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ELECTRICITY CORPORATION OF NEW ZEALAND

Report on the Methodology for PMF Computation at ECNZ Dams in the Context of International Practice

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Frank
18/6

Executive summary

- New Zealand has an excellent record in dam safety by international standards.
- The nation's hydrologists are well able to utilise advances in R&D in timely fashion to aid flood estimation.
- Whereas the PMP analysis is recent and sophisticated, the conversion procedures to PMF are by old well-tested methods, with no comprehensive "proof" by calibration that such procedures are apt.
- New Zealand has not yet made the large financial investment that regional flood process calibration requires, hence some uncertainty over methodology remains for dam owners and others with flood control structures.
- Dam safety will remain a matter of prime concern to any owning authority that knows its water storage assets are located upstream of communities; economic growth and population expansion will only serve to accentuate that.
- No country known to the author has a fully satisfactory system of ensuring that its dams are safe enough through the range of floods that will occur over their lifetime. This is because advances are driven by the need for sufficient storm, flood and damage experience to be gathered before new research can be initiated. Meanwhile dam technology advances and new combinations of circumstance have to be addressed.
- New Zealand, and in particular ECNZ, has a good safety record in the dams field, no doubt due to the professional attention given to the subject and the use of such overseas experience as is seen to be relevant.
- It would be advisable, nevertheless, for ECNZ to keep a combined record in one rank order for all of its dams of the nearest approaches to overtopping that have occurred. This should be updated regularly, say annually, with any freeboard change due to remedial works or rule alterations, in order to have a quick check on whether the risks involved are reducing or otherwise.
- A refinement on the above would be to sub-divide such a ranking of ECNZ dams into hazard classes.
- Specific research recommendations are made in Section 7.

Contents

1. Introduction

ECNZ owns the biggest group of large dams of any owner in New Zealand, although during the course of this work these were divided between the Corporation and Contact Energy Limited. Like any dam owner ECNZ Ltd owes society a duty of care in its planning, design, construction supervision, operational management, surveillance, maintenance and remedial works. Of all civil engineering structures, dams around the world have long held a particular concern for both public and legislators because of their potential for loss of life and property damage. Although far more people die on roads, those events are often treated as random "accidents". However the failure of a dam is taken to reflect badly on the local civil engineering profession; the community tragedy that can accompany it lives on for generations; communities elsewhere living downstream of other dams become uncertain about their future and stress levels rise.

Dams fail most often just before, during or immediately after first filling; ICOLD statistics show this as clearly as they show that few countries are immune from embankment and dam wall failures. Although most failures are among the most numerous group of small low dams, there are dangerous incidents regularly with even the largest of structures, often because of their novelty (either in design or geotechnical setting).

Causes of failure include, but are not limited to:-

a) **floods**

- rainstorm/snowmelt
- inadequate construction flood capacity
- avalanche or landslide into lake
- failure wave from upstream dam or waterway blockage collapse
- mal-operation of upstream gates or pumped transfer
- crest settlement causing loss of freeboard
- wavestorm attack, accentuated by any slope/crest protection weakness
- spillway ice jam
- inadequate spillway capacity and consequent erosion of bank
- hillside runoff erosion of dam mitre
- downstream slope shallow slip due to rain and spray saturation
- upstream slope failure after over-rapid drawdown
- changed catchment conditions (urban growth/deforestation/irrigation saturation)

b) **geotechnical**

- faulted or weak foundations or abutment
- inadequate cutoff design to prevent groundwater flow erosion
- borrow pit materials below expected strength range
- piping through embankment fill or around outlet works
- earthquake fracture or slippage
- hydraulic fracture of core
- settlement with time or additional load (steady or fluctuating)
- inadequate recognition of foundations not be as expected from prior site investigation

c) **construction**

- not keeping to design specification
- inadequate bank compaction or weak materials
- continuing work under adverse weather conditions
- missing or extending the planned construction season
- materials problems (cement composition/aggregate type)

ECNZ will always have a pressing need for PMFs that are defendable within the current state of knowledge worldwide. However the Corporation recognises that it cannot bear all the costs of national research in this field and hence it prefers to access external expertise to keep abreast of developments, rather than generating leading edge technology.

This review attempts to:-

(i) address the appropriateness of the PMP methodology in present use (Refs 1 and 2).

