Dam. The FN Chart plots above the Limit of Tolerability and as such the risk would be deemed intolerable.

The original risk analysis for Wivenhoe Dam was developed by SKM. The Wivenhoe Alliance revised this work to incorporate the risks associated with a Somerset failure. The FN Charts for total loss of life is shown at Figure 6 and indicates that:

- The original Wivenhoe Dam plots well above the ANCOLD Limit Line;
- The Stage 1 Upgrade for Wivenhoe brings the risk below the ANCOLD Limit Line provided Somerset does not fail;
- If allowance is included for Somerset Dam failure case, the plot rises just above the Limit Line;
- The Stage 2 Upgrade brings the risk well below the Limit Line.

The total risk to Wivenhoe Dam as a stand-alone construction following the Stage 1 Upgrade works is assessed at $0.84*10^{-5}$. Introducing the risks associated with a Somerset failure increases these risks by a factor of 2.4 to $2.0*10^{-5}$.

The risk to life matrix (F-N Chart) using the incremental loss of life figures is reproduced at Figure 7. This shows the Wivenhoe risks plotting below the ANCOLD Limit Line.

Limitations of Risk Studies

The SMEC, 2004 study of Somerset Dam is considered a detail risk assessment, with the limitation that it does not consider the likelihood of a failure of Somerset Dam resulting in a failure of Wivenhoe Dam. The Report uses the SKM loss of life figures. The SKM Report was a preliminary assessment and as SMEC notes the consequence study is not developed to the same standard as the failure analysis.

The Wivenhoe Alliance study is a modification of the SKM study and as such is a Preliminary Risk Assessment. If the risk profile is a concern, a detailed risk analysis should be carried out, that includes a detailed assessment of the consequences, particular loss of life.

Hazard Category

The Dam Safety Management Plan, SEQWater (2005) at Section 6.1 states that "The Corporation's dams are classified under the ANCOLD classification guidelines as HIGH hazard because of the significant consequences of a dam failure". These are presumably the 1986 ANCOLD Guidelines.

The hazard classification was determined by GHD and the following statement included in GHD (2000).

"A hazard assessment was conducted in accordance with the DPI (DNR) Dam Safety Guidelines Procedure DS003 and the June 2000 ANCOLD Guidelines on Assessment of Consequences of Dam Failure. Both methods indicate that the dam should be classified as having a High Hazard Category."

No discussion of the hazard classification was provided at GHD (2000). It is assumed that the hazard classification allows for the possibility of a cascade failure of Wivenhoe Dam and, given the financial loss assessments noted at 0, that this would be a High A classification for flood under ANCOLD.

It is recommended that the Hazard Classification be given further consideration on the basis that:

- The PAR from a cascade failure would be in excess of 1,000, and the ANCOLD Guidelines would indicate a an Extreme Classification;
- The Hazard Classification for a sunny day failure would be lower, possibly High B or High C.

Conclusions

Somerset Dam as a stand alone structure satisfies the ANCOLD risk to life criteria. There is scope for substantially reducing the risk of failure, but the value of this work needs to be assessed in terms of the SEQWater risk management procedures.

A cascade failure of Somerset and Wivenhoe Dams is possible and stability is marginal for the 1 in 100,000 AEP event. Preliminary risk assessments indicate the cascade failure is close to the ANCOLD Limit of Tolerability.

SEQWater has completed Stage 1 of an upgrade program and Wivenhoe Dam now is now capable of handling a flood with an AEP of 1 in 100,000. Stage 2 would provide full PMF security. This would satisfy the ANCOLD Limit of Tolerability and the ALARP principle.

While Somerset Dam can also handle a 1 in 100,000 AEP flood event, upgrade work, if required at all, would reasonably attract the same degree of urgency as Stage 2 Wivenhoe works.

The various Reports however, raise a number of issues that require investigation:

- Cracking observed in the Upper Gallery walls may also exist above or below the Gallery. While such cracked concrete sections would just satisfy stability criteria for a storage level of EL109.75, stability reduces rapidly for higher storage levels and failure could occur at EL110.1. It was recommended that some exploratory drilling be carried out to determine whether such cracks do exist. A similar recommendation was made in GHD (2000);

- The WIVOPS flood operation program at one time required that the Somerset spillway gates be lowered if Wivenhoe Dam is in danger of being overtopped. This is a difficult procedure that would raise a number of operational and safety issues and require a review of the stability conclusions given above.

