Climate change impacts in the Hunter Valley

Stakeholder workshop synthesis

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September 1999

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Introduction

This document presents a synthesis of the outcomes from a workshop undertaken as part of the "Scoping study for integrated assessment of climate change impacts for the Hunter Valley", held in Newcastle on 6 May 1999. A report of the workshop has already been prepared, and this synthesis builds on those results.

The aims of the workshop were:

- to brief stakeholders about potential climate change in the Hunter Valley;
- to gain an overview of climate-dependent issues and thresholds in the Hunter Valley;
- to describe tools which can be used in impact assessment;
- to select and prioritise issues for exploration in a simple assessment process;
- to identify relevant databases, research and impact models; and
- to understand how climate change fits into planning strategies.

A risk assessment framework for climate change is being investigated because due to behavioural, economic and scientific uncertainty, and complex system behaviour, it is impossible to give a straightforward prediction of future climate. At best, a range of future climate giving an upper and lower limit for specified climate variables and encompassing most or all of the quantifiable uncertainty for those variables can be produced. By relating a level of outcome (eg. an impact threshold) to a projected range of climate change, it is possible to analyse the probability of that threshold being exceeded. If exceeding the threshold is equated with a certain level of damage (or benefit), then it is possible to ask stakeholders, “Is x probability of exceedance by year y sufficient motivation for you to adapt to climate change?” Thresholds can be positive in terms of a target for sustainability, or negative, in terms of setting a limit of tolerance. A large number of thresholds are listed in Appendix 1.

The workshop aimed to identify one or more climate-related thresholds suitable for use in a simple risk assessment to demonstrate and test the methodology developed by CSIRO. A major part of a risk assessment is risk communication. In this project a number of complex concepts and interactions linking climate change science with activities in the Hunter region need to be assessed and communicated. A major test for the proposed risk assessment framework is to determine whether establishing conditional probabilities of critical threshold exceedance for a particular activity at some time in the future is sufficient motivation for stakeholders to want to adapt. A subsidiary aim is to investigate the issue of integration on a regional basis, and how that may influence adaptation to other agents of change.

Methods of risk communication used so far include presentations, preparation of information papers, a meeting and a workshop. Three further analyses to illustrate other methods to communicate risk have been prepared from data obtained from the workshop. They are:

1. A sensitivity analysis of climate and climate-related variables as they affect the Hunter Region showing the major climatic drivers and activities.
2. A cross impacts analysis of the Hunter River catchment.
3. Visual mapping of impacts.

These illustrate how the components of a complex system can be prioritised for the purpose of assessing risk.

The central component of the risk assessment framework under examination is a risk analysis that aims to determine the conditional probability of an impact threshold being exceeded under climate change. This requires the linking of a climate-related threshold with projected ranges for the key climatic variables that influence that threshold. The conditions required for carrying this out are detailed below and a recommendation made for analysing heat stress in livestock.

Sensitivity analysis

The activity/variable matrix in the workshop report, listing key climate variables and climate-related variables and relating them to nominated activities in the Hunter Region was reconstructed with the weightings 3,2,1, to denote the strong, moderate and weak influences of these variables. The relationship being explored here was “does this variable influence this activity?” Table 1 shows the results. Activities are divided into four main groupings: agriculture, coastal and marine, catchment and the built environment. The row and column values are summed and the results shown in Table 2.

Table 1. Weighted sensitivity matrix of key climate variables and climate-related variables compared with selected activities or exposure units based on Table 1 of the workshop report.

