THE UNIVERSITY OF
NEW SOUTH WALES

WATER RESEARCH
LABORATORY

School of Civil and
Environmental Engineering

15th July 2008

Our Ref: WRL 08029.01 CW:DJA 080715

Mr Matthew Zollinger
Penrith Lakes Development Corporation
PO Box 457
CRANEBROOK NSW 2749

Dear Matt,

SENSITIVITY OF RIVER DISCHARGE AT PENRITH TO -7% TO +30% CHANGES IN DESIGN RAINFALL INTENSITY

During May 2008 the Water Research Laboratory (WRL) provided Penrith Lakes Development Corporation (PLDC) with a brief letter report (ref L080523) indicating a 10% increase in river discharge at Penrith would increase 50, 100 and 200 year ARI river flood levels by as much as 0.6m. PLDC subsequently commissioned WRL to determine the relationship between changes in river discharge at Penrith and rainfall intensity. This letter report presents the results of that commissioning.

Background

PLDC have requested that this letter report be prepared to comply with Section 1 of DECC's Floodplain Risk Management (FRM) Guidelines for the *Practical Consideration of Climate Change* (Version 1.0, 25/10/2007). These guidelines suggest that the following climatic variations should be considered in the flood risk management process:

1. 0.18 m to 0.91 m increases in the 2090-2100 sea level,
2. 10%, 20% and 30% increases in peak rainfall and storm volume.

This desktop analysis only address the rainfall component of this sensitivity analysis as WRL considers that a change in the sea-level would not impact the flood levels at Penrith. The sensitivity analysis is performed by interpolating results from previous flood studies.

Flood risk management at Penrith Lakes requires consideration of the 50, 100, 200 and 500 year ARI 72-hour rainfall and associated flood events. Rainfall events with durations less than 72-hours are not used for flood risk assessment because Webb McKeown and Associates (WMA, 1996) found that flooding from these events was less severe. Floods with recurrence intervals below the 50 year ARI do not currently present a risk to life or property inside Penrith Lakes and have only nuisance impacts on water quality.

In preparation for this investigation WRL was unable to find any national or international peer reviewed literature describing the impacts of climate change on 50, 100, 200 and 500 year ARI 72-hour rainfall or flood events. Hydrology experts at

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UNSW and the University of Newcastle subsequently indicated to WRL that this is not a topic of active research.

It was therefore apparent that the only studies describing the relationship between climate change and increased extreme rainfall intensity in Australia were the recent NSW Government and CSIRO publications:

- *Climate Change in the Hawkesbury Nepean Catchment* (CSIRO, 2007), and
- *Climate Change in New South Wales. Part 2. Projected Changes in Climate Extremes* (Hennessy et. al., 2004).

These reports detail possible climate change impacts from a limited set of climate change models for a range of seasonal projections for rainfall events up to the 40 year annual recurrence interval. For the Hawkesbury Nepean Catchment the CSIRO reports predict that by 2070 the 40 year 1-day extreme rainfall intensity may change by -7% to +10%. Values for the 40 year 3-day extreme rainfall intensity were not published, however, the reports note that 3-day extreme rainfall events are mostly similar to the 1-day events except primarily during spring with most models simulating a decrease in rainfall intensity. This decrease was not quantified.

Application of these CSIRO findings to assess the sensitivity of climate change upon flooding at Penrith Lakes is therefore questionable. Until further information becomes available WRL suggests that it would be sufficient for PLDC to consider the flood risk management implications of a 10% only increase in extreme rainfall intensity and storm volume. This would need to be approved by DECC.

WMA Derivation of Design Flood Hydrographs at Penrith

The current design flood hydrographs at Penrith Lakes are those from the Webb McKeown and Associates (WMA, 1996) RUBICON model for the Warragamba Dam Auxiliary Spillway EIS study. These hydrographs were adopted by PLDC in 2003 to satisfy DECC recommendations for consistency in flood planning at Penrith. This change required the re-evaluation of all flooding assessments completed at Penrith Lakes during the previous ten years.

The WMA hydrographs are derived from RORB-RUBICON simulations which route the WMA design 72-hour rainfall events in the Warragamba and Windsor catchment to Brooklyn. WMA adopted the 72-hour rainfall distributions for design because they predicted higher peak flood levels (the Warragamba catchment has an area of 9,051 km^2).

The WMA (1996) 72-hour 5 year ARI to 100 year ARI design rainfalls were derived for 110 points throughout the Warragamba Dam and Windsor catchments using the methods presented in Chapter 2 of Australian Rainfall and Runoff (AR&R, 1987).

The WMA 200, 500 and 1000 year ARI design rainfalls were derived by extrapolating the 72-hour 100 year ARI design rainfall to the 72-hour Probable Maximum Precipitation (PMP) event in the Warragamba and Windsor catchments. A 72-hour PMP of 770 mm at Warragamba was derived using an unpublished Meteorology

(BOM, 1992) study commissioned by the Sydney Catchment Authority (SCA)[1]. Extrapolation to the PMP was achieved using the methods described in Section 13.5 of AR&R and a PMP AEP of 1 in 10^5.

WMA (1996) design rainfall and flood events were based on the assumptions presented in Table 1.

Table 2
Assumptions Governing WMA (1996) Design Rainfall and Flood Events

Assumption	Comment
A PMP AEP of 1 in 10^5	Flood frequency analysis indicated that the PMP AEP at Windsor and Warragamba was in 1in 10^5 and 1 in 10^4 respectively
A constant rainfall area factor of 0.95 for the 22,000 km^2 Hawkesbury Nepean Catchment	AR&R only provides methods for calculating rainfall area factors for catchments up to 1000 km^2
Unsmoothed rainfall temporal patterns are appropriate for events up to the 100 ARI	The Bureau of Meteorology considered unsmoothed patters more appropriate than those in AR&R because they were derived from observed storms over large catchment areas
Initial losses of 70 mm and continuing losses varying from 2.8 mm/hour to 1.9 mm/hour are appropriate for the 5 year ARI to 100 year ARI rainfall events	
Initial losses of 10mm and continuing losses of 1.9 mm/hour are appropriate for the PMP rainfall event	Loss rates for events between 1 in 100 and PMF varied between these values
Warragamba Dam full at the commencement of every flood	The WMA model predicts flood levels at Penrith are sensitive to dam draw-down. Flood levels at Penrith Lakes are sensitive to minor changes in discharge at the 100yr ARI.
Warragamba Dam gates operate to the H14 procedure	

The peak river discharges at Penrith for various design events as computed by the RORB-RUBICON models is provided in Table 2.

Table 2
Recurrence Intervals of Peak River Discharge at Penrith

ARI	Peak River Flow at Penrith (m^3/s)
20	8,600
50	10,920
100	13,460
200	16,410
500	19,630
1000	25,990
100,000	40,800

[1] BOM have indicated that this study was revised in 2006 and have suggested that requests for the results of the 1992 and 2006 study results be redirected to SCA.

Sensitivity of River Discharge to Changes in Rainfall Intensity

WRL has used the following procedure to predict the potential impacts of changes in rainfall intensity on peak river discharge and flood levels at Penrith Lakes:

1. Utilise the WMA (1996) 3-day rainfall frequency curve for the Warragamba and Windsor catchment - see Figure 1. WRL used the predicted PMP rainfall at Warragamba Dam and the methods described in WMA (1996) and reproduced the gradient of this curve in the 100-500 yr ARI interval with an accuracy of 7%.
2. Derive new 3-day rainfall frequency curves for -7 %, +10 %, +20 %, +30 % variations in rainfall intensity - see Figure 2.
3. Present changes in rainfall frequency in (2) as a function of -7% to + 30% changes in rainfall intensity – see Figure 3.
4. Derive a relationship between peak river discharge at Penrith and rainfall for the purposes of (5) – see Figure 4.
5. Compute changes in 50, 100 and 200 year ARI flood levels at Penrith Lakes due to -7% to +10% changes in rainfall intensity using the methods and assumptions described in WRL Letter Report L080523 – See Table 3 and Table 4.

