Resilience, transition and transformation: learning from and influencing social-ecological change in the Goulburn Broken Region, Australia

"There is nothing so hard as to change the existing order of things." (Machiavelli 1952)

ABSTRACT

This paper summarises what we have learned from two consecutive assessments of the resilience of the Goulburn Broken Region, Australia. The first was during a drought, but before the 2008 Global Financial Crisis. The second was made in 2013 after the drought and in the aftermath of the Global Financial Crisis. The paper updates our understanding about: defining the boundaries of social-ecological systems; the impacts of drivers; identifying thresholds and assessing the proximity of the system to them; the need and potential for transformation, and the roles of cross scale governance in facilitating or inhibiting it.

The paper argues that while major infrastructure improvement since the first assessment has postponed the transformation of irrigated farming and made available more water for maintaining rivers, wetlands and floodplains, the decadal drought and Global Financial Crisis have pushed farms and processing industries closer to economic thresholds identified in the first assessment. Meanwhile the Goulburn Broken Catchment Management Authority has continued to invest in social networks, knowledge and distributed governance that enhance the Region's general resilience and transformative capacity.

The paper is, above all, about embracing uncertainty. We hope our reflections will be useful to the growing numbers of practitioners, policy makers and researchers worldwide who are using resilience thinking to counter the challenges and realise the opportunities in our increasingly uncertain World.

INTRODUCTION

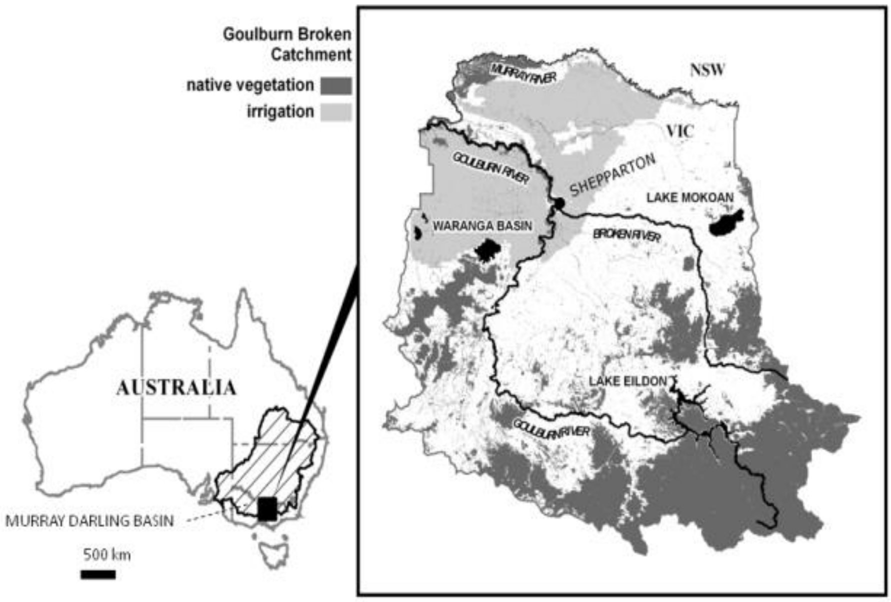
This paper is about the resilience of the Goulburn Broken Region in the Murray Darling Basin, Australia (Figure 1). The region contains 204,000 people, covers 2.4 million ha, and is described in GBCMA 2013. The evolution of the region since its Indigenous peoples were overwhelmed at the beginning of the 19th century by British colonists was summarised in Walker et al. (2009), who assessed its resilience during a decadal drought but before the Global Financial Crisis. Subsequent climatic and economic drivers and shocks have changed the region and our understanding of its dynamics. Growing global uncertainties meanwhile correlate with a surge of interest among practitioners and researchers in 'resilience thinking' (Walker and Salt 2006, 2012) around the World (Xu and Marinova 2013). Resilience thinking at catchment scale, pioneered by the Goulburn Broken Catchment Management Authority (GBCMA) is now used in catchment management strategies in New South Wales Queensland, South and Western Australia, and elsewhere in Victoria. This paper contributes to the further development and application of resilience thinking by:

- describing recent effects of social, economic and bio-physical drivers and shocks on the region, and the responses of governance and resource users;

- presenting new understanding about the resilience and transformability of the region, and making recommendations.

The paper updates Walker et al. 2009 (‘the 2009 Paper’ hereafter) by synthesising the GBCMA’s (2013) Regional Catchment Strategy, (‘the RCS’ hereafter), the findings of a researchers’ and practitioners’ workshop organised by the GBCMA (‘the Workshop’) and a fresh literature review.

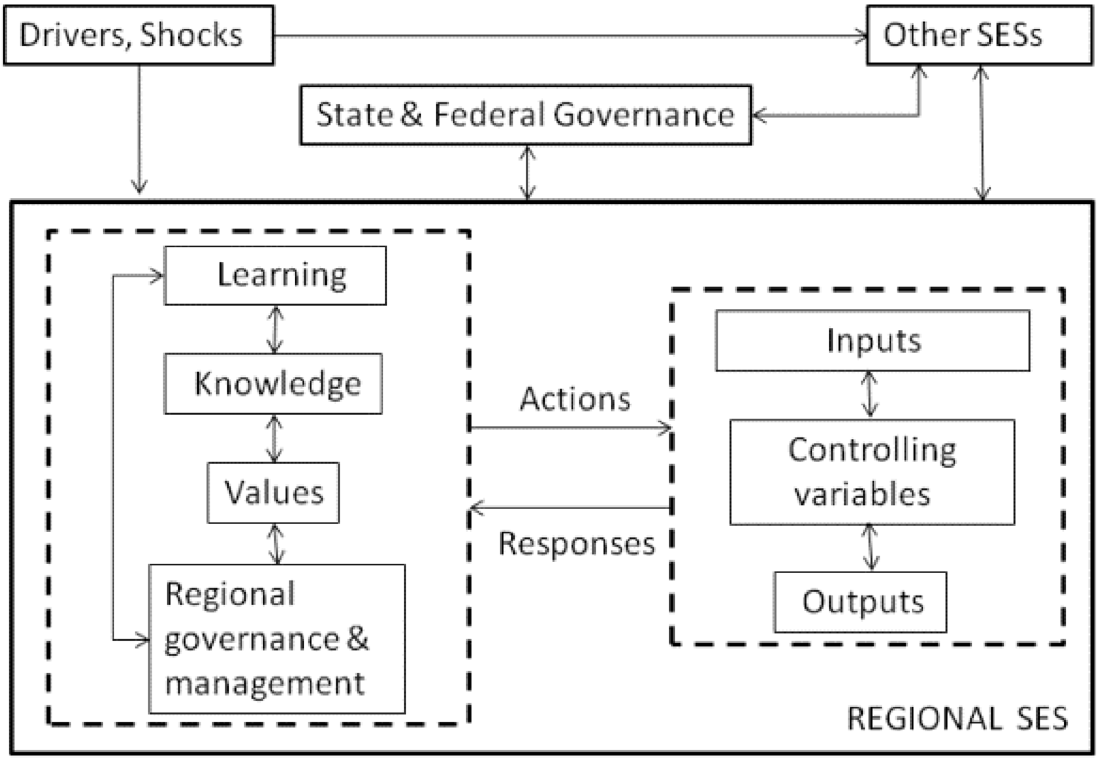
Figure 1



The paper applies resilience theory (Figure 2 and Walker and Salt 2006, 2012) to social-ecological systems (SESs) in which human and bio-physical sub-systems interact dynamically through linkages that tend to cluster at particular spatial scales. Resilience researchers and practitioners choose scales on which to focus and put ‘boundaries’ around clusters, but to account for cross-scale interactions, they seek to understand the dynamics of SESs at scales broader and finer then the focal scale.