	Poultry	Dairy	Grazing	Cropping	Wine	Horses	Marine (esp. fisheries)	Beach	Coastal water supply	Harbour	Inland water supply	River management	Dryland/irrigation salinit	Forest & biodiversity	Urban infrastructure	Air quality	Waste	Industry, coal & power	Health	
Rainfall - average		2	1	2	2				1		3	2	2	2	2	1			1	21
Rainfall - extreme		1	2	2	1	1	1	2	2		2	3	3	2	3		2	2	1	30
Rainfall - variability		2	3	3	2		2		1		3	3	1	1	2					23
Drought		2	3	3	2	1	1		2		3	2	2	3				2	2	28
Temperature - average	1	2	1	2	2		2			1		2	1	2		2	1		1	20
Temperature - max	3	2	2	2		2	1					3		1	3		2	1	2	24
Temperature - min		2	2	2	2	2								1	2		1	1	1	16
CO_2		2	2	2	2	1								2						11
Cloud				1											1	1				3
Pressure																1				1
Humidity	2	1			2									1	2			1	1	10
Wind		1	1	1	1		1	2		2				1	2	2		2		16
Evaporation	2						1				2	1	2	1			1			10
Soil moisture		3	3	3	3	2					1			2	1		2			20
Stream flow							2		1		3	3	2	1	1			3	1	17
Flood		2	1	1	1	1	1			3	2	3	2	1	3		3	3	2	29
Watertable							2		3		1	1	1	1	1		2			12
Water salinity				1	1		1		3		2	2	3	1				2	1	17
Irrigation		2	1	2	3						2	2	1							13
Sea level							1	3	3	3					2					12
Storm surge								3		3					1					7
Waves							2	3	1	2										8
Lightning														1	1				1	3
Hail				2	3										2					7
Fire			1		1	1								3	1	2		1	2	12
	8	24	23	29	28	11	18	13	17	14	24	27	20	27	30	9	14	18	16	

Table 2 shows two outcomes of the analysis. The climate variables with the highest forcing in the Hunter Valley are dominated by the extremes of rainfall, with a lesser emphasis on temperature. Moisture levels on land or in the atmosphere dominate the variables with moderate forcing. The activities showing the largest climatic influence are largely rural land-based activities with the exception of urban infrastructure. This analysis does not take adaptation into account, so although climate does influence urban infrastructure in many ways, there is substantial adaptation to current climate to at the planning and construction phase. Coastal aspects have a moderate exposure to climate variables due to a few ocean-related variables being very important while most others have little influence. Air quality and poultry have a narrow exposure. By and large, those variables with a broad exposure will be very difficult to assess due to the number of forcing variables and feedbacks. This conclusion is confirmed in the next section.

This type of analysis identifies the variables that pose the greatest potential risks in a region, and therefore need to be examined in the greatest detail. These results are obtained independently of the ability of climate modellers to predict specific climate variables. Modellers have a higher confidence in projections of temperature than rainfall, and even less for a number of other variables, but stakeholders will place their greatest emphasis on rainfall and extreme events. This creates a problem for the suppliers of climate change information and the users of that information, who often need climate information that has a low confidence attached. The analyses carried out here can contribute to strategies aiming to resolve that problem.

Table 2. Results of sensitivity matrix showing the climate and related variables with the greatest forcing and activities with the broadest sensitivity to climate.

	Climate and related variables (forcing)	Activities (sensitivity)
High	Rainfall - extreme Flood Drought Temperature - max Rainfall - variability Rainfall - average Temperature - average Soil moisture	Urban infrastructure Cropping Wine River management Forest & biodiversity Inland water supply Dairy Grazing Dryland/irrigation salinity
Moderate	Stream flow Water salinity Temperature - min Wind Irrigation Watertable Sea level Fire CO_2 Humidity Evaporation	Industry, coal & power Marine (esp. fisheries) Coastal water supply Health Harbour Waste Beach Horses
Low	Waves Storm surge Hail Cloud Lightning Pressure	Air quality Poultry

Cross impacts analysis

As outlined in the workshop conclusions, the complex relationships between climate variables and impact outcomes present a major difficulty for a regional analysis where many non-climatic factors and major feedbacks exist. Cross impacts analysis is one method that can be used to map some of these relationships. Building on the approach used in the previous section, an analysis was carried out for the Hunter River Catchment that examined the link between climate variables, catchment-related variables and major activities within the catchment. Note that economic and social activities have been omitted and activities not directly related to water supply are included as sectors (eg. agriculture, urban areas). In this analysis, each variable was examined to determine whether it is likely to force a change in all other variables.

Where this condition was true, an entry was made in the appropriate cell with a matrix. Table 3 is a matrix constructed of 41 variables showing where these relationships have been identified. A caveat with this type of analysis is that the identification of cause-and-effect is subjective, where:

(i) two variables may be interdependent but this interdependence is not well understood, or

(ii) a sequence of consequences may indirectly link a variable and an activity.