In this assessment WRL has disregarded the following factors which may mitigate post-climate change flood impacts at Penrith Lakes:

- Initial and continuing losses may be higher than those modelled by WMA.
- Draw-down at Warragamba Dam will decrease the flood level at Penrith. A two metre draw-down in Warragamba Dam is predicted to decrease 1 in 100 AEP flood levels at Penrith and North Richmond by 0.1 and 0.3m, respectively (WMA, 1996).
- Increased evaporation may lower water levels in Penrith Lakes (this effect can be significant for floods with peak discharges lower than 13,500 m^3/s).
- A change in the flood hydrograph will affect the flood level at Penrith as tested by WMA (1996). Under pre-dam conditions, two events with the same peak discharge but differing volumes were simulated. A 23% decrease in flood volume produced a flood level 0.53 m lower at Windsor.

Results

The estimated relationship between 20 to 500 year ARI flood frequency at Penrith and -7% to +30% changes in rainfall intensity and storm volume is presented in Figure 3. The estimated relationship between total rainfall depth and peak river discharge at Penrith is presented in Figure 4. The estimated sensitivity of peak 50, 100 and 200 year ARI flood levels about Penrith due to -7% and +10% variations in rainfall intensity are presented in Tables 3 and 4, respectively. These changes were computed using the same methods and assumptions discussed in WRL Letter Report L080523.

Table 3
Estimated changes to 50, 100 and 200 year ARI peak flood levels about Penrith Lakes as a result of a 7% decrease in peak river discharge

WMA RUBICON Design Hydrograph	Peak Discharge at Victoria Bridge (m^3/s)	Change in Peak Flood Level (m)							
		RW	R0	RX	R1	R2	R3	R4	RD
50yr ARI -7%	9,987	-0.5	-0.5	-0.6	-0.7	-0.9*	-1.0*	-0.9*	-0.9*
100yr ARI -7%	12,383	-0.6	-0.6	-0.4	-0.5	-0.2*	-0.3*	-0.2*	-0.3*
200yr ARI -7%	14,599	-0.6	-0.6	-0.5	-0.6	-0.7	-0.7	-0.9*	-1.0*

* These predictions unreliable. Refer to discussion on assumptions in WRL Letter Report L080523

Table 4
Estimated changes to 50, 100 and 200 year ARI peak flood levels about Penrith Lakes as a result of a 10% increase in peak river discharge

WMA RUBICON Design Hydrograph	Peak Discharge at Victoria Bridge (m^3/s)	Change in Peak Flood Level (m)							
		RW	R0	RX	R1	R2	R3	R4	RD
50yr ARI + 10%	12,943	+1.1	+1.0	+0.8	+0.9	+0.3*	+0.5*	+0.4*	+0.6*
100yr ARI + 10%	15,777	+0.8	+0.7	+0.6	+0.8	+0.9	+0.9	+1.1*	+1.3*
200yr ARI + 10%	18,398	+0.6	+0.3	+0.3	+0.4	+0.6	+0.6	+1.0*	+0.8*

* These predictions unreliable. Refer to discussion on assumptions in WRL Letter Report L080523

Discussion

These results indicate that river discharge at Penrith is highly sensitive to changes in rainfall intensity and storm volume. With respect to flood recurrence intervals Figure 3 indicates that a:

- 7% decrease in rainfall would result in the:
  - Current 50 year ARI flood event being observed once every 75 years.
  - Current 100 year ARI flood event being observed once every 155 years.
  - Current 200 year ARI flood event being observed once every 330 years.
  - Current 500 year ARI flood event being observed once every 840 years.
- 10% increase in rainfall would result in the:
  - Current 50 year ARI flood event being observed once every 30 years.
  - Current 100 year ARI flood event being observed once every 60 years.
  - Current 200 year ARI flood event being observed once every 110 years.
  - Current 500 year ARI flood event being observed once every 260 years.

This sensitivity arises because the RORB-RUBICON model predicts that every millimetre of additional rainfall between the 50 and 500 year ARI rainfall events contributes an additional 64 m^3/s to the peak river discharge at Penrith.

WRL Letter Report L080523 notes that the flood frequency analysis at Penrith have confidence intervals of approximately ± 1 m. Tables 3 and 4 suggest that climate change driven -7% to +10% changes in rainfall intensity would result in an equivalent or slightly smaller level of uncertainty. These uncertainties are compared in Figure 5.

Conclusion

DECC's Floodplain Risk Management (FRM) Guidelines for the *Practical Consideration of Climate Change* (Version 1.0, 25/10/2007) state that the FRM process should consider the sensitivity of flooding to 10%, 20% and 30% increases in peak rainfall and storm volume. The 10% to 30% range for sensitivity analysis appears to be based on the range of CSIRO predictions of climate related changes to rainfall intensities for various catchments throughout NSW. In cases where changes in catchment rainfall intensities are small, i.e. less than 30%, the range appears to be based on the precautionary principle.

A review of available literature and consultation with leading Australian hydrologists indicates that:

- 72-hour rainfall events are responsible for the most severe floods at Penrith,
- Design floods at Penrith are based upon 72-hour rainfall events,
- CSIRO's climate change assessments are based on changes to the 1 - 40 year ARI 24-hour rainfall events not 72-hour 50 – 500 year events.
- CSIRO's climate change assessments indicate that changes to 72-hour rainfall intensities are not as severe as changes to 24-hour rainfall intensities.
- CSIRO predict 1-40 year 24-hour rainfall intensities in the Hawkesbury Nepean Catchment will change by -7% to +10% in 2070.
- No research has been or is being undertaken into the effects of climate change on 50 to 1000 year ARI 72-hour rainfall intensities.

These findings suggest that it would be unnecessarily conservative to consider 20% and 30% increases in 2070 rainfall intensity at Penrith Lakes in the FRM process.

An assessment of the sensitivity of 50 to 500 year ARI flood levels at Penrith Lakes due to -7% to +30% changes in design rainfall intensity is provided in Figure 3. This sensitivity analysis indicates that a 10% increase in 72-hour design rainfall would result in future 110 year ARI flood levels at Penrith being equivalent to current 200 year ARI flood level predictions. This is equivalent to a 0.9 m increase in peak flood levels outside Penrith Lakes.

These predictions are based on interpolation of current flood routing. The results are not expected to be significantly different if rainfall patters were actually routed through the RORB-RUBICON models if the impact of climate change is translated to a change in the overall rainfall intensity. However if hydrograph volumes or temporal and spatial patterns were assumed to differ due to climatic variations it would be necessary to commission Webb McKeown and Associates to re-run the RORB-RUBICON models for a range of scenarios.

Should you have any queries regarding this matter please do not hesitate to contact Doug Anderson or Brett Miller on 02 9949 4488.

