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Making Waves

How a water-resources crisis highlights social-ecological disconnects

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ABSTRACT

The sustainable management of water resources is required to avoid water scarcity becoming widespread. This article explores the potential application of a social-ecological framework, used predominantly in the fields of ecology and conservation, as a tool to improve the sustainability and resilience of water resources. The “red-loop green-loop” (RL-GL) model has previously been used to map both sustainable and unsustainable social-ecological feedbacks between ecosystems and their communities in countries such as Sweden and Jamaica. In this article, we demonstrate the novel application of the RL-GL framework to water resources management using the 2017/18 Cape Town water crisis. We used the framework to analyse the social-ecological dynamics of pre-crisis and planned contingency scenarios.

We found that the water resources management system was almost solely reliant on a single, non-ecosystem form of infrastructure, the provincial dam system. As prolonged drought impacted this key water resource, resilience to resource collapse was shown to be low and a missing feedback between the water resource and the Cape Town community was highlighted. The collapse of water resources (“Day Zero”) was averted through a combination of government and community group led measures, incorporating both local ecosystem (green-loop) and non-local ecosystem (red-loop) forms of water resource management, and increased rainfall returning to the area. Additional disaster management plans proposed by the municipality included the tighter integration of red and green-loop water management approaches, which acted to foster a stronger connection between the Cape Town community and their water resources.

We advocate the wider development and application of the RL-GL model, theoretically and empirically, to investigate missing feedbacks between water resources and their communities.

1. A social-ecological framework for water resources management

The sustainable management of water resources, globally, is required to avoid water scarcity becoming widespread. There are a number of human pressures (e.g. urbanisation, intensive agriculture, over-abstraction, inefficient distribution and exceptional demand) underpinning climate change, pollution and biodiversity loss that contribute to water scarcity (Eslamain and Eslamain, 2017). The idea that anthropogenic water systems can be resilient to the pressures of scarcity only through economic decision-making (e.g. cost-benefit analysis), engineering and technology is beginning to be undermined. Damming predictions (Boretti and Rosa, 2019) and real-world crises on many of the world's continents seem to be increasing. We propose that civic water resource management could benefit from the application of a recently developed social-ecological framework, which highlights the importance of feedbacks between humans and ecosystems (Cumming et al., 2014; Hamann et al., 2015; Blythe et al., 2017; Dajka et al., 2020). This framework has not previously been applied within the realm of water resources management and may prove a useful tool in planning for better management and, ultimately, future resilience.

Feedback-based models have long been used in ecology and conservation research with the aim of improving habitat management (Scheffer et al., 2001). Cumming et al. (2014) proposed the "red-loop green-loop" (RL-GL) model which classifies social-ecological dynamics into red and green feedback loops. These loops are based upon human dependence on, and interactions with, the local ecosystem, in addition to the sustainability of that ecosystem. Green-loop systems are defined by a sustainable relationship

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between a human population (often lower density) and their local ecosystem, such as a rural society practicing subsistence agriculture. Green-loop systems are reliant on ecosystem goods and services derived from their local ecosystem. Red-loop systems are characterised by the sustainable relationship between a human population (often higher density) and the local/regional socioeconomic system (often more metropolitan) they utilise to supply non-ecosystem goods and services. However, both green and red-loop systems can drift into unsustainable traps. Green traps are initiated by overconsumption and inadequate productivity, which if left unchecked can lead to rural poverty and ecological degradation which amplify each other, resulting in a green trap. At the other end of the spectrum, red traps can occur through overconsumption and the failure to manage ecological decline. Such ecological decline can progress unnoticed if the signal-response chain between the ecosystem and society is masked (e.g. missing feedback fostered by lack of ecological knowledge; Dajka et al., 2020). Both trap types can lead to ecosystem and resource degradation if they are not addressed (Cumming et al., 2014).

