Discovering resilient pathways for water management: two frameworks and a vision

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Abstract

Resilience is the amount of change or disturbance a system can withstand and still maintain its essential structure, function, and identity. Because social-ecological systems (SES) undergo constant change, managers of SES must recognize and focus on resilient 'pathways,' in which learning about and maintaining resilience is a dynamic process; a journey to a more desirable and achievable future based on a long-term perspective of the system. Several compelling frameworks and models now exist to better understand resilience from this perspective and to improve management of practical problems. In this paper, I compare the ability of two frameworks to discover resilient pathways, using the case of water management in South Africa as a focal example. These are: 1) the conceptual framework of the Millennium Ecosystem Assessment and 2) the "panarchy" model of the adaptive cycle described by Holling and elaborated by numerous others. Current South African water policy is guided by an overarching vision to balance efficiency, equity, and sustainability, but as of yet, the concept of resilience has not been fully incorporated into plans to achieve this vision. While both frameworks yield insights in this arena, each has limitations that may reduce its usefulness to managers, especially in regard to the representation of dynamics across space and time, changes in perception, and trade-offs. Improving these or other frameworks so that they are more useful to management should be a top priority, in order to more rigorously incorporate the concept of resilience into the water management discourse in South Africa, particularly at this critical time of change and opportunity.

Resilience in social-ecological systems: the temporal dimension

The view of humans and nature as coupled complex systems is gaining currency in ecological and social science, and with it, theory is proliferating to understand how these systems work and how management can consciously make them more robust (Walker et al 2002, Allison and Hobbes 2004). Increasingly, the ability to understand why management regimes for social-ecological systems (Berkes et al. 2003) succeed or fail is seen to hinge on the crucial property of resilience (Allison and Hobbes 2004, Ludwig and Stafford-Smith 2005). Resilience has multiple meanings, but is used here to refer to the ability of a system to retain its essential structure and function in the face of disturbance or change (Rappaport 1968, Holling 1973, Levin 1999). This may be expressed in terms of identity, meaning the system's critical components, their relationships in space and time, and the innovation and/or self-organization that maintain them (Cumming et al. 2005), or the ecosystem services the system provides (Walker et al. 2002). Resilient systems tend to be flexible, self-organizing (rather than controlled by external forces), and can build the capacity to learn and adapt (Carpenter et al. 2001). Though seminal work on resilience has addressed mainly its ecological dimensions (Holling 1973), there is an increasing recognition of the need to better understand social aspects of resilience (Gunderson and Folke 2005), as well as relationships between the two (Adger 2000, Cumming et al. 2005). This accompanies recent developments in resilience theory that focus on fostering sustainability by embracing change and transformation (Gunderson and Holling 2002, Walker et al. 2004).

Resilience has an important temporal dimension in that social-ecological systems tend to shift over time (and correspondingly, space) between alternative configurations. It may therefore be more useful to view resilience as a property of a particular configuration of a system than of a system itself (Carpenter et al. 2001). These alternative system configurations provide different combinations of ecosystem services; a lake in a eutrophic state may offer nearby communities the service of waste disposal for agricultural runoff, while an oligotrophic lake may offer the services of recreation and a domestic water supply that requires little treatment (Carpenter et al. 2001). This is not to say that these services are tied exclusively to these configurations; instead, the same services may be derived from ecosystems under different management regimes and degrees of conversion (Balmford et al. 2002). However, disturbance and change can result in abrupt, non-linear shifts that move the system past a threshold, beyond which services can no longer be provided as they were previously (MA 2005). In this case, configuration *x* of a social-ecological system can be said to lack resilience to disturbance *y*, and is forced to transform, or flip, into another configuration – in what may appear to be the collapse of the system as it is presently known. Such a collapse, however, does not usually affect the entire system, but rather a particular configuration and associated ecosystem services. Numerous empirical studies exist that demonstrate this in a range of ecosystems under different management regimes, such as the lakes described above (see Scheffer et al. 2001 for a review).

Because such changes may be driven by slow variables (Carpenter and Turner 2001) and are often not observable within the average human lifetime, studies of resilience that appropriate a 'deep time' perspective that incorporates a system's past, present, and future are of interest in social-ecological systems research (van der Leeuw and Aschan-Leygonie 2000, Redman and Kinzig 2003). Understanding of resilience has benefited in particular from the study of ancient societies, from which rich social-ecological histories can be reconstructed (Janssen et al. 2003, Redman and Kinzig 2003). In addition, a long-term perspective encapsulates the changing social contexts for managing social-ecological systems (Bohensky and Lynam 2005); definitions of what is socially desirable are always anchored to a temporal reference point. The ecological contexts for management also change. As Scheffer et al. (2001) observe on the challenge of ecosystem restoration: "resilient approaches acknowledge that recovery of systems from one regime to another must acknowledge that the path back is likely to be very different from the one forward."

Given the dynamic properties of resilience, the concept of "resilient pathways" (Walker et al. 2002) offers an appropriate frame for understanding resilience in social-ecological systems and managing to enhance resilience. The identification of these pathways can be seen as a process of discovery, a journey that involves learning from the past, along with the recognition that the future may be quite different from anything experienced before, and the acceptance of uncertainty (Redman and Kinzig 2003). Discovering resilient pathways is about learning by doing – improving understanding through management, and vice versa (Lee 1993).

Resilience is becoming an integral concept in water management worldwide (Falkenmark 2003, Folke 2003, Moench 2005) and has particular relevance to South Africa, where much change in its water sector is now occurring (Mackay et al. 2003). However, the potential benefits of resilience theory sit precariously alongside the danger of overwhelming policymakers with confusing, conflicting, or - because it is not arrived at through consensus - mistrusted information (Dent 2000), leading to inappropriate or limited interpretation (Cumming et al. 2005). Mechanisms are thus needed that allow stakeholders to develop a shared understanding of past trajectories, and be able to link theory to practice so that they are able to identify and navigate water management along more resilient pathways. A number of frameworks exist, but their ability to contribute to the real-world problem of water management in South Africa is not clear.