Yours sincerely,

BRETT MILLER
Manager

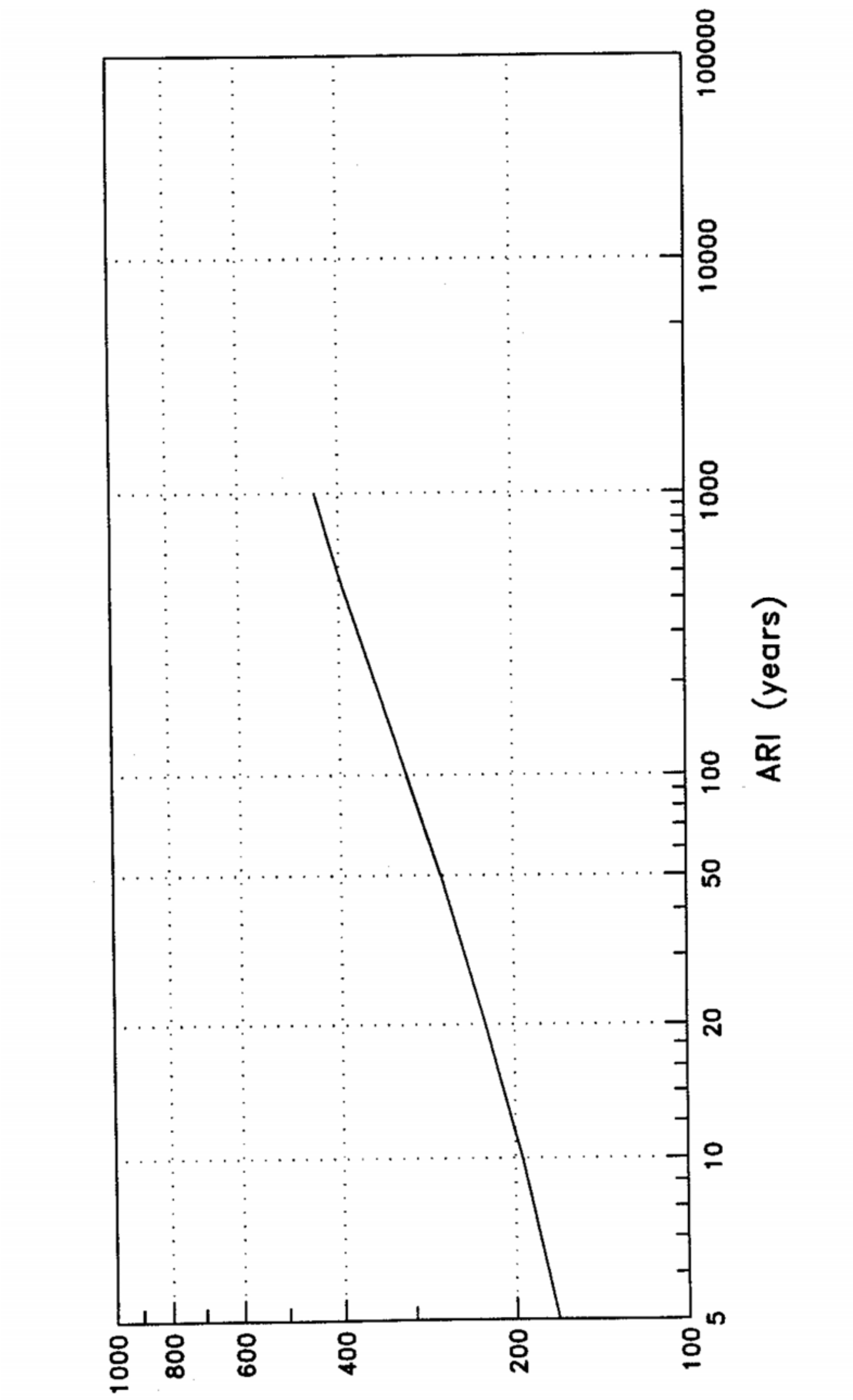
References

CSIRO (2007), *Climate Change in the Hawkesbury Nepean Catchment*, Commonwealth Scientific and Industrial Research Organisation

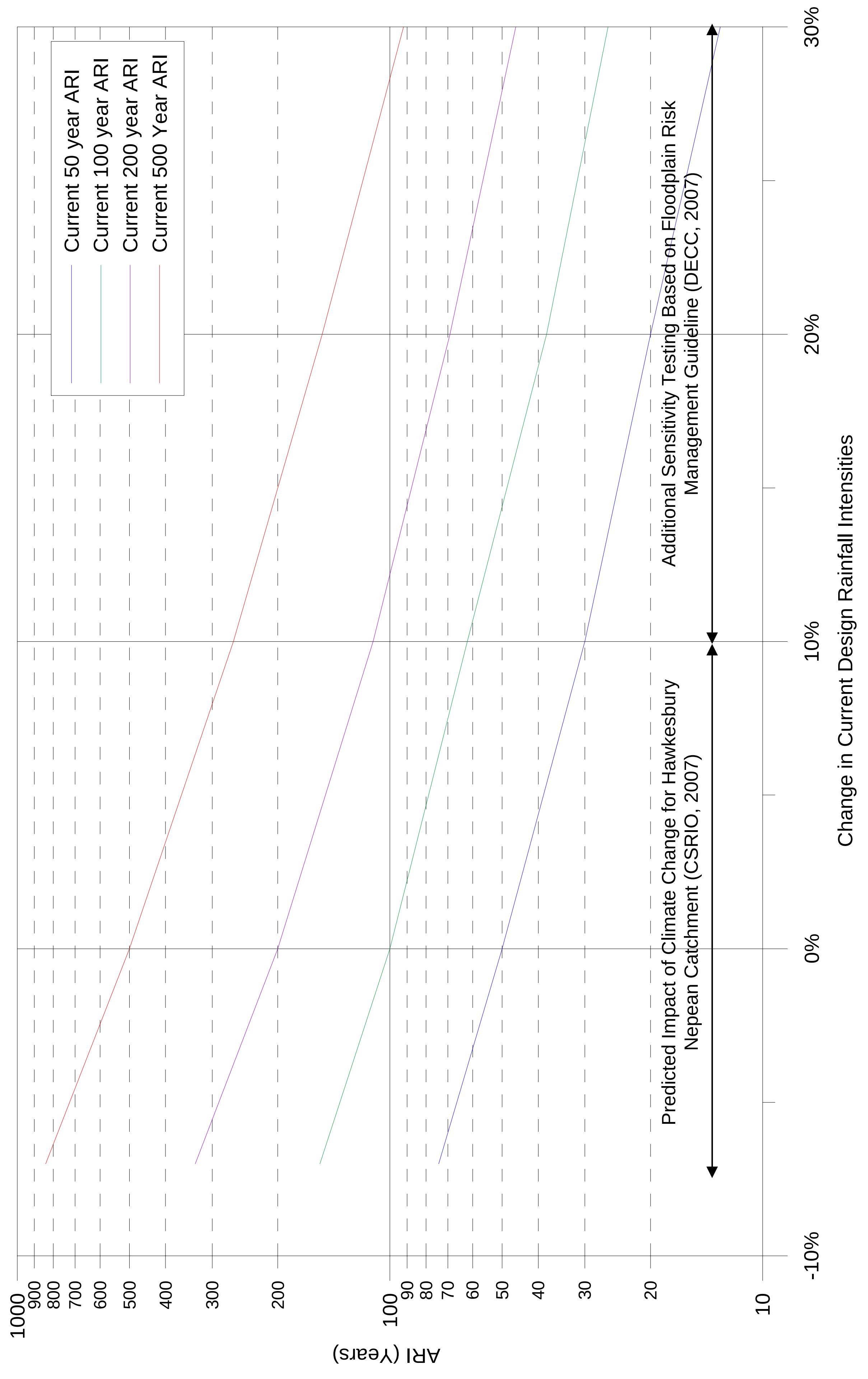
DECC (2007), *Floodplain Risk Management (FRM) Guidelines for the Practical Consideration of Climate Change*, Version 1.0, 25/10/2007, Department of Environment & Climate Change