The RL-GL concept has been applied to a handful of national-level systems, including Sweden (Cumming et al., 2014) and Jamaica (Dajka et al., 2020). Sweden experienced a transition from green loop to red loop. For over 1000 years, the country had a low human population based on primarily agrarian lifestyles and was classified as a green loop system (Cumming et al., 2014). Accelerating population growth beginning in the mid-18th century, triggered a transition towards a red loop system at the latter end of the 19th century. Economic development, driven mostly by the industrial sector and growing export markets, fuelled the transition from the 1870s. Then, from 1950, the industrial and service sectors expanded whilst the agricultural sector remained largely stagnant. Swedish agricultural employment subsequently declined from close to a million in 1880 to less than 50,000 people in 2000. In a red loop system, disconnects between people and local ecosystems (missing feedbacks) and resulting environmental degradation are expected (Cumming et al., 2014). During the 1950s, great losses were beginning to be recorded in Swedish grassland biodiversity and old-growth forests. Further, overfishing in the Baltic Sea was recorded throughout the 1990s and still is today. Swedish imports and exports increased sevenfold between 1975 and 2000, with unknown impacts on external ecological systems. Many of the country's increased requirements were met by upscaling, with Sweden employing technological advances and modern farming methods that aided in reducing local environmental degradation whilst stabilising increased food production. Using this strategy, Sweden managed to retain a sustainable red loop system and not drift into an unsustainable red trap.

Jamaica on the other hand has moved through all RL-GL states (green loop, green trap, red loop, red trap) since the first human settlement around the year 600, up to 2017 (Dajka et al., 2020). Here too, missing feedbacks between people and the local ecosystem were most detrimental to the Jamaican nearshore ecosystem. In contrast, it appears that the previously upscaled exports of locally caught reef fish are largely responsible for keeping Jamaica in a red trap scenario in recent years rather than a red loop as was the case for Sweden. More commitment to ecological monitoring and conservation appears to be the main difference between Jamaica's red trap state (Dajka et al., 2020) and Sweden's red loop state (Cumming et al., 2014).

The RL-GL model has not been used, however, to map the state of a nation's water resources, or to reveal any 'missing feedbacks' that may be driving management practices that are detrimental to a local ecosystem's ecological sustainability and a community's natural resources. Social-ecological approaches have only recently been seen as useful for water resources planning and forecasting (e.g. Jaeger et al., 2017), with the aim of improving the sustainable management of these systems. In this article we look to demonstrate application of the RL-GL model to analyse a water resources management system. We use the RL-GL model to identify functioning and missing social-ecological feedbacks across some specific management scenarios (real and hypothetical) of a single water resources system. As an example, we capture the water resources management of South Africa's Western Cape capital - Cape Town - and the water crisis of 2017/18. Using the RL-GL model enables us to provide an analysis of the human-environment relationships which defined the course of the Cape Town water crisis and highlight some of the dynamics which helped foster greater sustainability (Laurent, 2015).

2. An application of the red-loop green-loop model

The RL-GL framework provides a unique social-ecological lens through which to view the management of Cape Town's water resources management, preceding the implementation of emergency measures by the City of Cape Town (CCT) local municipal authority. However, first it is necessary to first provide some wider context of water resources management across South Africa and the Western Cape. The post-apartheid government of South Africa have introduced a number of policies designed to improve access to, and availability of, potable water, such as the Water Services Act (1997), and the Free Basic Water policy (2001). However, access to clean water, although greatly improved, remains a persistent problem (Muller, 2008). South Africa is a water scarce country (Cole et al., 2017), and a series of droughts in recent years have put pressure on the limited water resources. As a result, water scarcity became the focus of a major crisis, particularly for the Western Cape Water Supply System (WCWSS) which fed the province's major city, Cape Town.

In May 2017, water storage capacity at the WCWSS dams had reduced to around 20% (Climate Systems Analysis Group, 2019). This shortage resulted in the CCT triggering a disaster management plan that imposed a per capita limit of 50 litres (L) of water per day (Enqvist and Ziervogel, 2019; GreenCape, 2018), and warned that should storage drop below 13.5%, these limits would be reduced to 25 L (Enqvist and Ziervogel, 2019; GreenCape, 2018). This final action would be implemented by switching off municipal water supplies and installing communal distribution points to enable water rationing; an event that colloquially became known as "Day Zero" (City of Cape Town (CCT) 2017).