In this paper I evaluate the potential of two existing conceptual frameworks to assist the discovery of resilient pathways for South African water management. The first is the conceptual framework of the Millennium Ecosystem Assessment, an effort to provide decision-makers with information about relationships between ecosystems and human well-being (MA 2003). The second is the "panarchy model" of linked adaptive cycles described by Holling (1986, 1987, 2001) and central to the work of the Resilience Alliance (http://www.resalliance.org), which seeks to understand the source and role of transforming change in social-ecological systems (Gunderson and Holling 2002). Both are to some extent already informing water policy and policy-relevant research in South Africa (see Rogers and Biggs 1999, Rogers et al. 2000, Turton and Henwood 2002, Nel et al. 2004, Turton et al. 2005), and both enable long-term perspectives on resilience or closely related concepts. Only the panarchy model deals explicitly with resilience, but the Millennium Assessment framework addresses it implicitly. Below I describe the evolution of water management in South Africa to date, and the Water Act's fundamental vision of an efficient, equitable, and sustainable water management future. I then explore these frameworks and how they may help to inform this vision.

Evolution of water management in South Africa

Water management in South Africa has historically been challenged by a semi-arid climate and the distance of mineral deposits from large rivers, which encouraged settlement far from major water sources (Basson et al. 1997). From the mid-19th century until the present day, water management has become increasingly complex as the relationship between people and water changed (Turton and Meissner 2003) and human populations and their aspirations for water use grew (Table 6.1). For much of this period, the sector's focus was on getting water to farms and industries, with increasingly costly technical interventions such as dams and diversions assuring supplies and subsidies for commercial agriculture that discouraged sustainability (WCD 2000). Until 1994, which saw the end of minority rule under the apartheid system, water management in South Africa was rooted in highly inequitable policies that favored White individuals and the support base of the ruling political parties of the day.

Table 6.1. Water management in South Africa: a timeline of events

Year(s)	Event
1800s	Korana people farm on Gariep (Orange) River banks; Europeans build irrigation scheme at Upington
1820-1870	A large influx of settlers from around the world introduces 11 of the 12 invasive species that now cause the greatest problems in fynbos biome
1872	First dam constructed in Gariep basin
1880	Gold discovered in Johannesburg; water demands rise throughout surrounding Witwatersrand region
1880s-1890s	Botanists begin to note the spread of nonnative plants over mountain slopes and losses of endemic species in fynbos vegetation, while foresters promote mountain plantations of non-native trees
1895	All major Witwatersrand aquifers tapped; Johannesburg experiences water shortages
1903	Rand Water Board established
1912	Passage of South Africa's Irrigation and Conservation of Water Act lays foundation for future water allocation, reserving surplus water for private property owners and establishing irrigation boards
1920s	Controversy about effects of forest plantations on water supplies begins; demand for commercial timber products will drive high rates of afforestation with non-native hardwoods for next 60 years
1928	Department of Irrigation conceives idea of Orange River Development Project, but considered too costly
1937	Passage of the Weeds Act; poor enforcement due to lack of field staff and resources
1935	Salinity levels in Vaal Dam begin to increase due to increasing industrial activities
1943	Annual flow of Gariep River reaches 62-year high of 25,472 million cubic metres[†]
1949	Purification works built to clean or divert highly saline water in the Vaal catchment
1940s-1970s	Hydrological studies show that plantations have a negative effect on streamflow; efforts to control invasives are launched, but are uncoordinated, erratic, and hampered by limited follow-up clearing
1950s	First survey of Basutoland (now Lesotho)'s water resources undertaken to assess viability of water exportation to South Africa
1956	South Africa passes Water Act no. 54 to accommodate needs of industrial expansion
1962-3	Political climate enables Orange River Development Project to win approval; poor planning results in delays and a quadrupling of initial budget
1965	Marked acceleration of Vaal Dam salinity problem
1970s	Blackfly (*Simulium chutteri*) acquires pest status along Vaal, Gariep and Great Fish Rivers after completion of Bloemhof, Gariep, Van der Kloof Dams and Orange-Fish Tunnel.
1970	Mountain Catchment Act passed, giving responsibility for high-lying catchments to Department of Forestry; alien plants are cleared from tens of thousands of hectares
1971	Gariep Dam completed; storage capacity (5341 million cubic metres) equal to roughly one-third of Gariep basin's total runoff
1971	Water Research Commission created to initiate and fund research projects related to water management
1975	Orange-Fish Tunnel begins delivering water from Gariep River to Eastern Cape Province
1978	Vanderkloof Dam completed, the highest (108m) in South Africa
1986	Treaty signed to implement Lesotho Highlands Water Project (LHWP) after 8 years of negotiations
Late-1980s	Mountain catchment management responsibility passed from Department of Forestry to provinces; lack of funding hampers integrated invasive plant control programs and plants re-invade cleared areas
1992	Annual flow of Gariep River reaches 62-year low of 818 million cubic metres[†]
1995	DWAF minister Kader Asmal founds Working for Water Programme, which hires 7,000 people and clears 33,000 ha in its first 8 months
1995	Katse Dam – at 185 metres, the highest in Africa - completed in Lesotho's Maloti Mountains
1998	South Africa's Water Act no. 36 declares adequate water a basic human and environmental right
1998	LHWP completed; first LHWP water is released
2004	National Water Resources Strategy completed, paving the way for Water Act implementation; first proposals to establish Catchment Management Agencies completed
2005	Olifants River stops flowing into lower reaches for first time in recorded history, threatening biodiversity in downstream Kruger National Park

Sources: Herold et al. 1992; Chutter et al. 1996; World Commission on Dams 2000; WRI 2000; Thompson et al. 2001; Turton and Meissner 2002; DWAF 2003; Metsi Consultants 2002; Myburgh and Nevill 2003.

[†]Based on annual flow records from 1935-1997; mean flow for period was 6980 million cubic metres.

Non-White individuals were restricted to certain areas, typically of higher aridity, lower productivity, and lacking in formal water services (Turton and Meissner 2003).

In the years that followed South Africa's democratic elections in 1994, the National Water Act No. 36 of 1998 was penned to set the course for dramatic change in the management of water. Founded on the principles of efficiency, equity, and sustainability, the act defines water for basic human needs and for the maintenance of environmental sustainability as a right, and promotes economic efficiency of water use through charges for the financial costs of providing water to users (DWAF 2004*a*). The Act enforces a "Reserve" that sets water aside for the purposes of meeting basic human and ecosystem needs. Critically, the law devolves management of water to new institutions at the catchment level, called Catchment Management Agencies (CMAs). While the CMAs are the pivotal institutional entity in the new water management framework, they will work with local Catchment Management Committees and stakeholder organizations, which will guide the process within each catchment to decide the desired balance between protection and utilization of water resources and to establish a course of action to achieve this. They will also be subordinate to the national ministry, who will retain certain functions. Thus, there will be three tiers of water management: operational (catchment), strategic (catchment or Water Management Area (WMA)), and policy (national or regional) (MacKay et al. 2003), each operating on a different spatial as well as temporal scale.

