1. This is an **objection** to the exhibited EIS as a basis for determining the proposal to raise the level of Warragamba Dam by 14 metres, submitted by James IRISH, a retired engineering hydrologist.

2. My expertise is in the fields of statistical hydrology, insurance, risk management and the evaluation of risky and uncertain investments. I have presented many original conference papers in each of these fields, as well as taught each of them at post-graduate level. Several relevant papers are cited at the end of this document. I have experience in dam construction. I am a graduate of UNSW, with the degrees of Bachelor of Science, Bachelor of Engineering in Civil Engineering and Master of Engineering by research. I was also awarded a graduate certificate in environmental policy by UNSW, and I am a Fellow, by examination, of the Australian and New Zealand Institute of Finance and Insurance, as well the winner of several prizes awarded by that institute. I taught environmental science and engineering, mainly at post-graduate level, at three universities, for more than twenty years, particularly environmental risk assessment.

3. I was the author of the section of the 1977 edition of *Australian Rainfall and Runoff* dealing with flood frequency analysis, and was the manager of the statistical hydrology section of what was then the NSW Department of Water Resources and a member of the Hydrology Sub-committee of the NSW Dam Safety Committee at the time when emergency raising of Warragamba Dam was being considered. I practised as an independent consulting engineer for many years in the fields of risk and environmental engineering, and I wrote the first *Floodplain Develop Manual* for NSW as a consultant. I developed and taught the only post-graduate subject on statistical hydrology offered in NSW in several decades, which was jointly offered by UNSW and UTS. I am now retired.

4. My dissatisfaction with the exhibited EIS concerns nine topics, which are detailed below.

In outline, these are:

- Verbosity.
- Overly-long, inadequate cross-referencing, and poorly presented or incorrect figures and associated discussion.
- The risk that the project will deliver far less benefits than claimed.
- The extremely large uncertainty in the assessed present worth of benefits for the project.
- Given the history of over-estimation of the benefits of water resources projects and underestimation of costs, the claimed benefit cost ratio is NOT an adequate basis on which to approve the project, especially when the non-monetized adverse impacts of the project are considered.
- The claimed benefit-cost ratio is far less precise than suggested by the use of three significant digits.
- In recognition of the risk and uncertainty and the desirability, in accordance with sustainability principles, of actions with less severe consequences for heritage cultural and ecological values than the proposed should have been explored in detail.

- Identification of options not explored in the EIS for partially ameliorating the flood risk, especially via combinations of property buy-backs, lowering the FSL, cancellation of prospective further development on the floodplain in current plans, and flood insurance (including novel forms tied to achievement of reduction in property damage and lives lost).
- A critique of the methodology used to estimate the area required to offset the likely damage by inundation of ecologically sensitive areas above the current FSL.

5. Verbosity

The report uses English words and syntax, but fails to present facts, analysis and deductions in a sensible, sequential manner. Two examples will suffice to demonstrate this, though dozens more could be cited.

- The term *executive summary* is used as the title of the main document, as well as in at least one appendix. What does the word *executive* add? And do 'executives' *need* (or will they bother to read) 43 pages? Presumably, a briefing note of less than two pages will need to be distilled from the EIS for Cabinet! Even with the current length, the so-called Executive Summary fails to summarise the monetised costs and benefits of the options for which an economic analysis was undertaken. More worryingly, this volume includes numerous photographs but does *not* summarise the conclusions of the later volumes. It might best be described as a *project brochure*.

- *Appendix M: Socio-economic, land use, and property assessment:* This Appendix does not appear to have undergone a final edit: it begins with a weird confidentiality notice which is not appropriate for a document on public display. It also has a significantly different description of the project: it states (page 9, Executive Summary of the Appendix) that it relates to a proposal to increase the height of the dam crest level by *approximately 12 metres*. Did anyone from SMEC or the proponent read this appendix before approving it for publication?

<u>*A*</u> social and economic impact assessment was mandated by the project SEARs, but did it need to be at a length of 359 pages? What is the environmental impact (trees, money) of such verbosity? Will *anyone* read it in its entirety? *Could* anyone? Couldn't the SEARs requirement be met more simply?