Several reasons have been identified for the water shortages that led to the crisis (Muller, 2017), notably: (i) a prolonged period of reduced rainfall; (ii) increased demand associated with population growth; (iii) the poor management of, and investment in, water management infrastructure; (iv) overallocation of water resources to the agricultural sector; (v) the overreliance on surface water; and, (vi) the spread of water intensive invasive vegetation (Parks et al., 2019; Taing et al., 2019). Similarly, there were a number of events and interventions that helped to mitigate the severity of the crisis: (i) a return of normal rainfall rates; (ii) supply augmentation via diversifying water-sources (e.g. increasing groundwater supply capacity); and, (iii) improvements in water recycling and distribution efficiency (Parks et al., 2019). These factors should be understood when considering the RL-GL concept, applied in the South African context.

Pre-crisis, the CCT municipality operated the distribution of clean water for public use (Fig. 1), sourced mainly from the WCWSS and as a quota allocated to the municipality by the nationwide Department of Water and Sanitation (Enqvist and Ziervogel, 2019). This consisted of typical piped infrastructure, engineered to distribute the water between the different consumer types (e.g. domestic or agricultural users) (Muller, M. 2019). Water levels in the WCWSS were monitored at the provincial

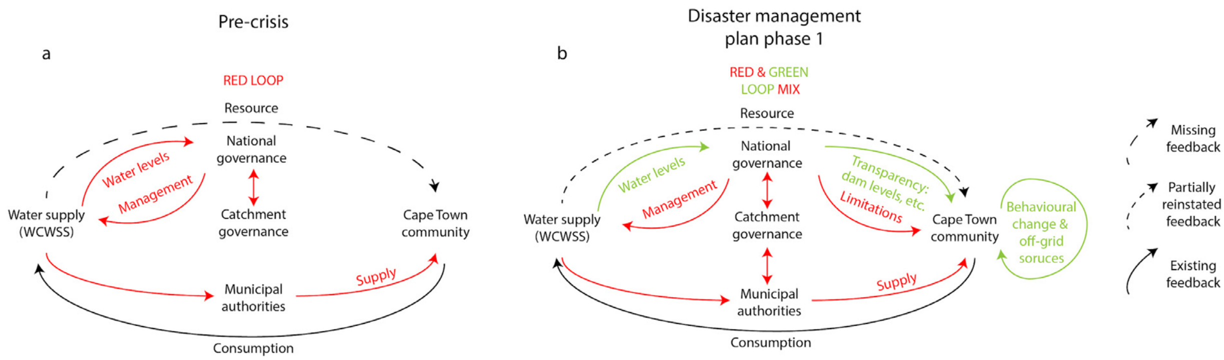

Fig. 1. Outline of the management of the City of Cape Town's water resources, (a) prior to 2017 (i.e. pre-crisis), and (b) during phase 1 of the disaster management plan response to 2017–2018 crisis; WCWSS = Western Cape Water Supply System.

level, though there was limited transparency between the national/provincial level and the municipal level, as well as the public. We argue that this lack of transparency produced a missing feedback (Fig. 1a). Within the predominantly red loop relationship between water resources and the Cape Town community, a lack of transparency on the state of resources, and therefore, a lack of consumer behavioural change, further reinforced the disconnect and intensified resource depletion. Alongside this, the one-way, top-down governance of water supply management (e.g. the limited scope for negotiation between the CCT and the Department of Water and Sanitation for water allocation quotas) further reinforced the missing feedback between provincial catchment supply management and municipal authority quotas (Fig. 1a). Furthermore, reliance on a single supply water supply (i.e. the WCWSS) limits the options for water resource management to address drought resilience (Muller, 2018).