Drivers and shocks cause changes in ‘fast’ variables, and the more stable, ‘slow’ variables that control them (Zeeman 1976, Ludwig et al. 1997, Walker et al. 2004). The former can vary widely, but the system stays within its current ‘regime’ so long as controlling variables remain within thresholds, otherwise either of two types of transition to a new regime may occur. In the first, the new regime produces the same outputs as before, though in different quantities. It is bounded by the same controlling variables, but within different threshold levels. The second type of transition leads to a regime with a changed set of controlling variables with new thresholds, and different outputs. Only the second type is defined in resilience theory as a transformation. Metaphorically, the system retains its original ‘identity’ through the first type of regime shift, but transformation changes the system’s identity in the second.

Figure 2



Humans learn from observing the changes that drivers, shocks and their own actions cause in the SES, and can respond with changes in the governance and management of the system, but socio-economic, technological and bio-physical changes generally happen ahead of changes in values and formal rules of governance (laws, policies, regulations etc.). This generates conflicts between resource use and ecosystem sustainability, and among resource users (the 2009 Paper). These tensions drive the co-evolution of values, governance and environmental management in SESs, including regime shifts. The easing of conflicts by re-alignment of values, rules and bio-physical processes enables periods of relative stability (Kingston and Caballero 2009, Krall and Klitgaard 2011, Norgaard and Kallis 2011) either within the current regime or, following crisis and reorganisation, within a new one.

These dynamics are captured in the concept of the four stage 'adaptive cycle'(Gunderson and Holling 2002). The growth stage (relatively simple, high resilience, wide range of options), is followed by conservatism (complex, lowered resilience, narrow range of options for change), crisis (loss of structure) and reorganisation into another growth stage. We have renamed two of the stages to suit this study –'conservation' is renamed 'conservatism', and 'collapse' becomes 'crisis'. The new growth stage may be in the same regime, or a new one. The transition between regimes through crisis and reorganisation can be intended or unintended, with transitions at finer scales often but not always triggered by broader scale dynamics. The resilience of an SES is therefore its capacity to remain within a regime, plus its potential capacity to make an intended transition to a new one.

In the next section we discuss shifts in the boundaries of the Goulburn Broken Region (GBR) since Walker et al. (2009) was published, then changes in drivers, shocks, trends and uncertainties, followed by an update of our understanding of controlling variables and their thresholds. That leads into our re-assessment of the resilience of the GBR's sub-regional SESs, and a discussion of the need and potential for transformation of some of them. We end with a synthesis of our current understanding of the region, what we have learned, and how it might be applied.

RESETTING THE BOUNDARIES OF THE REGION

The boundaries of the GBR are defined by river catchments. The 2009 Paper treated it as a single SES though within it there are diverse urban centres landscapes, resources and stakeholders, and eight Local Governments. The RCS has now addressed the diversity by identifying six sub-regional SESs within the GBR SES: the Agricultural Floodplains, Upland Slopes, Southern Forests, Productive Plains, Commuting Hills, and Urban Centres.

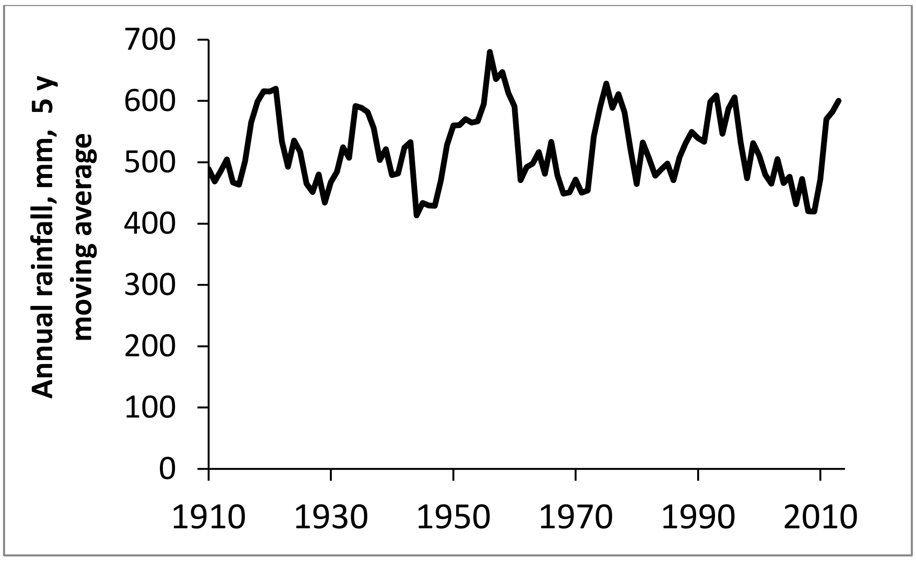
DRIVERS, SHOCKS, TRENDS AND UNCERTAINTIES – AN UPDATE

We used the concepts of drivers and shocks loosely in the 2009 Paper. A driver is a variable that causes a system to change but is not itself affected by the change because there is no feedback to it from the change (Walker et al. 2012*b*). A shock is a driver that spikes then subsides. Drivers and shocks can be well known or new and surprising. Our current understanding is that the dynamics of the GBR are affected by the drivers and shocks below. More detail on some drivers is in Appendix 1.

Climatic change

South Eastern Australia has always experienced high climatic variability, but the low irrigation water allocations during the drought were unprecedented (Figures 3, and Appendix 1 figures A.1.1. and A.1.2.). In 2010 it was predicted the GBR's main water storage (Lake Eildon) would take 6 years to refill after the drought – with record floods it took six months. A climatic change influence is now indicated (Post et al. 2012). From here on climatic change is expected to be a major driver and source of shocks through its effects on the frequency and magnitude of droughts floods and fires. Climatic change projections are uncertain, but a warmer and drier future is expected.