- Stability analyses assume that the gallery systems are not flooded by water overtopping the abutment monoliths. The dam layout should be reviewed to ensure this is the case and waterproof doors installed where necessary.

- SMEC, 2004 notes that should the spillway gates not operate as intended, the dam could become unstable and, “as part of its risk reduction strategy, SEQWater needs to consider this aspect”. Risk reduction methods considered included “removal of the sector (radial) gates, or anchoring the dam to the foundations”.

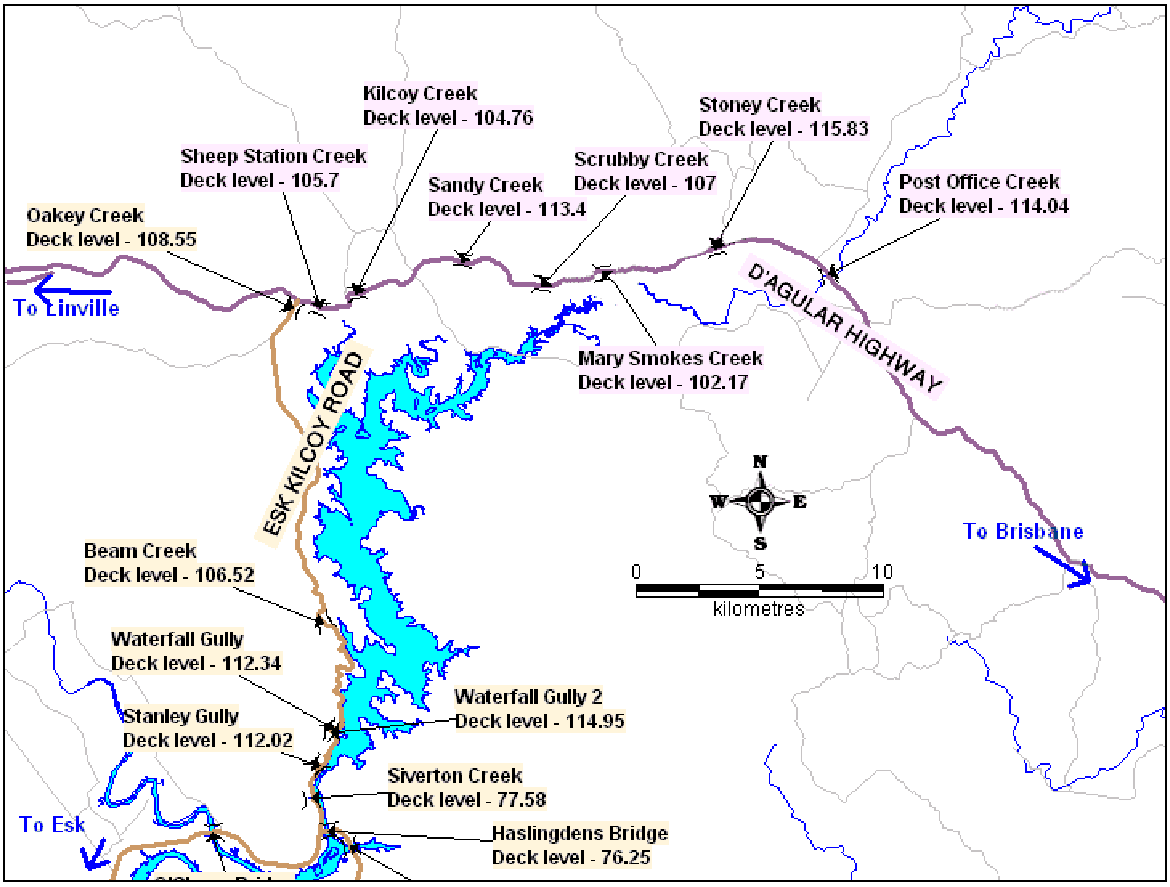
Appendix I. Cost Estimates for Raising Somerset Dam