In late 2017, Phase I of the CCT's disaster management plan was implemented (Fig. 1b). This involved imposing water consumption restrictions to 87 L per capita per day (Taing et al., 2019) as well as the following additional actions: (i) improving the efficiency of the piped water distribution system; (ii) increasing the stepped pricing structure of additional water beyond the basic household allowance of 6000 L per month; and, (iii) organising and coordinating an Information, Education and Communication (IEC) campaign to improve the reporting and transparency of water-use and supply-based data to the municipal authorities and the public. These measures aimed to reduce water use by: (i) reducing leakage; (ii) changing consumption behaviour by making 'luxury' water costly; and (iii) informing the public about the state of water resources. The IEC campaign specifically fostered a partial feedback between the consumer and the state of the water resources (Fig. 1b), bringing the interaction closer to a green-loop dynamic. Using data transparency such as 'The Big Six Monitor' (Climate System Analysis Group, 2019) and educational campaigns like "If it's yellow, let it mellow…" (Booysen et al., 2019). There was a resulting improvement in water use from these actions, with Booysen et al. (2019) reporting a per day household decrease of 48% throughout the duration of the drought and crisis (2015–2018). Alongside this campaign to reduce water consumption and waste, the CCT also pursued supply augmentation policies (notably the large-scale abstraction of groundwater from three regional aquifers, and the expansion of both desalination and wastewater treatment capacity), further improving diversification and resilience (Taing et al., 2019). This suite of measures adopted by the CCT demonstrates a successfully implemented combined red and green loop approach to resource management.

The added transparency, and the consequent partially reinstated feedback (Figure 1b), led many of the Cape Town community to change their behaviour. Some of these changes were positive, e.g. the steep reduction in personal water usage, and the supply augmentation policies adopted by CCT (notably the large-scale abstraction of groundwater from three regional aquifers, and the expansion of both desalination and wastewater treatment capacity) (Taing et al., 2019). Other behavioural changes were also observed, notably a reported increase of people utilising new 'off-grid' sources of water, such as personal boreholes and small springs and streams to supplement or replace their local supply. Although these changes are not necessarily socially or environmentally positive (e.g. individuals having to travel to collect potentially unsafe water, or the use of unregulated boreholes), what they represent is a shift from what Simpson et al. (2020) describe as "dam mentality". That is, people reassessing their perceptions of water security, and sought to look beyond the state supplied resource and its highly engineered network. It is argued that a transition away from a dam mentality coincided with behavioural change, partially reinstating the missing feedback between consumers (i.e. the Western Cape community) and the WCWSS (Fig. 1b). This behavioural change may also have initiated a new green-loop through the use of external (to the WCWSS) water sources. Unfortunately, however, this scenario likely resulted in further water inequality (Cole et al., 2017; (Enqvist and Ziervogel, 2019)).

Ultimately, Day Zero was avoided; normal rainfall in mid-2018 restored the water levels in the dams to a manageable level, but the in-crisis responses of the CCT and the Cape Town community also played a significant role in preventing a much more serious situation (Taing et al., 2019). The course of the progressing crisis and implementation of phase 1 of the CCT's disaster management plan illustrate how green loops were increasingly integrated into the overall red loop system as the crisis progressed. Next, we will discuss further (though hypothetical) green loop integration, as demonstrated by phases 2 and 3 of the disaster management plan which was proposed by the CCT to alleviate the crisis should the drought have continued.

3. Balancing social-ecological feedbacks to improve sustainability

The additional emergency strategy of phases 2 and 3 of the disaster management plan were agreed in advance to account for a continued period of little or no rainfall (Taing et al., 2019). We interpret this additional emergency strategy using the RL-GL framework, to demonstrate how a mix of red and green loops are employed to improve the sustainability of Cape Town's water resources, and ultimately, the state of the ecosystem providing these water resources (Fig. 2).

The RL-GL framework highlights, that during phases 2 and 3 of the disaster management plan, knowledge of the state of water resources and the source ecosystem was transparent at a national