Figure 3



Laws, policies and values

Laws and policies stem from State and Federal governance. They are not strictly drivers, because they are influenced to some extent by regional scale social and environmental feedbacks.

Murray Darling Basin (MDB) water policy is crucial to the GBR because it determines regional water allocations, which impact the GBR's agriculture, wetlands, floodplains and streams (Barr 2011, Connell and Grafton 2011, Montecillo 2013). The Murray Darling Basin Plan, legislated in 2012, is an agreement among State and the Federal Governments to set limits on surface and groundwater abstraction, improve efficiency of use and security of access, and provide environmental flows. Within the MDB, Catchment Management Authorities operate under State law, are funded by State and Federal governments and are vulnerable to policy shifts by either.

State and Federal constitutions, laws and policies influence conservation and land use in the GBR through State and private property rights, laws on rare and endangered species, national parks and reserves, native vegetation clearing restrictions, and incentives for growing and protecting it on farmland. The international Ramsar Convention is an additional protection for the Barmah Forest wetland.

Recreational and tourism values based on the GBR's rivers, wetlands and floodplains, uplands, wine and food remain strong (Dyack et al. 2007, Hatton-MacDonald et al. 2011, Montecillo 2013), and overlap substantially with environmental values.

Urban-employed people value 'lifestyle' blocks on rural land, and subdivision has taken more dryland farms out of production since the 2009 paper, impacting on farmers' land-focused social networks and ability to increase farm size to offset declining terms of trade.

Laws and policies are subject to shifts in society's values, with consequent political pressure on governments (Connell 2007) Workshop participants felt that the balance between environmental and agricultural production values fluctuate depending on current policy, economic conditions and drought rather than following a trend (c.f. the 2009 Paper). Climatic and economic turbulence will probably continue to shift values, with the possibility that there is a tipping point past which there is a lasting shift.

Commodity prices, exchange rate, and agricultural terms of trade

This set of drivers impacts farm financial viability, a controlling variable. The relative stability of the Australian economy during the Global Financial Crisis raised the value of the Australian dollar, making agricultural exports uncompetitive even as the long term decline in the ratio of farm revenue to input costs continued (Barr 2012). By contrast, energy costs have risen more slowly than other input costs (ABARES 2013). Fossil fuel's climatic externalities are not paid for, and agricultural diesel fuel is tax-exempt. Both may change with climatic trends.

Demographic change

The farming population is ageing This enables farm amalgamations that realise economies of scale (Barr 2011), but it also reduces the sizes and perhaps effectiveness of social networks (discussed later). This driver was not identified in the 2009 Paper.

Diseases and pests

The vulnerability of the GBR to pest and disease shocks is high and increasing for these reasons:

- genetic uniformity of crops, orchard trees and dairy cattle
- adjacency of similar farms
- high frequency of movements of water, people and stock onto and across farms
- growing numbers of international travelers and volumes of imports
- the threat of antibiotic resistance.

Among current risks are: a return of the anthrax outbreak of the late 1990s; the honey bee (*Apis mellifera*) parasite *Varroa destructor* – its arrival could disrupt pollination of fruit and other crops (Cunningham et al. 2002); and newly introduced Myrtle Rust (*Puccinia psidii*) that can infect native *Myrtaceae*, including the genus *Eucalyptus* a major component of native vegetation (Booth and Jovanovich 2012, Kriticas et al. 2013).

CONTROLLING VARIABLES AND THRESHOLDS RE-VISITED

Managing controlling variables is an effective way of influencing system behavior because at a particular scale their number is a small proportion of all the variables that could potentially be managed. Resilience theory focuses especially on controlling variables that have thresholds, because crossing them could initiate a regime shift (the 2009 Paper).

The controlling variable concept was not used in the RCS. Thresholds were identified or suspected on 32 variables chosen by the GBCMA and stakeholders. One reason for the large number was the division of the region into six SESs, each with a particular variable set. Not all were controlling variables, because they did not appear to be critical to maintaining the current regime. Some had been included because of pressure from stakeholders or because of statutory requirements. Biggs et al. (2011) would see this as good practice, but notes the need to distinguish between thresholds on critical processes, and less important thresholds. Actions not aimed at controlling variables draw resources away from those that are.

The quality and amount of evidence about a controlling variable affects our confidence in identifying it as a controlling variable and in setting the limits within which it can vary without transgressing a threshold. Appendix 2 Table A2.1 shows the estimated levels of these two types of reliability. It also shows the details behind some of the summaries that follow.

Farm financial viability

Profit levels for Victorian farms have been growing slower than debt since 1990 and continue to do so (Figure A.2.1). This correlates with a decline in the number of dryland and dairy farms and orchards in the GBR, which was hastened by the drought, the Global Financial Crisis (GFC) and the contraction of the region's fruit processing sector. New international trade agreements may lead to improved farm viability.

Sizes of dairy and fruit processing sectors

The sizes of these sectors were judged in the 2009 Paper to be controlling variables because a contraction in either would flow through the rest of the regional economy, due to their high employment and economic multipliers (Plant et al. 2003, Montecillo 2013), causing declines in producers' incomes in the Agricultural Floodplain SES and job losses and declines in household and business incomes in the Urban Centre SES. We have not so far determined quantifiable thresholds in the sizes of the sectors, though both have shrunk since the 2009 Paper. The last remaining fruit processing company announced its intention to close, but instead established a link with a supermarket chain and secured State Government support. The number of milk processors declined from seven to three in recent years, but the short term outlook for those remaining appears strong.

International demand for dairy and fruit products is expected to grow, but processors are multinational companies with relocation and purchasing options outside the GBR. Divestment was probably in response to market competition and commodity prices. The high relative value of the Australian dollar during and following the GFC made many Australian exports uncompetitive. If there are size thresholds for processing industries below which large scale production of fruit and milk in the region becomes financially unviable, both controlling variables have moved closer to them, reducing the resilience of these sectors.

Irrigation infrastructure

Irrigation infrastructure configuration and condition determine water price, availability and efficiency of use. The 2009 Paper recognized a threshold of investment needed to renovate a system that was leaking to groundwater and increasing the salinity threat. Since then over $2 bn of public funds has been spent to raise water use efficiency in the Northern Victorian irrigation region in which the GBR is set (NVIRP undated). Reduced leakage to groundwater lessens the salinity threat from a rising water table, and within changing climatic limits, more water is available for irrigators and environmental flows.

Water table depth

During the drought the saline water table in the Agricultural Floodplain SES fell well below the threshold of 2m from the surface used in the 2009 paper. After the drought the level rose much faster than expected (Appendix 2 Figure A.2.2.). The hydro-geological assumptions on which the 2009 Paper was based were incorrect, and over-estimated the resilience of the irrigation system. The consequence of transgressing the threshold is irreversible soil degradation, but the GBCMA and regional public water agency have been monitoring the bores and pumping from the aquifers. This strategy remains effective while rainfall remains average to dry and interstate agreements for salt discharge to the Murray Darling Basin remain. Both are subject to rapid change.