The discovery of resilient pathways takes on critical importance at this time of change. Because of large-scale interventions in South Africa's water supply and investments in expensive water quality treatment schemes (Herold et al. 1992), the capacity of what are actually highly transformed freshwater systems to deliver provisioning ecosystem services (water for people, farms, and industry) may appear to be highly resilient particularly to the many water users who are unaware of the great distances over which their water has travelled to reach them (Snaddon et al. 1998). However, the generation of runoff is only one function of these systems, and other ecosystem services have not fared as well. Water managers, like other natural resource managers, have had a tendency to trade off ecosystem services in space or time, often optimizing for a certain output and disregarding others (Gunderson 2000). In South Africa as elsewhere, most past responses improved provisioning ecosystem services and some regulating services (protection against drought and floods, and dilution of pollutants), with benefits flowing to many, but certainly not the whole of society (WCD 2000, MA 2005). These improvements have often come at the expense of supporting services (in-stream flows for aquatic biota), and cultural services (recreation, nature-based tourism, preservation of sacred sites, and cultural appreciation and use of water), and sometimes the provisioning and regulating services that they were originally intended to secure. The building of the Orange River Development Project in the 1960s, for example, improved water availability for the commercial farming sector, but altered river flows so drastically that a prolific pest blackfly (*Simulium chutteri*) invaded a large section of river used by livestock farmers, and has required significant investments in mitigation ever since (Myburgh and Nevill 2003).

At present, South African water management sits on the brink of a major transformation. The new policies enable water users and managers to collectively decide how to reap the multiple benefits of water, asking them to carefully define their objectives for the systems in which they live and the pathways they will follow to get there. However, they are faced with the formidable task of striking a balance between social equity and ecological sustainability: How to derive benefits for all – including some 5 million South Africans who still lack access to a safe and reliable water supply and another 16 million without sanitation (DWAF 2004*b*) – without taxing the ecosystems that produce them? The pathway forward depends to a large degree on the capacity of water users, managers, and institutions to plot a sustainable course to govern resources in the coming years, based on a mutual vision of the future (Rogers and Biggs 1999).

A vision for water management

A vision in terms of the South African Water Act refers to a universally-accepted conceptualization of how water will be managed in the future and the ecosystem services that will be maintained, so that the three Water Act principles of efficiency, equity, and sustainability are upheld. Such a vision is expected to be achieved through the integration of social values, scientific knowledge, and management experience in a multi-party system (Rogers and Bestbier 1997, Rogers and Biggs 1999).

Defining a desired trajectory for water management requires a sound and shared understanding of the biophysical processes that govern water resources and the array of ecosystem services that they provide; it also demands an understanding of the human (individual, social, and cultural) dependence and impacts on these services (MA 2003). To date, more progress has probably made on the first aspect in South Africa (van Wyk et al. 2001). Initiatives such as the National Spatial Biodiversity Assessment (Driver et al. 2005), which have analyzed the spatial distribution of freshwater biodiversity and the level of threat imposed by current land use, water abstraction, and other human activities, provide a reasonably good basis for understanding ecological integrity and vulnerability (Nel et al. 2004). Efforts to actually map the full range of ecosystem services provided by freshwater in South Africa are only beginning (Bohensky et al. 2004, Reyers et al. 2005) and must currently be inferred from an water resources classification system (Palmer et al. 2004) that indicate the extent of modification of each water resource in the country. As the classification process is still being refined, only desktop estimates are presently available (Kleynhans 2000) based on data collected in 1998 and 1999 and regional expert knowledge, but allow for a rudimentary comparison of present, suggested, and default ecological management classes, and the plotting of various pathways of future water management. Figure 6.1 illustrates such a pathway, revealing how past actions have increased the range of ecosystem services in some areas but have reduced it in others. This also suggests one possible vision for the future, and identifies areas to target for restoration.

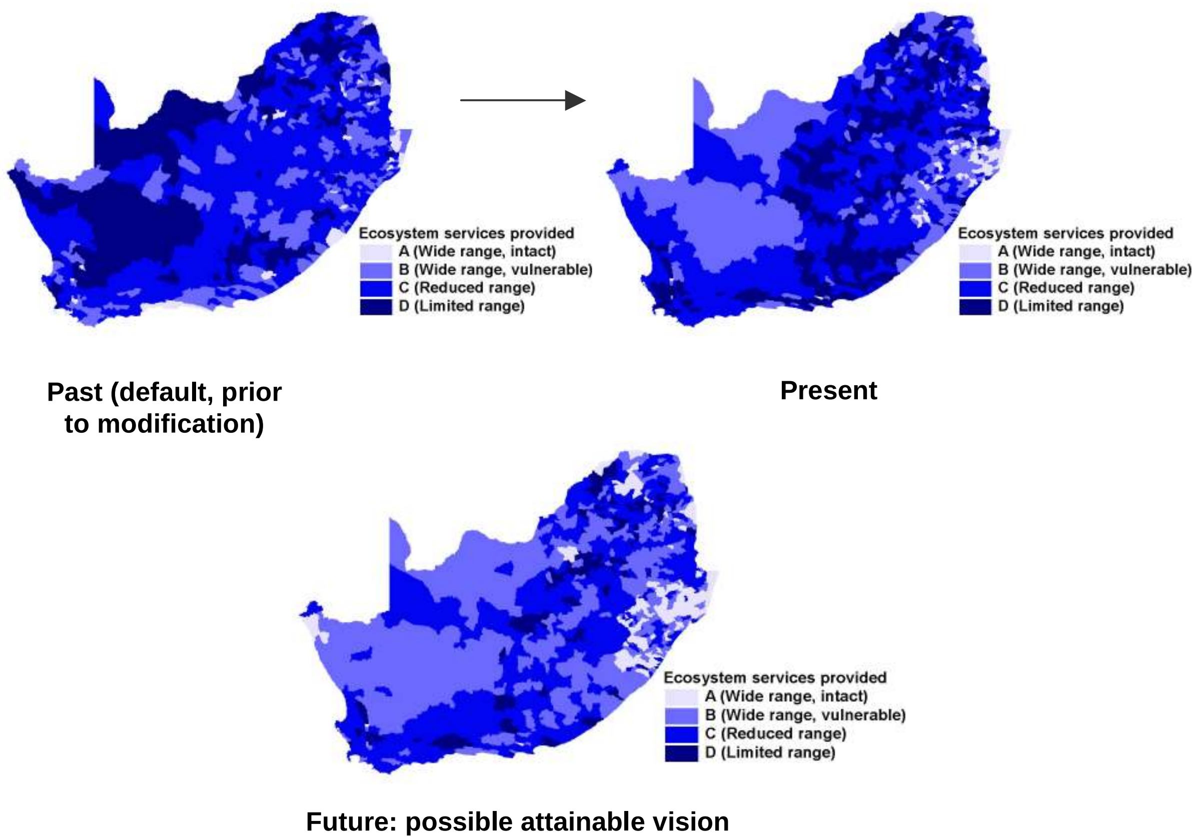

Figure 6.1. A possible pathway of water use, based on past, present and suggested future ecological management classes (Kleynhans 2000).