In Appendix 1, the sequence of cause and effect may assume this type of link, whereas in Table 3 cause and effect has been incorporated into the matrix more explicitly.

The purpose of this analysis is to show the dependence of various activities on variables that may be forced by climate change. Figure 1 shows the results from Table 3 on a forcing/dependence graph. The upper right hand corner variables are those that show strong external forcing, in this case due to climate change, with little internal forcing, or feedback. Those labelled autonomous may be important in specific cases but are not significant from a systems point of view. The upper left variables are the relay variables that are strongly forced but also force other variables themselves. These variables are likely to exhibit strong feedbacks. On the lower left are the dependent variables that show a wide sensitivity to both climate and to catchment processes such as land-use, catchment condition etc. These are often variables that are measure of environmental quality, and are the subject of environmental monitoring and reporting. They are also the most vulnerable.

Table 3. Interaction matrix for climate change – catchment forcing under climate change marking where a change in the variable on the vertical axis forces a change in a variable on the horizontal axis.

Table 1. Interaction Matrix for Catchment-Climate Change Impacts	Temperature (average)	Temperature (maximum)	Temperature (minimum)	Precipitation (average)	Precipitation (intensity)	Precipitation (variability)	Drought	Radiation/sunshine	Cloudiness	Humidity	Evapotranspiration	Evaporation (open water)	Wind	CO_2	Soil Moisture	Recharge	Runoff	Streamflow (peak)	Streamflow (average)	Streamflow (variability)	Water storage	Water supply (domestic)	Water supply (irrigation)	Water supply (power)	Riverine aquifer	Mine dewatering	Water quality (nutrients)	Water quality (turbidity)	Water quality (dO)	Water quality (salinity)	Stream/wetland ecology	Algal blooms	Land degradation (erosio	Land degradation (salinity	Fire	Vegetation cover	Biodiversity	Forest	Agriculture	Urban areas	Coastal zone	Forcing
Temperature (average)		1	1		1						1	1			1						1						1		1		1	1			1	1	1	1	1	1	1	18
Temperature (maximum)	1										1	1																	1		1	1			1		1	1	1	1	1	12
Temperature (minimum)	1																												1						1	1	1	1	1	1	1	9
Precipitation (average)							1	1	1	1					1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1		1	1	1	1	1	1	1	1	29
Precipitation (intensity)															1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	25
Precipitation (variability)				1			1			1					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	30
Drought				1		1		1	1	1	1	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1	1	33
Radiation/sunshine	1	1					1		1	1	1	1			1																1	1					1	1	1	1	1	15
Cloudiness			1	1	1	1	1	1		1	1	1			1																	1							1			12
Humidity				1	1		1		1		1	1																							1	1	1	1	1			11
Evapotranspiration	1						1		1	1					1	1	1		1	1	1	1	1	1		1	1		1	1	1			1	1	1	1	1	1		1	25
Evaporation (open water)							1														1	1	1	1						1	1										1	8
Wind											1	1																					1		1	1		1	1	1	1	9
CO_2	1														1																1					1	1	1	1		1	8
Soil Moisture										1	1					1	1	1	1	1	1		1		1		1	1			1		1	1	1	1	1	1	1			20
Recharge																			1	1			1											1								4
Runoff																1		1	1	1	1	1	1				1	1		1	1	1	1	1		1	1	1	1	1		19
Streamflow (peak)																1				1	1				1	1	1	1	1	1	1	1	1			1	1	1	1	1	1	18
Streamflow (average)																		1			1	1	1	1	1	1	1	1	1	1	1	1							1	1		15
Streamflow (variability)																1			1		1	1	1	1	1	1	1	1		1	1	1										13
Water storage																		1	1	1		1	1	1	1	1	1	1	1	1	1	1							1	1		16
Water supply (domestic)																			1	1	1		1								1									1	1	7
Water supply (irrigation)															1				1	1	1	1			1		1				1			1					1			10
Water supply (power)																			1	1	1	1	1			1					1								1	1		9
Riverine aquifer																		1	1	1	1		1				1	1	1	1	1								1			11
Mine dewatering																			1	1									1	1	1											5
Water quality (nutrients)																													1		1	1									1	4
Water quality (turbidity)																													1		1	1								1	1	5
Water quality (dO)																															1											1
Water quality (salinity)																										1		1			1								1	1		5
Stream/wetland ecology																											1	1	1			1					1				1	6
Algal blooms																						1						1	1		1						1			1		6
Land degradation (erosion)											1				1	1	1	1			1	1					1	1	1		1	1		1		1	1	1	1	1	1	19
Land degradation (salinity)											1											1	1			1		1		1	1		1			1	1	1	1	1		13
Fire											1			1	1	1	1	1		1							1	1	1				1			1	1	1	1	1	1	17
Vegetation cover	1									1	1			1	1	1	1	1		1							1	1	1	1	1	1	1	1	1		1	1	1		1	22
Biodiversity											1																1		1		1		1	1	1	1		1	1		1	11
Forest	1									1	1			1	1	1	1	1	1	1	1		1	1			1	1	1	1	1		1	1	1	1	1		1			24
Agriculture											1			1	1	1	1	1		1			1		1		1	1	1	1	1	1	1	1	1	1	1	1		1		22
Urban areas			1							1			1	1	1	1	1	1			1	1		1			1	1	1	1	1	1	1		1	1	1	1	1		1	24
Coastal zone																															1	1			1	1	1					5
Dependency	7	2	3	4	3	2	7	3	5	10	15	7	1	5	16	15	12	15	15	19	19	16	18	11	11	12	22	21	23	18	34	21	14	13	17	20	24	22	29	22	22	