Is the length of this Appendix, when considered with the total length of the report and appendices, an attempt to grind opponents of the project into submission? Are "environmental terrorists" thought to have a short attention span? Does an *appendix* require an Executive Summary of nineteen pages, a four-page Table of Contents beginning on the twentieth page twenty of the document, and a further nine (sub)appendices? This appendix is a parody of the environmental impact assessment process. Neither Dickens nor Swift could match this satire. It might, with less violence to the language than in the term 'environmental terrorism', be characterised as *environmental vandalism.*

The survey of economic and social conditions in the region lacks the detail needed (social characteristics of those living in different flood zones, rather than different local authority areas). It also failed to carefully assess the availability, affordability and uptake of flood insurance, or the accuracy of occupants' assessment of their level of risk.

At the risk of further deforestation (given the numerous and voluminous reports on this and similar proposals over the last few decades), I suggest that the EIS should be withdrawn and re-written, with limits on the number of words and pages. To assist that objective, I further suggest that the SEARs for any future proposal to reduce the flood risk downstream of the Dam should be written in a more focussed manner, with a SEARs requirement that the EIS comprise a main document which describes what was done, the main results, and cross-references to appendices (with page numbers), followed by as many as one hundred appendices with the details, and that it be a SEARS requirement that the EIS be written in standard Australian English.

6. Length, absence of cross-referencing, poorly presented or incorrect figures and associated discussion

The document is unreasonably long. In many places, it recycles text or figures from earlier reports without updating them to the situation at the time of preparation, or consistently across the document. While much of that recycling is referenced, there are almost no cross-references between the Chapters of the report and the Appendices, and much illogicality in the arrangement, not aided by the online version being presented in separate chapters – which limits searching for specific words or phrases.

Even with a reading of fewer than five hundred pages of this enormous EIS, numerous infelicitous tables and associated discussion have been found. In part this seems to be because large sections have been cut-and-pasted from earlier reports. The English language has been mangled by the authors. Some examples are:

- Figure 4-9, *Contribution of flood events to average annual flood damage in the valley, 2018 development levels.* The x-axis is the continuous variable annual exceedance probability, while the Y-axis is labelled as the proportion of flood damage. It is a mathematical fact that the contribution to the AAD of (for example) the flood with an AEP of 1 in fifty years is precisely zero (because it is the integral of a continuous value over an infinitesimally small interval). A contribution can only be from some *range* of AEPs. This is clarified in the text. The bars in the histogram need to be shifted into the spaces, or the bars widened. Since the figure presents *relative* contributions to AAD, it is only meaningful if the accompanying text states what that estimate was (which it doesn't).

- under the subheading *Net benefit* in section 4.4.3.4, one finds "For the alternative to raise Warragamba Dam for a 14-metre FMZ, comparing the benefits to the costs showed that there was a net benefit of $165 million. The net benefit was retained under low and high assumptions". It uses English words and grammar, but the meaning is opaque. What does *retained* mean in this context? *Which* assumptions took on high or low values and where is a table specifying those values? Varying any relevant assumed parameter value must change the NPV, so whatever was changed was irrelevant to the computation. It would be nice to have a list of assumptions which turn out to have little or no impact on NPV, with a discussion of why this is so. Table 4-8 states that the NPV of the proposal was estimated at $51M; which ($165M or $51M) is correct? If both are correct (because they refer to different sets of assumptions), then this needs to be clarified.
- Table 4-11 requires re-formatting. As printed, it suggests that, for the BAU case, the AAD of flood damages *and* lives lost was $141M in 2020 and is forecast to be $176M in 2041 (presumably in constant dollars). The sub-heading of *Benefits (annual average)* should exclude the BAU column. A reader shouldn't need to mentally rewrite confusing material. Presumably, the benefits listed for (reduction in) loss of life are expressed as millions of dollars, though this is unclear.
- I cannot find a clearly-presented graph in Chapter 4 showing the estimated monetized benefits of the proposed project as a function of AEP. If this is to be meaningful, it would need two versions: one with a *logarithmic* scale for AEP and the other with an *arithmetic* scale (to assist integration to obtain the average annual benefit). Alternatively, the aggregated monetized *damages* could be shown in a figure for the BAU case, the preferred 14m raising and for one or two other options. The desired information might be in Appendix H1 or H2; if so, a cross-reference was needed. I can find no cross-references to those or indeed any appendices in Chapter 4. (I eventually was referred by a colleague to Table 8-25 in Appendix M. That table uses inconsistent numbers of significant digits across the several columns, showing a disregard for the convention that the number of significant digits employed should be consistent with the magnitude of the uncertainty in each estimate.) In the absence of a plot or a clear statement of the method of estimation, it is difficult for a reader to know precisely how the AAD and average annual benefits for various options were estimated. These might, for example, have been averages from the simulation used for another purpose; if that was the case, the details of the simulation model are crucial.
- It is provocative to discuss, in Chapter 4, the costs and benefits of raising the Dam by *20* metres, and to fail to discuss the costs and benefits of increasing the crest level by amounts less than 14 metres, given the controversy about the project. The KPIs were pre-ordained; there is a lack of objectivity or neutrality in identifying and scoping realistic options – a matter to which I will return.