Little work has dealt with the other side of the equation – the extent to which these services actually reach people, growing human demands for water, and trade-offs between services and human well-being. In moving from the present to the future of water management, sacrifices will be made: which ones will be considered acceptable, and where will the power to make such decisions reside? Such questions are rooted in the social dimension of resilience. One avenue of research related to social resilience in South African water management is Ohlsson and Turton (2000)'s exploration of social adaptive capacity. Social adaptive capacity is defined as the ability of society to manage water scarcity (what the authors call "first order scarcity"), usually through economic ("second order scarcity") means. More recent work by Turton et al. (2005) proposes a model of water governance, which unites government, society, and science in an integrated view of the water scarcity concept. This model shows promise as a mechanism for linking social aspects of water management to those related to ecological resilience.

Two frameworks

Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment (MA) was a four-year international work program to bring scientific information about the relationships between ecosystems and human well-being to decision-makers in government, institutions, communities, and private industry (MA 2005). The program was designed around a conceptual framework that identifies the relationships between indirect and direct drivers of ecosystem change, ecosystem services, and human well-being (Figure 6.2). Indirect drivers include demographics, economy, institutions, technology, and culture and religion which influence human behaviour. These can affect human well-being directly or indirectly via direct drivers, which include environmental processes such as climate change, land use change, hydrological change, which in turn affect ecosystem services. Human well-being may have feedbacks on indirect drivers. Within the framework there are opportunities for responses, or strategies and interventions that can halt, reverse, or otherwise change a process in order to enhance human well-being and conserve ecosystems. The interactions depicted by the framework occur at and across various spatial and temporal scales. The Millennium Ecosystem Assessment did not focus explicitly on resilience, but acknowledges both ecological and social aspects of

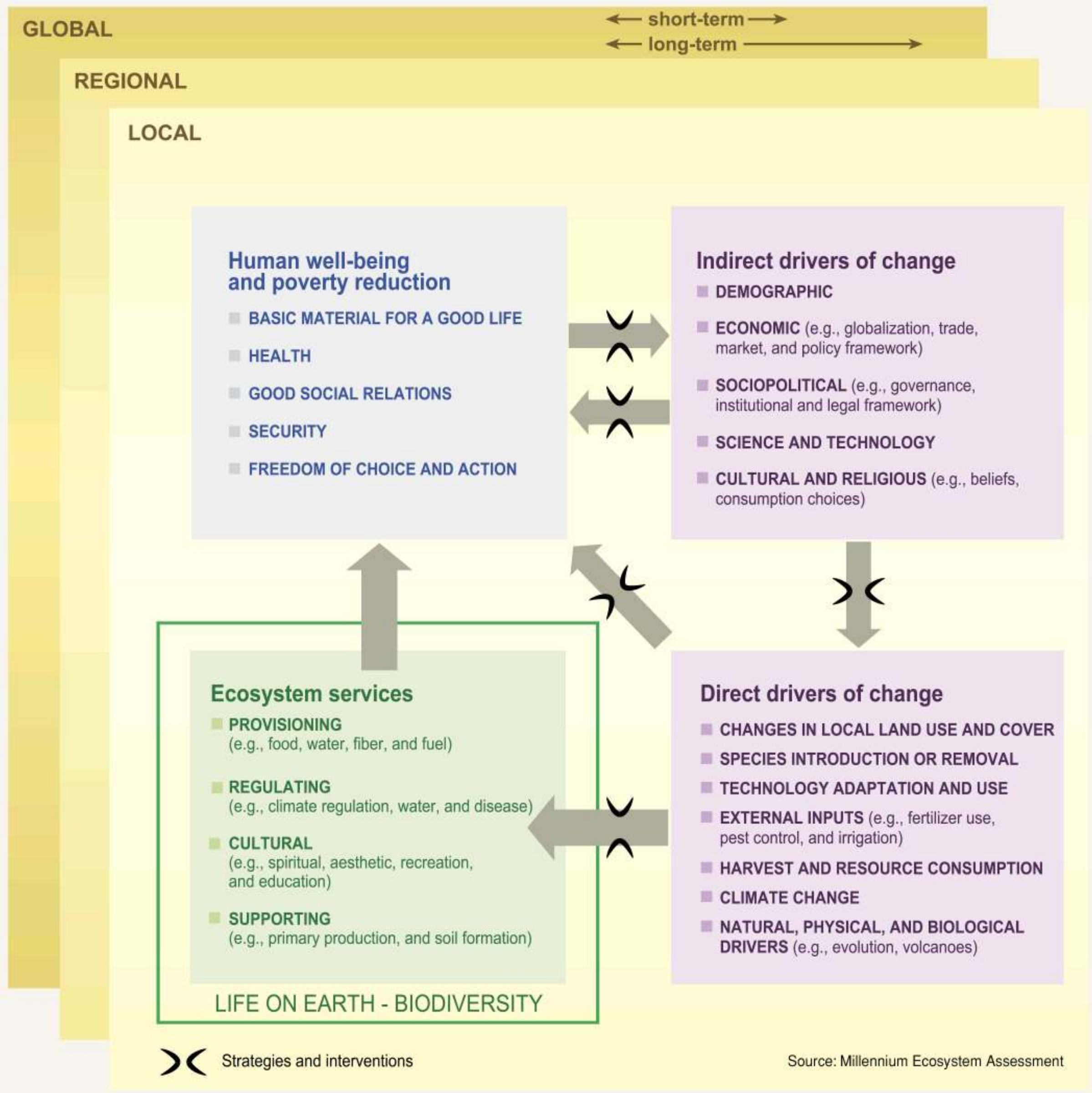

Figure 6.2. Conceptual framework of the Millennium Ecosystem Assessment (MA 2005). Key components of the framework are indirect drivers, direct drivers, ecosystem services, and human well-being and poverty reduction, and the relationships between components. Note that there are no interventions in the relationship between ecosystem services and human well-being, which is assumed to be unalterable, although it is possible to alter this relationship through the drivers that act on ecosystem services and human well-being.