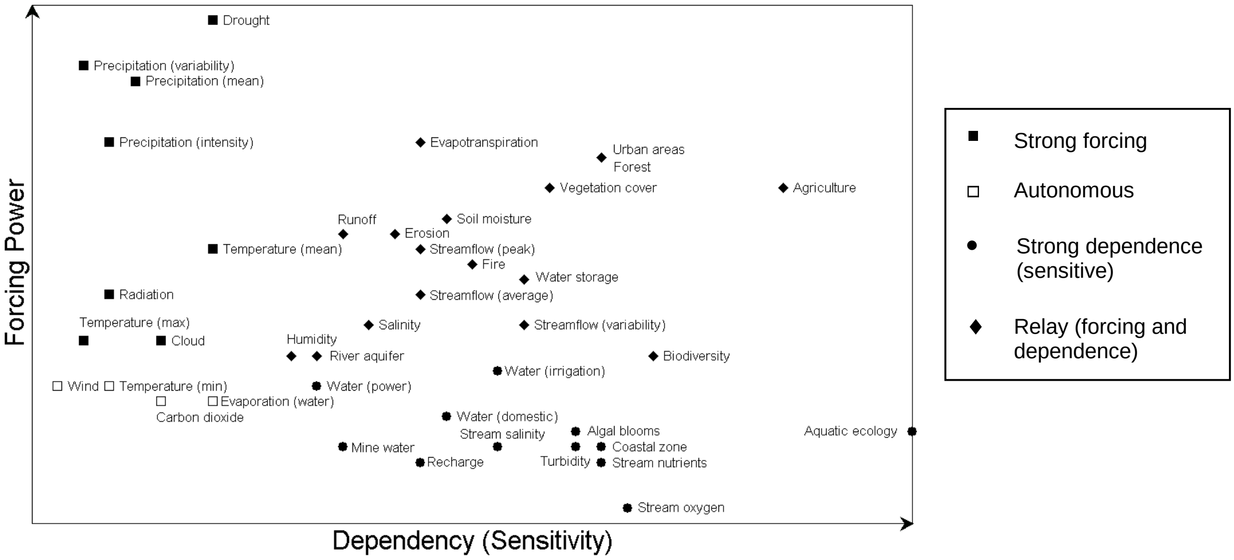

Figure 1. Forcing/dependency chart for climate, catchment processes and catchment-based activities in the Hunter River Valley based on the cross-impacts analysis presented in Table 3.

This type of analysis can be enhanced by adding weightings to the various interactions as applied in Table 1. The strongest links can then be followed through their interactions (especially following the links between the forcing and relay variables to the dependent variables). The outcome can be used as a precursor to integrated assessment modelling (IAM) where these interactions are modelled explicitly. However, economic and social interactions, both of critical importance within IAMs, have not been included in the example presented here.