Terrestrial native species habitat thresholds

Thresholds for native vegetation, a proxy for native species habitats, were set at GBR scale in the 2009 Paper, but the RCS identifies different area, patch size, inter-patch distance and habitat condition score thresholds for remnant native vegetation in each SES (Bennett, 1999, Lindenmayer 2002, Bennett et al. 2006).

Following the region's experience of severe and widespread bush fires, the GBCMA has added the minimum and maximum tolerable return intervals of fire to its thresholds for several native plant species and vegetation communities. Climatic change is expected to increase the number of days with extreme fire danger, and lengthen the fire-risk season (Clarke et al. 2011).

Land use regulation and farm-scale land use decisions

Land cover - urban, agricultural, or native vegetation - affects biodiversity, runoff and stream flow, erosion, water quality and drainage to water table (Anderies 2005, Bartley et al. 2012) The extent of native vegetation in national parks, reserves, State forests and as remnants on farmland is controlled by State legislation and policy as discussed under drivers, but within the GBR local government regulates the conversion of farmland to housing or other development, and receives advice on this from the GBCMA. Regulations aside, other land use decisions by farmers (e.g. arable or grazing, annual or perennial, dryland or irrigated) can be influenced by information and incentives.

River, wetland and floodplain thresholds

The species composition and structure of wetland and floodplain vegetation communities are set by thresholds in the flow regime, and if these are crossed a transition is initiated (Colloff in press, Roberts and Marston 2011). Natural flow regimes of most streams, wetlands and floodplains in the region have been radically altered by storage, abstraction and unseasonal release for irrigation, so it is likely wetlands and floodplains are not yet in equilibrium with current watering regimes. They will remain so if flow regimes continue to change. The structure, functioning and conservation values of river, wetland and floodplain ecosystems now depend on engineering and political-economic processes. The identification of controlling variables and quantification of thresholds at SES scale is still in progress.

Water quality controlling variables

In the 2009 Paper we used nitrogen and phosphate levels as controlling variables. Though correct at the scale of a water body, at the scale of a catchment or an SES, water quality is controlled by land use regulation and flow regimes.

Interactions among controlling variables

Potential interactions among controlling variables in the GBR was emphasized in the 2009 Paper because of the risk that if one threshold is crossed it will drive other controlling variables across thresholds, causing system collapse. Here we have simplified the equivalent figure for the Agricultural Floodplain SES (Figure 4) because of revised hydrological understanding, and the focus in this SES on irrigation, streams, wetlands and floodplains. Interactions among controlling variables in the other rural SESs are in Figure 5, though lifestyle land use is relatively unimportant in the Productive Plains SES.

Figure 4

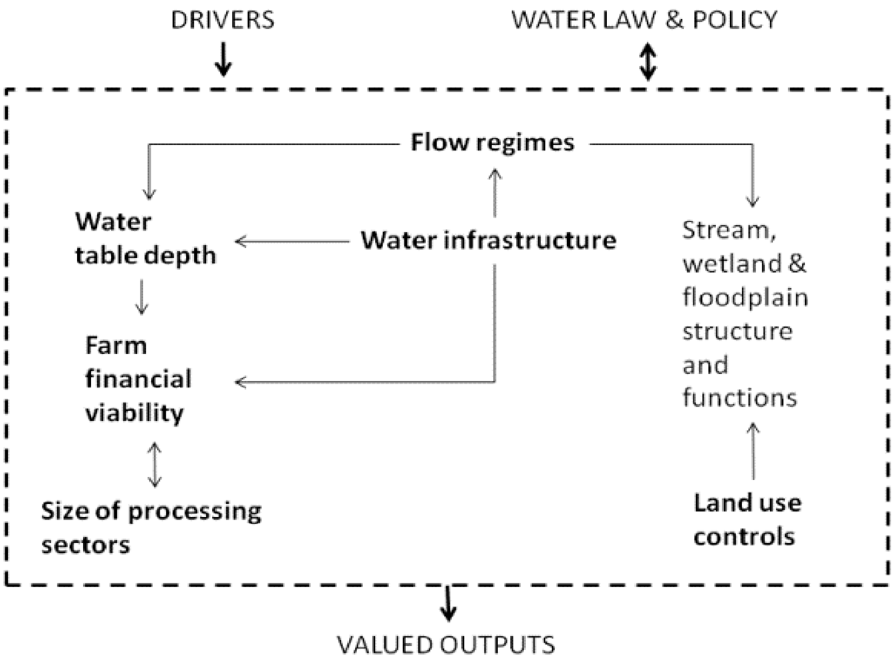
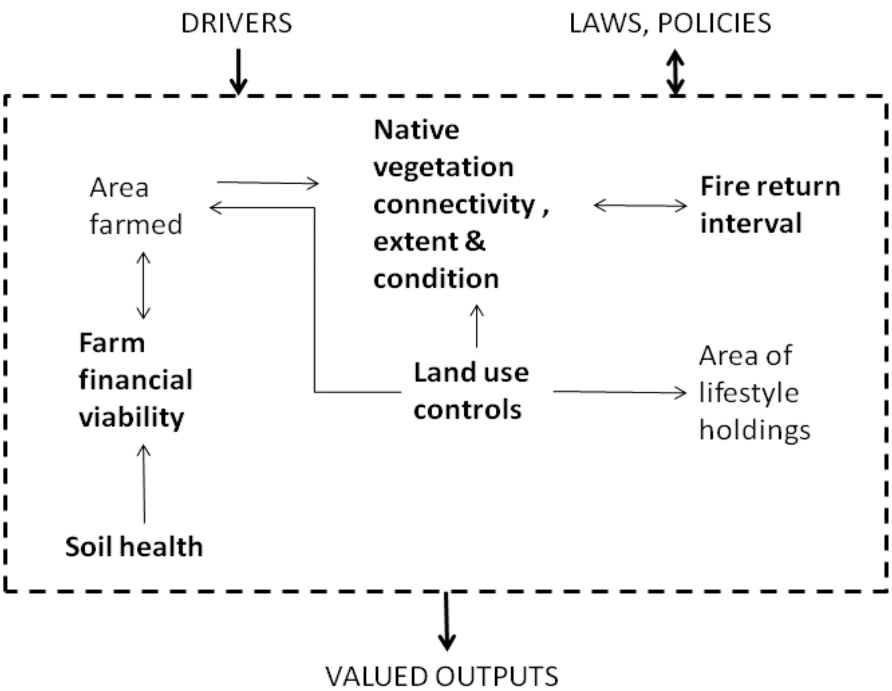


Figure 5



General Resilience

We have so far discussed drivers, shocks and thresholds that we think exist – that is, specified resilience. Over-investment in specified resilience can increase vulnerability to unexpected shocks and unknown thresholds (Anderies et al. 2007). The 2009 Paper advocated strengthening of general resilience to them at GBR scale by investing in:

- knowledge, capabilities and leadership
- political influence
- governance, and social networks within and outside the GBR
- learning, monitoring and experimentation
- building and maintaining reserves, options and redundancies
- heterogeneity, modularity and connectivity.