7. The risk that the project will deliver much smaller benefits than claimed

The benefits of the proposal to raise Warragamba Dam are risky, in the sense that the present worth of the benefits of the project depend on the timing and severity of floods capable of being alleviated during the period used for economic evaluation. For the discount rate employed (7% p.a.), whether such floods occur in the first decade after completion is crucial. If no such flood occurs, or only a modest one, the present worth of the benefits will be much less than the average annual damage. The converse is also true: if the raised wall moderates one or more major floods in the first few years after completion, the *post facto* benefit-cost ratio will be far better than asserted in the EIS. The costs, however, are sunk, so there's a mismatch between the risk in relation to the benefits and to the costs (as well as in their timing). Discounting only deals effectively with the timing issue.

It is traditional to use the present worth of the *average* of the annualised benefits for project evaluation of projects with risky benefits. The rationale is that, if many such projects are implemented and the criterion of the B/C ratio computed using mean values serves to allocate scarce capital, the Central Limit Theorem of statistics will 'smooth' the variability in benefits aggregated over a portfolio of investments (as long as the projects have uncorrelated benefits, and no single project dominates the portfolio).

There is a simple way to quantify the risk for a single risky investment, or for a portfolio. Indeed, the writer has published methods to estimate the moments of the distribution of the present worth; see the references below. Some standard texts on portfolio theory or on actuarial methods present equations for the variance.

Presenting a single metric to decision-makers suggests that the variability of that estimate, as realised *post facto*, is so small that it can be ignored – that it has a magnitude comparable to the impact of differing opinions about the appropriate discounting horizon, discount rate, uncertainty about project costs, and the myriad other assumptions underlying the economic evaluation. But what if the decision-maker were aware of the magnitude of the risk? Assuming they were comfortable using multi-objective criteria, might the magnitude of the risk caution the decision-maker to explore less risky options, or a *portfolio* of options, some of which have deferred costs relative to a project which is only effective once capital has been sunk? Such options do exist, and some are briefly explored below.

Second, utility theory suggests that everyone has a different set of risk preferences, and the decision-makers need to consider the range of preferences. Not everyone can be a winner! Hence, contrary to the opinion of the Chicago school of economists, decisions about risky investments are an inherently subjective or political matter rather than one well-suited to delegation to economists, or to economic methods implemented by an engineer (as seems likely to be the case for this EIS). Otherwise, value judgements masquerade as rational choices. Opponents of a project such as this are then (falsely) labelled as 'irrational' when the differences concern what counts as value.

The data on the frequency-damage relationship presented in Chapter 4 is inadequate to deduce the standard deviation of the distribution of the *prospective* present worth of benefits. Had the relevant data been readily available, it would be a simple task. However, I have located a table (Table 8-25, in Appendix M) which presents some data, although it would be a herculean task to know what set of assumptions underlie that Table. The text states this includes direct and indirect benefits. But does it include the value of the reduction in lives lost?