Linking the strongest relationships within Figure 1 leads to another method of analysis that is used to illustrate complexity: visual mapping. Two simple examples are mapped in Figure 2, showing the relationship between climate change, climate variables and heat stress affecting cattle and poultry. They display the links between climate variables and a stress index threshold that is explicitly linked to outcomes involving a level of production loss or stock mortality.

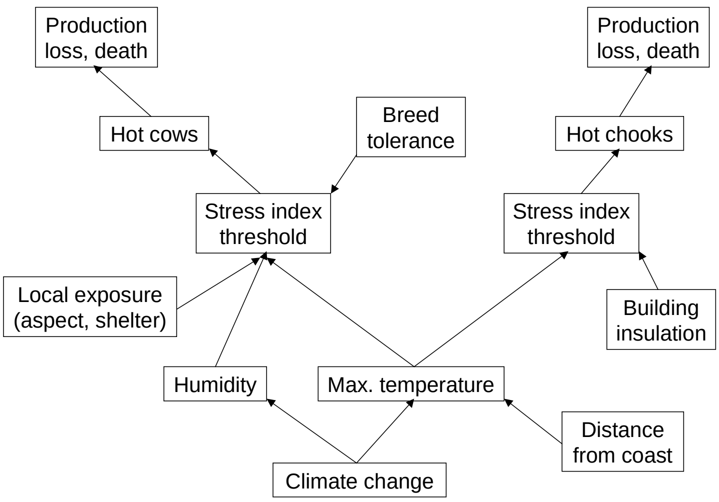

Figure 2. Visual map of the relationship between climate change, climate variables and heat stress affecting cattle and poultry.

Visual mapping has been developed as a tool for communicating complexity. It can also be used for in risk assessment by diagnosing the major links and interactions between elements in complex systems. A number of computer modelling systems utilising object-oriented programming use visual mapping as a link between system components to carry out analyses and communicate the system structure.

Risk analysis

The demonstration of CSIRO's risk assessment methodology using a pilot risk analysis requires the following criteria to be met. The example must be:

- an activity with high sensitivity to a limited number of climate variables
- the variables must have a moderate to high confidence attached by climate modellers
- the impact model must be computationally simple
- the activity must be closely associated with planning and/or operational processes that support adaptation.

This synthesis report has identified a number of activities that are affected by rainfall variability and extremes, but scenarios of rainfall change have low reliability and the impact models associated with water supply and water use tend to be complex.

A much simpler example may be provided by models of heat stress on livestock that simulate some of the interactions in Figure 3. Heat stress can be measured using daily maximum temperature and humidity and there is high confidence in temperature scenarios and moderate confidence in humidity scenarios. In the workshop, the Primary Industry working group indicated that dairy cattle were more sensitive to heat stress than poultry. Cattle tend to graze in open fields with a few shade trees while chickens are kept in a more controlled environment, such as insulated sheds. Planning processes supporting adaptation in the dairy industry are well established through the Dairy Farmers Association and NSW Agriculture. Relevant research on heat stress effects on dairy cattle is available in:

- Davison, T. et al. (1996): "Managing hot cows in Australia", Queensland Department of Primary Industry, 58 pp.
- Howden, S.M. and Turnpenny, J. (1997). Modelling heat stress and water loss of beef cattle in subtropical Queensland under current climates and climate change. Modsim '97: International Congress on Modelling and Simulation Proceedings, Hobart, 8-11 December, pp. 1103-8.
- Howden, S.M., Hall, W.B. and Bruget, D. (1999). Heat stress and beef cattle in Australian rangelands: Recent trends and climate change. Proceedings of the VI International Rangelands Congress, Townsville, Australia, July 1999, pp. 43-5.

Davison et al (1996) found that production loss for dairy is related to maximum temperature and relative humidity. The temperature-humidity index (THI) was confirmed as the best predictor of animal comfort and productivity in 17 regional studies analysed. A THI exceeding 77-80 greatly reduces milk yield (eg. 27^{o}C at 80% humidity, or 31^{o}C at 40% humidity). For Queensland sites, a THI exceeding 83-84 reduces fat and protein content. When the THI exceeds 72 (eg. 25^{o}C at 50% humidity) reproductive performance declines significantly, indicating that reproductive efficiency declines before milk yield. A dramatic decline in dry matter intake occurs above 30^{o}C. Younger cows have a superior heat tolerance due to their larger surface area to weight ratio - they can shed more heat per kilogram by sweating. Adaptive management responses are suggested (eg. shade trees, shade sheds, fans and sprinklers). The Hexam factory database indicates that 60% less milk is produced at 30°C if humidity increases by 8%.

