Catastrophic Risk Assessment of Warragamba Dam

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Summary of Conclusions and Recommendation:

1. The raising of the dam wall does not build resilience for Sydney, NSW or Australia, but increases the vulnerability of the dam to both natural and behavioural catastrophic risk. These risks were not canvassed or discussed in the EIS in breach of the SEAR's Guidelines for a sustainable future. The consequences of dam failure (including deliberate destruction) are so extraordinarily severe that these risks must be properly addressed by the EIS and associated studies.
2. The trend in water engineering internationally is to replace dams with alternative water and energy resources and to seek non-environmentally intrusive solutions.
3. It has been concluded in this Report that the assessment of the impact of raising the dam wall on the World Heritage Area, Aboriginal Heritage and Culture is invalid because it is not aligned to the environmentally sustainable development of resilience for Blue Mountains and Hawkesbury-Nepean Valley communities.
4. It is recommended that new options be considered that do increase resilience for Sydney, NSW. This includes developing desalination technology powered by renewable energy. which has advanced significantly since the first desalination plant was built in Sydney. The dam water level could be reduced progressively as each plant comes online, reducing the existing flooding risks and preventing the additional risks associated with raising the dam.
5. It is recommended that there be a lowering the dam water level by some 30m to increase environmental sustainability and to reduce the population risk downstream. This will also ensure that Gundungurra land is not impacted in the future and is protected for future generations.
6. It is recommended that Ministers and Heads of Government Departments seek analysis of a range of options which will demonstrate wide consultation and data assessment and, on this basis, make a reasonable judgement that will be upheld for the life cycle of the dam.
7. It is recommended that the SES with water engineering and catastrophic risk consultants develop and test plans for failure of this dam and apply findings to all other major dams in NSW. This plan testing is an essential process in reducing the catastrophic risk to the population of Western Sydney from collapse of the Warragamba dam. The benefits to the population and the environment will be a significant lowering of catastrophic failure risks and an advancement in procedures for sustainability of the environment.
8. It is recommended that the NSW Government Treasury should include calculations, risk assessments and the externality risks and identify funding responsibilities for ongoing projects and have oversight on the procurement before contracts. This action will minimise unquantified proposals and create an audit trail.
9. It is recommended that funding be provided for a multidisciplinary water engineering, risk, archaeological and anthropological study of the 300 or so sites identified in partnership with the local Gundungurra community.

10. It is Recommended that the Blue Mountains World Heritage area be universally protected from development including the land surrounding this area and that the area adjoining the World Heritage Areas be assessed to extend the World Heritage Area.
11. It is a conclusion of this Report that the drought-flood cycle can be used as a means for providing sustainable futures to the Western Sydney and Western Plain Communities and in particular sustainable water resources. This can be incorporated into ongoing analysis of options.
12. It is recommended that funding be provided for a multidisciplinary water engineering and scientific study of building offshore desalination plants to take advantage of wind, wave and current energy. This option can be used to purify seawater and provide the energy to pump the water to supply the Western Plains.
13. It is recommended that an engineering report be sought on the safety and life expectancy of the dam and to consider strengthening the dam and upstream and downstream infrastructure if recommended.

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Introduction

The EIS to raise the dam wall at Warragamba has several problems in the way it has portrayed risks to residents in the Hawkesbury-Nepean valley and to the UNESCO World Heritage Area of the Blue Mountains and its associated risks involving environmental and indigenous heritage destruction. In particular, it has failed to demonstrate that catastrophic risks can be avoided, and in many respects whether they were considered at all. Such risks impact on both world heritage status and the population in the Hawkesbury-Nepean Valley and indirectly on the population of Sydney.

This document will attempt to redress this situation so that the public can understand the true nature of this project. It will also point to a sustainable alternative to this project in the future that does not cause the detrimental effects seen in this project.

Strategic Requirements for a Sustainable Future

A sustainable and resilient future requires a rethinking of how new technology can be utilised to reduce the risks in 1950's technology solutions and how the use of new technology can avoid the loss of World Heritage status that depends on retaining the natural beauty of the environment, the unique flora and fauna and the cultural heritage lying within and on its boundaries.

The Secretary's (SEARS) requirements of the Department of Planning, Industry and Infrastructure, seems to be only interested in saving money in the construction and operation of this 1950's technology, rather than providing a sustainable future for the people of NSW.[1] It only attempts to maximise conservation of the World Heritage area not ensure that destruction is absent. This SEAR requirement goes against the values of UNESCO. World Heritage Committee member Kishore Rao noted: "You don't only maintain the authenticity of the site – that means that the structure itself is not damaged or modified – but also that it is presented in its historical context"[2] when discussing the loss of the Liverpool docks from World Heritage status in the UK. While it is difficult to quantify the financial value of a World Heritage Area, such as the Blue Mountains in NSW, such status certainly helps Sydney, and the Blue Mountains, attract investment and Tourism. But it also goes beyond money to non-economic benefits that are difficult to quantify, such as historic importance, symbolic meaning and aesthetic value. It is these benefits to the population that are not being conserved in the EIS as though they are less important.

The Blue Mountains National Park and World Heritage Area has the highest visitation of any National Park in Australia, more than 5 million visitors per annum, due to its accessibility and impressive natural features.[3] More than 2 million visitors per annum are estimated to converge on Echo Point (Three Sisters), with the next popular attraction being Scenic World with 850,000 visitors[4]. An estimated 1.25 million visitors per annum physically undertake a bushwalk[5]. The majority of recreational visitors are day trip visitors and the most popular activities are dining, bushwalking,

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[1] Revised SEARS.pdf, p15/31, Sustainability: The project reduces the NSW Government's operating costs and ensures the effective and efficient use of resources. Conservation of natural resources is maximised.

[2] From https://inews.co.uk/news/world/liverpool-what-losing-the-unesco-world-heritage-status-will-mean-for-the-city-1072255, By Michael Day, Chief Foreign Commentator, June 26, 2021 7:00 am(Updated 7:01 am)

[3] annual-visits-to-nsw-national-parks-and-wildlife-service-managed-parks-2016-state-report.pdf.

[4] Scenic World Visitor statistics

[5] https://www.destinationnsw.com.au/tourism/facts-and-figures/regional-tourism-statistics/blue-mountains/blue-mountains_time_series_ye_dec_2019.pdf

abseiling and canyoning.[6] Tourism accounts for 13% of jobs within the Blue Mountains adding some $M220 per annum to the local economy.

The proposal to raise the dam wall will physically impact on 1300 hectares but the alterations to the landscape will leave visible scars that can be seen from many of the clifftop vantage points. While this is 0.13% of the heritage area, it also destroys other land outside the World Heritage area through inundation to bring the total affected to 5000 hectares (0.5%).

According to the Guardian a leaked report indicated "The proposed increase in inundation levels … would result in permanent environmental changes to the ecosystems and ecology of these areas."[7] In the same article, the Minister for Western Sydney states that the reason for raising the dam wall is to "reduce the existing risk to life and property on the Hawkesbury-Nepean floodplain….While there will be environmental impacts from temporarily holding flood water from behind a raised dam wall, they must be measured against the social and financial impact a catastrophic flood would have on Western Sydney communities."

In response the NSW opposition environment spokeswoman, Penny Sharpe, said the dam plan was driven by a "*rapacious development agenda*" and should be abandoned. "*Instead of improving flood evacuation routes in the Nepean Valley, the real agenda here is for the government to open up more urban development to house an extra 134,000 new residents on the floodplain.*"[7]

Harry Burkitt, from community group Give a Dam, said "The world heritage area impacted is more than 4.5 times Sydney's CBD. More than double what Minister Ayres has admitted to parliament and the public. The world is watching Australia, and the federal government needs to act and stop this developer driven dam project. It would be nothing other than a national disgrace if the Australian government approved the dam and the Blue Mountains lost its world heritage status."

Periods of drought are no less important than flood. A sustainable future for water supply has to take account of the nature of the drought-flood cycle otherwise inappropriate decisions for the population of NSW occurs. The EIS does not do this and only assesses Flood impacts.

A sustainable future requires that the full risks and benefits in this project are properly understood and transparent to the people of NSW. It can be demonstrated in this EIS that critical information on risks have been hidden from the people in Western Sydney and in particular the people in the Nepean-Hawkesbury valley. As a consequent they are unable to properly judge whether the proposal to raise the dam wall causes intolerable risks and that an alternative strategy should be engaged.

Uncertainty in Risk Assessment and Control

The basis for tolerability of risk to society is based on the premiss that many risks can be tolerated by society but a few are of such severity should they occur that they are considered intolerable. The Dam Safety Committee of NSW requires that the safety of scheduled concrete dams, such as Warragamba, should be reviewed every 15 years. The last review was for the 2006 changes to heighten the dam wall and add five spillways that operated at different levels of flood. In addition to flood, there are other risks such as loss of the World Heritage status, permanent loss of endangered

[6] Blue Mountains Lithgow Oberon Tourism Destination Management Plan, 2013, cited in BMEE-Tourism-Industry-Profile-2015.pdf.

[7] Naaman Zhou, Blue Mountains wilderness would be 'permanently' changed by raising dam wall, leak reveals, Thu 13 Jun 2019 18.50 AEST,Last modified on Fri 14 Jun 2019 10.42 AEST.

habitat and species, permanent loss of cultural heritage. None of the risks outlined in the over 4000 pages of the EIS is considered in a realistic way and the whole exercise seems to be a propaganda exercise than a proper and independent assessment of risks to people and their property or to indigenous heritage or the environment.

Assessment of risk is often based on empirical historical data of a threat or hazard occurring (see Figure 1). There usually is plenty of data on common risks but as risks become rarer there is decreasing data and much larger uncertainties in its interpretation. At some point there are examples around the world of events but no local data. At this point assessment of risk must rely on foreseeable *credible* mechanisms for the threat or hazard to occur. Beyond this thought experiments and imagination can lead to incredible mechanisms of failure, often in the realm of science fiction. A problem is that with the passage of time there are changes that occur in technology, society, the natural world and community, that bring future scenarios of threat from fantasy to being credible.

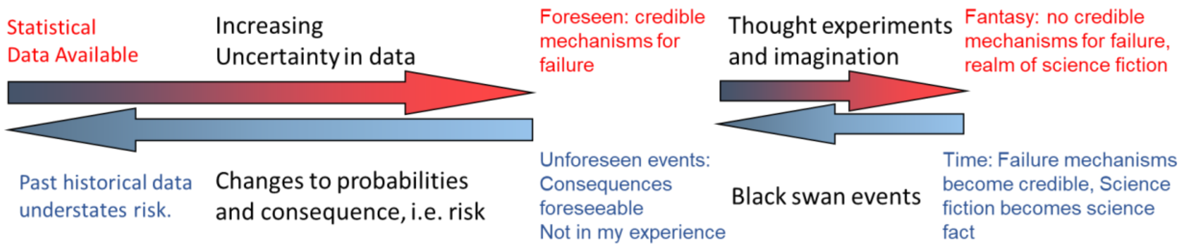

Figure 1 Risk assessment and Uncertainty.