(ii) put the work of the 1995/6 panel (Refs 3 and 4) in terms of current world practice.

2. Methodology used by ECNZ Consultants

Recent reviews of the safety of ECNZ dams have been carried out by using:-

* References 1 and 2 to obtain PMP values[1] applicable to the catchment, including a temporal pattern; no explicit concurrent snow melt is involved in those generalised PMP calculations.

* Judgement (extrapolated from precedent/local experience) to provide a percentage run-off in the extremity of PMP.

* A unit hydrograph model to convert the consequent rainfall excess to reservoir inflow.

* Assumptions about antecedent flows and catchment soil wetness.

* Level pool routing, using appropriate seasonal operational lake starting levels.

Reference 2 was produced to eliminate uncertainty of interpretation of Ref. 1, and so brought the benefit of beta testing experience. It contains helpful advice on antecedent condition assumptions when it says:-

> "In a catchment with lake storage the hydrologist needs to have rational and defensible criteria upon which to base initial lake level at the beginning of routing a PMF. Merely assuming a worst case scenario of lake full to maximum control level may not always be appropriate.
>
> In some catchments (eg inland South Island) the PMP is likely to fall upon a saturated catchment. Comprehensive rainfall/run-off studies are a necessary step in the process leading from PMP to Probable Maximum Flood. These provide an understanding of the role of antecedent conditions and a basis for using a storm runoff percentage relative to catchment rainfall.
>
> ... care needs to be taken to ensure PMP/PMF is physically and reasonably possible for a given catchment."

The importance of this is that some early NZ PMF work assumed saturated catchments and a full lake. Consequently the new work opened up potential savings to ECNZ without raising risk to communities.

The documents available are in hard copy, including the maps. As far as is known there is no complete software package to guide users with Ref. 1 and 2, nor any common digital dataset that could eliminate different users reading the maps differently for the same catchment.

NZ PMP is based on 21 out of 94 candidate rainstorm records across the nation. These are concentrated over the 1967-1988 era, with the others being in 1924, 1936, 1938 and 1958. Maximisation and transposition were used, with attention to synoptic scale and thunderstorm PMP processes. No seasonal distinction was made in using the results of the work, but care was taken by the NZ Met. Service authors to only use seasonally apt maximising factors for the case study events that determined the synoptic scale PMP maps. Dewpoint maximisation was generalised to help represent precipitable water using probability analysis of 13 sites across the country (each with up to 29 years of record). Persisting 12 hour values for a 1 in 100 year rarity were obtained for each month of the year and differentiated by latitude so that all

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[1] No climate change adjustment is added, but Ref. 1 indicates an expectation that PMP will rise by at least 7% by the time carbon dioxide levels are double their pre-Industrial Revolution level. (However this doubling is unlikely before 2050).

sites could have inferred results; it does not appear that the all-year 1% chance event was computed although this would undoubtedly give a slightly higher value for the full season around Feb/March. Interestingly the synoptic rainstorms of record have actually been in Nov/Dec and March/April; the historic thunderstorm short events fell rather more evenly over October to May.

PMP for a catchment is prescribed by a generalised 24 hour PMP index map which is modified downwards for any mountain barrier to moisture inflow, and for catchment size. A depth/duration table permits the extrapolation of the 24 hour PMP to 12 to 84 hours. The methodology requires that a specific PMP duration relevant to a reservoir system is chosen; the symmetrical distribution of rain in that event is then given (by table and figure) as a percentage of storm total with percentage time.

PMP from shorter duration thunderstorms is separately computed and most relevant to smaller areas, said to be up to 1000 sq. km. Fifteen storms form the underlying database for maximisation and a national maximising dewpoint of 24.5°C is given, with no great detail of its source. Calculation is from a 1 hr reference PMP equation, reduced for location from north to south by up to 30%. An additional altitude reduction is applied for basins above 1500 m. A table provides multiplying factors to extend the 1 hour storm total over the 0.5 to 6 hour range. A further table gives temporal distribution from the well-regarded average variability method; this produces a forward skewed distribution of rain. An idealised elliptical storm footprint of isohyets is then used to spatially spread the catchment average rain figures produced previously for those case where location of the storm core is important.