Hennessy K., K. McInnes, D. Abbs, R. Jones, J. Bathlos, R. Suppiah, J. Ricketts, T. Rafter, D. Collins and D. Jones (2004), *Climate Change in New South Wales. Part 2. Projected Changes in Climate Extremes*, New South Wales Greenhouse Office

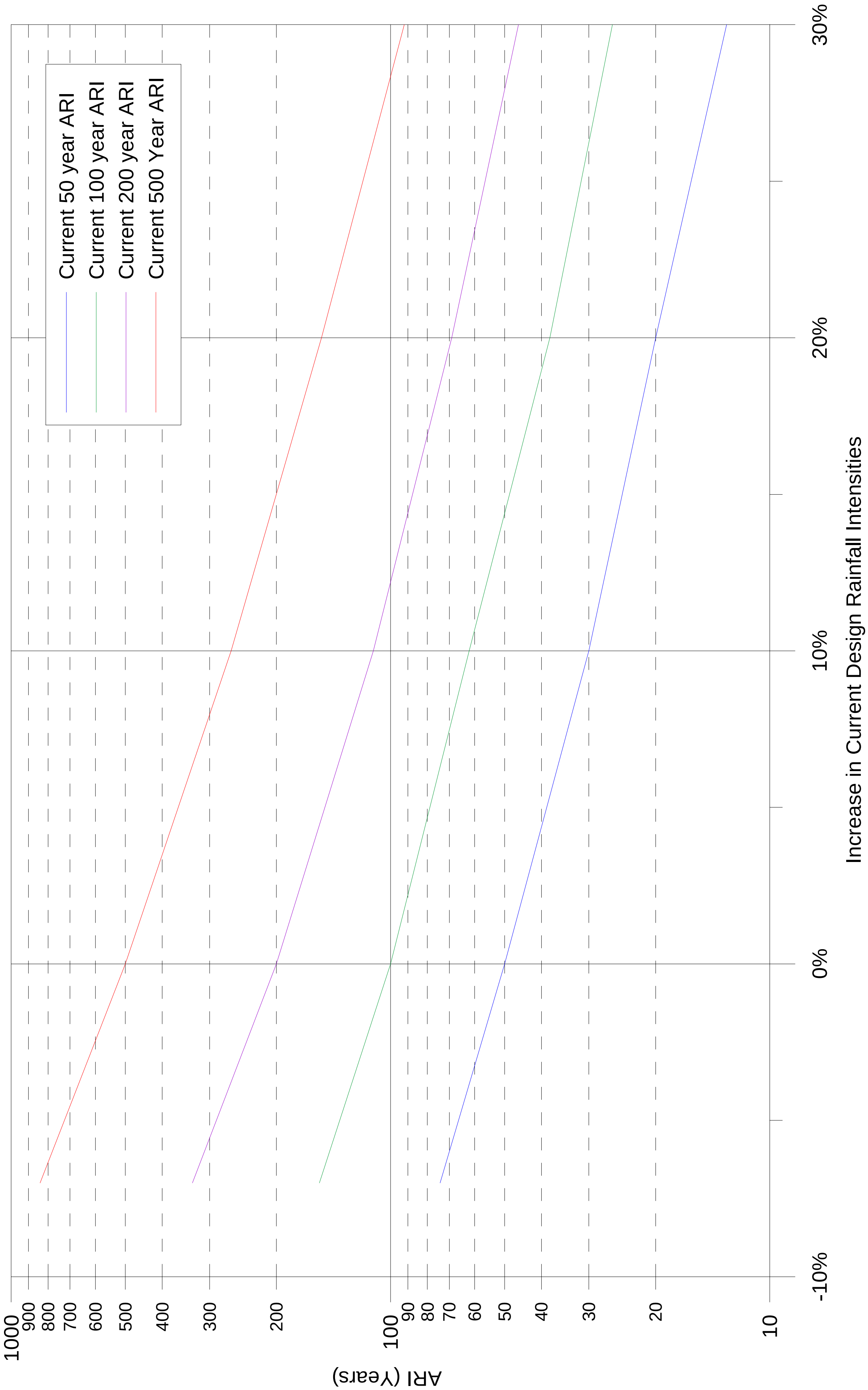
WMA (1996), *Draft Warragamba Dam Auxiliary Spillway EIS Flood Study*, Webb McKeown and Associates.



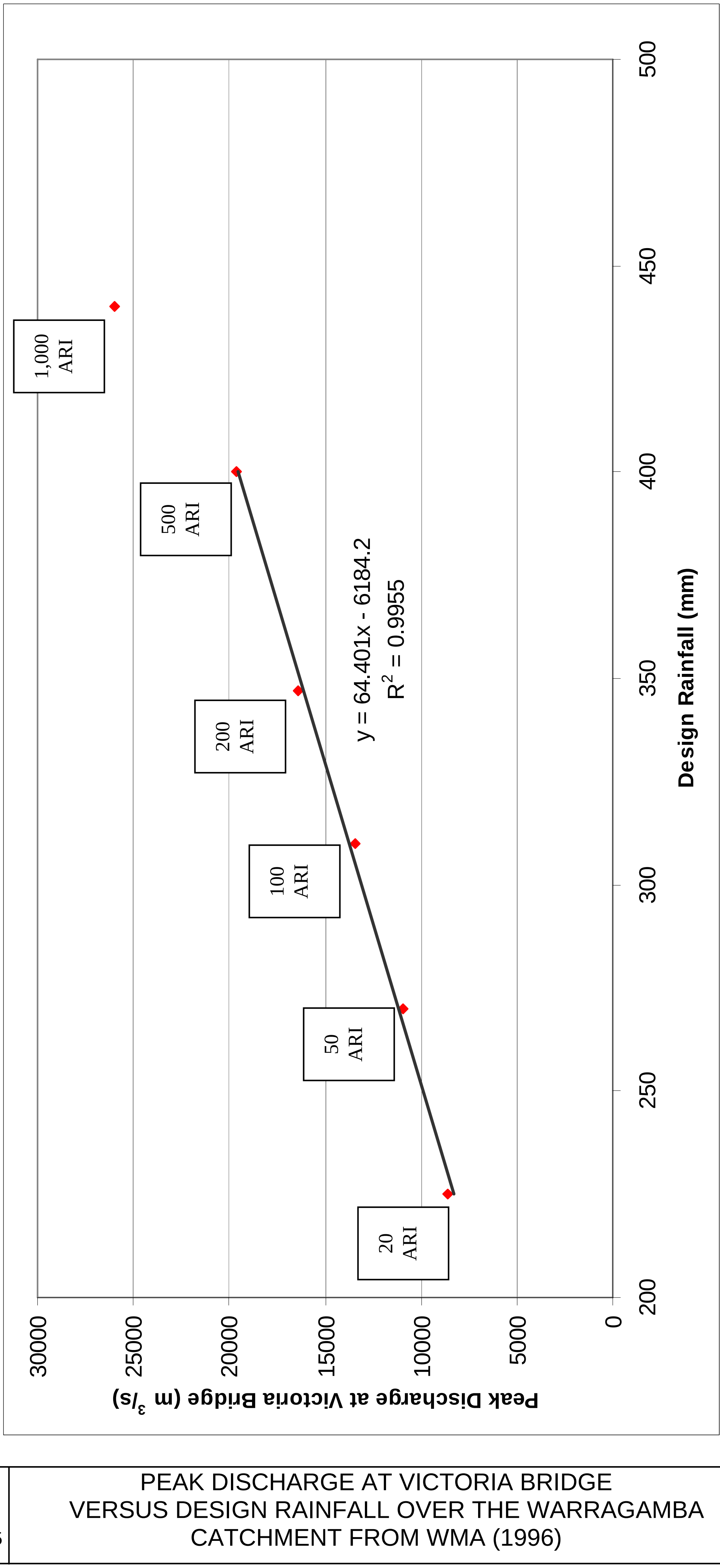
WRL Report No. L080715	FREQUENCY CURVE OF AVERAGE 3 DAY RAINFALLS OVER WARRAGAMBA CATCHMENT (WMA, 1996)	Figure 1