When these previous fantastic events occur, it is often claimed that they are unforeseen, or "*not in my experience*". Prior to the event occurring there is a presumption that it cannot be foreseen, or it cannot be controlled. There is little analysis of rare events, which are only rationalised after the event, and historically considered as outliers.

For example, the Tokohu Earthquake and Tsunami has resulted in $\$_{US}$424 billion (2021 estimate) in direct losses and nearly 20000 people died or went missing[8]. The recovery 10 years later has been hampered by the radiation effects of the Fukushima nuclear power plant on the local area. There were, however, intergenerational warnings for tsunami in this area. There were over 300 stone markers indicating that it was unsafe to build below that height with inscriptions similar to "The homes on higher places will guarantee the comforts of the descendants, remind the horror of the tsunami, do not build homes below this point. We suffered tsunamis in 1896 and also in 1933, only 2 villagers in the former disaster and 4 in the latter survived. Keep on your guard even years pass by."[9] Most of these stones date from the 1896 Meiji Sanriku and !933 Shawa Sanriku tsunami. The authorities knew that the wall around the nuclear plant was inadequate for a tsunami generated by a Magnitude 9 earthquake, but nothing was done to correct it.

It was a similar story with Hurricane Katrina with a cost of S_{us}167 billion and between 1200-1850 deaths, with levees that were of 1950's construction and known to be inadequate in the early 1990's for a category 5 Hurricane. There was no review and the political expedience was for more immediate requirements.

The reality from these events, as well as other examples, demonstrate that factors which lead to catastrophic outcomes are dynamic and change with time. The dynamic behaviour is poorly

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[8] https://en.wikipedia.org/wiki/List_of_disasters_by_cost, current cost to the period 2017-2021.
[9]Mark Willacy, personal communication, 2013

understood. Catastrophic outcomes are ignored because there is thought to be no immediate impact on society with any assessment focussing on static assumptions. As it is a long-term problem it is often politically difficult to fund adequate and appropriate control for these risks.

Out of Sight, Out of Mind and Doomed to Failure.

Risks from a Heightened Dam wall

When considering risks involved in raising the dam wall as a mitigator of flood, there several consequences that have not been discussed or have been downplayed in the discussion. This gives a false impression on the worth of the project as the downside has not been factored into the costs that would be borne by society.

As already discussed, the major threats to this project lie in flood and inundation, loss of world heritage status, loss of indigenous heritage and loss of habitat and flora and fauna. As you can see from Figure 2. A problem immediately noticeable from the EIS is that the risk exposure of the Government and hence the impact on society has not been properly costed. This arises because: 1) the full impact taking account of changes in technology, politics, climate and society have not been properly assessed, 2) Indigenous loss, habitat and flora and fauna loss, and the loss of World heritage status all have an extensive aesthetic value for society which cannot be put effectively into a dollar value. The second of these provides an overarching analysis that naturally leads to the first.

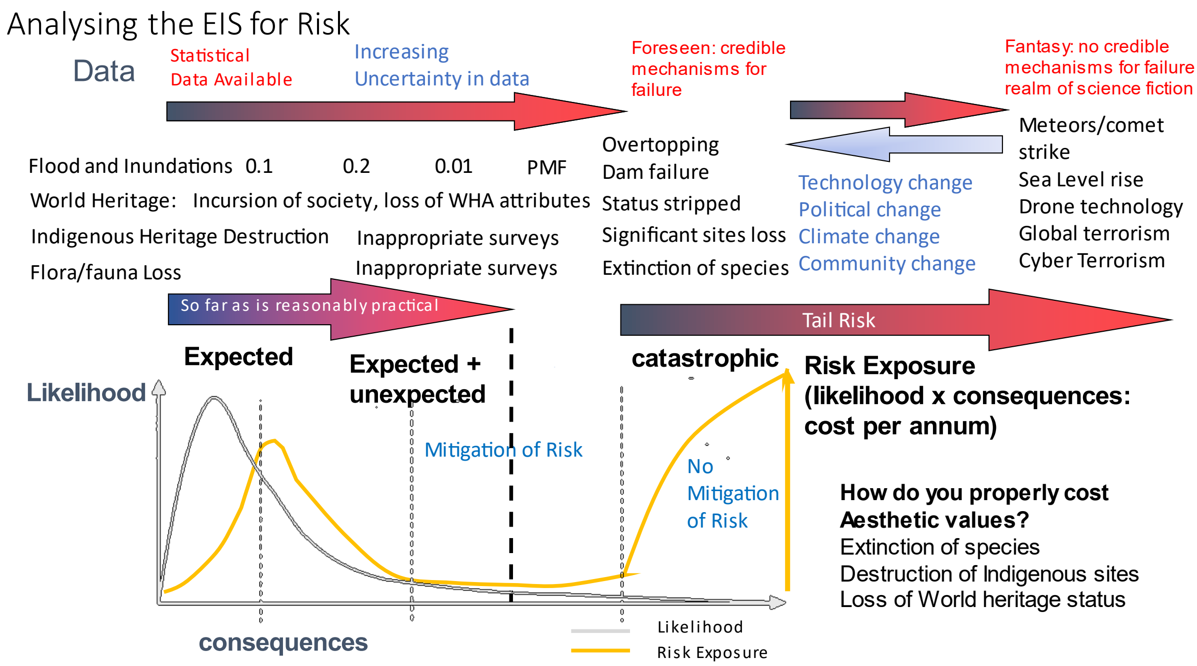

Figure 2 Basic hazards and threats that give rise to Catestrophic outcomes for Warragamba Dam.

Domains of influence on Catastrophic Dam Risks

Catastrophic risks occur because of failure to assess the many feedback loops that occur across society all with competing requirements and which change through time. Figure 3 is a schematic showing a dynamic process of assessing the risk across different domains and what controls need to be monitored to provide timely feedback as to whether the risks are being controlled or are leading to a runaway situation. The first four domains will influence to a lessor or greater extent, the decisions that affect regulation of an industry or the zoning of land that can be affected by the fifth domain: the water industry surrounding the development of the dam and its infrastructure that is the subject of the EIS. It is possible to measure the control performance in this system by having sensors that give continual feedback which are used to assess the status of other factors through inference.[10] Qualitative factors can be assessed as being present or absent, or if a control, on or off. This allows quantification of the status of the system with time.

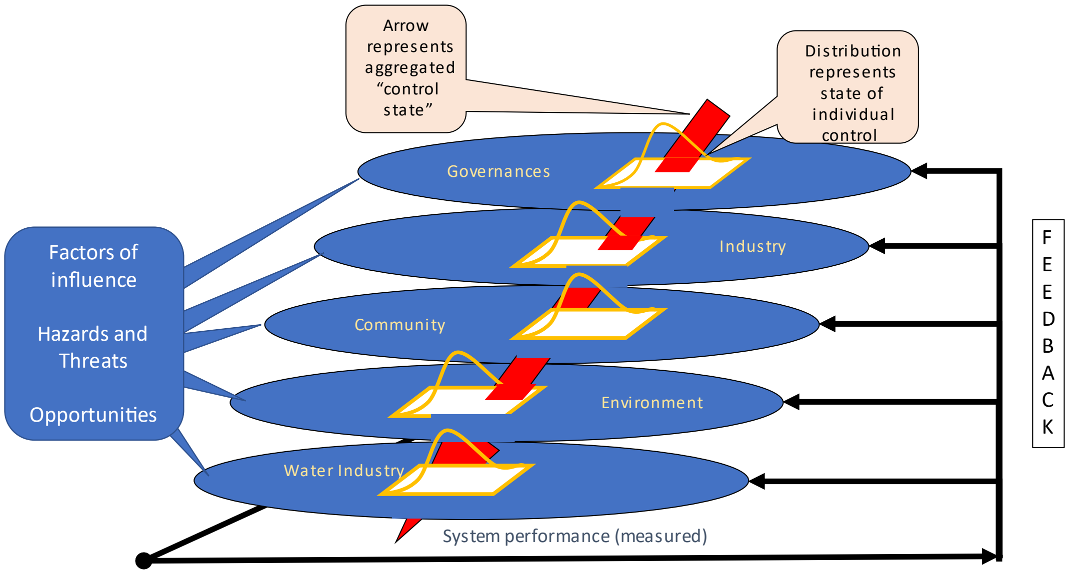

Figure 3 Framework for Risk assessment and evaluation

Before applying this type of assessment to the raising of the dam wall, it is important to understand the objectives of the NSW Department of Planning, Industry and Environment and how they propose to achieve these. In the context of the Dam raising there are several objectives that are the responsibility of the Department. These include a strong and liveable New South Wales, a resilient and sustainable environment, sustainable and secure water resources. Figure 4 shows the current relationships in the decision making process. The Dam Safety regulator requires an assessment of the safety of the dam every 15 years. This uses a quantitative approach based on engineering principles of likelihood of an event occurring and the magnitude of its consequences. This approach does not stop major failures in a system. In particular, it is the absence of an assessment and control of human factors in government that lead to such failings. Having a Department that combines industry, investment with planning and environment leads to continual conflicts of interest and increases the potential for corruption of ministers and heads of sections by industry to achieve their outcomes rather than a sustainable future which is the stated goal of the Department. Figure 4 indicates that there is a natural feedback loop every 10 to 15 years to change the function of the dam either by raising the wall or enclosing the wall to make a temporary upstream zone a permanent one or by increasing the upstream impact zone. It is neither sustainable or an appropriate use of land.

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[10] An example of this process is Bayesian Inference of Asteroid Physical Properties: Application to Impact Scenarios, Jessie Dotson, Lorien Wheeler, Clemens Rumpf, & Donovan Mathias, NASA Ames Research Centre, given at the 2021 Planetary Defence Conference.