In the maximisation procedure an important step with the synoptic case study storms was the separation of the orographically induced rain from that due to convergence. The details need not be repeated here, only the broad concurrence with recent Australian and American practice. However it is worth noting the creation of a national 10 km gridded dataset to perform the calculations, a feature that is likely to be common in all future work of this type. By definition such work can always be refined as spatial gaps in measurement are plugged or longer datasets become available. However such datasets do no more than evolve and it might well be 20 years before sufficient extra information is available to warrant an update.

New PMP storm models are constantly being devised to suit different localities and climatic regions (Refs. 9,10,11); it would be surprising if some were not germane to NZ conditions and warrant further examination of the Tomlinson/Thompson model.

A recurring difficulty with all reservoir flood studies is that the critical storm duration can only be found by trial and error as this may well alter each time there is a control rule modification or spillway/freeboard change. It is crucial that the hydrologist concerned understands the way in which the dam is runoff volume sensitive. Typical reservoirs are well handled by normal methodology but it is necessary to recognise the extreme cases. These are not normally those with no routing attenuation but the ones with so great a control that the critical duration is easily under-estimated. This is less likely with ECNZ storages because of the large catchment sizes involved in big hydro-power schemes but occurs with flood retention basins and high regulation water supply dams all too often. In the cases of concern behind this report the issue of whether a 96 hour storm sequence was sufficiently long was a live issue to all involved (as it had been in issuing Ref. 2 (see its page 8). Nevertheless long storms imply a large range of meteorological changes that can take place during them, many alternative temporal profiles, and uncertainty about preceding conditions that are real.

It does not appear that NZ has a report to match the UK one (Ref. 12) on formal calculation of a flood through a cascade of reservoirs. This is necessary if it is wished to get repeatable calculations from different hydrologists for the same set of dams. However the synoptic description of a storm that contains all that is needed to test a headwater dam spillway and every successive one downstream can be rather contrived. Indeed it may be possible to prove by attention to seasonality that it would not be possible for every reservoir to be severely tested by a single storm sequence. Thus each dam needs to be given individual attention about its performance in the light of what may happen concurrently upstream.

So far as is known, no checks are currently made on ECNZ dams to see if they can withstand the failure of the storage immediately upstream.

3. Concurrence and contrast with practice overseas

3.1 LEVEL OF RISK

Recently the ICOLD members in Europe have been encouraging working groups to look at emerging best practice in specialist areas. One such group is that on "Floods", on which I sit on behalf of The British Dam Society. Instead of there being a sharp clash between those nations favouring PMP/PMF and those favouring 10,000/1,000 year floods, it is noticeable that members are seeing the strengths and weaknesses of each position.

It seems that those regions where the rainstorm database is large, and/or where the rain bearing mechanisms are efficient (eg hurricane and monsoon systems), favour using PMP/PMF. Conversely where the database shows either marked outlier floods, as in Mediterranean countries, or flat probability growth curves, as in the lake terrain of Finland, there is a tendency to adopt a T year flood.

The value of T that is chosen[2] in any nation also reflects the unquantified margin of safety introduced by the associated freeboard and the implied chance that storage will be drawn down by a control rule in the flood season (Ref. 5). Occasional examples exist of calculations of overall risk incurred at a dam (Refs. 13, 14); they show that combined risks are lower than those chosen arbitrarily although not by a great margin.

Nations using T year dam safety criteria can be seen to raise the value(s) of T after major incidents; a recent example is that of Spain (Ref. 6). Nations favouring PMP/PMF methods are still going through recalculation of upper bound storm models or adjustment of transposition region boundaries. As NZ came relatively late to PMP estimation it does not suffer unduly low initial values and it is likely that current work can be given a good number of years before major research is commissioned to undergird any change or refinement.

New Zealand practice on risk choice is well supported internationally. However there is no document that matches that by the Institution of Civil Engineers in the UK (Ref. 8) where every dam owner can see that normal practice is to define for dam hazard categories (four in all) different combinations of:-

- flood rarity (PMF/10000/1000/150 year)
- starting lake level
- concurrent windspeed (annual maximum 1 hour peak value).

3.2 STORM ANALYSES

Internationally these have included in the past:-

a) Hershfield's statistical extrapolation (Ref. 20) to a high multiple of the number of standard deviations of the Annual Maximum series of rainfalls (1,2 ... n days); this is then termed PMP by some but that should be frowned on for the sake of its better use to describe upper bounded rainfall according to the WMO definition. Were the whole population of storm sizes to be known at a site there would be no practical difficulty about reconciling all methods of PMP computation. However most climates are so variable that even 100 years of good rain data at a site is far from certain to produce an unequivocal probability growth line.