I have used the data in that table. I deduce that, if one accepts all of the underlying assumptions behind that Table and whatever notion 'benefits' refers to, the average annual benefit of the proposed project is about $60M p.a., and the *standard deviation* of the distribution of annual benefits is of the order of $45M p.a. The *standard error of estimate of the average annual benefits* is therefore about $7M. The coefficient of variation of the distribution of the annual benefits is of the order of 0.75. (A *coefficient of variation* is a *relative* measure of variability.) Only one significant digit is justified for the estimate of the average annual benefit.

The *standard deviation* itself has a standard error of estimate of about $5M p.a.

All of the numerical estimates in the two preceding paragraphs are based on the Central Limit Theorem. Strictly speaking, that is not appropriate in the face of the long-memory stochastic process which appears to underlie flooding in the Warragamba catchment. The nature of that process cannot be discerned from the available data, though I can confidently say that it is not cyclical. See Beran (1994) for a competent discussion of long-memory hydrological processes. The actual standard errors of estimation etc will be larger than suggested by the Central Limit Theorem.

Not only does the prior distribution have large variability, it is also positively skewed. I am unable to estimate the skewness and kurtosis of the distribution, or percentiles, as I don't have access to Irish (1979) nor Irish (1993) during the pandemic.

Applying the equations found in Irish and Burton (1973), I estimate that the present worth of whatever benefits are encompassed by the data in Table 8-25 has a mean present worth of about $720M for a discount rate of 7% p.a., ignoring likely ramping of the benefits during the discount period: it can be shown that that will have little effect on the average present worth. The standard deviation of the distribution of the present worth is about $120M. This would be a very risky investment: the coefficient of variation for the distribution of the present worth is *at least* 0.16, considering flood timing alone. Other risks (alternatively, uncertainties) would increase the CV, as would consideration of the seemingly long-memory nature of flooding in this valley.

I note that the present worth I've obtained from the data in Table 8-25 is different from that in Table 4-8 in Chapter 4. I attribute this to the different notions of benefits in each place in the EIS, the limited data in the Table from which I've estimated the moments of the distribution, or the date used for valuing damages and therefore benefits. My deductions will remain if the analysis were repeated with data of the relationship between *all monetized benefits* and *AEP* were used.

8. Project benefits are highly *uncertain*

There does not appear to be a formal analysis of the uncertainties in the benefit-cost ratio asserted for the project. (I apologise if there is one; but I can't find it by a simple search of the Table of Contents. The uncertainty is treated in a cursory way in Appendix C, which purports to deal with risk assessment but is limited to issues such as noise during construction.)

There are, understandably, many matters which are relevant to this proposal which are highly uncertain. Judgements must be made; else decisions are impossible. But in many fields, it is normative to undertake a formal analysis of the main sources of uncertainty, to attempt to quantify each of them, and to aggregate the magnitude of the major sources of uncertainty by adding the assessed variances.

One obvious source of uncertainty concerns flood frequency estimation. Given the difficulties of reconstructing the inflow hydrographs of earlier floods for current conditions, we do not have of the order of 150 years of reliable data for simulating the *outflow* hydrograph for a range of initial conditions. Furthermore, Figure 4-8 demonstrates that the propensity for floods in the Hawkesbury-Nepean isn't a realisation of a random process.

Nor do we know the *distributional form* of the flood peak inflow rates or volumes. The statistical theory which underlies standard methods of parameter estimation for an assumed distributional form are therefore of no avail. All we know is that uncertainty is larger when floods follow a long-memory process than is the case if floods occur randomly.

We may have the equivalent of about fifty years of random independent *rainfall* data with which to assess the proposal. Even if the equivalent length of record is judged to be longer, this is of negligible importance because the uncertainty scales as the inverse of the square-root of the length of record.

The uncertainty in the estimated frequencies of floods which occur rather less than once in ten years is therefore huge. There is a non-parametric way to assess the uncertainty in the point estimate of an exceedance frequency which has been estimated from limited data. But methods to estimate confidence bounds for the exceedance frequency for a stated AEP do not translate to derived quantities, such as the average annual damage, when this is highly dependent on the frequencies for rare floods.

The impact of uncertainty about flood frequencies on an economic analysis *can* be assessed. This was done for the assessment of Wivenhoe Dam. To ignore it is hubris. The technique for assessing economic uncertainty arising from uncertain flood frequencies can be found in Irish (1980). Alternatively, the method in Irish (1979) and in Irish (1993) can be adapted.