There is a strong case for testing the CSIRO risk assessment method on the dairy industry in the Hunter Valley.

CSIRO therefore proposes to undertake a pilot project to assess "The vulnerability of dairy cattle to heat stress due to climate change in the Hunter Valley". To do this, we will collaborate with the authors of the three research reports above so that we can build on their modelling and adaptation experience in the dairy industry.

Conclusions

The analyses contain in this synthesis illustrate the difficulty in obtaining simple factors for assessing risk in complex systems. The methods being applied as part of the project involve linking key climatic variables with impact thresholds and these are summarised both in the project report and in Appendix 1. However, the analyses above show that although many of these links are conceptually simple (eg. the link between heavy rainfall and infrastructure damage costs) they are procedurally difficult. Figure 1 shows why this might be so. The number of relay variables and feedbacks between climatic variables and activities showing strong dependency demonstrate the complexity of catchment processes. It would be expected that if cross-impact analyses for agriculture, the coastal zone and urban settlements were carried out, similar complexities may result.

However, several of the systems investigated in the workshop were not as complex. Two of these are illustrated in Figure 2, the impacts of changing heat stress on poultry and cattle. It is recommended that:

(i) a procedurally simple risk analysis such as the heat stress example be carried out as part of the next step of the project, and

(ii) that the analyses presented here be carried through to the conclusion of the project to illustrate some of the more complex issues associated with regionally integrated assessments of climate change impacts.

Appendix 1

Key climate change issues, variables and thresholds in the Hunter Valley

A sectoral summary based on stakeholder input

This table is collated from information climate change issues, key climatic variables and impact thresholds in the Hunter Valley supplied by NSW government departments, the Hunter River Management Committee, the Hunter Water Corporation and the workshop report.

Issue / activity	Climate variables	Thresholds
Agriculture		
Intensive animal production		
Poultry	Maximum temperature	Critical maximum temps: 18–20°C for mature chickens, 30–32°C for young chickens
Pigs	Maximum temperature	Critical temperatures: 18–21°C for mature pigs
Dairy		
Heat stress	Temperature, humidity	Level of production loss, death
Effluent control	Flood, rainfall intensity	Failure of facility
Flooding	Flood	Intensity of 1-in-20 year flood
Grazing		
Beef (dam design, cattle ticks, vector-borne diseases, pasture digestibility)	Run-off rates, rainfall, temperature, CO_2	Gross margin per ha, safe stocking rates
Hay production	Rainfall	Dry matter per ha
Cropping		
Plant productivity	Increased CO_2, dry spells, temperature, humidity	Yield or gross margin per ha
Sowing	Soil moisture, temperature	During optimum season
Harvesting	Soil moisture, humidity	Before seed/fruit loss
Wine		
Grape production (mildew, berry character)	Humidity, temperature, rainfall, frost, hail	Winter chill, fruit quality, fruit yield
Horses	Min and max temperature, wind chill	Disease, death

Issue / activity	Climate variables	Thresholds
Coastal & marine		
Marine (esp. fisheries)		
Estuarine salinity	Rainfall intensity/duration/seasonality, air and water temperature, wind speed and direction, sea-level, tides, droughts, surge	“Safe” levels for breeding etc.
Estuary erosion and siltation	Floods, flushing flows	Maintenance of navigation
Aquatic vegetation (seaweed, sea-grass)	Sea-level	Percentage cover
Prawn fisheries	Rain events, river discharge	Population/harvest levels
Beach		
Beach stability	Rainfall, waves, winds	Loss of amenity
Coastal management	Sea level, wind, wave heights, tides	Damage or loss to wetlands, or coastal infrastructure
Coastal water supply		
Groundwater	Rainfall intensity, evaporation, soil moisture, water table, sea level	Maintenance of current levels
Harbour	Sea level, water quality, surge, waves, tides, storms	Days per year closed