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[2] But note that Spain has recently altered its regulations based on T year floods to give more protection, presumably a political consequence of the Tous Dam failure (Ref. 6).

b) The Gradex method from France, which is analogous to Hershfield but is taken up "only" to once in 10,000 years. Its advocates press its universal value too strongly and Reed's critique (Ref. 7) shows how unwise it would be to import it to NZ as a method.

c) Maximising precipitable water content of the atmosphere during key recorded large storms which could be expected to occur over any dam site in a nominated transposition region; checking the result against any catastrophic flood incidents in the region to ensure that no known event is disregarded. (This is essentially the NERC Flood Studies Report method, as derived from early USA technology).

d) Maximising a generic synoptic event model (eg the US hurricane model) which may then be used in other global zones subject to the same meteorological genesis of storms. Australian meteorologists have been attracted to this approach, but proof of the region of applicability can be very contentious as the debates over PMP in parts of peninsular Malaysia have revealed.

e) Introducing to moisture maximisation techniques some additional features of importance, as with the US National Weather Service wind convergence adjustment (Ref. 21).

f) Distributed grid modelling of PMP (eg Ref. 16 covers Alpine work by Austria and Switzerland)

g) Models of local synoptic sequences capable of maximisation by more complete complex methods (eg the Henz model for Colorado mountain areas (Ref. 9) and the new UK Met. Office model used at Greek and UK sites - see Refs. 10 and 11)

NZ practice includes elements of (e), (f) and (g). The only lack is of a matching PMF research programme to demonstrate that the use of PMP with chosen catchment response functions is not too conservative.

3.3 CONVERSION TO RUNOFF

Occasionally methods overseas concentrate on creating the peak inflow (as with the Gradex method - see Ref. 7) but the majority aim to give the complete hydrograph for subsequent routing purposes. Some nations retain a parallel short-cut method to facilitate prioritisation of an inspecting engineer's work (as Ref. 8)

Unit hydrographs predominate, with an increasing tendency for synthetic dimensionless ones to be adopted to save the analytical expense of deriving a local one, which may also be too "gentle" in response shape if the catchment has missed a severe event over the period of record. Transposition of a local one is also uncertain in areas of rapidly changing geology. The pressure in many countries for cheap computerised analysis has the risk of too little time being spent examining the local hydrological data, and too little understanding being acquired of a catchment's sensitivity to certain variables. The statistical methods volume of the Institute of Hydrology Flood Estimation Handbook (due in the coming year) will seek to draw its users into recognising the importance of incorporating local data; this will embrace data elsewhere on the same stream, from an adjacent river, or from an analogous pool of data.

The use of different models of runoff response, say from RORB, or some deterministic multi-parameter set of equations, has mainly been concentrated on small, often peri-urban drainage areas or on the largest of catchments. In the latter case this is because of the likelihood that the same storm not being extensive enough to make the whole basin respond in a pseudo-linear manner as is required by UH theory.

Advances in computer power and cheaper disk storage have made distributed catchment modelling a research reality (Refs. 17,18); in this approach the grid choice will depend on the underlying digital datasets that are available. A typical grid size of 1 sq km is likely to be adequate in larger basins but some regional terrain models are already in use at a 50 metre grid spacing or less. Consultancy use of distributed modelling is better known in the groundwater sphere but its growth in use for reservoir inflow modelling will help overcome the present weakness about how to lump or combine properly the separate stream responses coming into the sides and head of a major lake.

The Waikato PMF Study Extension (Ref. 22) was explicit that the original loss function and unit hydrograph had been checked to the satisfaction of the reviewer and had been retained. This pre 1972 work stood, notwithstanding overplots of later storms, as the events of record were captured by the earlier work. UK experience confirms how elusive can be the recording at a specific site of further flood extremes even over two extra decades. There is a hint that afforestation may be subduing floods but it is not followed through. The lack of any summary of percentage land use change with time is a pity, given that the instinct of experienced hydrologists suggests that ECNZ may be receiving some cost-effective flood protection by forest growth. (There may be a downside of timber jams in a massive flood of course).