Although I wrote those papers, I don't have copies at my current address which would enable me to sketch the magnitude of this source of uncertainty using the data in the EIS.

An initial estimate was presented above; the standard error of estimate of the average annual benefit of the proposed project is about $7M p.a.

There are many other sources of uncertainty, such as the judgements made in the EIS about the risk of loss of life due to incomplete evacuations, future encroachment or intensification of flood-liable property on the floodplain, adherence to the spillway gate operation rules assumed for the simulation, future household depth of flooding versus damage relationships, the availability of flood insurance and therefore property values, as well as the "unknown unknowns".

9. The history of unwarranted optimism in the economic analysis of water resources projects

While Haveman (1972) was published many years ago and refers to the situation in the USA in the previous few decades, It would seem that little has changed since, and that the conclusions are sobering for water resources investments proposed for Australia. See also Davidson (1969), and the absence of a coherent demonstration that all has changed, or these writers were wrong.

The bias typically present in the estimates of project benefits and costs is optimism about both: costs are generally under-estimated (for many reasons, including mission-creep and unforeseen difficulties). Benefits are generally not fully realised. This may be because the private sector fails to respond in the forecast manner, once the project has been completed.

So, one should begin with a scepticism about reported B/C ratios.

10. The actual precision of the benefit-cost ratio

Because the distribution of the annual benefits is positively skewed, there is a modest but non-negligible probability that the present worth of the benefits will be substantial. This would occur if a flood is successfully mitigated in the first few years after commissioning. On the other hand, the probability that the *ex post* benefits are less than the pre-project estimate of the mean of the present worth is larger than 50%.

What does this mean for the benefit-cost analysis? The project would, in expectation, produce a benefit for the monetized outcomes (reduction in damages and reduction in the number of lives lost). But a dollar value for this average can only be assessed with just one significant digit with the available data. It is therefore almost meaningless to compare the present worth of the expected benefits to the costs, compounded to the date of commissioning. The SEARs may call for a BCA, but a meaningful one CANNOT be produced with the available data. Uncertainties introduced via the assumptions underlying the models employed (ANY models!) add to those due to the hydrological uncertainty.

The precision implied by the benefit-cost ratio (1.05) on page 4-46 is misleading. The ratio is the ratio of two highly uncertain quantities. All one can conclude, if one trusts the assumptions employed, is that the costs and benefits are of the same order (in expectation).

The lack of an overwhelming economic case for the project, together with the significance for many groups of the (non-monetized) ecological, heritage and cultural values which would be adversely affected by the project were it to be implemented, impels me to the opinion that the project *SHOULD NOT* be approved. It should similarly impel anyone in government who considers that high-cost proposals should be implemented only if the economic case is strong, and with all costs and benefits monetized, to reject the proposal.

11. The desirability, in accordance with **sustainability principles**, of actions with less severe consequences for heritage, cultural and ecological values than the proposed project should have been explored in detail.

Ways in which combinations of strategies can be used to reduce the flood risk downstream of the Dam with less severe impacts upstream of the Dam are outlined below. These are likely to also have better economics.

12. Reservations about the hydrological modelling

Sketchy details of the hydrological modelling are scattered throughout the EIS, partly in Chapter 15 but also in Appendices H1 and H2. Appendix H1 seems to have the most coherent description. That Appendix seems to have been prepared for SMEC by BMT Commercial Australia Pty Ltd. It uses, uncritically, information provided from earlier investigations by WMAwater (chiefly design storms, and the output of a RORB model) and WaterNSW (MIKE11 model results), as well as other modelling which is not relevant to the reservations I have.

The absence of a coherent description for what is arguably the most critical aspect of the EIS – the design storms used to generate all of the estimates of the economic, ecological and other impacts of the proposal – causes this objector to call for the EIS to be rejected. The fantastic methods employed uncritically after using these data are further grounds for rejection of the EIS.

A reader of such a lengthy EIS should not be presumed to have access to all of the relevant prior reports, nor to have the time to read and assimilate them. Only someone who has worked in the flood mitigation 'industry' in NSW would have an idea of how to critique the hydrological basis of the EIS.