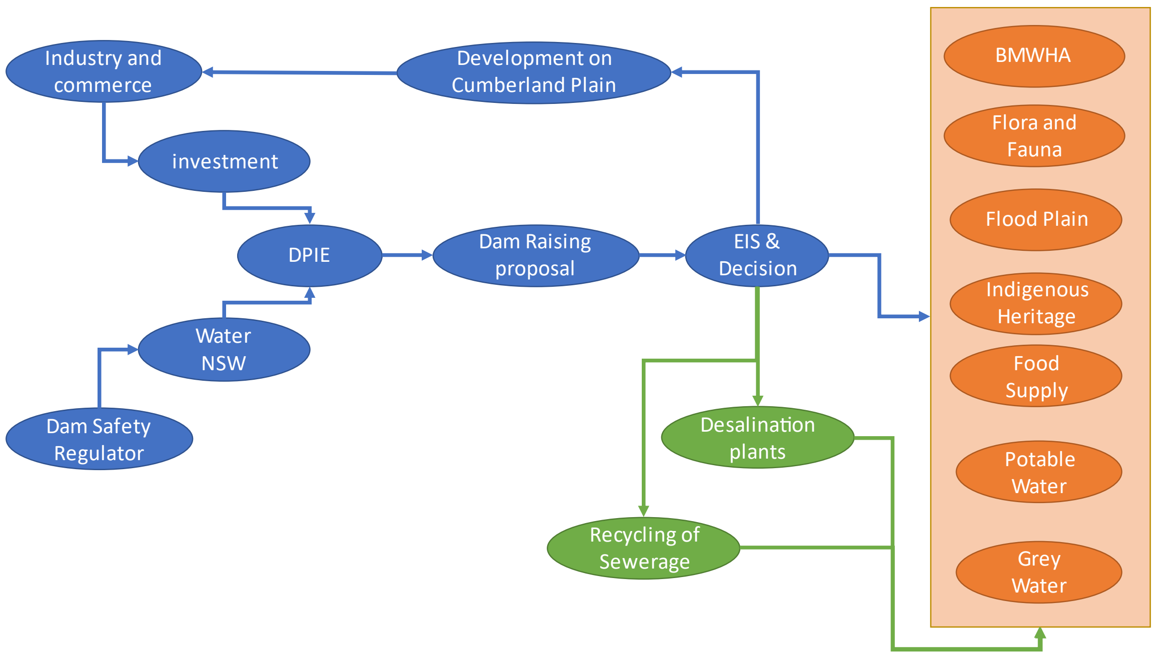

Figure 4 The process that occurs with raising the dam wall.

The decision to raise or not raise has an impact on all the boxes in brown. Any decision to raise the dam wall leads to adverse impacts on all the brown boxes including the securing a portable water supply for the population of Sydney. Because the process is unsustainable, it will lead to loss of flora and fauna in the WHA and surrounding parklands, will destroy Indigenous and early European heritage and loss of World Heritage accreditation because of impacts in the WHA and from over commercialisation and building in the Blue Mountains area that lesson the natural beauty, impact on noise and other aesthetics within the WHA. The process ignores the impact of the local food chain supply into Sydney as well as ensuring that Warragamba becomes an increasing National security risk due to its increasing vulnerability.

The process also ignores the drought cycle for water management and how this impacts on the ability of Warragamba to supply potable water to Sydney.

Note there is no process for getting representative input from the general population except through a response to the EIS or through the local Councillors or MPs at both Federal and State levels. Surveys that do not give an indication of the risks and their uncertainties involved in a project are not reliable.

If instead of assessing only the flood cycle, the drought-flood cycle is used for the EIS, then some alternatives such as building desalination plants and recycling of water can be used to provide water security while ensuring a better national security objective is achieved as Warragamba dam is seen in the Global Context as being less vulnerable. It also ensures there is no impact on the WHA or water supplies to Sydney. Even the ability to build to a limited extent on the Cumberland Plain can occur as long as the natural flood levels from all the tributaries are taken into account. This is a much more sustainable outcome for the communities within the Hawkesbury-Nepean River systems.

Flood and Inundation risks

The EIS discusses the effects of floods with an annual exceedance probability (AEP) from 0.1 to the PMF but fails to take account of changes in the future that impact dam safety. Figure 5 shows many of these and how they contribute to both flooding and dam failure. They can be broadly categorised as Natural or Human-behavioural.

Impact of climate change

While climate change was partly assessed, they did not include any discussion involving the uncertainty involved. For example while the Government takes the view that sea level rise will be in the order of 1.3 to 2m by 2100, it ignores the 1% chance that it will be 7m espoused by Scientist involved in ice melt mechanisms.[11] That degree of sea level rise will affect the Nepean River all the way to the Penrith Wier, not only will this impact the natural flood levels but also alter the water tables in the Hawkesbury-Nepean system. Depending on how fast such a rise actually occurs, the EIS flood levels are going to be underestimated. Any sea level rise above 2m will cause an increase in flood levels compared to the EIS and this has ramifications for the built environment into the future. The other effect of climate change is the positioning of an east coast low that is blocked from moving to the east causing heavy rain to fall for five or seven days. Currently 3 days of 100mm-150mm from east coast lows is not uncommon. The impact does depend on which part of the Hawkesbury-Nepean catchment it falls.

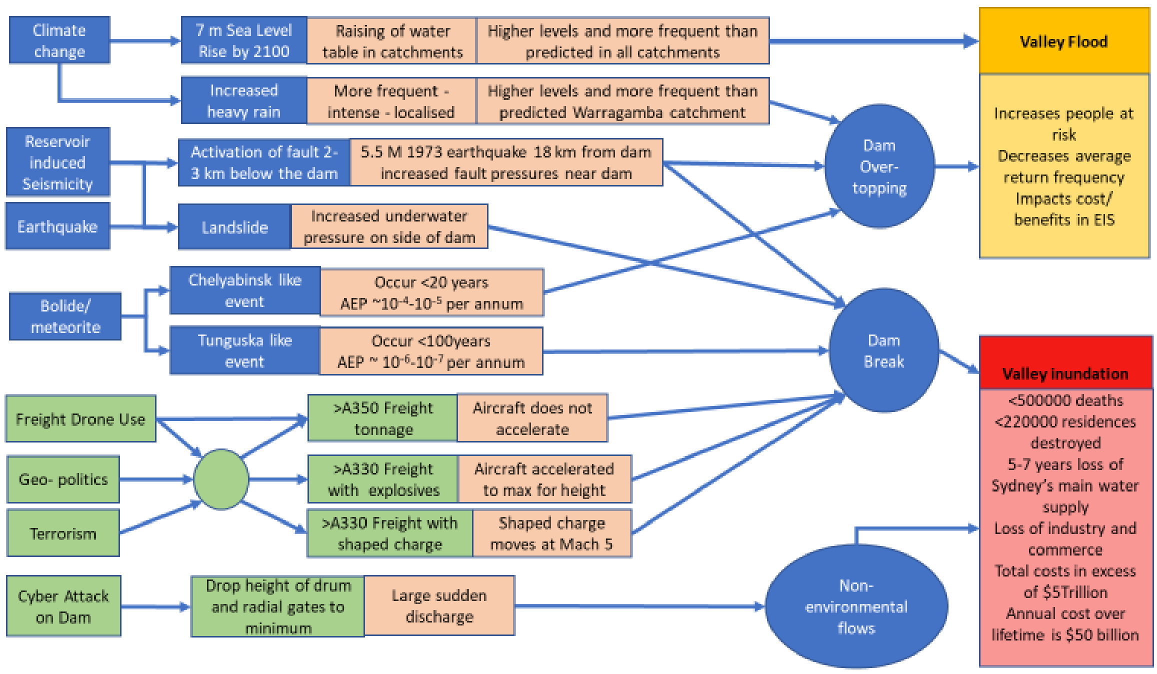

Figure 5 Catastrophic pathways to Valley Flood and Valley inundation

The March 2021 floods occurred because of three days of heavy rain over the Grosse Valley and Upper Blue mountains. The flow down the Grosse River, Bedford Creek and Glenbrook Creek contributed to the majority of the flood waters in the Nepean Hawkesbury rather than outflows from Warragamba dam. A sizeable event over all the catchment would have exceeded the PMF.

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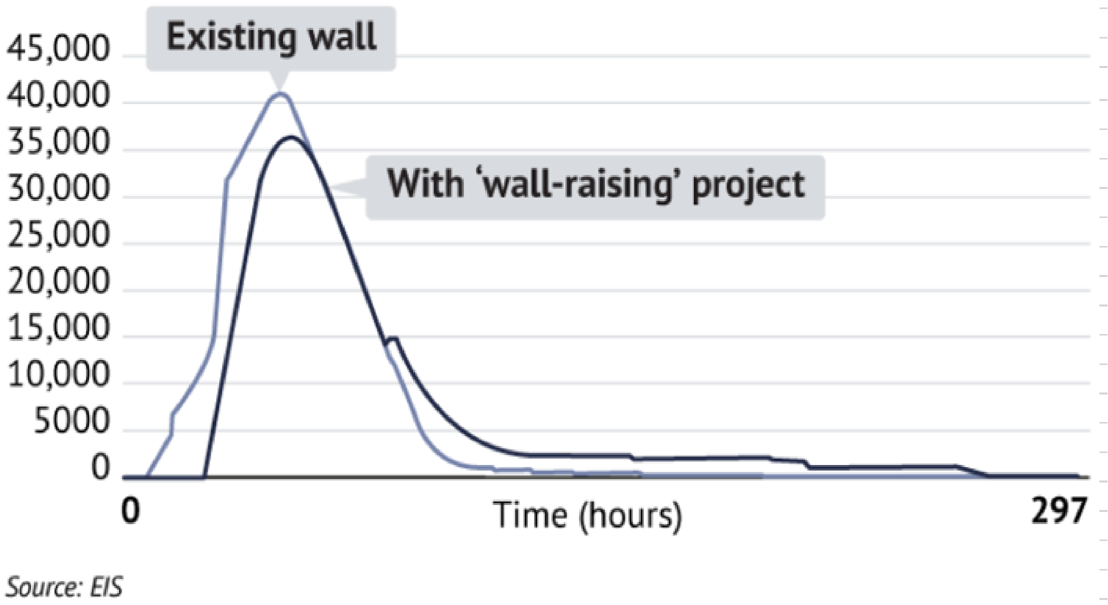
[11]Expert assessment of sea-level rise by AD 2100 and AD 2300, Benjamin P. Horton, Stefan Rahmstorf, Simon E. Engelhart, Andrew C. Kemp, Quaternary Science Reviews 84 (2014) 1-6, http://dx.doi.org/10.1016/j.quascirev.2013.11.002