Reference 23 indicates that the Waitaki work used the UH approach but that three rainfall run-off curves were used. One of these was adjusted upwards for snowmelt in a manner that is not explicit in Ref. 23. The Clutha work was similarly UH based with time of travel introduced between tributaries and reservoirs. Recalibration was carried out with data from the January 1983 and December 1984 floods. Reference 23 does not indicate how substantial or otherwise were the changes from the addition of that 1983/84 data.

The Waitaki (Ref. 24) has been broken down into 12 drainage units, with each being characterised with one of the three percentage runoff values in the form of a constant loss rate:-

Plains (8 units)	60 per cent
Alps (3 units)	70 per cent
Pukaki Alps (1 unit)	86 per cent

This reflects an appropriate response to earlier suggestions from the reviewer of preceding work (Ref. 25, page 6). Reference 24 (page 57) says "the standard method of extrapolating a line that passes through the data for discrete events is used. This assumes an initial loss and continuing constant loss rates. This has some limitations as it ignores factors such as the duration of the event but it has tended to be 'standard practice' in New Zealand over the years."

It is always likely that the loss function will be more important to overall flood safety than the actual runoff routing model (providing the latter is sensibly calibrated). As Works Consultancy observe "There is not a high incidence of large general storms covering the whole catchment" (Ref. 24, page 50). Consequently the knowledge of the loss function for such events is limited. Compared with the examination of the effect of operation rules there does not appear to have been a formal sensitivity study of the end result to say a 10 per cent variation in the loss function. This could be revealing and would be worth commissioning when PMF is next reviewed.

3.4 STARTING CONDITIONS

Flood routing is often taken from a loose definition of a "full" storage, but more specific instructions may exist on whether the spill (and/or power) facilities are already passing a nominated flow condition at the outset. Increasingly across the world major storages are operated to follow a seasonal control rule that recognises various demand priorities. Then the chief need is to ensure that the synoptic description of the design or check flood event is interpreted for its seasonal definition; the starting level and corresponding outflow then follows.

NZ practice in this area is rational but not strongly codified. Nor is it clear that a new review of dam safety would be triggered automatically by any change of the prevailing operational control rule at a site. This must bring some temporary risk. However I have not come across any work elsewhere that has used simulation to set bounds to the control rule changes that would have no significant effect on safety. It probably remains the case that few sites are affected greatly by actual operational procedures before or during the ultimate flood provided that there is no associated problem (stuck gate/power loss to motorised valve/flooded access route to control panel).

Attention is drawn here to the common Appendix to Refs. 3 and 4 which gives as thorough an overview as is obtainable at the present time of this issue.

3.5 CONCURRENT EVENTS

Whether a country specifies an accompanying wind regime during PMF depends, it would seem, on the general wind climate rather than on any records of wave damage at the height of a reservoir flood. Thus the UK, which has the windiest climate of any EU country, is careful to specify its concurrent wind strength assumption by return period[3]. However it is likely that countries using a large measure of flood rise and freeboard to permit the routing of rare floods may have less concern over wave damage. It is noticeable to this reviewer that none of the reports on the Waikato, Waitaki or Clutha dams (Ref. 27) make mention of any analysis of potential wave attack at the time of PMF.

Only fill dams, or mixed concrete/fill dams, are prone to damage by wave slop and wind-driven spray. Valley steering of winds, and refraction/reflection of waves close to a dam wall, can cause difficulty for anyone attempting prior calculation of damage risk. Reference 19 (and Ref. 8) gives up-to-date advice that could be utilised at more exposed NZ sites.

Seiches and set-up are not considered a problem compared with windstorm damage. It would be valuable to have a review of outstanding wave generating storms on NZ reservoirs in case their potential for damage is being overlooked.

The extreme energy event that is represented by PMP can be expected to have winds associated with it. However a thunderstorm cell cluster involves a complex of three dimensional winds on a small scale and the chance of the wind being towards the dam when at the peak of a routed PMF is very small. No known instances of a tornado ever cutting across a dam top has ever come to my attention; this is despite the considerable collection of tornado statistics that has gone on in recent years. However in synoptic scale rainstorms the associated wind might be expected to affect a few lakes along a direct fetch to the dam for sufficient time to produce a full wave spectrum. The most complete investigation of this chance of "flood plus wind" has been the subject of a 3 year doctoral study in the UK; in the event only a very slight difference from statistical independence of wind and rain was found (Ref. 14). Joint probability research remains on the agenda in both Australia and the USA.