Appendix J. Raising Somerset Dam Feasibility Investigations by SMEC

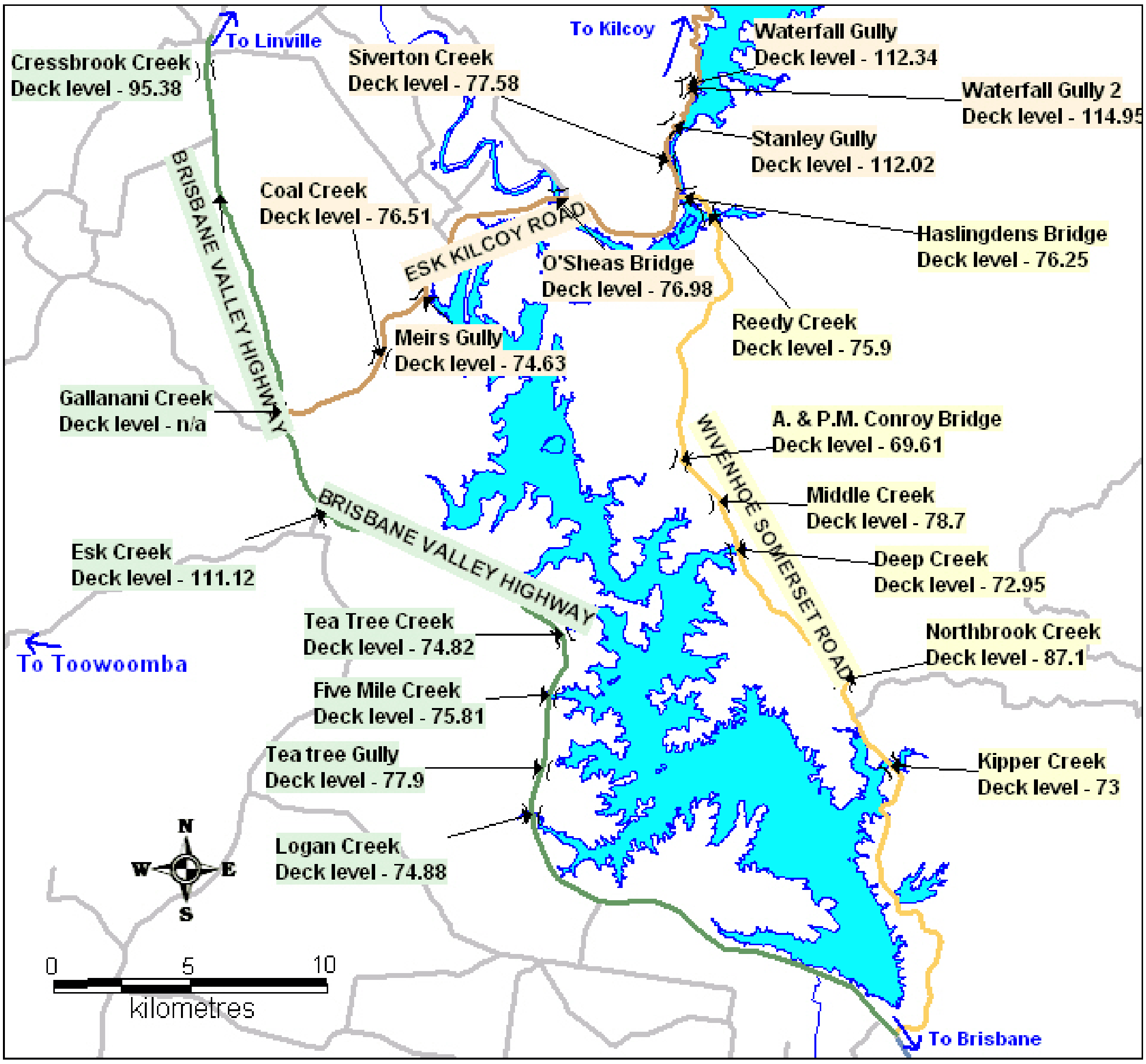
Appendix K. Inundation Maps for Wivenhoe and Somerset Dams