WMAwater is said, in Appendix H1 and elsewhere in the EIS, to have somehow synthesized tens of thousands of storm scenarios. It is asserted that the method employed to do this somehow drew on concepts in the recent revision of *Australian Rainfall and Runoff*. From those myriad scenarios, 'representative' storms were somehow selected, which were claimed to represent *storms* of a particular AEP. **The *flood* flow rates, inundation levels and flow velocities modelled with those storms are the edifice on which the EIS stands – and falls**.

Let me leave aside reservations about using 141 nested RORB models for the entire Hawkesbury-Nepean catchment, and focus on the storm data which was the input to that model.

There is very limited ***point*** rainfall data for the catchment upstream of the Dam. It is inadequate for the production of depth-duration-***area***-frequency curves or design temporal patterns *for rare storms*. The data is completely inadequate for any representation of the spatial and temporal cross-correlation of rainfall rates across the forty of so sub-catchments upstream of the Dam (an area of 9500 km^2) *for rare flood inflows*. To attempt to also do this for the eighty or so sub-catchments downstream of the Dam is to dream rather than apply the scientific method or known facts.

A further serious defect in the method is that the nominal AEP of a synthesized storm selected as 'representative' is assigned to the flood which it generates when routed through the catchment. I am aware that RORB is a non-linear model, but the absence of data from severe floods with which to (properly) calibrate the model parameters means that the fatal defect remains.

Why is this problematic? The standard deviation of the logarithm of design rainfall rates for the Warragamba region is of the order of 0.2, whereas it is larger for the slope of a plot of either flood volumes or peak discharges for AEPs less than (say) 20%. This issue is acute for only a few regions globally: for arid zones, for Australia generally (apart from a few areas in the wet tropics and in Tasmania) and for southern Africa. It is known to be acute for the Warragamba catchment. And this has been known for more than sixty years.

13. Identification of **options** not explored in the EIS for **partially ameliorating the flood risk**, especially as combinations of property buy-backs, lowering the FSL, cancellation of prospective further development on the floodplain in current plans, and flood insurance (including novel forms tied to achievement of reduction in lives lost and property damage)

The EIS treats options other than raising the Dam as single solutions rather than as potential elements of a multi-faceted response. This is not the case. *Selective* property buy-backs should have been considered, along with 'smart' ways to lower the Dam FSL by less than twelve metres, the active promotion of the availability and sensible pricing of flood insurance, *selective* limitations on future development on the floodplain, encouraging the *sensitive* withdrawal of inappropriate development (and prevention of future such development from the floodplain), and others.

Consent for future development or re-development might be conditional on the availability of insurance and require constructive notice be given (to prospective purchasers of property) of a statement of the flood risk. This should include a statement about the likely insurance premium rate, separately and specifically for the building as well as for contents at the site.

The active involvement of a major insurer would have assisted the preparation of the EIS, as would a careful survey of the availability, affordability and uptake of insurance.

In a second objection to the proposal, I sketch a different model for financing residual flood risk, which can be implemented so as to complement other strategies.

Finally, the detail about the feasibility of buy-backs is sketchy; it assumes that it's an all-or-nothing approach, and restricted to properties below the estimated 1% AEP flood level. Some of those may be flood-tolerant (and thereby be of lower priority for buy-back), whereas some properties outside that zone may have an exceptional hazard of loss of life during a flood. Some are manufactured homes, which, it could be contended, should never have been allowed and which might be readily relocated at modest cost. There does not seem to have been consideration to the real value of property below the planning level; rather, there's an argument that the median or average value of that category of building for the suburb be used as a proxy.

Buy-backs may appeal to some *after* a flood, whether or not it affected their property. If that is so, a buy-back scheme needs to be ready, on the shelf, for implementation. There is a non-negligible risk of a flood between now and the implementation of the project (if it proceeds). Why wasn't a suite of interim measures actively considered?

While I do not favour *any* raising of the Dam (because of the dam paradox), why wasn't raising by less than 14 metres considered? The answer seems to be that the Task Force ordained it, as well as the objective of reducing average annual flood damages by at least 75%. Why not 40%, 50%, 60% or 70%?