3.6 LEVEL POOL ROUTING

Rarely is any check made as to whether the passage of a flood down through a lake or reservoir will involve a noticeable head loss. This is the situation that will arise at the Sardar Sarovar dam, Gujurat, India during the PMF because of a valley constriction in a very long thin lake at the bottom of a large catchment. So far as I am aware only conventional level pool routing has been considered in New Zealand. Recently my Institute was challenged about whether its reservoir flood routing software (MicroFSR) was in effect presuming that calibration was never needed for any valley situation, however hydraulically rough the sides. My own expectation is that any error is no greater than the small figures recently computed by scientists for the suppression of waves by concurrent rainfall. The Australian software WBNM likewise uses level pool routing without qualification (Ref. 28).

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[3] This has been reduced in the UK third edition guide in response to joint probability research results.

4. Meteorological research constraints

No country has yet been able to tackle simultaneously every aspect of the atmospheric science research that could be necessary to find the complete answer to dam flood safety questions. Budget limits, the available personnel and their skills, the pressing need for design decisions at a cluster of dams, the nature of the prior storms that have stimulated research initiation, knowledge of what other countries have tackled successfully - all these affect the work that is carried out in one specific research programme.

In the case of New Zealand Refs. 1 and 2 are a considerable achievement. Even so some loose ends had to remain (and PMP has been based on a relatively small sample of all possible large events or sequences). There is no list of recommended further research given within those references but the authors do indicate where gaps remain:-

a) closer definition of when and where to change from the small area-short duration model to the generalised method (Ref. 1, page 7; Ref. 2, page 10).

b) precipitation probability distributions as PMP is approached (Ref. 1, page 7).

c) barrier height evaluation (Ref. 1, page 7; Ref. 2, page 11).

d) antecedent storm sequence definition (Ref. 1, page 7; Ref. 2, page 12).

e) maximisation routinely of any major new storm (Ref. 2, page 25) of a spatial scale and duration of relevance to ECNZ dams; "major" could be defined as a rain total only expected to be exceeded at that site once in 500 years or more, or one propagating a flood that would only be exceeded once in 100 years (on average); checking its depth-area-duration curve can be added.

f) method for maximising and distributing two or more storms in sequence for large catchments (Ref. 2, pages 4,8,18); checking depth-area-duration curves for twin storm events can be added.

It is unlikely that anywhere else in the world can be found with exactly the same climatic storm regime as NZ. Nevertheless, in order to widen the database consideration could be given to agreeing, possibly through the expert panel method, two reference regions with storm regimes just bracketing the Ref. 1 maps and tables. They may or may not be at the same latitude. Their equivalent of Table 8.1 (Ref. 1) could then be maintained for review purposes.

It would be worth re-examining whether the controlling storm(s) governing the PMP map at short durations (below 24 hours) are unduly maximised as the original work does not explicitly state that such a check was made; maximising by multiplying up by more than 1.8 was halted for good reason but the storms eliminated that way were all winter events. It seems possible that the largest measured storm could also have been given a maximising factor just below 1.8 (Canterbury, end Nov 1979) - that would be unusual as the biggest of storms are so often the meteorologically efficient ones.

5. Hydrological research constraints

ECNZ consultants have wisely resisted the temptation to introduce novelties into their PMF methodology at a time when the necessary background national research had not been done. However this makes any test against best international practice difficult if the comparator nations have invested in that research, say after some significantly damaging floods. In Britain's case the Flood Studies Report methodology was commissioned after the separate 1968 floods through Bristol and SW London. Spain made changes to its procedures after the Tous Dam failure.

PMF methods need calibration in the rarest possible conditions across the range of catchment types of relevance. Such work is always hampered by the limitations of real datasets. However with regional pooling, preferably grouping regions not simply by geographic proximity but by similar regime (Ref. 26), events can be located for calibration in sufficient quantity to determine parameters, relationships and appropriate uncertainty measures as well. The essence is to define an event model that is suited to the design requirement, to calibrate it fully, and thereafter not to deviate from any part of that modelling sequence. Such a national study may require 10 or more person years of effort but without it major questions will always remain. (Australia lacks a comprehensive and consistent system of analysis because Australian Rainfall and Runoff has been the product of the worthy zeal of its professional engineering institution rather than the outcome of a national research programme).