Carpenter et al. (2012) summarise researchers' current thinking on general resilience, and Walker et al. (2014) synthesise the ideas of five CMA's, including the GBCMA. A component of resilience is transformability. Most of the elements of general resilience are foundations for transformability. We discuss them in the next section.

RE-ASSESSING THE REGION'S RESILIENCE AND TRANSFORMABILITY

We summarise our assessments of the current resilience of the SESs in Table 1.

Table 1

Social-ecological system	Stage in Adaptive Cycle	Resilience status
Agricultural Floodplains	*Irrigated farming* - late conservative stage	Reconfigured and renovated public irrigation infrastructure plus a drier climate are expected to reduce the risk of transgressing the 2m saline water table threshold, but that will remain a threat following wet periods. The annual security of water allocations to irrigators is unchanged, but average inflow volumes are expected to fall and annual variability to rise with climatic change, perhaps sending more farms across financial viability thresholds. The sizes of the dairy and fruit processing industries have already decreased towards lower size thresholds, adding to the vulnerability of producers, though they are not bound to produce commodities that depend on local processing.
	Streams, Wetlands and Floodplains - probably in transition under changing flow regimes	The infrastructure upgrade is expected to increase % of inflows allocated to environmental flows, but climate change is likely to reduce average inflow volumes and increase their variability, with the risk of crossing flow regime thresholds. The persistence of this system is highly vulnerable to shifts in values away from conservation when water is scarce.
Urban Centres	*Shepparton City* – late conservative stage	Subject to the same thresholds as irrigated farming, but with the option of developing new industries.

Upland Slopes	*Dryland farming* – late conservative stage	Vulnerable to climate change, commodity prices, exchange and interest rates and ageing of farmers, which may push it across thresholds of financial viability and social network effectiveness, but more resilient than irrigated farming.
	Lifestyle living – in growth stage driven by Melbourne growth	Decisions of lifestylers to buy, keep or sell properties are driven by interest rates, land values, land use controls, fire risk, access to services and family demographics. No regional scale threshold is apparent.
	Terrestrial biodiversity – climatic change likely to initiate transitions	Vulnerable to changes in climate, fire regime, land use, diseases, pests and weeds, which may drive the system across native habitat thresholds
Southern Forests	Climatic change likely to initiate transitions	Vulnerable to changes in climate, fire regime, land use, diseases, pests and weeds, which may drive the system across native habitat thresholds
Productive Plains	*Dryland farming* – late conservative stage	Vulnerable to climate change, commodity prices, exchange and interest rates and ageing of farmers, which may push it across thresholds of financial viability and social network effectiveness, but more resilient than irrigated farming.
	Terrestrial biodiversity – climatic change likely to initiate transitions	Vulnerable to changes in climate, fire regime, land use, disease, pests and weeds, which may drive the system across native habitat thresholds.
Commuting Hills	*Dryland farming* – late conservative stage	As for Productive Plains.
	Lifestyle living – in growth stage driven by Melbourne growth	As for Upland Slopes.
	Terrestrial biodiversity – climatic change likely to initiate transitions	As for Productive Plains.

The emphasis of the RCS is to remain within current regimes. Dryland farming, with relatively low capital requirements and no need for local processing, is likely to adapt incrementally rather than undergo a regime shift. Irrigated farming has lower resilience and is in the long term more likely to transform, intentionally or not, to a new regime with different controlling variables and outputs. Scenarios of potential futures developed with irrigators did not include transformation (Robertson et al. 2007), but we shall argue that by increasing its transformability - the capacity for self generated transition to a new identity - the Agricultural Floodplain SES would become more resilient to impending uncertainties.

In this update of the transformation discussion in the 2009 Paper, we identify elements that interact across scales and over time, as environmental, psychological, political, technological and economic 'windows of opportunity' open and close (Olsson et al. 2006, Kahan et al. 2011, Leach et al. 2010, Pelling 2011, O'Brien 2012, Wilson et al. 2013), and the path and pace of an intended transition changes (Wise et al. 2014). The elements are:

1. *Change in values* among a sufficiently high proportion of influential individuals and groups is a necessary condition for intentional transition (2009 Paper). Justifiable fear of short term losses reinforces adherence to current values and norms. The GBCMA has only limited potential for influencing values outside the GBR, but it could further increase its regional influence through elements 2-9.
2. *Processes that link local, scientific and inter-disciplinary knowledge and learning* – the GBCMA already integrates local, scientific and inter-disciplinary knowledge through its Community Advisory Groups, interactions with stakeholders and scientists and community consultations. Bringing them together in workshops on climate, energy and economy, for example, is likely to be fruitful (Marshall 2013). This process has already started with the Regional NRM Planning for Climate Change projects (http://www.environment.gov.au/cleanenergyfuture/regional-fund/publications/pubs/vic-successful-projects.pdf).
3. *Distributed governance*: we propose that effective transitions require knowledge and learning, authority, resources and actions to be distributed across scales (Ostrom 2010, Cash et al. 2006). That depends on formal government structures connecting with social networks (Beilin et al. 2013, Moore and Westley 2011, Newig et al. 2010, Pelling 2011, Rathwell and Peterson 2012). Tensions arise at the interface from lack of trust, and mismatches of goals, power and resources (Jones et al. 2011, Booher and Innes, 2010, Graham 2011, Tomkins 2001). They also arise because governments are sectorally-divided hierarchical structures pursuing centrally-defined targets and efficiency. Social networks, by contrast, are flat, self-organising cross sectoral structures with multiple decision-makers, redundancy, and multiple, frequently conflicting and changeable goals. Though funded by State and Federal governments, therefore susceptible to pressure from them, the GBCMA bridges this interface, and also links with other CMAs, local governments, and its stakeholders. It's new SES's align management with the scale at which a number of controlling variables and feedbacks operate. The GBCMA is planning to expand its bridging role to include the running of deliberative processes (Marshall 2013) at SES scale, where transition options are canvassed. Parallel deliberative processes are needed at MDB and national scales, and in other MDB regions.

4. *Effective social networks:* social networks, like leadership, can block change, or facilitate it through their communications and activism (Muñoz-Erickson 2010, Pelling 2011). Members can strengthen network cohesion, recruit new members, and link with other networks (Olsson et al. 2006, Rathwell and Peterson 2012,). Strong social networks, including Landcare, exist in much of the GBR, but are weaker in the Commuting Hills, Upland Slopes and Southern Forests from which residents commute to work. The RCS commits the GBCMA to strengthening and extending its networks.