WRL Report No. L080715	ESTIMATION OF -7 %, +10 %, +20 %, +30% RAINFALL FREQUENCY CURVES AT WARRAGAMBA DAM FROM WMA (1996) RAINFALL FREQUENCY CURVE	Figure 2



WRL Report No. L080715	ESTIMATED CHANGES IN DESIGN FLOOD ARI AT PENRITH DUE TO VARIATIONS IN DESIGN RAINFALL INTENSITY (DERIVED USING WMA, 1996 RORB-RUBICON MODELLING)	Figure 3



WRL Report No. L080715	PEAK DISCHARGE AT VICTORIA BRIDGE VERSUS DESIGN RAINFALL OVER THE WARRAGAMBA CATCHMENT FROM WMA (1996)	Figure 4

Department of Environment and Climate Change
PO Box 3935
PARRAMATTA NSW 2124

28064/L090512_DECC

8 July 2009

Attention: Mr David Avery

Dear David,

Re: Assessment of Potential Impact of Climate Change on Flooding in the Hawkesbury Nepean River

BACKGROUND

The Hawkesbury-Nepean River valley stretches from Lake George in the south, Lithgow in the west, skirting around Sydney and draining into Broken Bay. The valley is typified by exceptionally heavy rainfall and the valley topography leaves many areas prone to severe flooding often metres deep. The valley is also home to much of Sydney's rapidly growing population making an assessment of the potential impacts of climate change on flood levels essential.

In the past few years current best practice for considering the impacts of climate change (ocean level rise and rainfall increase) have been rapidly evolving. Key developments have included:

- the release of the Fourth Assessment Report by the Inter-governmental Panel on Climate Change (IPCC) in February 2007 (*Climate Change 2007*), which updated the Third IPCC Assessment Report of 2001;
- the preparation of *Climate Change Adaptation Actions for Local Government* by SMEC Australia for the Australian Greenhouse Office in mid 2007;
- the preparation of *Climate Change in Australia* by CSIRO in late 2007, which provides an Australian focus on *Climate Change 2007*;
- the release of the Floodplain Risk Management Guideline *Practical Consideration of Climate Change* by the NSW Department of Environment and Climate Change in October 2007 (referred to as the DECC Guideline 2007).

As a result of the information provided in the above and other documents, and to keep up to date with current best practice, the Department of Environment and Climate Change (DECC) have engaged WMAwater to undertake an assessment of the impacts of climate change on flood levels in the Hawkesbury Nepean Valley.

WMAwater (formerly Webb, McKeown & Associates Pty Ltd) were responsible for undertaking the major Flood Study of the Hawkesbury Nepean catchment which commenced in late 1987 and proceeded through various stages over the next several years, ending with the Warragamba Dam Auxiliary Spillway Environmental Impact Study Flood Study (1996). In order to carry out the 1996 study, a RORB hydrologic model and a RUBICON hydraulic model were established. For the purposes of this study, both RORB and RUBICON models were used.

METHODOLOGY

The purpose of this investigation was to assess possible impacts of climate change on flood behaviour in the Hawkesbury Nepean valley. The existing hydrologic (RORB) and hydraulic (RUBICON) models were utilised to undertake this assessment.

In accordance with the DECC Guideline 2007, the following climate change scenarios were modelled using the RUBICON and RORB models for the 20, 100, and 200 year ARI events:

- ocean level rise:
  - low level ocean rise = 0.18 m,
  - medium level ocean rise = 0.55 m,
  - high level ocean rise = 0.91 m.

- increase in peak rainfall and storm volume:
  - low level rainfall increases = 5%,
  - medium level rainfall increases = 10%,
  - high level rainfall increases = 20%.

- increase in peak rainfall and ocean level rise:
  - 20% high level rainfall increase , 0.91m high level ocean rise

A 5 year ARI event was also run with a high level ocean rise (0.91m).

While a high level rainfall increase of 30% is recommended for consideration in the DECC Guideline 2007 due to the uncertainties associated with this aspect of climate change, current research suggests that this prediction is not likely to occur within the Hawkesbury Nepean catchment. This assessment has therefore considered potential rainfall increases of 5%, 10% and 20%. The 5% increase is not included in the DECC Guideline 2007, however due to the consequences of a flood in this catchment, it was felt it was necessary to better understand the impacts of a lower level increase. The combined high level rainfall and ocean level rise scenario was used to assess if changes in both parameters changed flood behaviour.

All of the assumptions used in the corresponding design events including rainfall losses, dam levels and rainfall patterns were adopted for use in this study, and were considered to be not affected by climate change for the purposes of this study. However, it is likely that climate change will have some impact on these assumptions, but further study is required to determine these.

RESULTS

In order to quantify the impacts of climate change for the Hawkesbury Nepean valley, the results from the above climate change scenarios were compared with design flood levels at a number of key locations across the valley. Results from the increase in rainfall runs are shown in Tables 1 to 3, and results from ocean level rise runs are shown in Tables 4 to 7. Changes in flow and velocity are documented at key locations in Tables 8 and 9.

Table 1: Rainfall Increase Events, 20y ARI

			Peak Flood Level Impact (m)		
Location	**River**	**Design Level (mAHD)**	**+5% rainfall**	**+10% rainfall**	**+20% rainfall**
F4 Bridge	Nepean	24.47	0.49	0.95	1.82
Vic Bridge Gauge	Nepean	22.94	0.45	0.87	1.65
McCanns Island	Nepean	20.35	0.58	1.12	2.08
Yarramundi	Nepean	16.13	0.40	0.71	1.17
Nth Richmond Bridge	Hawkesbury	15.11	0.33	0.63	1.14
Freemans Reach	Hawkesbury	13.72	0.47	0.94	1.84
Windsor Bridge	Hawkesbury	13.63	0.50	0.98	1.90
Wilberforce	Hawkesbury	13.55	0.51	0.99	1.92
Gronos Point	Hawkesbury	13.14	0.52	1.01	1.94
Sackville	Hawkesbury	10.09	0.45	0.90	1.70
Portland	Hawkesbury	8.62	0.47	0.92	1.72
Wisemans Ferry	Hawkesbury	5.30	0.37	0.74	1.42
Sth Ck/Eastern Creek Junction	South Creek	13.61	0.50	0.98	1.90
Eastern Creek	Eastern Creek	13.61	0.50	0.98	1.90

Table 2: Rainfall Increase Events, 100y ARI

			Peak Flood Level Impact (m)		
Location	**River**	**Design Level (mAHD)**	**+5% rainfall**	**+10% rainfall**	**+20% rainfall**
F4 Bridge	Nepean	27.91	0.31	0.55	0.95
Vic Bridge Gauge	Nepean	26.05	0.27	0.49	0.88
McCanns Island	Nepean	24.06	0.32	0.62	1.21
Yarramundi	Nepean	18.22	0.40	0.77	1.51
Nth Richmond Bridge	Hawkesbury	17.53	0.45	0.86	1.66
Freemans Reach	Hawkesbury	17.31	0.47	0.89	1.70
Windsor Bridge	Hawkesbury	17.29	0.47	0.90	1.71
Wilberforce	Hawkesbury	17.23	0.47	0.90	1.72
Gronos Point	Hawkesbury	16.89	0.49	0.93	1.77
Sackville	Hawkesbury	13.14	0.42	0.81	1.58
Portland	Hawkesbury	11.37	0.50	0.95	1.82
Wisemans Ferry	Hawkesbury	7.57	0.49	0.90	1.69
Sth Ck/Eastern Creek Junction	South Creek	17.27	0.47	0.90	1.71
Eastern Creek	Eastern Creek	17.27	0.47	0.90	1.71