An element that almost always emerges from a thorough study of catchment response in any temperate climate is the seasonal differences that obtain. It would be valuable to examine catchment moisture wetness probability chance tables by time of year (Ref. 2, page 19), but once response processes are investigated in detail it becomes apparent that many differences prevail over the seasons of a year. Thereafter the concern can switch to the arbitrary nature of starting conditions for any event model, or to the validity of over-riding a regional PMF methodology because of some local flood data that gives a different response statistic.

It was not clear to me that all the datasets that are desirable to hydrology consultants are available in a readily usable form. In particular does NZ have seasonal snowpack probability maps in terms of stored water equivalent? And have infiltration/soil drainage maps been produced in a digitally usable form?

6. Specific issues arising from the NZ PMF review

6.1 COMMON THREADS

From Refs. 3 and 4, it is seen to be wise to:-

- identify recorded storms to ascertain their meteorological origins, movements and durations of precipitation.
- distribute in time the PMP according to the most critical recorded scenario for the appropriate season, ensuring the spatial storm distribution is apt; this requires trial and error simulation through to final lake level.
- use local data to determine the best rainfall/runoff relationship in rare storm conditions.
- model sub-catchments separately and in combination as appropriate.
- route inflows to and through the storages involved, using appropriate seasonal starting levels and release rules; rerun to check sensitivity to those release rules.
- compare results with historic maxima and flood frequency graph extensions.

6.2 INTERNET SEARCH ON LAKE LEVELS ANTECEDENT TO PMF

References 3 and 4 reveal a striking success in obtaining a snapshot of concurrent views on this subject, primarily because enough people active or interested in the field had given their email address in the public domain and so could be contacted by ECNZ efficiently.

The impression is left by the text that no firm rules exist. I do not disagree with the ECNZ summary but draw from the widely dispersed contributions:-

- that the storage level before a flood is a normal operating case for the season concerned, but that where long operating records exist then a typical lower level (defined by exceedence probability) may be appropriate.
- that if that level is at spillway crest, then it is not accompanied by any initial flow depth over that crest; this infers that the severe preceding storm scenario is now less likely to be assumed (or that it is known that the storm separation in time from the PMF event is sufficient for the tail of preceding discharge to have disappeared).
- tougher starting conditions can prevail where the antecedent condition is regular seasonal snow pack melt.
- that sensitivity analysis is wise.
- that there is movement towards joint probability (AEP) calculation.

7. Issues of priority for ECNZ research in flood hydrology

There seems little relevance in making miscellaneous suggestions for improvements to current methodology when root and branch options are on the horizon internationally. ECNZ could do to examine the relevance for its catchments of:-

(i) using the long term potential of continuous simulation of runoff from precipitation to remove the unwelcome assumptions in flood event modelling of arbitrary antecedent conditions and critical storm duration; however this does require considerable computer power for the multi-century runs involved as well as confidence in the spatial rain generation process and good calibration decisions.

(ii) adopting distributed grid modelling, using digital catchment characteristics in a form that removes the problem of routing sub-catchment elements of flow; this can bypass UH derivation, loss function choice, and time of travel routing.

In the meantime it will be worth:-

(1) fostering doctoral theses of case studies of the joint probability of environmental variables in New Zealand in order to quantify the possible oversafe combinations now used.

(2) conducting a mini-review of flood safety at a dam each time a change is made in its operation rules.

(3) re-examining the Tasmanian extreme flood data presented in the NERC Flood Studies Report to see whether the shortening of the time to UH peak which the UK event model required to explain such rare events might also apply in NZ.

(4) checking that flood probability growth curves can be linked to the upper bound value of PMF at key NZ sites (Ref. 15); this has the side advantage of enabling the cost/benefit relationship to be worked out for any lesser standard than PMF.

(5) encouraging university research into seasonality of PMP and the appropriate antecedent conditions, together with the maximisation of two or more storms that have occurred in close sequence.

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The views in this report are my own by definition. They are given with the permission of the Director of the CEH Institute of Hydrology, a component part of the Natural Environmental Research Council of the UK; NERC operates under Royal Charter, its staff being public servants (but not civil servants). NERC reports to government through the Office of Science and Technology, a part of the Department of Trade and Industry.

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