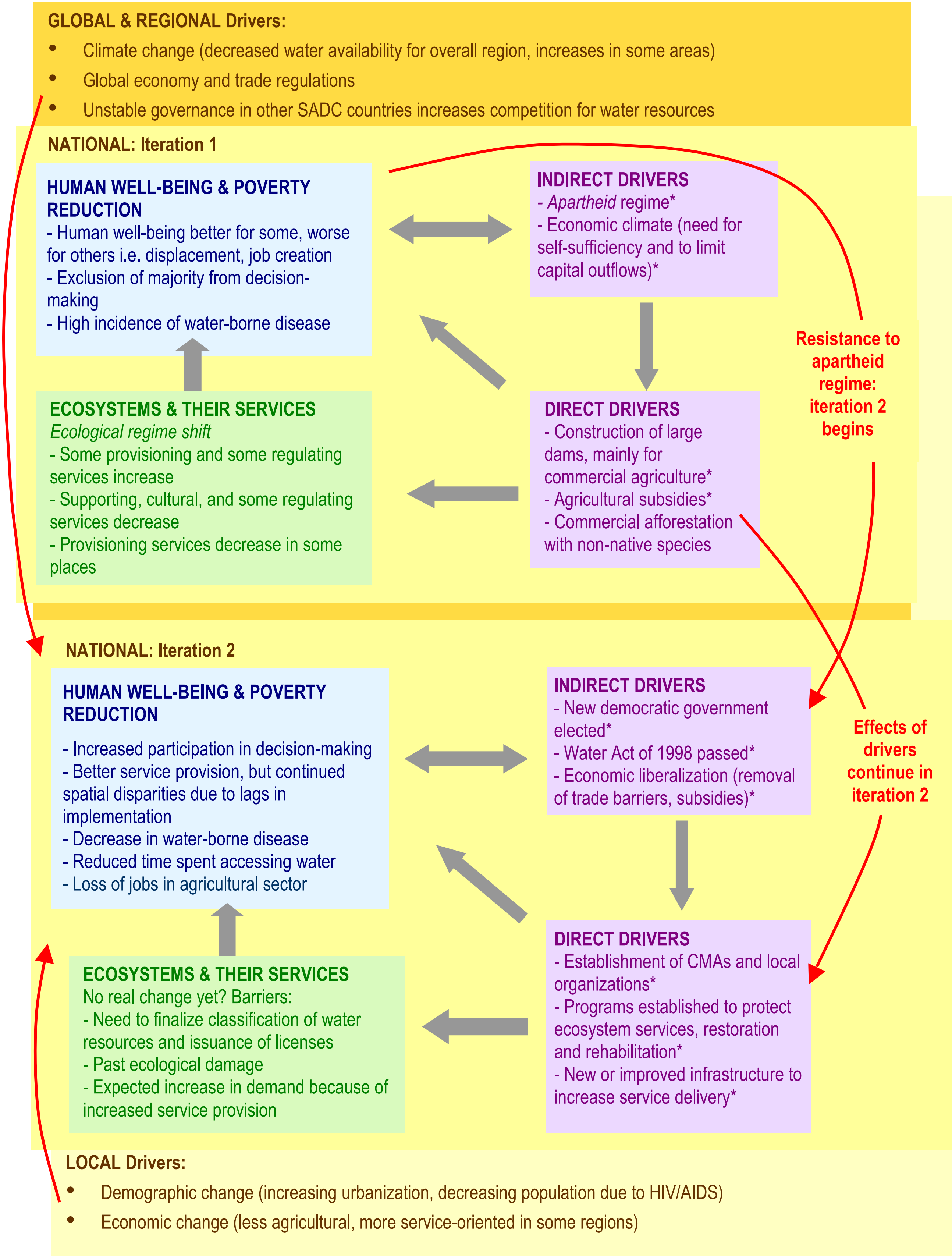

Figure 6.3. Adaptation of the MA conceptual framework to depict two iterations of South African water management. An asterisk (*) denotes features that are both drivers and (direct and indirect) responses for managing water.

resilience in line with the definition above (MA 2005).

In Figure 6.3, the generic components of the framework shown in Figure 6.2 are populated with the South African water example. For the sake of simplicity and clarity, only the dynamics that are thought to be most relevant to social-ecological system resilience are included. Because water management today is significantly shaped by numerous events and processes that have dominated the past century, two iterations of the framework are shown, each of which depicts an era of water management. In addition, because water management at the national scale is linked to processes at global, regional, and local scales, two boxes are added to Figure 6.3. in which some of the main higher- and lower-level drivers are listed.

In the first iteration, the apartheid regime and its policies (indirect drivers of change) encourage the building of large dams and other infrastructure in support of commercial agriculture (direct drivers of change). These effect an ecological regime shift in the most modified catchments of the country, whereby highly altered flow regimes cause large changes in aquatic chemistry and biota (Chutter et al. 1996). There are adverse effects on human well-being but also beneficial ones; the dam projects displace some communities but commercial farms are a major source of employment (MacKay 2003). During this time, commercial forestry plantations of non-native species in mountain catchments proliferate and reduce streamflow (Görgens and van Wilgen 2004); they also facilitate the spread of non-commercial invasive alien plant species (Le Maitre et al. 2004).

The transition from the first to second era comes about as part of the growing internal and external resistance to apartheid and its economic, social, and environmental consequences (MacKay 2003). In the second iteration, the nature of drivers shifts to some degree from technical responses aimed at supporting commercial agriculture and industry to a broader, integrative approach that makes legal provision for the satisfaction of basic human and ecological needs. Since this era is still in progress, few of the effects of this new approach on ecosystems and their services are observable at present, although efforts such as the Working for Water Programme to restore ecosystems through invasive plant eradication have demonstrated substantial benefits for water resources (Görgens and van Wilgen 2004). Human well-being is expected to improve in time from the policy changes, particularly through increased access to water supplies (DWAF 2004*b*) and participatory decision-making, but there is limited evidence of improvement at present. Gains may also be offset by the past erosion of ecological integrity and detrimental feedbacks on current and future human well-being, though thus far not well documented or understood. Additionally, the new water management policies eliminate subsidies for commercial agriculture with the aim of internalizing some of the high costs of agriculture that were previously passed on to society and ecosystems, but to some extent compromising the economic viability of this sector (MacKay 2003).