5. *Effective agency* – top-down leadership has proven ineffective in guiding SESs but leadership in some form is necessary (Olsson et al. 2006). Westley et al. (2013) introduce the concept of 'institutional entrepreneurs'- individuals that pool knowledge and influences through allegiances that address shared problems. This shifts the focus from conventional leader-follower roles to self-organising social arrangements for addressing problems. The GBR has been replete with institutional entrepreneurs at times, but their efforts have been aimed at maintaining current regimes. The GBCMA could foster entrepreneurship that seeks new paths within the GBR and among other CMAs in the MDB.
6. *Opportunities for developing unconventional ideas* - in an SES in a late conservative stage it is easier to fund activities that reinforce path dependency than to provide for those that challenge it. That requires a degree of insulation from economic and political pressures during testing and initial establishment (Geels 2011, Olsson et al. 2006, and the 2009 Paper). The GBCMA in collaboration with other institutional entrepreneurs could seek substantial domestic or overseas funding to establish pilot projects for testing radical adaptation measures of national or international significance, e.g. renewable energy and irrigation, wetland and floodplain management, or terrestrial biodiversity conservation under climatic change.
7. *Changes in rules* that reinforce current path dependency (Abel et al. 2010, Marshall 2013). To establish a transition, new rules must create dependency along a new path. The transaction costs of changing rules need to be weighed along with other costs and expected benefits (Marshall 2013). They are high because current rules are socially accepted, while new ones often are not, because of justified fears over the redistribution of benefits of costs, and because humans place a higher value on a loss than they do on a gain of the same amount (Arieli 2009). This signals the need for compensation and legal costs to be in budgets (Abel et al. 2010, Ryan et al. 2011). The GBCMA acting as an institutional entrepreneur could help influence rule changes.
8. *Divestment from the status quo and investment in change* is necessary to break current path dependency and build dependence on a new path (the 2009 Paper). Infrastructure is an obvious example relevant to water management and to fossil fuel dependence. The GBCMA, acting as an institutional entrepreneur could help influence public investment and divestment decisions.
9. *An ability to monitor the transition paths of focal SESs*, and if changing circumstances require it, revisit and revise steps 1-8 to change the path (Wise et al. 2014). The GBCMA already monitors the catchment. CMAs in the Basin could standardize and pool monitoring data and analytical capabilities in keeping with resilience theory to support Basin-wide learning and knowledge generation, detect impending regime shifts, and influence transition paths.

WHAT HAS BEEN LEARNED, AND HOW SHOULD WE USE IT?

Boundaries of Social Ecological Systems

Subdividing the GBR into six SESs has potentially increased the GBR's resilience, by enabling the GBCMA to:

- devolve some governance functions to SES level;
- deal separately with stakeholder groups that identify with an SES in a way they did not identify with the GBR;
- strengthen social networks that identify with the SES;
- specify different controlling variables, thresholds, and consequent management actions for each SES, leading to better prioritization of strategies, actions and resource allocations;
- describe more accurately the stage each SES has reached in the adaptive cycle, its current resilience and its transformability (Table 1);

Drivers, shocks and uncertainty

It is now better established that the GBR is likely to face a future climate that will be drier, warmer and more variable than in the past. Water policy will become even more important, but its implementation depends on shifts in current values.

Policies on climate change, water and energy are increasingly tightly linked. Climatic change mitigation depends on raising fossil fuel prices, increased water use efficiency depends on increased energy use, a shift to renewable energy could resolve this paradox, and the Agricultural Floodplain SES has the potential to show the way.

The importance of farm financial viability as a controlling variable for individual farms was emphasised by the drought and GFC. Upgrading the irrigation infrastructure will increase the security of water allocations to remaining irrigators, but climatic change is expected to reduce inflow volumes and increase their variability, with the risk of sending farms across financial viability thresholds. Fruit and dairy processing sectors have shrunk closer to lower sector-size thresholds, increasing this risk.

The refurbishment of irrigation infrastructure will reduce the risk of water table rise under irrigated land, but its unexpectedly rapid post-drought rise shows our previous hydrological assumptions to have been incorrect. A safe minimum depth to water table of 2m still holds, but the system is less resilient to water table fluctuations than previously thought, requiring pumping and completion of the proposed drainage system to be able to respond to wet phases.

Habitat thresholds for native terrestrial species are now being set for each SES. Severe and widespread bushfires caused the GBCMA to add thresholds for minimum tolerable return intervals for fire to the list of thresholds. Fire intensity and frequency are expected to increase with climatic change.

The GBCMA has improved its methods for assessing the condition of streams and wetlands and potential controlling variables are identified, but thresholds on these have not yet been established.

Transitions and transformations

The emphasis of the GBR community and the RCS continues to be on staying within current regimes, which may be feasible for the dryland SESs, but more difficult in the long term for at least the Agricultural Floodplains SES, and its main urban centre Shepparton. We discussed elements necessary for a transition to a new regime – value change, integrating knowledge and learning, distributed governance, effective social networks, effective agency, 'safe arenas' in which to develop and test new ideas, rule changes, new investment patterns, and monitoring and adjusting the transition path. The transition would necessarily cross scales from urban centres and farms to SES to GBR to Basin, to State and Federal Governments.

Governance

Current governance arrangements for the MDB are not conducive to resilience, but examples of resilience thinking by this and other CMAs plus the agency of 'institutional entrepreneurs' together with social networks may help induce cultural and structural shifts at higher levels of governance. Meanwhile the GBCMA is leading by example by seeking to devolve some functions to its SESs.

The GB CMA continues to distribute a large proportion of its funding to on-ground projects. However its shrinking budget together with the CMA's lack of authority over the management of either private or public land limits the direct influence of the GBCMA on the resilience of biophysical systems. Its strengths lie more in its ability to influence actors, connect them and foster their understanding and motivations. This is exemplified by the nine roles we identified for the GBCMA in planned transitions. While transgression of some previously identified thresholds - the condition of irrigation infrastructure and the groundwater level in particular - have been avoided through investment, management and beneficial changes in drivers, the strong desire of humans to avoid change is expected to clash increasingly with the realities of climatic, economic and policy shocks. The resulting crises will also bring opportunities for the GBR, which could be realised if prior investment has increased the capacity to transform.

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Appendix 1. More details on some drivers

CLIMATIC CHANGE

Climatic change projections are uncertain, but a warmer and drier future in the southern Murray Darling Basin was expected even with a 2^0C average global temperature rise(Post et al. 2012); a higher temperature rise is now expected (Stocker et al. 2013), and the frequency of high rainfall events and consequent floods are also expected to increase (Steffen et al. 2013).

Figure A.1.1. Goulburn Broken Region % Allocations of High Reliability Irrigation Water from Rivers.