Issue / activity	Climate variables	Thresholds
<u>Catchment</u>		
<u>Inland water supply</u>		
Security	Droughts, evaporation, rainfall intensity	Design drought frequency & length
Volume	Evaporation, temperature, humidity, cloud, soil moisture, raindays, droughts	Storage capacity
Dam safety	Rainfall intensity, soil moisture	Sea level and groundwater at Tomago
Infrastructure planning	Droughts, runoff and dry spells	Probability of failure, overtopping
Groundwater	Droughts, floods, evap, temp, soil moisture, water table, sea level	Probable maximum precipitation
Irrigation water supply	Temperature, rainfall, evaporation, cloud, humidity	Maintenance of current levels
Irrigation demand	Evaporation, rainfall seasonality, soil moisture, humidity, drought sequences	Meet all rights plus environmental flows
<u>River management</u>		
River flow	Duration and spacing of rain events, rain intensity, duration and frequency of flushing flows, flash floods	Environmental flows & supply targets met
Stream sediment load	Runoff, floods	Quality targets
Riverine aquifer recharge	Floods	Water level x time
Environmental flows	Rainfall variability & intensity, runoff	Design flow frequencies set through water reform
Flood frequency	Rainfall intensity, soil moisture	Exceedance of set levels
River nutrient loading	Frequency and spacing of runoff and flushing flows	Water quality targets met
River salinity	Flushing flows for saline discharge from coal mines, dryland salinity etc	Ec units at Singleton
Erosion	Rain intensity/frequency, soil moisture, evaporation, wind, water table, vegetation	Area under threat, tonnes per ha per year
Estuary/freshwater boundary	Sea-level, wind, storm-surge, rain	Location

Dryland/irrigation salinity		
Dryland salinity	Runoff, water table, flushing river flows, vegetation	Area affected
Stream salinity	Runoff, water table, flushing river flows	Set Ec units at defined locations, frequency of exceedance
Forest & biodiversity		
Conservation of fauna/flora (population viability, design corridors for dispersal, adaptive management to assist dispersal, extinction)	Daily max/min temperature, rainfall, humidity, sunlight, wind, cumulative effects	Extant distribution/new distribution related to conservation status
Fire management	Rainfall, drought, soil dryness, wind, humidity, temperature	Outside design fire frequency, forest/property damage, large wildfire
Vegetation	Rain intensity/frequency, soil moisture, evaporation, temperature, drought, water table, extreme weather events	Loss of cover, biodiversity or condition
Wetland protection zones	Rainfall, evaporation	Loss of breeding events
Nutrient release	Temperature, soil moisture	
Fungal disease	Temperature, rain, humidity	Area affected
Tree growth	Temperature, transpiration, soil moisture, ground water	Harvestable biomass per ha, stems over certain width
Logging operations	Rainfall intensity	Targets met

Issue / activity	Climate variables	Thresholds
Human settlements		
Urban infrastructure		
Storm water	Rain intensity, floods	Failure of system, contamination
Flood-prone land (restricted development)	1-in-100 year flood level	Exceedance of level
Fire prone-land (restricted activities)	Fire, temperature, wind, humidity	Increased frequency
Roads and railways	Storms, floods, tides	Damage levels or closure
Stormwater drain design	Rainfall intensity	Frequency of failure
Flood mitigation structures (eg. levees)	Floods, flushing flows	Exceedance of level
Air quality	ENSO variability, maximum temperature, pressure (anticyclones), fire	El Niño frequency, temperature above 23 °C for 2–3 hours, duration of high pressure systems
Waste		
Sewage treatment	Dry/wet spells, floods	
Underground water and sewage pipes	Dry/wet spells	Failure and contamination
Industry, coal & power		
Discharge of salinity from mines	Frequency and spacing of flushing flows	Salinity trading scheme limits
Power generation	Flow events and water level	Frequency and duration of suitable levels, design drought
Power demand	Max and min temperature	Exceedance of set levels
Health		
Vector-borne diseases	Rain, floods, temperature	Disease potential, vector population levels
Blue-green algae	Rain, flushing flows, temperature, cloud	Frequency and duration of bloom, water temperature
Water-borne diseases (hep, giardia, dysentery, gastro)	Rain intensity, floods	Low flow rates, high nutrients
Heat stress	Temperature, humidity, wind	Days above given threshold