Table 3: Rainfall Increase Events, 200y ARI

Location	River	Design Level (mAHD)	Peak Flood Level Impact (m) +5% rainfall	+10% rainfall	+20% rainfall
F4 Bridge	Nepean	28.71	0.21	0.42	0.85
Vic Bridge Gauge	Nepean	26.78	0.20	0.39	0.76
McCanns Island	Nepean	25.06	0.29	0.56	1.06
Yarramundi	Nepean	19.45	0.43	0.84	1.62
Nth Richmond Bridge	Hawkesbury	18.90	0.45	0.90	1.71
Freemans Reach	Hawkesbury	18.72	0.46	0.91	1.73
Windsor Bridge	Hawkesbury	18.70	0.46	0.91	1.73
Wilberforce	Hawkesbury	18.66	0.47	0.91	1.74
Gronos Point	Hawkesbury	18.36	0.48	0.94	1.77
Sackville	Hawkesbury	14.47	0.44	0.89	1.82
Portland	Hawkesbury	12.94	0.49	0.95	1.84
Wisemans Ferry	Hawkesbury	9.02	0.48	0.90	1.71
Sth Ck/Eastern Creek Junction	South Creek	18.69	0.46	0.91	1.73
Eastern Creek	Eastern Creek	18.69	5.78	0.91	1.73

Table 4: Ocean Level Rise Events, 20y ARI

Location	River	Design Level (mAHD)	Peak Flood Level Impact (m) +0.18m	+0.55m	+0.91m	+0.91m + 20%Rain
F4 Bridge	Nepean	24.47	0.00	0.00	0.00	1.82
Vic Bridge Gauge	Nepean	22.94	0.00	0.00	0.00	1.65
McCanns Island	Nepean	20.35	0.00	0.00	0.00	2.08
Yarramundi	Nepean	16.13	0.00	0.00	0.00	1.17
Nth Richmond Bridge	Hawkesbury	15.11	0.00	0.00	0.00	1.14
Freemans Reach	Hawkesbury	13.72	0.00	0.01	0.02	1.86
Windsor Bridge	Hawkesbury	13.63	0.00	0.01	0.02	1.91
Wilberforce	Hawkesbury	13.55	0.00	0.01	0.02	1.93
Gronos Point	Hawkesbury	13.14	0.00	0.01	0.02	1.96
Sackville	Hawkesbury	10.09	0.01	0.02	0.04	1.73
Portland	Hawkesbury	8.62	0.01	0.04	0.07	1.77
Wisemans Ferry	Hawkesbury	5.30	0.03	0.10	0.19	1.54
Sth Ck/Eastern Creek Junction	South Creek	13.61	0.00	0.01	0.02	1.92
Eastern Creek	Eastern Creek	13.61	0.00	0.01	0.02	1.92

Table 5: Ocean Level Rise Events, 100y ARI

Location	River	Design Level (mAHD)	Peak Flood Level Impact (m) +0.18m	+0.55m	+0.91m	+0.91m + 20%Rain
F4 Bridge	Nepean	27.91	0.00	0.00	0.00	0.95
Vic Bridge Gauge	Nepean	26.05	0.00	0.00	0.00	0.88
McCanns Island	Nepean	24.06	0.00	0.00	0.00	1.21
Yarramundi	Nepean	18.22	0.01	0.01	0.01	1.52
Nth Richmond Bridge	Hawkesbury	17.53	0.01	0.01	0.02	1.67
Freemans Reach	Hawkesbury	17.31	0.01	0.01	0.02	1.71
Windsor Bridge	Hawkesbury	17.29	0.01	0.01	0.02	1.72
Wilberforce	Hawkesbury	17.23	0.01	0.01	0.02	1.73
Gronos Point	Hawkesbury	16.89	0.01	0.01	0.02	1.78
Sackville	Hawkesbury	13.14	0.02	0.02	0.03	1.60
Portland	Hawkesbury	11.37	0.03	0.05	0.07	1.85
Wisemans Ferry	Hawkesbury	7.57	0.08	0.12	0.16	1.75
Sth Ck/Eastern Creek Junction	South Creek	17.27	0.01	0.01	0.02	1.72
Eastern Creek	Eastern Creek	17.27	0.01	0.01	0.02	1.72

Table 6: Ocean Level Rise Events, 200y ARI

Location	River	Design Level (mAHD)	Peak Flood Level Impact (m) +0.18m	+0.55m	+0.91m	+0.91m + 20%Rain
F4 Bridge	Nepean	28.71	0.00	0.00	0.00	0.85
Vic Bridge Gauge	Nepean	26.78	0.00	0.00	0.00	0.76
McCanns Island	Nepean	25.06	0.00	0.00	0.00	1.06
Yarramundi	Nepean	19.45	0.01	0.01	0.01	1.63
Nth Richmond Bridge	Hawkesbury	18.90	0.01	0.01	0.01	1.72
Freemans Reach	Hawkesbury	18.72	0.01	0.01	0.01	1.73
Windsor Bridge	Hawkesbury	18.70	0.01	0.01	0.02	1.74
Wilberforce	Hawkesbury	18.66	0.01	0.01	0.02	1.74
Gronos Point	Hawkesbury	18.36	0.01	0.01	0.02	1.78
Sackville	Hawkesbury	14.47	0.01	0.02	0.03	1.84
Portland	Hawkesbury	12.94	0.02	0.04	0.05	1.86
Wisemans Ferry	Hawkesbury	9.02	0.05	0.08	0.11	1.76
Sth Ck/Eastern Creek Junction	South Creek	18.69	0.01	0.01	0.02	1.74
Eastern Creek	Eastern Creek	18.69	0.01	0.01	0.02	1.74

Table 7: Ocean Level Rise Events, 5y ARI

Location	River	Design Level (mAHD)	Peak Flood Level Impact (m) +0.91m WL
F4 Bridge	Nepean	21.28	0.00
Vic Bridge Gauge	Nepean	20.15	0.00
McCanns Island	Nepean	16.28	0.01
Yarramundi	Nepean	13.05	0.02
Nth Richmond Bridge	Hawkesbury	12.45	0.02
Freemans Reach	Hawkesbury	11.58	0.02
Windsor Bridge	Hawkesbury	11.07	0.03
Wilberforce	Hawkesbury	10.77	0.03
Gronos Point	Hawkesbury	10.19	0.04
Sackville	Hawkesbury	7.83	0.08
Portland	Hawkesbury	7.34	0.10
Wisemans Ferry	Hawkesbury	4.43	0.24
Sth Ck/Eastern Creek Junction	South Creek	11.01	0.03
Eastern Creek	Eastern Creek	11.01	0.03