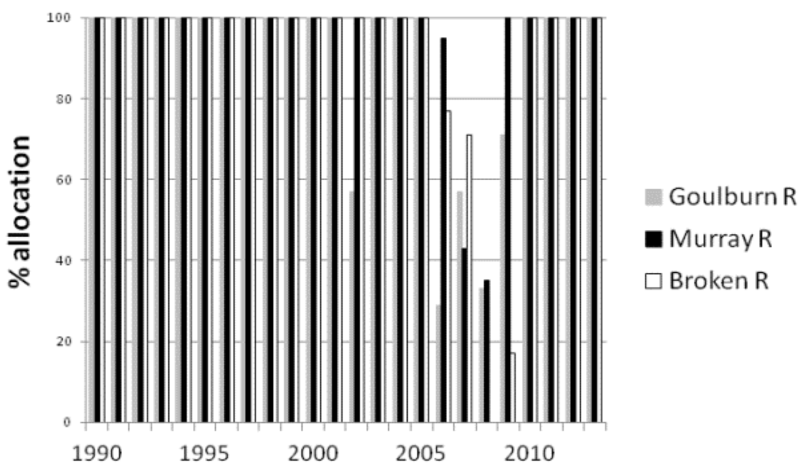
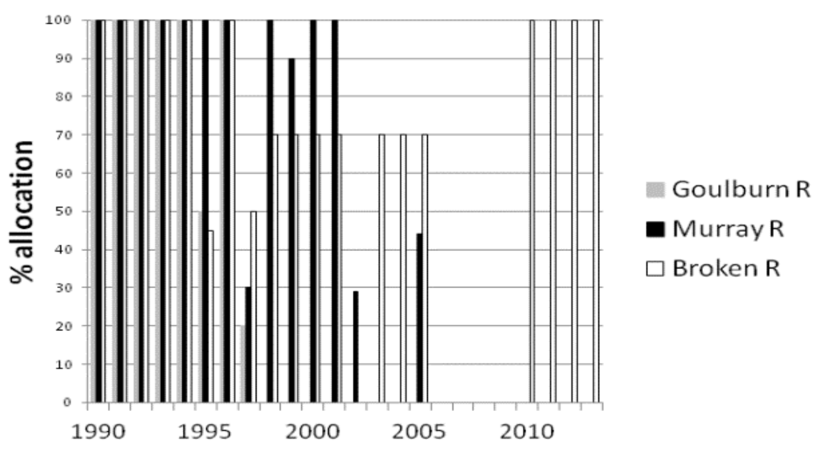


Figure A.1.2. Goulburn Broken Region % Allocations of Low Reliability Irrigation Water from Rivers.



Notes for Figures A1.1. and A.1.2.

Private water entitlements are a volume of water owned, but the full volume is allocated to a title holder only if inflow volumes are sufficient. The amount available in a particular year is the % allocation. Entitlements are split into ‘High Reliability’ and ‘Low Reliability’ water. A title holder is more likely to receive their High Reliability water.

The figures do not show allocation volumes because:

- an x% allocation of High Reliability Water and an x% allocation of Low Reliability Water do not have equivalent volumes;
- a y% allocation from one river does not have the same volume as a y% allocation from another river;
- volume data were not available.

Source: Goulburn Broken Catchment Management Authority database.

LAWS, POLICIES AND VALUES

The recent Murray Darling Basin Plan is an agreement among State and the Federal Governments that aims to "optimise social, economic and environmental outcomes" (Minister for Sustainability, Environment, Water, Population and Communities 2012) in the MDB by setting and enforcing environmentally sustainable limits on water use, while increasing security of supply for users and environmental flows. The Plan's objectives span agricultural and environmental interests which continue to compete for water. The plan relies on the water market and catchment scale extraction limits to drive on farm water use efficiency, on public infrastructure improvements to reduce distribution losses, and on the water thus saved to meet environmental and production objectives, even as the climate changes.

Subdivision for 'lifestyle' housing and smallholdings has taken more farmland out of production, and the price of agricultural land within commuting distance of jobs has risen (Barr 2011). Subdivision changes the functioning of erstwhile farmland (vegetation cover, runoff, weed control etc), and farming communities' land-focused social networks are weakened. Increased competition for land and local government planning restraints limit the ability of farmers to increase farm size to offset declining terms of trade (next).

COMMODITY PRICES, EXCHANGE AND INTEREST RATES, AND AGRICULTURAL TERMS OF TRADE

Farm-gate commodity prices are affected by the relative value of the Australian $, which spiked as a consequence of the Global Financial Crisis (GFC), making agricultural exports from the region uncompetitive. Interest rate was identified at the Workshop as a driver not listed in the 2009 Paper. It affects the relative value of the Australian dollar, and the cost of credit, impacting technological innovation as well as farm financial viability.

Since 2009 we have learned from Barr of the importance to farmers of agricultural terms of trade - the ratio of output revenue to input costs, which for Australian agriculture have fallen by two thirds since 1953. The fall has driven (in various cases) an increase in average farm size, a decrease in the number of enterprises, sales to 'lifestylers', on-farm innovation, economic efficiency, and greater reliance on off-farm income (Barr 2011).

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Appendix 2. More details on some controlling variables

CONFIDENCE LEVELS

Table A.2.1. Controlling variables and their confidence levels

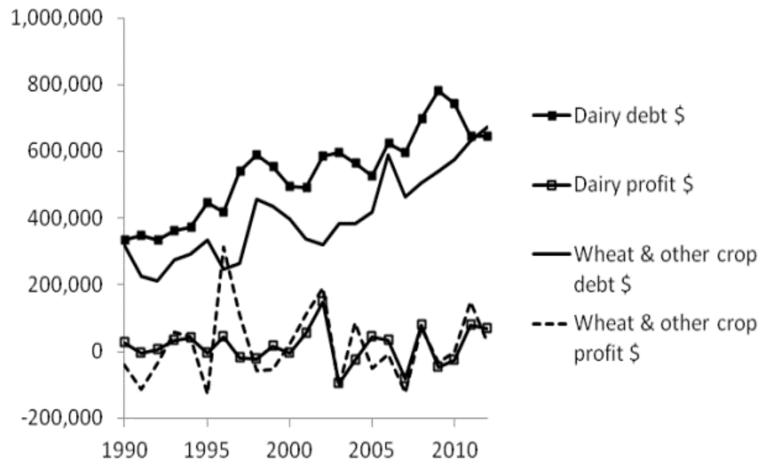
	Confidence it is a controlling variable	Confidence that quantitative thresholds are known
Experiential evidence, expert panel, etc.	1	i
Documented internal evidence, grey literature, etc.	2	ii
Peer reviewed literature	3	iii
Peer reviewed literature synthesized from several sources	4	iv

Controlling variables	Social ecological system, and confidence levels: Agricultural Floodplains	Productive Plains	Upland Slopes	Commuting Hills	Southern Forests	Urban Centres
Farm financial viability	2i	2i	2i	2 i		
Sizes of dairy and fruit processing sectors	4i					4i
Irrigation infrastructure	4ii					
Water table depth	4iv					
Terrestrial native species habitat	3iii	3iii	3iii	3iii	3iii	
Land use regulation	4i	4i	4i	4i	4i	
Environmental flow regime		2i	2i	2i	2i	

FARM FINANCIAL VIABILITY

The 2009 paper used average farm income and debt to indicate farm financial viability, but we now advocate use of profit and debt. Profit has been falling behind debt since 1990 (Figure A.2.1.). Data for fruit producers were not available.