Appendix L. BRIDGE Levels Upstream and Downstream of the Dams

Roads North of Somerset Dam

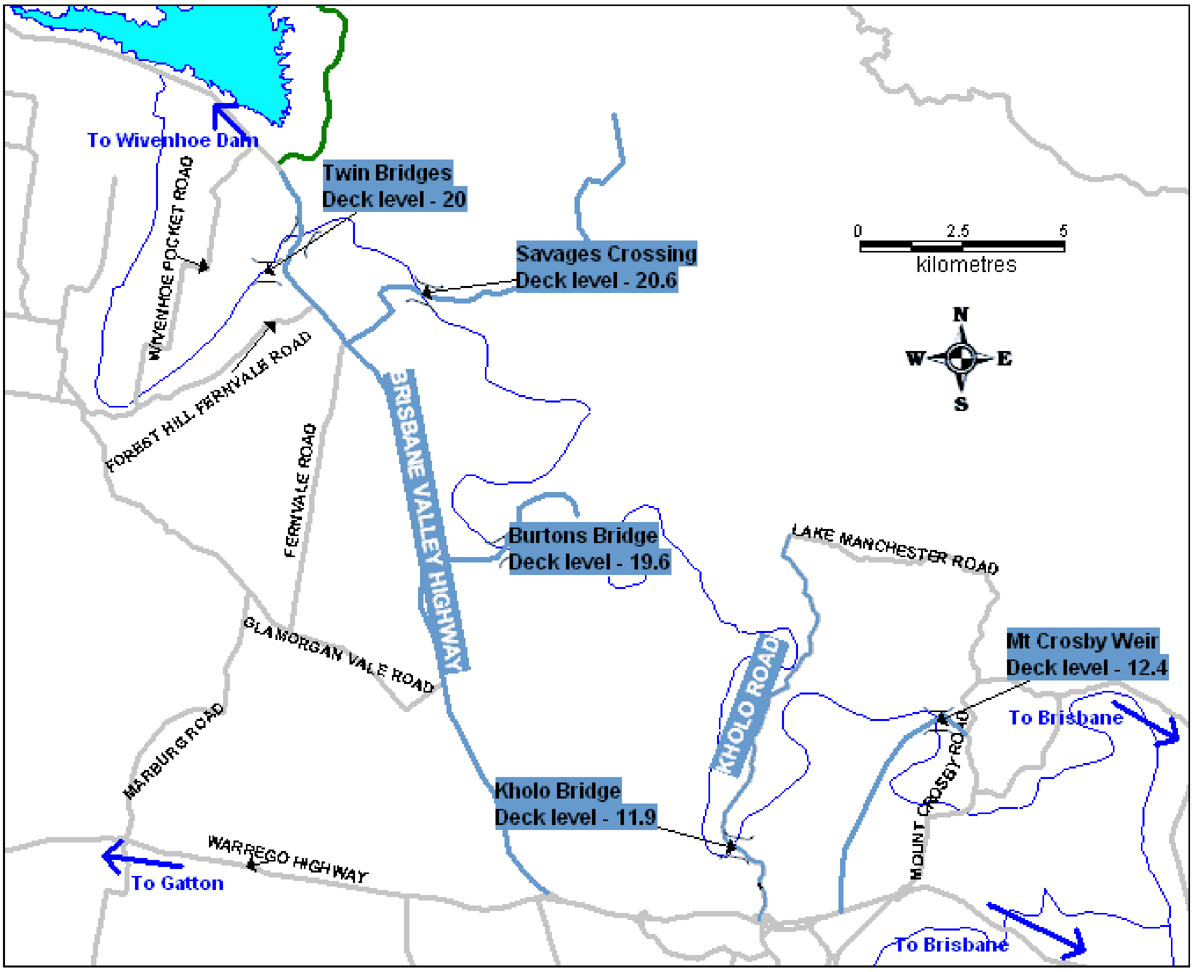


Roads Surrounding Wivenhoe Dam



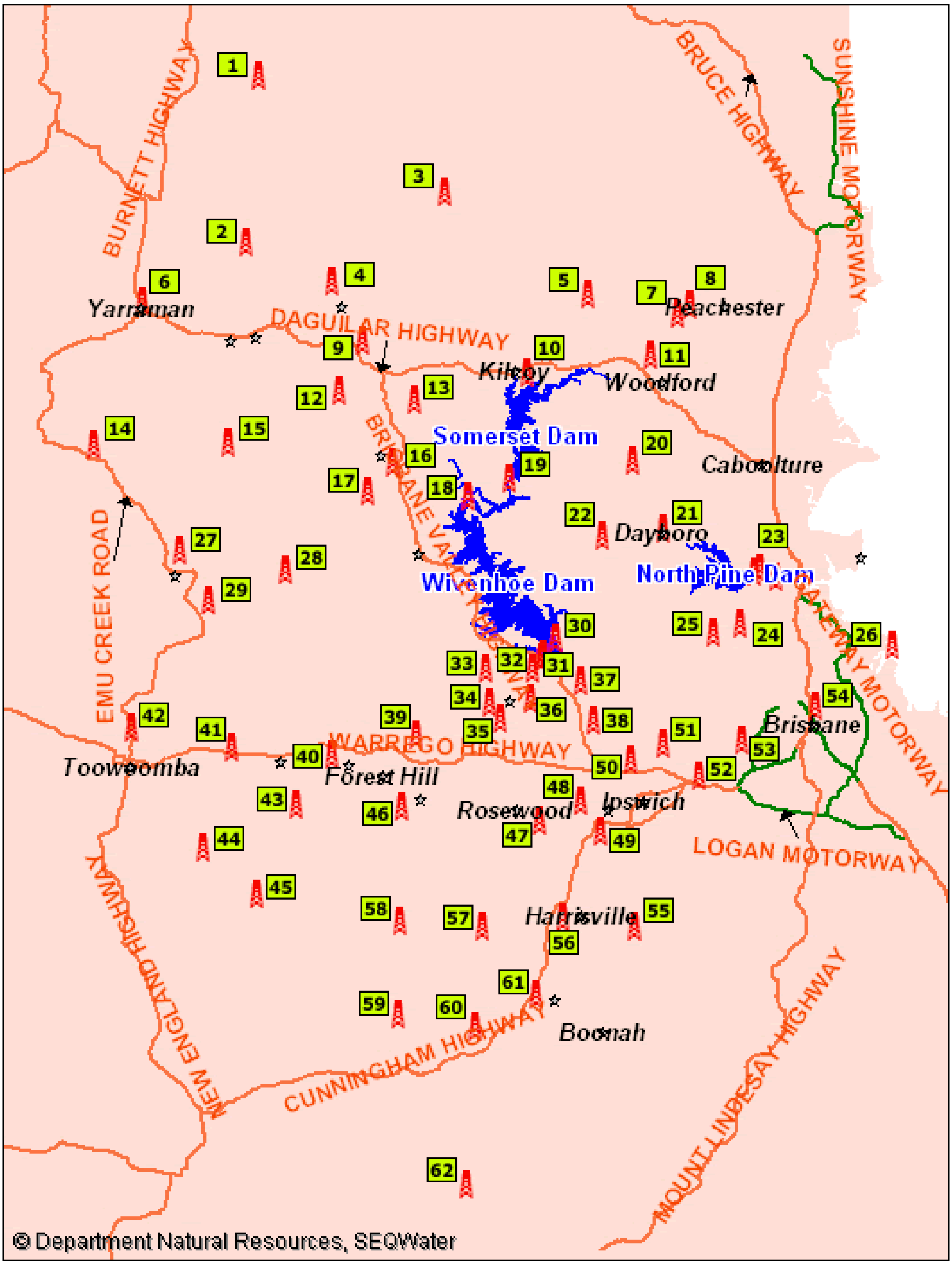
SEQWATER
Wivenhoe, Somerset & North Pine Dams

Bridges Downstream of Wivenhoe Dam



SEQWATER
Wivenhoe, Somerset & North Pine Dams

Figure 8 - Alert Station Locations



Appendix M. Somerset Drawings