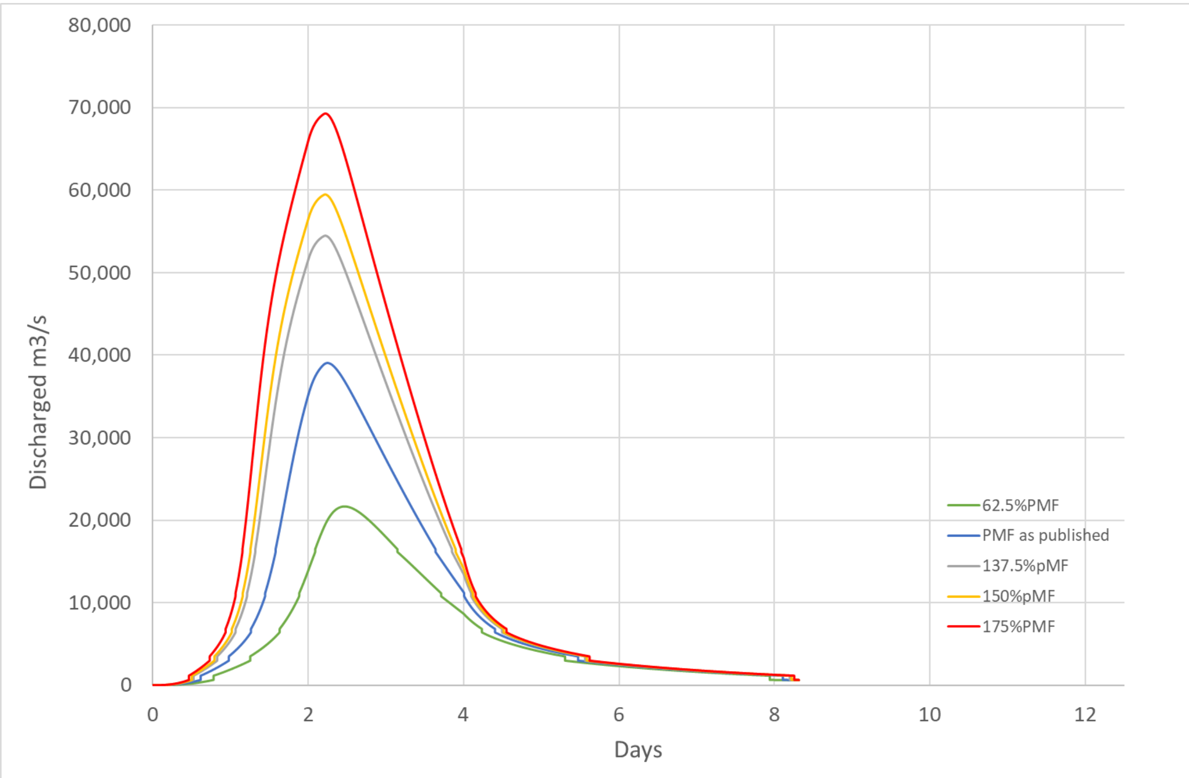


Figure 6 Comparison of discharge rates with published graph of PMF floods

Figure 6 is a comparison between discharge rates that have been published[12] and flow calculations over a broad crested weir[13] relative to the PMF. The PMF was used to calibrate a four day influx to the dam to get agreement with the published hydrological inflow curve. It corresponds to an average

[12] Leaked charts 'undercut' case to lift Warragamba dam wall: opponents, Peter Hannam, Sydney Morning Herald, August 5, 2019 — 12.00am.

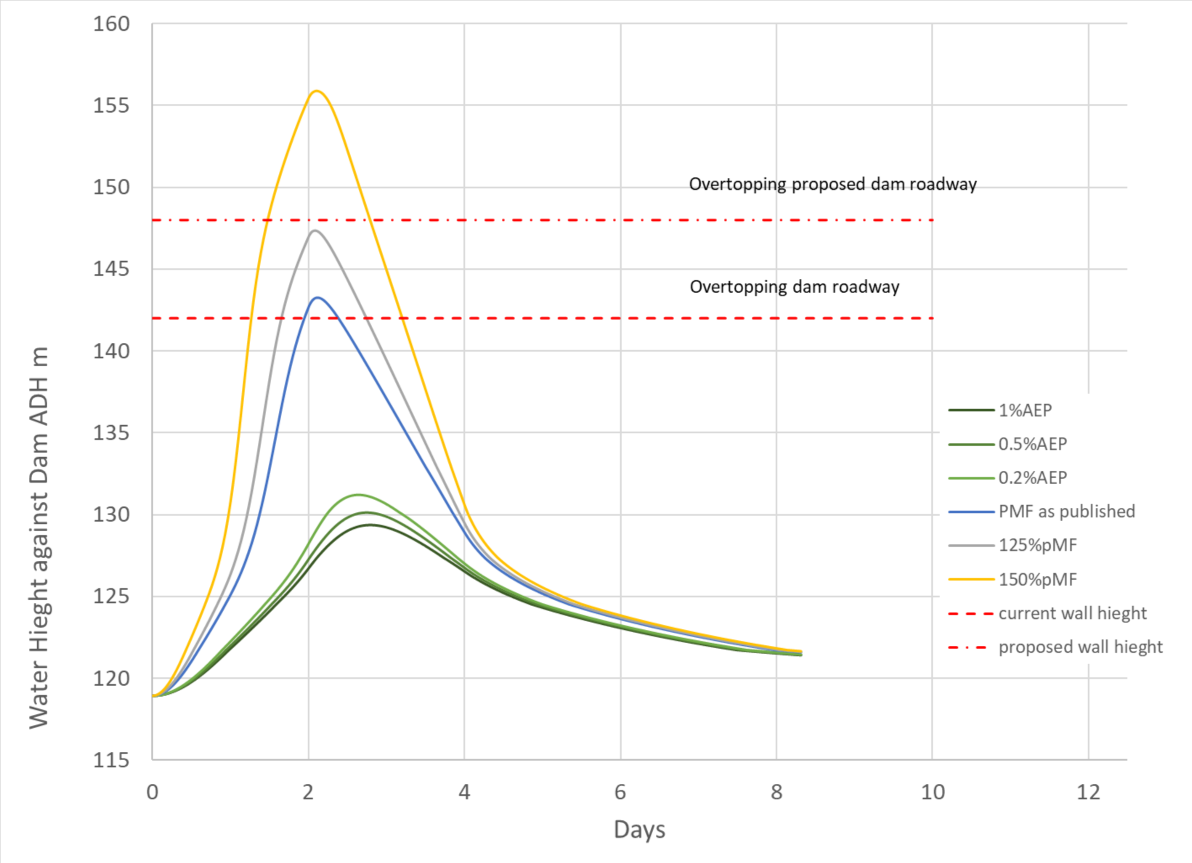


Figure 7 Water Height at the Dam Wall.

discharge of 10500m^3/s over the four days with a peak of 40950 m3/s. The peak is the same height as the published data from the EIS for a PMF flood. Climate change is likely to increase this amount.

The water height at the Dam wall for the variation in PMF is shown in Figure 7. This shows the current height of the roadway. The PMF value in the EIS give a similar maximum height of this roadway. Values higher that the PMF overtop the roadway and risk collapse of the upper portions of the dam. The second height reference is in relation to the increased wall height in the proposal. Anything above 150% of the current PMF estimate with cause overtopping of the new roadway and heavier flood heights in the valleys with a potential for partial dam collapse.

Seismicity and earthquakes

While Warragamba dam has been fitted with seismic sensors to monitor movement of the dam, they are not good predictors of movement from an earthquake particularly if the slip fault 2km below the dam becomes activated. The 1973, 5.5 magnitude earthquake 18 kilometres to the west not only caused problems with anchoring the dam to the western wall (tension bolts included as part of the construction of the spillway in 2006 to anchor the dam) but would have increased the pressure in the slip fault that is about 2km below the dam. Failure of this part of the slip fault would cause collapse of the dam. Any landslide from an earthquake into lake Burragorang may produce an impulse pressure at the base of the dam wall large enough to cause failure.

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[13] RM Khatsuria, Hydraulics of spillways and energy dissipators, Marcel Dekker, New York, ISBN 0-8247-5789-0, 2005.

Bolide and Meteorite Impacts

While the impact of meteorites and bolides are relatively rare events, recent data on Near Earth Orbit impacts suggest that estimates of the risk have been at least an order of magnitude too low. Because of the impact on cities and infrastructure such as Warragamba Dam is very high, the risks moves into an intolerable category of social risk even though the likelihood is very low. The 2013 20m diameter Chelyabinsk meteor caused 15000 injuries mainly due to flying glass. An event similar in size to the 1908 Tunuska River meteorite (which levelled about 2000 square kilometres of forest in Siberia), was thought to be responsible for the destruction of 15 cities in the Jorden valley including Sodom, Gomorrah and Jericho in 1569 BC increasing salinity and sterilising the area for at least 600 years.[14] While this risk is intolerable, an impact of this size would be much greater than just collapse of the dam.

Nearby Developments

The EIS, even though it was required as part of the Secretaries requirements[15] does not adequately deal with risks from nearby developments. The first is whether the building of the Western Sydney Airport had an effect on the risks associated with the security of people living in the Hawkesbury-Nepean Valley. The second is whether the need for increased housing that seems to be hidden behind the need for this project has unseen risks for the Hawkesbury-Nepean valley.

Behaviour risks that threaten the dam are mainly due to the construction of Badgerys Creek Airport and the flight paths which invariable can be used to hide destructive intent. Currently IATA are trialling remotely piloted air services (RPAS) for freight in the US. This type of aircraft use substantially changes the risks from current flying. The operating mode, 05, approach flight path into the airport (from the southwest) is shown in Figure 8. An aircraft on a standard approach would be at about 570m above the terrain (the low height is due to the airport being 300m below the escarpment over which the aircraft are flying) at a speed of approximately 330km/hr at the merge point of 10 nautical miles. This is some 12 km from the dam wall and several flightpaths from the North to land from the southwest come much closer. Previous studies in the 1997 EIS for WSA looked at controlled flight into terrain with the previous generation of aircraft at a strike angle of 20^o and 60^o on Warragamba dam. These studies are now irrelevant given that current dedicated freight aircraft can carry 100 tonnes of freight with a maximum range of 9200km and engines that can generate 500kN of thrust each. Near the end of its range, a fully loaded cargo plane would weigh about 250 tonnes. Consequently the plane can generate enough thrust to accelerate from a nominal land speed to its maximum speed close to the ground. Impact on the dam can be above the threshold for collapse.

Warragamba dam is vulnerable to terrorism or pilot suicide. This scenario is considerably different from a CFIT accident due to the ability to fly the aircraft at full speed into the dam wall at low level. This speed is well above the normal commercial speeds which aim to conserve fuel efficiency. This increases both the energy and the momentum at impact that can result in breaching the top 30m of the dam. Once the dam is breached in this way, the hydraulic pressure behind the dam, assuming it occurs when the dam is near full or in flood, will cause further collapse of the dam.

[14] A Tunguska sized airburst destroyed Tall el-Hammam a middle bronze age city in the Jordan valley near the dead sea, Ted E. Bunch et al, Scientific Reports, (2021) 11:18632.