To indicate the continuation of the cycle over time, the framework is amended with the addition of an arrow from the human-well being box in the first iteration to the indirect drivers box in the second iteration. While indirect drivers change from the first era to the second, some of the direct drivers that operate in the first era, such as investment in infrastructure to support supply-side water management, continue to operate in the present and are expected to form part of the national water supply strategy for the foreseeable future (DWAF 2004*a*). A second arrow is inserted to show the continued influence of the first-iteration direct drivers in the second iteration. Arrows are also drawn from the "global and regional drivers" and "local drivers" boxes to the second iteration of the national-scale dynamics, where these cross-scale links become apparent.

In populating the framework with this example, one observes that some elements can be categorized as drivers and responses, depending on the reference point in space and time. In fact, one can argue that all of the anthropogenic drivers of change in ecosystems and their services are human responses in one form or another. Indeed, the categorization of such elements may depend on the use of the framework: an assessment intended to identify or improve policies may prefer to consider these as responses, whereas an assessment focused on understanding processes may opt to label these as drivers. For the purposes of this paper, in which the intent is closer to the latter, these elements are identified as drivers in Figure 6.3, but are noted with an asterisk, while possible interventions in the relationships between components are not shown.

Panarchy

The panarchy model is a theory of complex system dynamics, of which the adaptive cycle is a central feature (Holling 1986, 1987, 2001, Holling and Gunderson 2002). The cycle describes four phases or ecosystem functions: growth or exploitation, denoted by *r*, in which recently disturbed areas are rapidly colonized; conservation (*K*), in which energy and material are slowly accumulated and stored; release (*Ω*), in which the tightly bound accumulation of biomass becomes increasingly fragile until it is suddenly released by external agents; and reorganization (*α*), in which resources are reconfigured to take advantage of new opportunities. While this description refers to ecosystems, it also applies to social or social-ecological systems, which likewise progress through phases of growth, conservation, release, and reorganization (Redman and Kinzig 2003).

The cycle can be illustrated as a heuristic model best represented as a "figure of eight" in two-dimensional space, with connectedness on the *x* axis and potential or capital on the *y* axis (Holling and Gunderson 2002; Figure 6.4). *Connectedness* refers to the strength of internal links or relationships that mediate external variability. A certain amount of connectedness has advantages, but it is possible for a system to become overconnected, which reduces external variability and increases system rigidity. *Potential* means the capability for change through accumulated resources, whether ecological, social, or economic. The length of the arrows between the phases indicates the speed of transition; the model suggests that the system moves quickly from exploitation to conservation, and more slowly from conservation to release and from release to reorganization. At this point, the system may exit from the cycle and enter a second iteration as an alternatively configured system (Holling 1986). The cycle then begins again. "Panarchy" refers to a series of linked and often nested cycles that evolve through space and time (Holling et al. 2002).

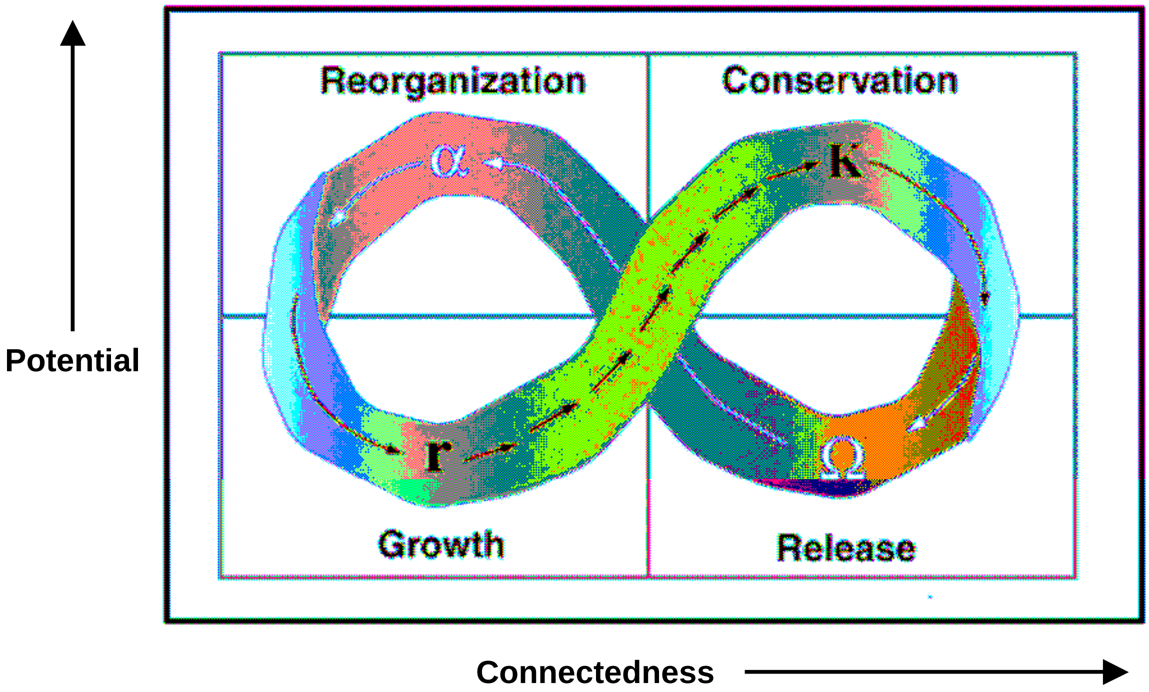

Figure 6.4. The panarchy model (Holling 2001) is comprised of four ecosystem phases (r, K, Ω, and α) and the flow of events between them. Figure adapted from Moench (2005).