Figure A.2.1. Average Victorian Farm Business Debt and Profit, 2012 Prices, A$.



Source: ABARES 2013

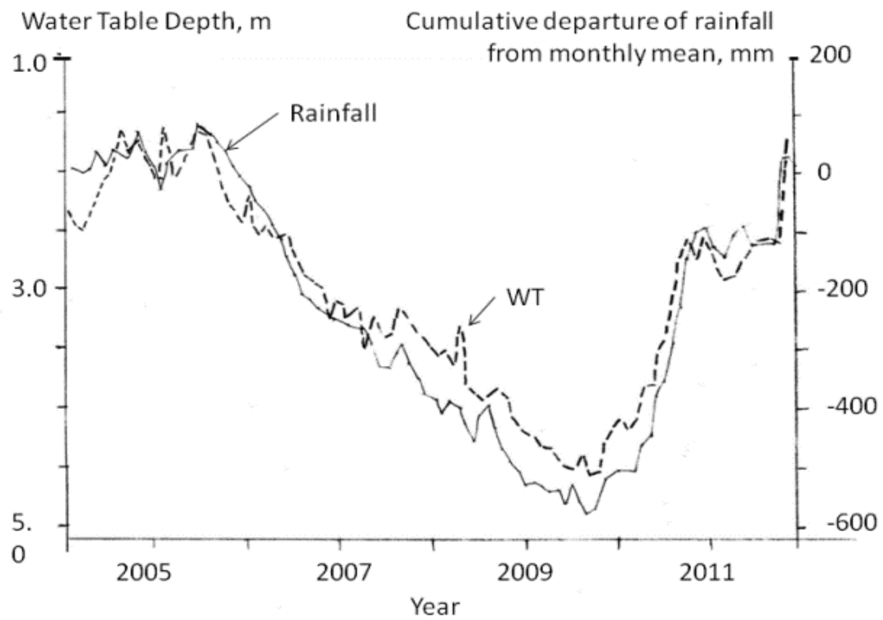
Average farm financial viability does not reveal thresholds at regional scale, where it is expressed in changes in the number of farms; GBR dairy farm number fell by 55% between 2000-01 and 2012-11 (Montecillo 2013). The number of fruit growers decreased by 28% in that period, but the area under production rose 26% (RMCG 2013). Since then the reduction in processing capacity is probably driving some producers below financial viability thresholds. However, demand for fresh fruit from the domestic market is said to be growing (RMCG 2013), and new trade agreements with Japan and Korea and potentially China will open new markets for fruit and dairy products. The economic outlook for dairy and fruit producers is good, provided processors remain in the region.

WATER TABLE DEPTH

The history of the battle to control the level of the saline water table is captured graphically in GBCMA 2012. Anderies (2005) modelled the dynamics by linking a threshold of tree cover to thresholds of water table depth and area salinised in the irrigated lower catchment (Agricultural Floodplain SES). His model assumed a single-level aquifer with significant lateral flow from the partly-cleared mid to the heavily cleared lower catchment. He assumed that if the water table rose to within 2m of the surface in the lower catchment the soil salinisation would be irreversible. Irrigation drains, increased water use efficiency, pumping saline groundwater into evaporation basins and the decade long drought have so far kept it at a satisfactory level, though in places and at times this was less than 2m (Figure A.2.2.). After the drought the water table in the Agricultural Floodplain SES rose rapidly with rainfall, rather than with a lag measured in years. The revised understanding is that there is a shallow aquifer under the irrigated lands that rises and falls in response only to local rainfall, irrigation and leakage from infrastructure, drainage and pumping (Holland 2012). The mid catchment is now understood to feed a deep aquifer that is isolated from the shallow aquifer by relatively impermeable rock (Q.J. Wang, pers. comm., 2013; Holland 2012). If average water availability declines under climatic change, the water table will be lowered, but the existence of the shallow aquifer means the Agricultural Floodplain SES will remain prone to post-drought salinisation that is more rapid than Anderies et al. (2006) had warned, and the option of replanting trees in the mid catchment to reduce the need to pump would be ineffective. The GBR was therefore less resilient to water table rise than we estimated in the 2009 Paper, but the GBCMA and the regional public water agency were not caught out by the rapid rise because they were monitoring the bores and acted accordingly. This strategy has been effective, but for the longer term the CMA can invest in calibrating the regional groundwater model of Goode and Barnett 2008.

Figure A2.2 . Water Table and Rainfall

(Example Bore No. 3460. Adapted from Holland, 2012)



SOIL HEALTH CONTROLLING VARIABLES

The 2009 Paper identified soil pH as a crop farm scale controlling variable with a threshold at pH 5. The GBCMA finds that simplistic and will replace it with variables that are not yet developed.

LAND USE REGULATION

Local Government Planning Schemes determine whether land is reserved for agricultural use or is available for housing or industrial development. On the advice of the GBCMA, housing development may also be precluded by a local government where flood risk is high. Since the floods of 2010/11 the RCS has identified property damage as a variable with a threshold that may affect future floodplain land use. Flood protection can include the building of levees that compromise the functioning of rivers, wetlands and floodplains (Langridge et al. 2003), or lead to the exclusion of development from flood-prone land.

RIVER, WETLAND AND FLOODPLAIN THRESHOLDS

The GBCMA has made significant progress in assessing the condition and resilience of rivers, streams (both called 'streams' hereafter) and wetlands since the 2009 Paper (GBCMA 2013). Approximately a third of stream reaches assessed were in poor to very poor condition, 54% in moderate condition and 16% in good to excellent condition (GBCMA 2013). Despite the radical alteration of stream flow regimes many wetlands remain ecologically functional and socially valued.

WATER QUALITY CONTROLLING VARIABLES

The 2009 Paper identified nitrogen and phosphate levels in water bodies as controlling variables with known thresholds above which algal blooms occur. They are not controlling variables at SES scale, because their levels are a consequence of land use area, type and location (Bartley et al. 2012), and these are influenced by land use controls. Stream flow regime also affects water quality, which we extend in this paper to include hypoxic 'blackwater' events caused by the release of carbon accumulated on floodplains during long periods without flooding (Whitworth et al. 2012)

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