[15] EIS Documents, Revised SEARS.pdf

The cargo fleet makeup now is different to 20 Years ago. Currently the main cargo plane used for major longhaul cargo is the B777. This is not the largest cargo plane by volume and larger payloads

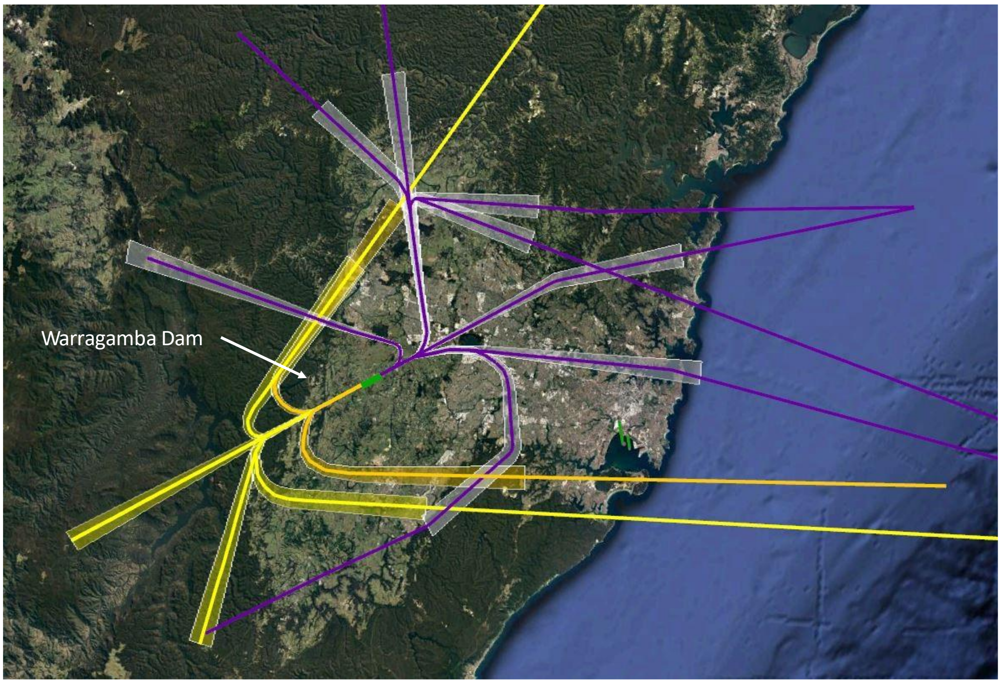

Figure 8 Flights paths of Operating mode 05 for WSA. The approach routes are shown in yellow, the slightly darker yellow is for a 4-degree glide slope into the airport and the lighter yellow is a 3-degree (standard approach). The standard merge point is 10 nautical miles from the runway threshold. The 4-degree merge point is about 0.6 nautical miles from the runway threshold The departure routes are shown in purple. The width as indicated by the coloured transparent zones represents a two degrees deviation from the runway threshold. This deviation matches the areas where crashes historically occur on approach and departure.

are possible. The engines on this type of aircraft have much more thrust than those on commercial aircraft of 20 years ago.

The cargo capacity of a B777 has a payload carrying capacity of 100 tonnes with a maximum payload and aircraft weight after a 9000km journey of 250 tonnes. A full cargo of high explosive that is initiated at impact will ensure the dam wall is breeched if the initial impact of the aircraft is not wholly successful. Modification of the internal fuselage to produce a shaped charge in front of the explosive would increase the impulse loading on the dam compared even to the 100 tonne explosives scenario.

The population at risk in these scenarios was not assessed. The NSW government has recognised that the Hawkesbury-Nepean valley has the highest flood risk in the State [16]. A 1 in 200 year flood risk study yields an estimate of the population that would be affected by flooding as approximately 350,000 residents in the Penrith, Richmond, Windsor and Hill districts of NSW. The population is expected to double by 2050 to 700,000 in the same area.[17]

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[16] EIS Documents

[17] Final Report for Infrastructure, NSW, Molino-Steward, 2012, Molino_stewart_hn_flood_damages_report_final.pdf

There is significant difference between a flood and a sudden inundation due to the timescale over which it occurs. With a flood there is usually a forecast of heavy rain and potential for flooding occurring over several days. This allows time for the SES to put evacuation orders into place. An inundation which would see a wave would cause a rise over the flood plain over a few hours at most. This wave would be approximately 50m-75m high coming from Glenbrook Gorge at Emu Plains. This is more than 20m above the flood levels discussed in the EIS. There will be no forewarning and if it occurs at night most residences will be occupied and the ability to evacuate limited. An upper estimate is about 300,000 killed in this type of scenario based on the current population and this will be double by 2050.

The economic impact of this loss is about $4 trillion based on comparison of the Fukushima nuclear disaster costs and Hurricane Katrina costs for New Orleans. It is made up of the following:

- Cost of rebuilding the dam.
- Cost of alternative water supplies to Sydney while the infrastructure is rebuilt.
- Cost of loss of business due to lack of water supply.
- Cost of moving businesses to other areas of the State or Country.
- Reparation to families who have lost loved ones.
- Rebuilding and refurbishing costs for residences affected.
- Rebuilding and refurbishing other infrastructure such as electricity supplies as the main supply lines will be washed away and several distribution centres are in the flood zone.
- Insurance and banking losses.
- Legal costs such as a class action against the government and the decision makers.

Aircraft can be within 8km of Warragamba dam wall from both directions as shown in Figure 8. The time to run into the dam wall is at most 90 seconds and less on a sudden turn. RPAS aircraft while having a remote pilot on the other side of the world may not be responsive to orders from Air Traffic Control as it will be possible to pre-program the flight and lock out alterations from remote pilots.

Any response to a sudden turn can be broken down into following time delays:

- ATC or Defence recognising that an aircraft has gone off course
- ATC alerting Defence or Defence Alerting their command that Aircraft has gone off course
- Response time from Defence to get crews into the air or fire automated weapons
- Flight time of aircraft or weapon to intercept the plane

The sum of these will be greater than the flight time into the dam wall. The nearest intercept capability currently is at Holsworthy (a helicopter squadron with hell fire missiles, other intercept capabilities are from Williamtown F18 strike fighter squadron and if in the maintenance facility at Orchard Hills has an operational system, a surface to air missile.

Reliance that Intelligence gathering would give notice of such a plot goes against historical evidence of surprise attacks:

- London bombings in 2007; the perpetrators had been noted as persons connected to a place where the main players were under surveillance. The individuals were not placed under surveillance because of lack of resources and were considered to be peripherals as a threat.
- Charlie Ebdo Attack Paris 2015.
- Pairs Attacks 2015; The bomb maker was not found until after the Brussels bombing in March 2016 and the system had been set up so that there was a clear disjoint in

communication between the making of the bomb materials and those who carried out the attack.[18]

- Belgium Group raids and findings 2016 after the Paris attacks; A manager of a nuclear facility in France was found to be under surveillance by the terrorist group. The intentions were not clear, but it was suggested that this was being set up as a kidnapping threat to gain access to the facility.[19]

Gated spillways such as at Warragamba are not as safe as their operation can introduce error which are not present with ungated dams. They can, however, mitigate downstream flood and is the reason why it was used in the building of Warragamba dam, and upgraded as the design of the gates and their operation improved. The additional risks to the dam, apart from aircraft crashes, involve both cyber-attack on the dam infrastructure and operational error in operating the drum and radial gates. This is likely to lead to an environmental release the size of the drum and radial gate height and width.

The discharge rates with time are shown for 6 scenarios: [20]

- Collapse of the radial and drum gates with a full dam, with and without a 10000m^3/s flood over 4 days. This assumes a width of 75m and mimics a cyber attack on the dam infrastructure. The dam discharge height is taken as 73.44m ADH
- A 60 m depth collapse of the dam across the drum and radial gates area with a full dam, with and without a 10000m^3/s flood over 4 days. This assumes an aircraft attack and collapses the pillars supporting the drum and radial gates. The discharge height is taken as 58.92m ADH
- A full depth collapse of the dam across the drum and radial gates area with a full dam, with and without a 10000m^3/s flood over 4 days. This assumes an aircraft attack and collapses the pillars supporting the drum and radial gates. The discharge height is taken as 26.2m ADH

The collapse of the dam gives considerably more water flowing down the Warragamba River than the PMF discharge rate and in a much shorter timescale. These large inundations are likely to result in water heights over 20 m higher than the flood levels contained within the EIS. The kinetic energy is also large enough to climb over the top of the ridge at the conjunction of the Warragamba and Nepean rivers producing flooding to Glenmore Park over the hilltop rather than from the river.

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[18] R Booth, 2016, Brussels attackers 'had enough for 10 more bombs', The Guardian, 24 March 2016, https://www.theguardian.com/world/2016/mar/23/brussels-attackers-had-enough-for-10-morebombs-expert

[19]K Vick, 2016, ISIS Attackers May Have Targeted Nuclear Power Station, 25 March 2016, http://time.com/4271854/belgium-isis-nuclear-power-station-brussels

[20] Flood inflows taken from averaging Figure 3-23, lake Burragarong inflow hydrographs, EIS Appendix H1 Flooding and Hydrology.pdf

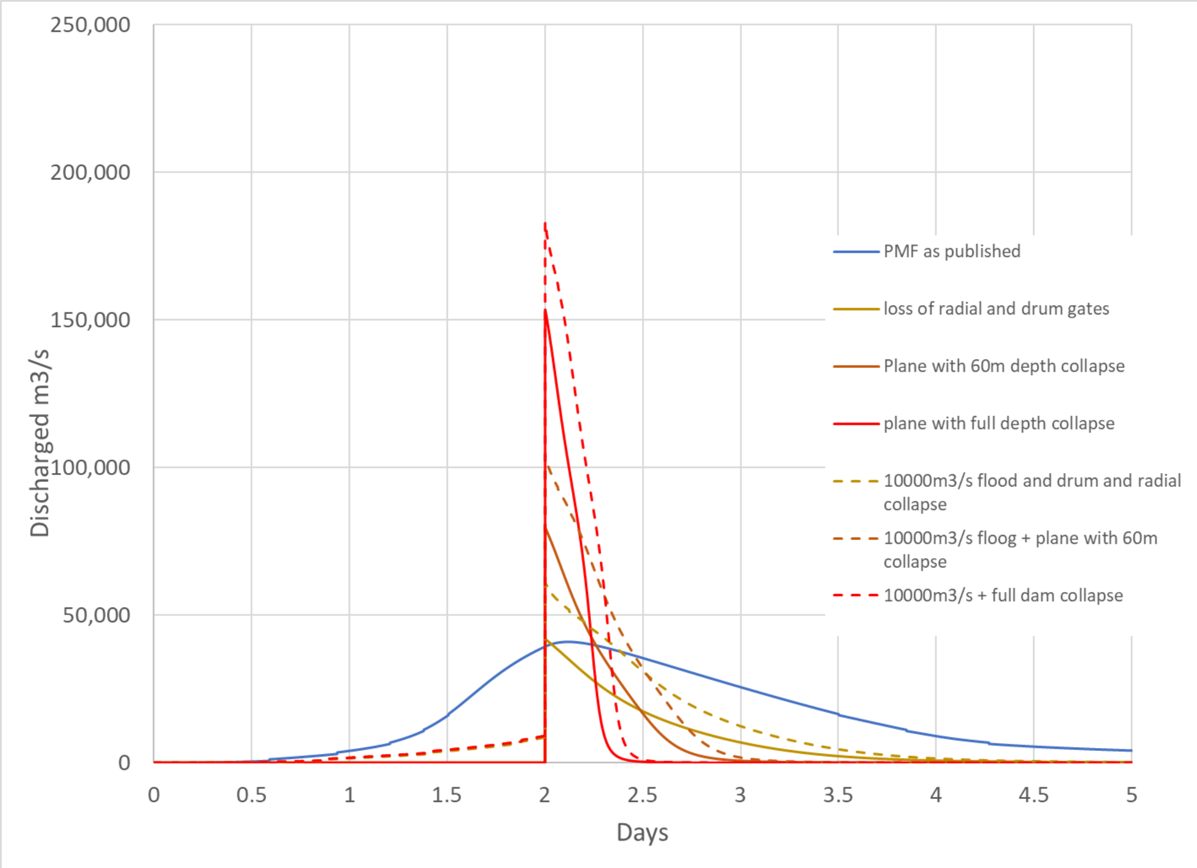

Figure 9 Discharges of collapsed dams in comparison to the PMF chart published in the EIS.