Table 8: Changes in Flow due to Increased Rainfall

	Design Flow (m^3/s)	Change in Flow		
Event	20Y	20Y + 5% Rain	20Y + 10% Rain	20Y + 20% Rain
Warragamba Dam	6230	8 %	16 %	24 %
Wallacia Weir	2670	8 %	16 %	35 %
F4 Bridge	7840	9 %	17 %	34 %
Yarramundi	7810	9 %	18 %	36 %
Sackville	6240	9 %	17 %	35 %
Event	100Y	100Y + 5Rain	100Y + 10Rain	100Y + 20Rain
Warragamba Dam	9410	5 %	11 %	22 %
Wallacia Weir	4350	6 %	12 %	24 %
F4 Bridge	13330	6 %	12 %	24 %
Yarramundi	13630	7 %	13 %	27 %
Sackville	10920	7 %	13 %	26 %
Event	200Y	200Y + 5Rain	200Y + 10Rain	200Y + 20Rain
Warragamba Dam	11010	6 %	12 %	24 %
Wallacia Weir	5160	6 %	12 %	24 %
F4 Bridge	15890	6 %	12 %	25 %
Yarramundi	16500	7 %	13 %	27 %
Sackville	13230	6 %	13 %	27 %

Table 9: Changes in Velocity due to Increased Rainfall

	Design Velocity (m/s)	Change in Velocity		
Event	20Y	20Y + 5% Rain	20Y + 10% Rain	20Y + 20% Rain
F4 Bridge	3.4	4 %	8 %	15 %
Victoria Bridge	3.5	4 %	7 %	14 %
McCann's Island	1.6	1 %	-1 %	-1 %
Yarramundi	1.0	2 %	6 %	12 %
Windsor Bridge	3.1	1 %	3 %	5 %
Sackville	1.8	4 %	7 %	13 %
Portland	1.8	6 %	9 %	16 %
Wiseman's Ferry	2.3	5 %	9 %	16 %
Event	100Y	100Y + 5% Rain	100Y + 10% Rain	100Y + 20% Rain
F4 Bridge	4.4	2 %	6 %	15 %
Victoria Bridge	4.4	2 %	4 %	5 %
McCann's Island	1.6	-2 %	-1 %	1 %
Yarramundi	1.3	1 %	2 %	4 %
Windsor Bridge	3.4	-1 %	-1 %	-4 %
Sackville	2.3	2 %	5 %	10 %
Portland	2.2	4 %	7 %	13 %
Wiseman's Ferry	2.9	2 %	4 %	10 %
Event	200Y	200Y + 5% Rain	200Y + 10% Rain	200Y + 20% Rain
F4 Bridge	4.9	4 %	9 %	18 %
Victoria Bridge	4.6	0 %	1 %	2 %
McCann's Island	1.6	1 %	3 %	3 %
Yarramundi	1.3	1 %	2 %	4 %
Windsor Bridge	3.3	-1 %	-2 %	-4 %
Sackville	2.5	3 %	5 %	10 %
Portland	2.4	3 %	5 %	11 %
Wiseman's Ferry	3.1	3 %	5 %	10 %

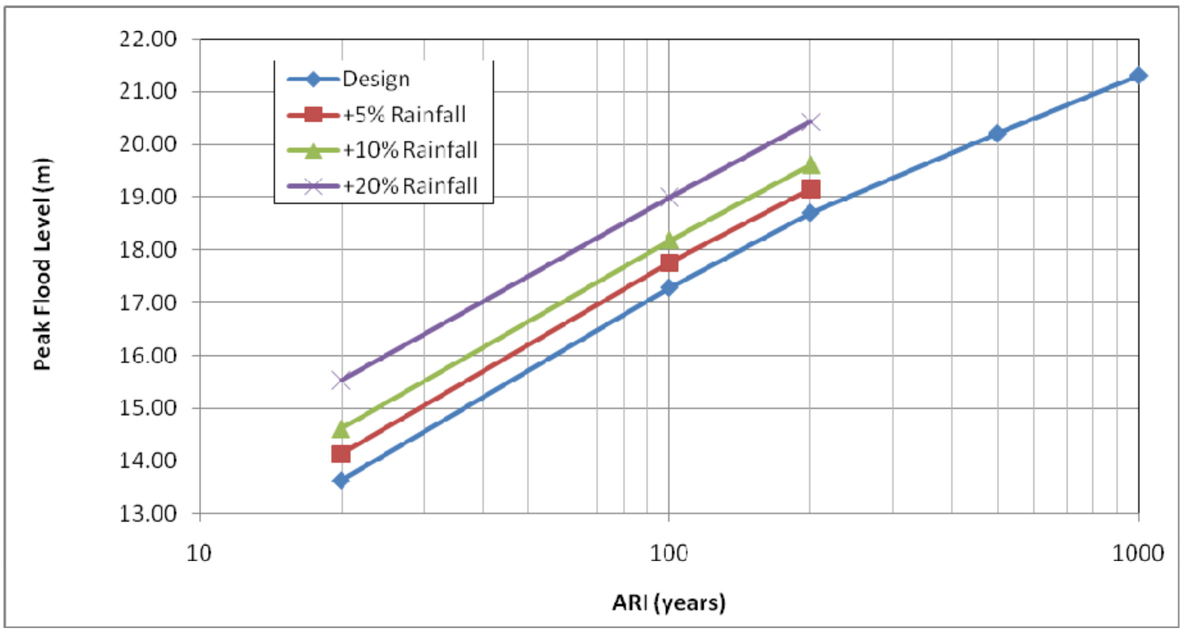
The results from the modelling runs can be summarised as follows:

- Increases of up to +0.91 m in ocean levels produced no significant increases in peak flood levels across the majority of the floodplain. Downstream of Portland some small rises are experienced, however, they are much smaller (0.24m in 5 year ARI) compared to the ocean level rise (0.91m). As most peak flood levels are at least more than 10m above the tidal range, ocean levels do not significantly affect areas other than those immediately upstream of the ocean outlet.
- Flows in a 20y ARI event are more sensitive to increases in rainfall. For the medium level rainfall increase (10%), changes in flows were 16-18% for the 20y ARI event compared to 12-13% in the 100y and 200y ARI events. All events showed a greater percentage increase in flows than the increase in rainfall .
- Velocities are less sensitive to changes in rainfall than flow, and generally show significant increases (>10%) only for the high level (20%) rainfall increase scenario.
- Due to the increases in peak flow, the peak flood levels are quite sensitive to increases in rainfall. For the the 100y ARI event, in the vicinity of urban areas such as Penrith, Windsor, and Richmond in the lower floodplain, peak flood levels are shown to rise by approximately 1.7m with 20% extra rainfall, 0.8-0.9m with 10% extra rainfall, and 0.4-0.5m with 5% extra rainfall.

- The low level rainfall increase (5%) still produced significant peak flood level impacts of approximately 0.5m across most of the lower floodplain.
- Some locations show much greater sensitivity for peak flood levels, including Nepean Junction and Penrith Lakes. In a 100 year ARI event peak flood levels at Nepean Junction and Penrith Lakes rise by 1.6 and 1.4 m respectively, much greater than the 0.8-0.9m across most of the floodplain.

The increase in rainfall scenario results are compared with design level flood frequencies at Windsor Bridge in Figure 1. This shows that an increase of 1.4m in peak flood levels at Windsor corresponds to an increase in ARI from a 100 year to a 200 year ARI flood. An increase of 1.7m in peak flood levels for the 20% increased rainfall scenario equates to an existing flood ARI of greater than 200 years. This effect is similar in the 200 year ARI with a 20% increase in rainfall scenario, which equates to an existing flood ARI of 500 years. In a 20% rainfall increase scenario, the current design 100 year ARI peak flood level would have an updated ARI of less than 50 years.