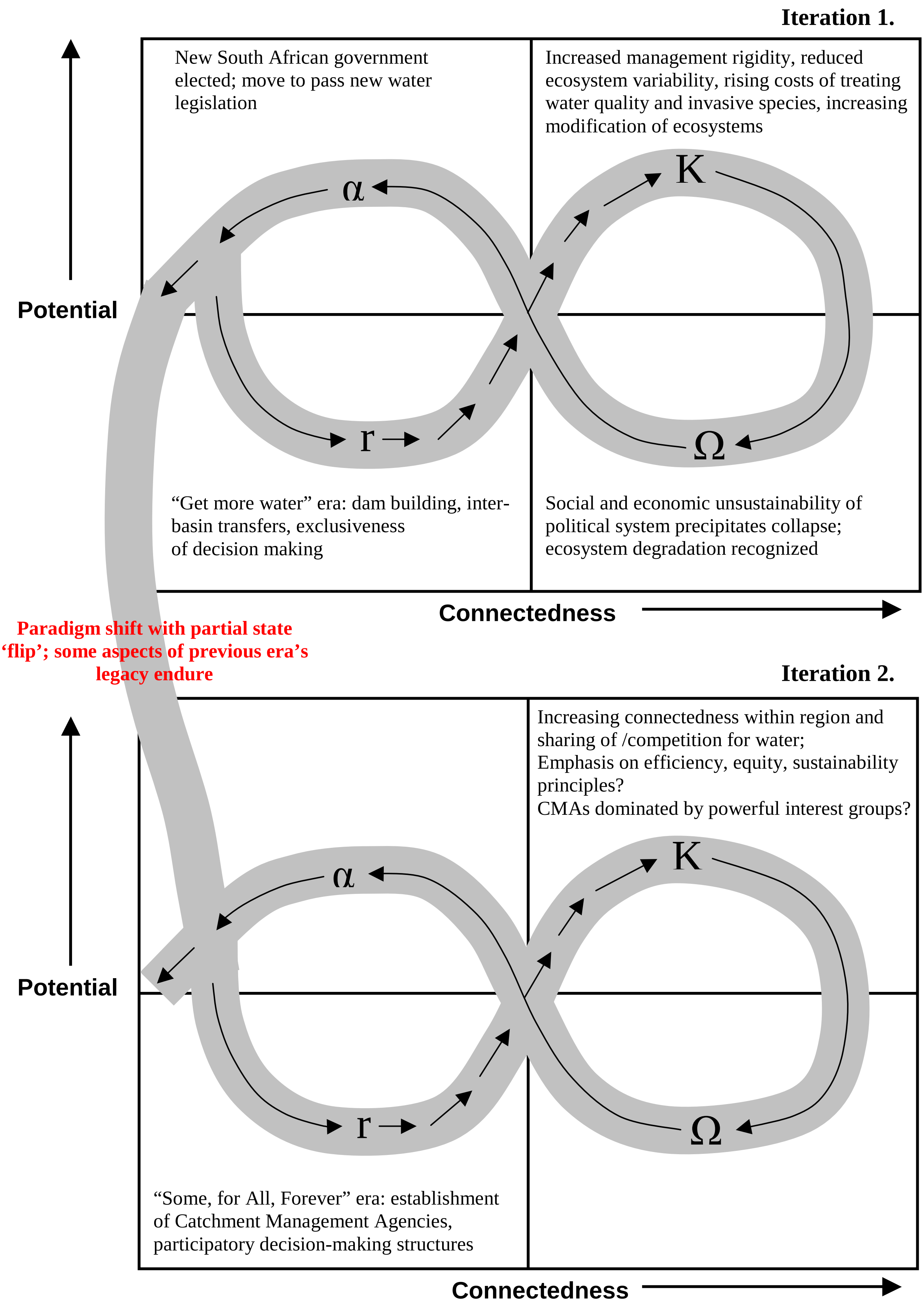

Figure 6.5. The panarchy model of the adaptive cycle is used to depict the dynamics in South African water management during the previous (iteration 1) and current (iteration 2) eras.

In Figure 6.5, the South African water management example is worked through the panarchy model. As with the MA framework, two iterations are shown. The first depicts the previous "get more water" era of management (Dent 2000), which has completed one full phase of the adaptive cycle. During the exploitation phase, increasing investment is made in large infrastructure as potential and connectedness both increase. This leads to greater management rigidity, and through reduced ecosystem variability, increasing degradation, though the ecosystem services of water and food production increase. Forces largely external to the water management system, in the form of social discontent, economic decline, and political pressure, eventually leads to the collapse of the apartheid government. As the system reorganizes, old water laws are repealed and an extensive consultation process commences to draft new laws.

The second iteration of the cycle begins. At this point in time, the overall system undergoes a paradigm shift but only a partial change in configuration. The Water Act marks a phase of reorganization, but the system is saddled with the legacy of the past era's high-cost responses that severely limit flexibility in achieving the Act's efficiency, equity, and sustainability principles: large dams, interbasin transfers, and treatment of invasive species and pollution. The system has endured some partial crises and collapses, but none that have overwhelmed it entirely because there has been sufficient ecological and social resilience overall to buffer the effects of disturbance. This does not preclude the future occurrence of a larger-scale crisis, however. Past actions have compromised many future options; freshwater biodiversity is considered transformed in 26% of the country's mainstem rivers to the point that rehabilitation is no longer possible (Nel et al. 2004).

As water management moves into the second iteration, there is increasing connectedness within the social-ecological system. The South African economy is highly dependent on inter-basin transfers. In Gauteng Province, which generates the majority of South Africa's wealth, all economically-productive water is transferred from catchments outside the province (Basson et al. 1997). South Africa is now highly reliant on the water resources of Lesotho through a multi-billion dollar water project (Metsi Consultants 2002). Water resources are shared with four additional neighboring countries, all with growing demands.

Connectedness extends beyond links between surface water resources; there are interactions between surface and ground water, for example, with groundwater becoming an increasingly important resource in many areas, over-abstraction may deplete surface water (Haupt 2001). There are also increasing water-atmosphere connections; in the Vaal catchment, salinity, already a substantial problem, is believed to have increased due to atmospheric deposition from the area's power plants and other industries (Herold et al. 1992).

The effect of the new Catchment Management Agencies (CMA)s on this connectedness is unclear; in theory; the devolution of water management functions to CMAs provides insurance against over-connectedness, as each develops its own system and style of governance in its Water Management Area. However, there is a danger that some CMAs may be dominated by powerful interests (Chikozho 2005), lack capacity to carry out their functions (Pollard and du Toit 2005), or revert to the old practices of the Department of Water Affairs and Forestry – simply becoming regional extensions of the national department rather than reasonably autonomous entities (Dent 2005).

Analysis of frameworks

A framework should be used to understand the past or guide the future; the resilient pathways concept suggests that it needs to do both. Bearing this is mind, can these frameworks help to clarify the vision of the South African Water Act and ultimately achieve it?