Cost of Loss of the Dam

Loss of the dam wall was not considered in the Hawkesbury-Nepean EIS study. This means that the mortality and costs associated with the impacts have been vastly underestimated. As indicated above this estimate is of the order of $4-5 trillion dollars.

The mortality rate for rapidly rising floods is shown in Figure 10 as a function of water depth and gives a good fit to observed data. [21] There is a lack of empirical data for high flood levels associated with dam breaks, but the data would tend to suggest the mortality rate trends towards 1. Jonkman also gives average mortality rates for riverine floods and flash floods of 0.0049and 0.036 respectively. It would be expected that normal flooding in the Hawkesbury-Nepean would have these range of mortality rates with larger values associated with larger floods. The loss of the dam, however, would give fatality rates between 0.8 and 1 with larger values associated with larger populations exposed because of the inability to evacuate.

[21] SN. Jonkman, J.K.Vrijling, Loss of life due to floods, J. Flood Risk Management 1 (2008) 43-56.

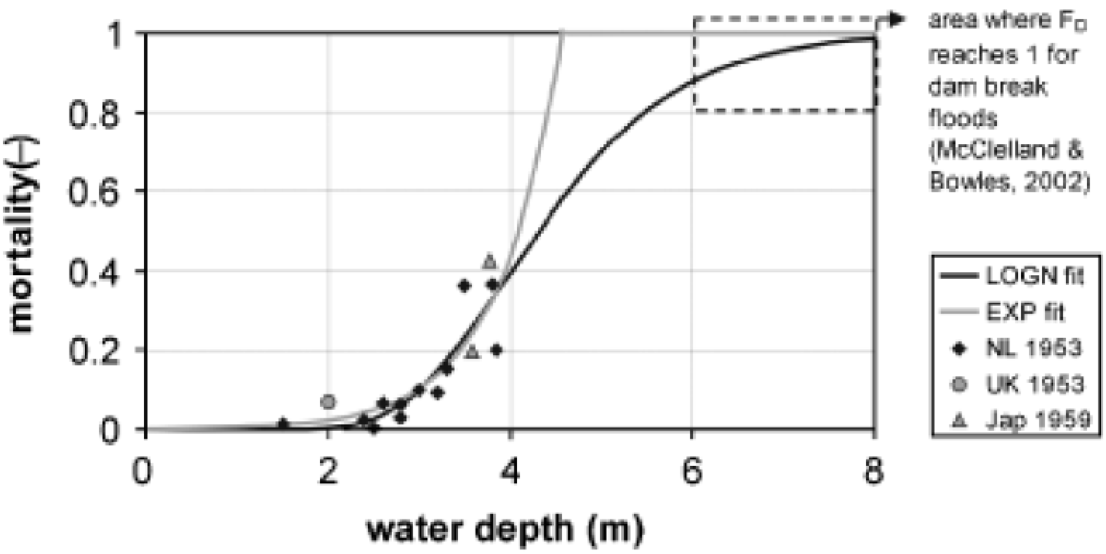

Figure 10 Mortality rate as a function of water depth with rapidly rising waters. Note that this reaches 1 for dam breaks.[22]

Estimates of building damage from floods is dependent on the inundation depth, the land use, the value of elements at risk and the susceptibility of those elements to damage. Examples of the variation of damage with water depth for different areas of Europe are shown in Figure 11.[23] A common feature is that they all tend to 1 for a water depth above 6m. While each area in the Hawkesbury-Nepean would need to be modelled in detail, gross estimates of the cost of damage can come from the number of properties exposed to different floods. Again the damage factor would be expected to increase from small to larger floods and approach 1 for loss of the dam.

Estimates of the cost of a human life in a flood event is on average, $M12.37 per person and immediate property loss is $855000 per displaced family over a two year period.[22] Note some building loss will also come from uninhabited buildings, many of these are commercial premises.

Table 1 estimates the cost of life lost as a function of the chance of losing a life for different flood and inundation events. The shaded areas are the probable extent of life loss for the different flood events. The probable cost from loss of the dam is 2 to 3 orders of magnitude greater than normal flooding. Note that the costs from a 50% event is probably an underestimate given that fatality rates will be 80% for a dam failure at night.

Table 2 indicates the range of loss from damage to buildings from different flood events. The number of dwellings has been calculated from the mean size of the population per dwelling.[24]

[22] Cited in 21:DM McClelland, DS. Bowles, Estimating life loss for dam safety risk assessment – a review and new approach. IWR Report 02-R-3-, 2002.
[23] H. de Moel, J.C.J.H Aerts Effect of uncertainty in land use, damage models and inumndation depth on flood damage estimates, Nat. Hazards (2011) 58, 407-425.
[24] https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/1

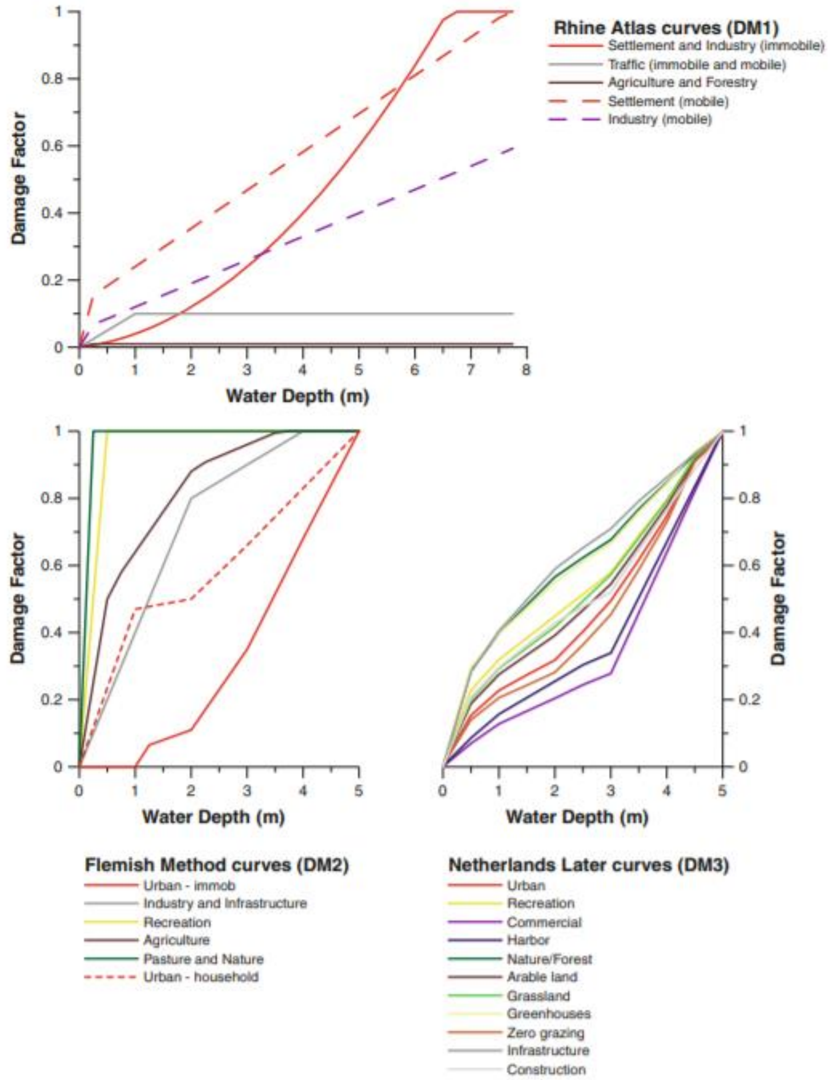

Figure11 Damage factors for buildings in Europe.

	Chance of loss of life	0.49%	3.6%	10%	50%
Conditions	Number at risk	Cost of a loss of life $B	Cost of a loss of life $B	Cost of a loss of life $B	Cost of a loss of life $B
1 in100 flood	5000	0.3	2.2	6.2	30.9
1 in 500 flood	12000	0.7	5.3	14.8	74.2
PMF flood	40000	2.4	17.8	49.5	247.4
Dam Collapse	300000	18.2	133.6	371.2	1855.8

Table 1 Estimated costs of loss of life for the current exposed population. The shaded boxes represent the most likely range for the different average chance of loss of life.

	Chance of loss of house	10%	20%	50%	100%
Conditions	Number at risk	Cost of a loss of house $B	Cost of a loss of house $B	Cost of a loss of house $B	Cost of a loss of house $B
1 in100 flood	1923	0.2	0.4	0.9	1.8
1 in 500 flood	4615	0.4	0.9	2.1	4.3
PMF flood	15385	1.4	2.8	7.1	14.2
Dam Collapse	1153846 (115,385 ?)	106.7	213.5	533.7	1067.3

Table 6 Estimates of building loss costs. The shaded boxes represent the most likely range for the different average chance of loss of a house.

The shaded areas are the probable damage ranges for the different flood types. Again it shows that direct damage costs for loss of the dam is at least two orders of magnitude greater than normal floods expected on the plane. Both the mortality and building estimates do not include loss of animals, loss of business and other causes of loss, which accumulate to a total of $4-5 triilion.