14. A critique of the **methodology used to estimate the area required to offset the likely damage by inundation of ecologically sensitive areas above the current FSL**

If one accepts the method used to produce the rainfall input to the flood-routing model (and I don't consider it to be an adequate basis for either economic analysis or assessment of the cultural, heritage or ecological impacts, were the project to be implemented), then we have estimates in Appendix H1 of the extent and duration of inundation of areas above the FSL upstream of the Dam, under recent conditions and if the project were implemented, for a range of nominal AEPs. See, for example, Tables 4-1 (page 100) and 4-2 (page 103).

It can be deduced from these tables that the area inundated by the largest flood in each year *averages* about 200 ha under current conditions. This might increase over the next 30 years with climate change, but decrease slightly if more water is drawn from the Dam for water supply as population increases. Like average annual damages, the nature of the area-AEP relationship means that the area inundated in a particular year may be zero or as large as 3000 ha for the PMF. *The variability is huge*.

If the project were to be implemented, I deduce that this area would average about 350 hectares. For relatively frequent inundations (1%<AEP<40%), the increase in *depth* is also likely to cause adverse effects for habitats close to the FSL. For example, for an AEP of 20%, the depth of inundation would increase from 0.7 metres under recent conditions to 2.9 metres if the project were implemented. The increase in frequency, duration and depth of inundation would have profound impacts on various ecosystems, including in the WHA and along the wild rivers.

Had SMEC assigned a monetary value to this adverse effect of the project (in accordance with the Treasury Guidelines for economic assessment), one would also need to take account of the increased *duration of inundation*. This will roughly treble for any AEP for which the water level rises above the Full Supply Level. Any realistic value for this adverse impact would have been significant. One can only speculate why it was ignored, and instead a crazy method used to assess the ‘required’ area of ecological offset. More on that method later.

I have noted why the hydrological modelling is an inadequate basis for assessing the ecological detriments of the proposal. *Similar reservations also to apply to some of the adverse cultural and heritage impacts.*

I use the word *synthesize* above to describe how storm hyetographs were devised for each sub-catchment. The EIS uses the word *simulation*. That word has a specific meaning in statistical hydrology. What was used in the EIS is *NOT* a ‘simulation’, but rather a strange method to form mixtures, rather like a recipe, and just as subjective. The strange procedure is described on page 13-12.

In the text following the two-word labels for four types of twenty-year flood inflow sequences, the words *average* and *likely* are used as though they are synonyms; even for the weird procedure employed, they aren’t synonyms, adding to the confusion. And this is then compounded by ‘upper’ and ‘lower’, for which mental gymnastics must be employed to guess a possible meaning. In just a few sentences, four English words receive the full mangle.

Let me go back, to discover the justification given for this.

On page 13-11 is the revealing sentence beginning *These and other factors contribute to* <u>*substantial uncertainty*</u> *with regard to quantifying the potential impacts on World Heritage values ….* Why was no attempt made to estimate the magnitude of this uncertainty? Might uncertainty also render meaningless the work-around?

The largest source of uncertainty, in my expert opinion, is the hydrological uncertainty arising from the limited period of data used to model inflows to the Dam over a long sequence of years. Since a non-parametric model was used, we can use a *non-parametric* estimate of the hydrological uncertainty, and then add a subjective estimate of the uncertainty which arises from the factors listed as dot-points on page 13-11.

The standard error of estimate of an exceedance frequency, p, derived from a record with an effective length of N years, is $SEE(p) = \sqrt{p(1-p)/N}$. Since we don’t know the true value of p, we use its estimated value. We are interested in $0.0001 < p < 0.2$. Rather than tabulating the standard errors (which are much narrower than a typically-used confidence interval), it is more meaningful to tabulate the *relative* standard errors of estimate (‘RSEE’, equal to SEE(p)/p)), for a range of AEPs. This is done in the following table. As argued above, the rainfall data for the catchment upstream of the Dam is equivalent to less than fifty years of random, independent data, and n=50 has been used in the equation.