It is possible to trace the past era of water management through a full cycle of the MA framework and the panarchy model. The previous era appears to be traceable through the direct drivers box in the MA framework; many of the effects of these drivers on ecosystem services and human well-being remain uncertain at present. The current era of water management is traceable through the very early exploitation and growth phase in the panarchy model; some elements are more likely to remain in the reorganization phase, while other elements have not actually exited from the previous iteration of the cycle. Beyond these points, only inferences may be made and possible scenarios sketched about the future course of events.

From this exercise, several findings emerge about water management dynamics and the application of these frameworks. The first is that cross-scale connectedness has increased over time. In the system's first iteration, during the "get more water" era, there is little need to include regional or local processes in either illustration of the example. During the second iteration, increasing awareness of global and regional change (e.g. climate, trade), and increasing involvement of local institutions and communities in decision making, create a need to expand upon the illustration with links to these processes. This emphasizes a particular limitation encountered in using the MA framework that arises from the static relationship that the framework implies (Zermoglio et al. 2006). As noted above, the distinction between drivers and responses can be somewhat ambiguous. In addition, issues of temporal scale are difficult to capture with the generic framework. Links between scales may change over time (Gunderson et al. 2002); in the example, they become more relevant in the second iteration, where connectedness to global and regional processes increases in the post-apartheid environment, while sensitivity to local processes increases with the decentralization of decision-making.

These limitations, however, underscore an important finding about the changing dynamics of water management: a fundamental change from the first to second iteration is one in the managers' *understanding* and acceptance of connectedness (Gunderson et al. 2002). Regional and local processes have always influenced water resource dynamics in South Africa, but were previously ignored by managers who treated the system as closed (Bohensky and Lynam 2005). While the MA framework does treat human behavior and perception as an indirect driver, neither of these two frameworks seem to cater for a distinction between "actual" and perceived dynamics, with the latter often being equally if not more important than any physical system change.

Secondly, managers rarely have a clean slate to work upon at the beginning of a new iteration because of the legacy effects of past management actions. Consequences of the past still linger now, as remnants from management decisions taken today will linger in the future. The adaptation of the panarchy model to the South African water situation suggests that some options have been eliminated or constrained, and even as a new iteration of the cycle begins after a partial release, the system may be too overconnected.

A third finding relates to trade-offs, which are inherent in social-ecological systems. The MA framework suggests that improvements in ecosystem services and human well-being are not always synergistic; more often there are trade-offs. One may be inclined to conclude - though never implied by the framework - that 'good' drivers will lead to 'better' ecosystem services and then to 'better' human well-being, but this is in fact a gross simplification. Interestingly, the MA invested great efforts in assessing trade-offs (MA 2005), and that the framework does not more explicitly accommodate their representation is somewhat surprising. The panarchy model, by contrast, does capture an important trade-off of a different nature, between connectedness and potential. This may manifest, for example, in the decision to manage for productivity or to manage for sustainability (Walker et al. 2002). Note that a system in the upper-right quadrant (high potential and connectedness) is unlikely to persist in its current configuration.

The emphasis of current work on ecological aspects of the vision for South African water management suggests that the social aspects of the vision need more development. Both frameworks, and indeed the broader study of resilience, may contribute in this regard, in that they begin to break down the barriers that have traditionally separated the study of human and natural systems. They do this in quite different ways, however. The MA framework includes the crucial feedback from human well-being to drivers of ecosystem change. This is an aspect of natural resource management and decision-making that is typically ignored and generally very poorly understood, though so often at the center of a debate on whether impoverished (in all senses of the word) people cause more environmental destruction than their more well-off counterparts (MA 2003). The panarchy model, on the other hand, does not use a compartmentalization that distinguishes ecological and human components of the system, but rather treats them as one. The MA framework, which treats ecosystem services and human well-being as distinct boxes or arrows, describes the elements of the system - though this may pose a challenge for elements which may not be neatly categorized, as noted above. The panarchy model describes its processes, fluxes, and transitions – how the relationships captured in the framework may change over time.

It is important to note the different intentions of these frameworks; the MA framework was developed to assist decision-makers in understanding the relationships between ecosystems and human well-being, while the panarchy effort sought to develop an integrative theory of adaptive change that applies to some, if not all, social-ecological systems. The MA framework may be more accessible as a tool for identifying management responses, whereas the panarchy model is somewhat vague as a mechanism for guiding action. Alternatively, the two could be used together, where researchers and managers use the MA framework to define the elements and their relationships to one another at a particular scale of space and time, and then use the panarchy model to see how these relationships may change or gain or lose relevance as the system evolves.

Both frameworks run the risk of being too general, but this does not make them useless where sufficient flexibility is allowed. The Millennium Assessment framework, for example, was considered too abstract and inaccessible to a sub-global assessment team in Peru who worked closely with local Quechua communities, so it was modified to better reflect their cosmologies (Zermoglio et al. 2006). The adaptive cycle and panarchy concepts have been replicated, elaborated upon, and adapted widely by contributors to Gunderson and Holling's edited volume *Panarchy* (2002) and the journal *Ecology & Society* (see Redman and Kinzig 2003, Allison and Hobbes 2004, Cumming and Collier 2005), among others (e.g.

Peterson 2000). Such innovations are likely to strengthen both the framework and understanding of the real-world examples studied.

Conclusion

The two frameworks explored in this paper appear able to help clarify the vision of the South African Water Act and challenges faced in achieving it. This is an essential starting point. Sizeable efforts are still needed to bring the understanding of resilience into sharper focus and to unite disparate strands of resilience-related research in the South African water sector. Thus far, most research appears to be limited to one or another part of the resilience equation rather than the whole: resilience is discussed either in an ecological and ecosystem services sense (MacKay 2000), or in a socio-political sense, though the word “resilience” may not actually be used (Ohlsson and Turton 2000, Pollard and du Toit 2005, Turton et al. 2005). In isolation, neither approach may prove to be extremely useful for moving water management forward, with convergence of the two required somewhere in the middle, as some of these contributions appear to recognize.

South Africa’s water sector is currently in the midst of an unprecedented transformation, with a unique history serving as an excellent opportunity to test and contribute to resilience theory and application from a long-term perspective. The exploration of existing frameworks can assist managers in the discovery of resilience and clarification of a vision, though the process of discovering resilient pathways – the journey itself – may be as important as the outcome. Further development of such frameworks could provide stakeholders with diverse interests a forum in which to interact around often difficult and contentious issues, where they may finally arrive at a desirable road map for the future.

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