Building Criteria are Inadequate for Flood Plain Management

The studies that have been done for the EIS use a 0.1%AEP as a demarcation for building or not building on the flood plain. This ignores larger floods that can occur and put people in harm's way. In Holland for instance, the level varies according to the type of land. Where levees or dykes are use the planning demarcation is 1 in 250 years where the population density is low and 1 in 10,000 years where the population density is high. A level of 1 in 2000 years is used near tidal rivers and 1 in 1250 years for the majority of rivers and 1 in 250 years in the upper reaches of the Meuse river.[25] In the UK the building criteria are based on zones, where unrestricted building is allowed in zone 1 corresponding to flooding of less than 0.1%AEP. No building is allowed in areas where the risk is greater than 1% AEP.[26]

[25] Richard Jorissen, Erik Kraaij and Ellen Tromp, Dutch flood protection policy and measures based on risk assessment, FLOOD risk - 3rd European Conference on Flood Risk Management , 2016, https://www.e3s-conferences.org/articles/e3sconf/pdf/2016/02/e3sconf_flood2016_20016.pdf

[26] https://www.ses.nsw.gov.au/hawkesbury-nepean-floods/

The reliance on a 1 in 100 year flood (1%AEP) as the sole criterion for building residences is clearly inadequate. It strongly suggests that opposition to changing this criterion has been from developers for the North West and South West Development areas as well as for Western Sydney Airport. Note that the 1in 10000 years adopted for high density populations in Holland, would preclude building the Northwest Development area. Note also that the Hawkesbury River is tidal to Windsor. A level of a 1in 2000 year flood would be a more reasonable criterion. The river is constricted at Sackville which prevents water escaping during flooding but does not prevent the effects of high tide and storm surges on increasing the heights of flood.

With climate change and more frequent heavier falls, the validity of using a 1%AEP is questionable as the original criteria of 1%AEP changes to 5%AEP or greater under climate change extremes. While the flood studies used for the EIS use a Monte Carlo Bayesian method for estimating the extent of flooding from climate change, there is no indication that the status quo has been treated the same. There are no anomaly graphs that show the difference in flooding between the status quo and the options for increasing the dam height.

Conclusion

The fallacy in the whole approach that has been taken with the EIS to argue for a heightened dam wall is that it ignores several mechanisms by which larger floods and impacts can occur. Collapse of the dam is not discussed and yet engineering texts require assessing the impact of dam failure through mechanical failure and through terrorism.[27]

Furthermore, the effect of development on increasing the runoff has been largely ignored. Water runoff from development within the Hawkesbury–Nepean catchment is a major concern. Runoff is much higher from developed areas of land than from natural runoff. There is anecdotal evidence that where new estates have been developed, flooding occurs into older property from runoff. While development areas are landscaped to provide areas for water runoff, they are only designed for a 1% AEP. They will not retain water from larger rainfall events. Because larger rainfall events can occur quickly overtopping of these holding areas contribute to flood levels.

Development covers the whole of the Nepean-Hawkesbury basin and different areas differ in the way it impacts the catchment:

- Development west of the Blue Mountains impact on the prediction of water heights in the dam catchment area
- Development in the upper Blue Mountains and those in the Lower Mountains increase the flows into Bedford Creek, Glenbrook Creek, Grosse River and other tributaries of the Nepean rather than into lake Burragarang.
- Development in the area around Camden which is due to house an additional 200000 properties of the south-western development area in the next decade flow into the Nepean River, South Creek and Prospect Dam.

[27] RM Khatsuria, Hydraulics of spillways and energy dissipators, Marcel Dekker, New York, ISBN 0-8247-5789-0, 2005.

- Runoff from the area around Penrith directly flows into the Nepean River. The runoff east of the northern road at Penrith flows into South Creek and then into the Hawkesbury River.
- Runoff from the Northwest development area directly flows into South creek and into the Hawkesbury River.
- The runoff from building in the Kemps Creek area around Kemps Creek and Leppington flows into Kemps Creek and then into South Creek and Hawkesbury River.
- The runoff from building in the Kurrajong, Glossodia and Colo Heights, designated by Hawkesbury council as areas of development, flow into the Colo River and then into the Hawkesbury River.

The non-inclusion of the effect of water flows from urban areas for more extreme periods of rainfall has a profound effect on prediction of flows in the wider catchment areas into the tributaries and increasing flash flooding in newly urbanised areas.

Future Sustainability

The SEARS requirements for the EIS are to show that the raising of the dam wall leads to a sustainable future. The problem with this, as has been shown above, is that it enables an endless cycle of development on the Cumberland Plain with increasing risks of collapse of the dam due to changes in technology and climate change. The current impact of loss of the dam is $4 trillion. This is of similar magnitude to the GDP of Australia. The risk exposure (See Figure 2) from this magnitude of exposure is of the order of $40 billion per annum if the dam breaks within 100 years due to the mechanisms outlined above.

When the full Drought-Cycle is considered, options that produce a sustainable supply of portable water for Sydney and reduce the effects of any Dam Break to a manageable level while allowing some building to occur within the Hawkesbury-Nepean Valley become cost effective. The solutions increasing water recycling will have an effect but the largest is through building desalination plants off the coast to take advantage of wind, solar and energy in the East Australian Current. All these renewable energy sources are mature enough to be utilised without too much additional cost. Not only can it supply enough water for Sydney but also enough to pump west of the mountains to prevent townships running out of water. While Sydney Water might object to pumping water uphill, proper use of renewable energy greatly decreases the supply and costs for desalination. Because it is also distributed the system can be extended from a few to many more reducing the on-going cost per annum.

Warragamba dam currently supplies 80% of Sydney’s water from dam resources. The other 20% coming from other dams in the Hawkesbury-Nepean catchment.[28] The desalination plant at Kurnell has capacity to supply 15% of Sydney’s daily water requirements.[29] The cost of building the desalination plant was $B1.83.[30] During the 2019 drought in NSW the desalination plant supplied

[28] https://www.waternsw.com.au/supply/Greater-Sydney/greater-sydneys-dam-levels

[29] https://web.archive.org/web/20090915004807/http://www.sydneywater.com.au/Water4Life/Desalination/documents/Desalataglance.pdf.

[30] https://en.wikipedia.org/wiki/Sydney_Desalination_Plant.

15% of Sydney's water and the Government was preparing to double the capacity to 500 m^3 per day (0.5ML per day).[31]

Since the first desalination plant was built, there has been technical advances in desalination systems worldwide which has brought the building cost down by a factor of 4 and have improved energy usage. Further cost and energy reductions by a factor of 5-7 is possible with newer technology.[32]

Parameter	No of plants 2	No of plants 5	No of plants 10	No of plants 20
Daily generating capacity (m3/day)	500000	1250000	2500000	5000000
Sydney Daily Consumption	30.00%	75.00%	150.00%	300.00%
Cost of additional plants ($B)	1.83	7.32	16.47	34.77
Operating costs per annum ($B)	0.11	0.27	0.55	1.10
Total cost over a 30 year lifetime ($B)	5.12	15.53	32.90	67.62

Table 7 Costs of building and operating more desalination plants.

For the purposes of this analysis the cost will be taken as a construction cost of $B1.83 and an operating cost of $M54.75 per annum[33] for producing 15% of Sydney's water supply throughout the year. Table 7 shows the daily generating capacity and costs associated with building more desalination plants.

These costs are conservative because current building costs and operating costs are lower than the value that has been used. There will be additional costs associated with the building and supply of green energy plant and equipment for all offshore desalination plants and for pump and pipeline systems required to distribute potable water within Sydney and to the west of the mountain. Even if this doubled the overall cost, a value of $B65 for 10 plants offshore is only 1.5 times the current risk exposure from the dam. It doesn't have to be built in 1.5 years and a longer timeframe of 10 years would reduce the cost to a manageable budgetary level for Government.

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[31] Sydney's desalination plant set to expand as drought continues, Australian Associated Press, The Guardian, Sun 11 Aug 2019 15.50 AEST.

[32] Nikolay Voutchkov, Seawater Desalination – Costs and Technology Trends, Chapter · April 2013, emst115NVProofredJAN282013.pdf, https://www.researchgate.net/publication/278309462.

[33] Based on a figure of $0.60 per m^3 of Water; https://www.sydneydesal.com.au/media/1136/desalination-operating-rules-cie-report.pdf.

This is an alternative strategy to raising the dam wall. It has benefits in terms of increasing society's resilience to threat as Warragamba dam is a key vulnerability for terrorism. Building desalination plants along the coast moves the water supply system from one dependent on Warragamba dam to many localised centres. Loss of one can be supplemented by the others and the dam system. This diminishes the terrorist risk as an international target.

This is also a strategy for increasing the resilience of communities in western parts of NSW in times of drought. Table 7 includes capacity to provide more than Sydney's needs. Consequently, excess water can be transported across the State to areas of need. Since droughts cause a loss to farming communities, it is clearly a way quality of life in the west of the State can be maintained as well as a sustainable living for those dependent on the land during periods of drought.

The effect of dam loss can be mitigated to some extent by keeping the dam wall at its current height but lowering the maximum water level to 30m below the current capacity. This option would give approximately 30m of additional headspace to cope with the largest inflows reported in the flood mitigation study. Because of this additional headspace the impact of large flood events will be mitigated because it would not require release of water of as much water from Warragamba dam. Flooding would therefore mainly arise from inflows into the Nepean and Hawkesbury rivers via their tributaries.

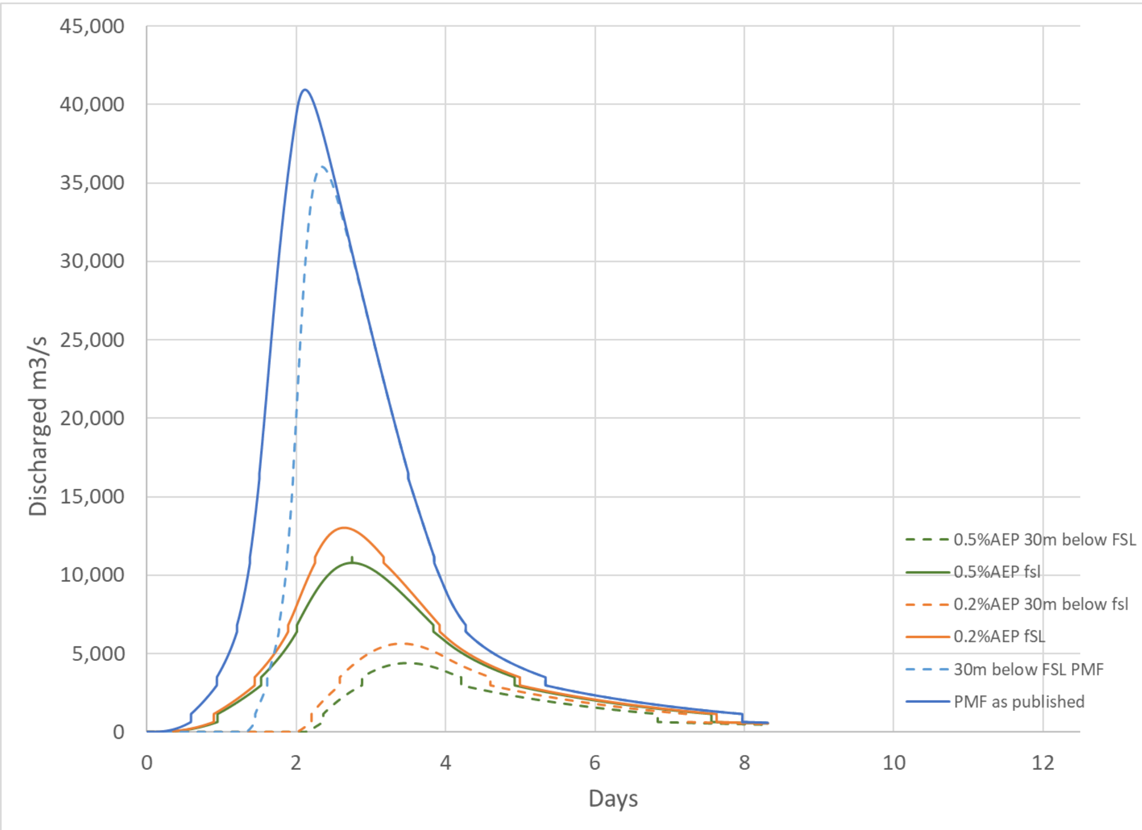

Figure 12 Discharge rates form lowering the dam water level by 30m.