AEP (%)	RSEE (%)
20	30
10	45
5	63
1	140
0.1	450
0.01	1400

The deduction is that we have only poor guesses of the true AEP of the inflows to the Dam under current or-post-project conditions *for* AEPs<10%. They should be considered to be *nominal* AEPs, and the nominal AEPs are hardly more than guesses for very small AEPs. This deduction applies even more strongly to the AEP estimates for site downstream of the Dam.

The first four dot points on page 13-11 affect the uncertainty in estimates of the extent of inundation for a particular nominal AEP. (The other dot points relate to assessment of the harm rather than of the area inundated.)

In addition to the hydrological uncertainty, there is uncertainty due to an inability of nested RORB models to accurately generate flows for rare floods (due to uncertainty in calibration for such floods) *even if precise knowledge of the rainfall was available for each sub-catchment*. A generous estimate of these five sources of uncertainty is that they are, additively, of the same order as for the hydrological uncertainty. If that is so, the values listed in the table above need to be multiplied by 1.4.

The authors of Chapter 13 (more precisely, those who directed that an unusual procedure be used to quantify the upstream area likely to be impacted) state that the uncertainty might be worked-around by using a '*different approach*', which was required '*in order to provide greater relative certainty'*. In this case, the 'relative certainty' achievable is illusory. But the paragraph reveals all that we need to know about the *values* which informed this part of the EIS (where *value* can mean monetized things, what sections of the community '*value*' (as a verb), or the intrinsic value of something). There is a large literature in the field of environmental politicy about contested notions of *value*.

Here, the value chosen was 'greater relative certainty' rather than a statement about the range of opinions about the heritage, wilderness and Aboriginal cultural impacts of increased inundation. But, as demonstrated, the 'greater relative certainty' (a concept unknown to statistics) is illusory.

Fortunately, Appendix H1 does provide estimates, derived from an imperfect model, of the areas inundated with or without the project for a range of nominal AEPs. But what to make of the 'results' presented on page 13-12?

How might one describe what was averaged? As near as I can guess, it is an estimate of the areas inundated by storms with a nominal AEP of about 5%. Why 5%, and not 2%, or 1%, or smaller?

The procedure outlined on pages 13-11 and 13-12 is not, in my opinion, a basis for deciding what offset areas might be required, were the project to be implemented.

Firstly, any Aboriginal heritage damaged by inundation is of irreplaceable value to current and future generations. It is not something to which willing consent can be given by the custodians of those heritage symbols.

Second, impacts on world heritage are conflated here with impacts on wild rivers and on rare and vulnerable ecological communities outside the WHA. Great care needs to be taken in an impact assessment when the primary goal is to avoid *any* adverse impact.

CONCLUSION

A careful reading of just a few crucial parts of the EIS shows that it should not be a basis for approving the proposed project.

References

Beran, J., 1994. Statistics for long memory processes. First edition, Boca Raton: Routledge. Also available as an e-book.

Brown, J.P., 1972. The economic effects of floods: investigation of a stochastic model of rational investment behavior in the face of floods. Berlin: Springer-verlag.

Davidson, B.R., 1969. Australia wet or dry? The physical and economic limits to the expansion of irrigation in Australia. Carlton, Vic.: MUP.

Haveman, R.W., 1972. The economic performance of public investments: an ex-post evaluation of water resource investment. Baltimore: Johns Hopkins Press.

Irish, J.L., and J.R. Burton, 1973. Flood insurance as a flood mitigation strategy – the economic and environmental impacts of flood insurance. Paper presented at the Hydrology Symposium, Perth, August 1973. Pages 173-194 in the Conference Papers, published by the Institution of Engineers, Australia.

Irish, J.L., 1979. Equations and graphs for the moments of the distribution of the present worth. Proceedings of the 3rd International Conference on the Applications of Statistics and Probability.

Irish, J.L., 1980. Influence of uncertainty on floodplain management, paper presented at the Floodplain Management Conference held at Canberra. Published in: AWRC Conference Series No. 4, AGPS, 1981.

Irish, J.L., 1993. Moments of the distribution of the present worth of risky outcomes. In: Probabilistic Risk and Hazard Assessment (R.E. Melchers and M.G. Stewart, eds.). Rotterdam: A.A. Balkema.

16 December 2021