Figure 1 – Peak Flood Levels at Windsor Bridge versus ARI



Conclusions

At present the increase in rainfall predictions are unreliable estimates, although current work undertaken by CSIRO and for the upcoming revision of AR&R is aiming to reduce the uncertainty of these estimates. However, as shown by the results of the modelling undertaken in this study, any potential increase in rainfall will cause a significant increase in peak flood levels and flows. A high level increase of 20% rainfall will cause 100 year ARI flood level increases of the order of 1.7m, equating to an existing flood ARI of greater than 200 years. The modelling also demonstrated that the potential impact of a rise in ocean sea levels is insignificant on flooding in the Hawkesbury Nepean River.

These results rely on assumptions made for the design events in the Warragamba Dam Auxiliary Spillway Environmental Impact Study Flood Study (1996), including rainfall losses, average rainfalls, dam levels and rainfall patterns, some of which are believed to be affected by climate change. However, the effect of these assumptions is considered unlikely to remove the net significant increase in flows and levels during flood events, especially for extreme events.

Yours faithfully,
WMAwater

E Askew
Associate

CLIMATE CHANGE FLOOD LEVEL SENSITIVITY AT PENRITH LAKES

DECC response to letter of 12th September 2008 from WRL to PLDC

INTRODUCTION

Assessment of the impact climate change has on flood levels, particularly in regard to rainfall impacts, is evolving. However, the "Practical Consideration of Climate Change" guideline from the DECC does provide a framework for evaluating the impacts on flooding resulting from climate change.

At this stage there is no single rainfall change figure for a given planning period that can be applied with a high degree of confidence for Penrith lakes or any other area. Nevertheless, information from the CSIRO work does provide some indication of range possible changes to rainfall intensities (and volumes) into the future.

Notwithstanding the above, given the extreme flood range at Penrith Lakes (e.g. from the 1 in 100 year flood level to the PMF level = about 8 metres), the important issue of providing safe and effective road based flood evacuation egress remains a similar challenge with or without climate change.

INTERPRETING CURRENT CSIRO INFORMATION

As indicated in the letter and the DECC guidelines, CSIRO have predicted that by 2070 the 40 year ARI 1 day extreme rainfall intensity (and rainfall volume) in the Hawkesbury – Nepean catchment may change by – 7% up to +10%.

Despite advice being provided by the CSIRO on the preliminary nature of the data, it is possible to interpret this range in at least two ways, viz:

a) the actual change in rainfall has an equal chance of being anywhere from -7% to +10%; or
b) the change in rainfall that should be applied is the average value of the upper and lower ends of the range, which equates to an increase of + 1.5%.

Option b) attempts to provide a neat and simple numerical solution to the complex climate change issue based on preliminary CSIRO data.

However, the DECC suggests that Option a) more accurately reflects how the range should be interpreted, given the current disparity between the results from the various climate models and the overall uncertainty with current climate change impact estimates . From a precautionary principle perspective, it would be considered unwise to give equal weight to the negative portion of the range.

Accordingly, the DECC believes that it would be more prudent to focus on the positive portion of the CSIRO range (i.e. from 0% to +10%) and beyond when considering a suite of potential floodplain risk management measures to deal with climate change impacts.

APPLYING THE DECC GUIDELINES

The current DECC Guideline indicates that a sensitivity assessment using 10%, 20% and 30% increases to rainfall intensity and rainfall volume should be carried out. However, in light of the current CSIRO data, it could be argued that the 30% increase (and possibly the 20% increase) would be overly conservative. With any sensitivity analysis it is the responsibility of those undertaking the analysis (including consent authorities) to ensure that adequate attention is given to dealing with impacts demonstrated by the analysis.

It is expected that consent authorities would normally exercise duty of care in making decisions regarding development on flood prone land. Accordingly, it would also be expected that all reasonable measures are considered in managing potential climate change impacts, even in the presence of some uncertainty of the magnitude of the actual change.

MINIMUM FILL LEVEL

In regard to Penrith Lakes, it is accepted that a minimum flood planning level (FPL) for residential development has to be initially set for the purposes of designing filling works. It has been agreed that this FPL would be the 1 in 100 year flood plus 0.5 metres for freeboard. Additionally, it has been agreed that the 1 in 100 year level should be preferably raised to accommodate any adverse impacts from climate change (i.e. increased rainfall intensities and rainfall volume).

Clearly the initial capital costs are greater to create a higher flood planning level by extra filling for a given foot print. The long term socio – economic impacts of adopting a higher level to mitigate climate change impacts need to be assessed.

By way of example, the following climate change scenarios could be considered for achieving a minimum filled FPL, viz:

Zero increase in rainfall (i.e. do nothing)
This approach may only be viable if other measures such as the requirement for multi level housing and/or flood aware 2 storey housing can be proven to be adequate measures on their own. However, this approach does not provide a clear and direct way of addressing climate change and also may lead to an increase in overall content damages. Accordingly, zero rainfall approach is not supported by DECC.

5% increase in rainfall
This figure represents the half way point for the positive part of the range. It has some merit from a precautionary principle perspective and may be acceptable from a socio – economic cost, particularly if adequate complementary measures (such as multi – level housing and/or 2 storey flood aware housing) are included with the option. This approach is more likely to be supported by the DECC, providing it is part of a suite of complementary measures.

10% increase in rainfall
Adopting a 10% increase in rainfall intensity (and volume) may reduce the need for complementary measures. However, this approach may be uneconomic because of all the extra fill needed. Complementary measures should still be included with this option, as + 10% increase may not necessarily be the real maximum increase to rainfall intensities and volumes.

COMPLEMENTARY MEASURES

Measures which complement the adopted FPL can be a necessary component of the strategy employed to adequately deal with the impacts from climate change. These measures can be required in order for the climate change adaptation strategy to be flexible and robust enough to be able to adapt to the full range of potential impacts resulting from climate change, which may include increased rainfall intensity and volume above the +10% figure.

Specific complementary measures may include:-

a) Zoning and Development Controls (e.g. to generally limit development to above the lower and more hazardous areas [i.e "floodways"]);
b) Elevated housing / buildings (e.g. on piers);
c) 2 storey flood aware housing design;
d) Multi storey developments, which offer a higher level of protection at the upper levels;
e) Steadily rising elevated roadways / walkways for flood evacuation purposes;
f) Ring (and perhaps deflector) levees to help protect development by excluding some floodwaters or reducing hazardous velocities;
g) Flood detention basins to attenuate increased flow. Whilst detention basins or dams are not feasible to attenuate mainstream flooding, they may be suitable for reducing local flows; and
h) A mixture of the above.

However, it should be noted that some of these measures (such as multi – level housing and/or 2 storey flood aware housing) need to be discussed with the SES, as the measures can create a "false sense of security" making early evacuation difficult to achieve.

When assessing complementary measures, consideration should be given to their initial cost and how effectively the measures reduce the following for say a +5%, +10% and +20 increase in rainfall intensity and volume due to climate change:

1. frequency of inundation;
2. property damage (both individual event damage and the AAD); and
3. risk to life (i.e. ability to safely and effectively evacuate).

In deciding on a climate change adaptation strategy, consideration might also be given to:-

- When redevelopment is likely to occur (i.e. 50 years time?); and
- How easily the initially proposed development can be modified to adapt to climate change (e.g. house raising?).

CONCLUSION

A precautionary approach to climate change impact on rainfall should be applied to the planning / design of new developments, including the proposed Penrith Lakes development. This approach can be achieved by providing a balance between increasing the minimum fill level and along with various complementary measures, such as 2 storey flood aware design housing. It is suggested that an increase of at least 5% in the rainfall intensity and volume should be considered when setting the minimum fill level, in conjunction with complementary measures. Use of the existing recommended freeboard allowance (i.e. 0.5 metres) to address climate change is not supported because of the need to cover underlying flood modelling uncertainty associated with modelling the complex Penrith Lakes area.

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