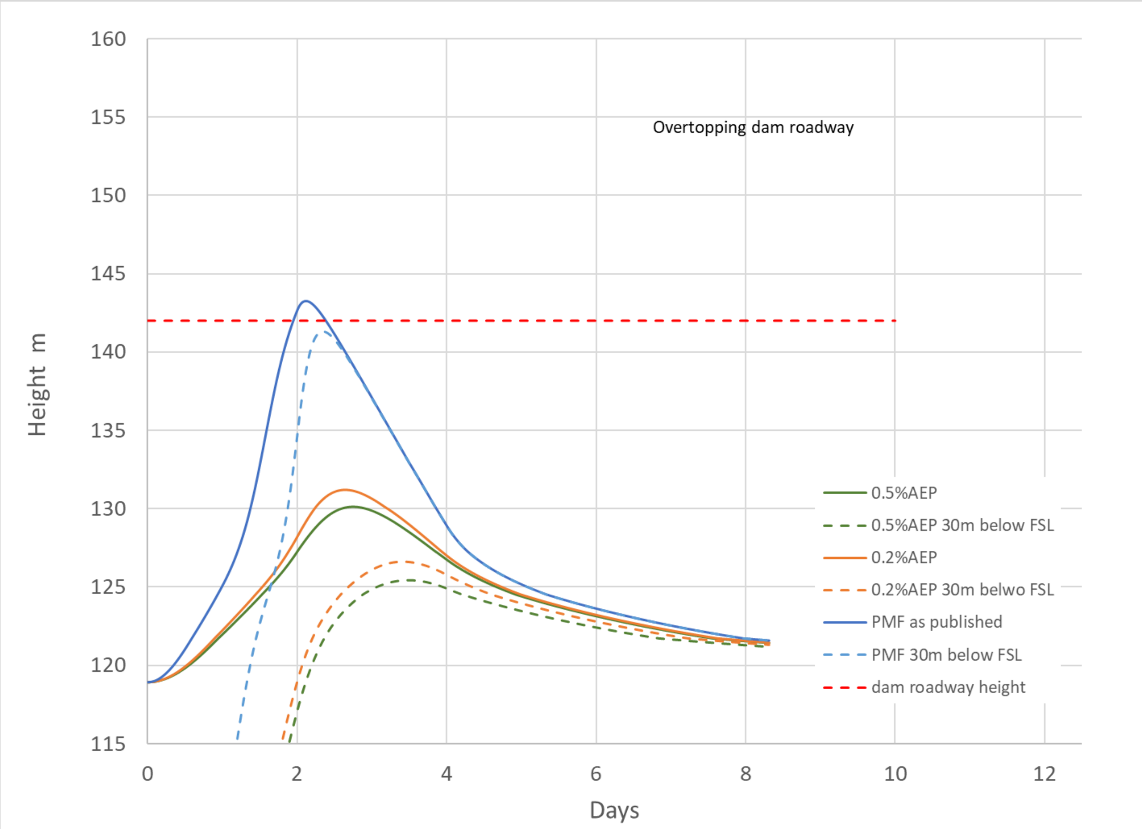

Figure 13 Water levels in the dam for a starting level 30m below full. This should be compared to Figure 7 to obtain a perspective on the risk reduction.

Figure 12 shows the effect of reducing the water levels in Warragamba dam by 30m. The conditions of inflow are the same as those that produced Figure 6. A comparison between the maximum flows in the EIS for the current dam and the proposed wall raising, This analysis and reducing the level in the dam by 30m is shown in Table 8. The reduction in water levels by 30m to lower flows than the proposed raising of the wall in the EIS.

Event	Existing flow m3/s	EIS project flows m3/s	Existing flow this analysis m3/s	This analysis for 30m lower dam levels m3/s
1%AEP	9660	3800	9660	3709
0.5%AEP	11061	5943	11150	4392
0.2%AEP	13019	8862	13019	5636
PMF	40950	36390	40950	36034

Table 8 Comparison of maximum flows for different sizes of floods above 1%AEP.

By reducing the water level to 30m below the dam full safe level (fsl), the height of floods outflowing from the dam are lower compared with the current fsl flood and occur later. This delay allows operational time to discharge water earlier than just waiting for the fsl to be reached as shown in Figure 13.

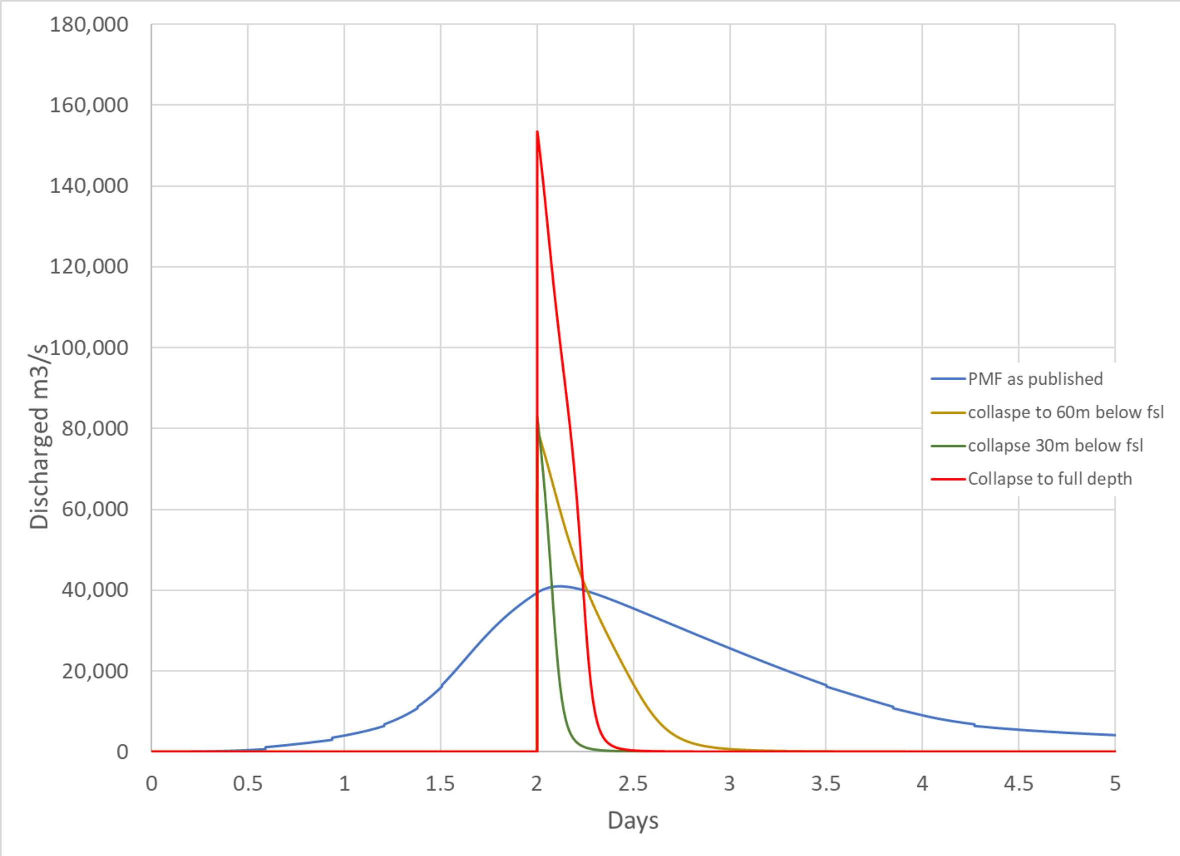

Figure 14 Comparison of a PMF flood, Dam break from a full dam with a plane taking out the full depth of the dam and collapse with a reduced head of 30m.

Figure 14 shows the effect of reducing the dam level by 30m below the safe level. It is compared with the EIS PMF flood and collapse of the dam under the same conditions as Figure 7. While this reduction in height produces a peak flow similar to a plane crash on the dam to a depth 60m, it occurs over a shorter time. Because the base of the dam is much thicker than the upper half of the dam and because building many desalination plants reduces the vulnerability of the dam, a plane attack may be less likely. There is a need, however, to ensure the SES develop and test for dam collapse for this and the other scenarios. This plan testing is an essential process in reducing the catastrophic risk to the population of Western Sydney from collapse of the Warragamba dam.

Conclusions

The EIS does not justify the raising of the dam wall. A detailed assessment of the catastrophic risks to the dam which are not assessed in the EIS indicate that the NSW Government strategy in the EIS project endangers World Heritage status, risks endangered species, the ecosystem and loss of European and Indigenous heritage. It does not serve the people of NSW and should be reviewed against a set of options that would give the Government a long term sustainable water supply.

If the full impact of catastrophic mechanisms on the dam is considered within a drought-flood cycle, then there is no need to extend the dam wall and indeed the water levels can be kept 25-30m below the full safe level and produce floods below 1%AEP that are lower than that given in the EIS project proposal

The best cost benefit to the State involves building about 10 desalination plants off the coast of NSW and provide portable water across the State. The cost over 30 years of operation is of the order

$B60. This compares favourably to the $B40 per annum risk exposure from loss of the Dam. Furthermore, this solution has other benefits as the World heritage area is not threatened and there is no affect on Indigenous site or on flora and fauna.

A decision to raise the Dam wall is not a sustainable answer to ensuring a sustainable State.

Governments would wish to demonstrate that there is no “moral hazard” in its decision making related to avoidance of options that deliver sustainability, climate mitigation and protect the population. It is proposed that a number of high quality studies can be done to deliver the options that would be recognised world-wide as Australia delivering long term sustainability in the environment and protecting the population against foreseeable catastrophic failures in dam engineering.