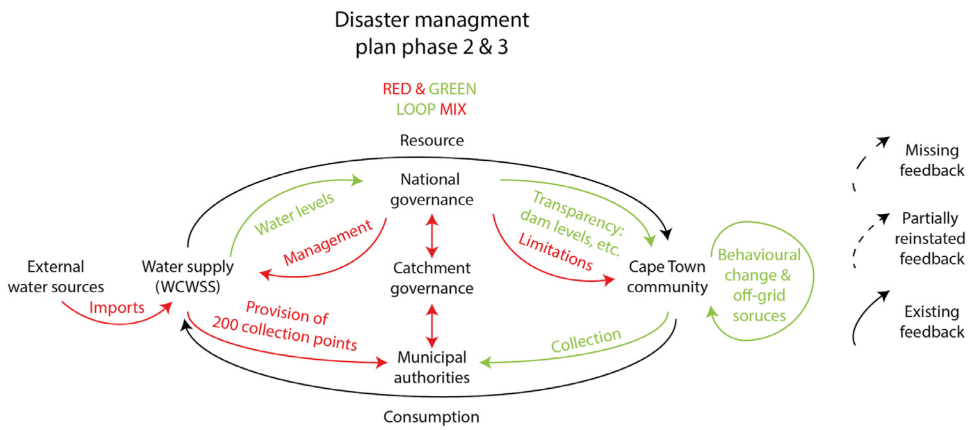

Fig. 2. Outline of the management of the City of Cape Town's water resources phases 2 & 3 of the disaster management plan, contingency phases that were not employed in the 2018 water crisis.

level, for provincial Water Boards, the CCT municipality and the Cape Town community; this is demonstrated by a fully reinstated feedback between society and the water resource ecosystem (WCWSS). In phase 1 of the disaster management plan, this feedback began to be partially reinstated via an increasingly transparent flow of information about the state of the water supply (e.g. WCWSS dam levels), fostered through an IEC campaign and more general media coverage (Fig. 1b). In phases 2 and 3, the CCT municipality planned to organise 200 water collection points across the city which would integrate a new green loop between the water resource and the Cape Town community (Fig. 2), that would be required to go to collection points and receive an allocated daily water provision of 25 L per capita (Taing et al., 2019). The introduction of this new green loop would likely have had implications for how Cape Town's community view their water resources, highlighting the severity of the scarcity through enforcing water collections. Although not necessarily a popular or safe strategy, this may have fully reinstated the feedback (Fig. 2). Fortunately, this scenario was avoided as the IEC of this phase of the disaster management plan may have triggered environmentally conscious behavioural changes (Geng et al., 2015), such as water-saving. Again, the Cape Town community seeking to avoid this scenario might also demonstrate a transition away from the typical dam mentality. The community adjusted their behaviour in accordance with a mixture of strategies aimed at increasing personal and public responsibility for water-use. Some attention has recently been given to explaining how a disconnect (in terms of human-nature interactions) between consumers and source ecosystems can result in unsustainable attitudes and behaviours towards the environment (Soga and Gaston, 2016; Dajka et al., 2020); a dam mentality may be an example of this, at a personal or societal level. Others argue that a strong connection with natural ecosystems (and their resources) is beneficial for human health and wellbeing (Ives et al., 2017). Moreover, there is potential for re-connecting communities with nature in order to promote sustainable behavioural changes (Ives et al., 2018; Dajka et al., 2020) and the improved management of water resources. Though, not at the risk of socially detrimental practices, as approaches to change behaviour for the benefit of sustainability must be balanced with improvements in technological efficiencies to not decrease standards of living.

Altogether, using the RL-GL framework to analyse the 2017/18 Cape Town crisis revealed that progressively integrating a typically red loop system with more green loops, helped to avert a deepening of the crisis (Fig. 1b). This balanced mix of loop types has the potential to improve the resilience of water resources and their management to avoid crisis, and potentially facilitate adaptation over time to suit a changing climate. However, there is a need for more empirical research to complement the theoretical development of the RL-GL framework. This includes interdisciplinary experimental and statistical work to link specific feedbacks and ecological indicators to state policy or social interventions (e.g. Baudoin and Gittins, 2021), specifically related to the management of water resources. For instance, Cumming and von Cramon-Taubadel (2018) used a statistical modelling approach to connect the United Nations' Human Development Index (HDI) to the RL-GL framework. This research attempted to link the notion of red and green loops to national development across a number of countries. The authors found 42 red loop countries to be mostly HDI category 1 (very high development) and 32 green loop countries as mostly HDI category 4 (low development), with HDI 2 (high development) and 3 (medium development) being transitory phases of development in between predominantly red (HD 1) and green loop (HDI 4) nations. In the most recent HDI assessment by the United Nations in 2018, South Africa was categorised as a HDI 2 country with a score of 0.705 (United Nations Development Programme (UNDP) 2019). Suggesting that indeed South Africa might be shifting from utilising both red and green loop dynamics within its social-ecological system, towards a predominantly red loop social-ecological system (e.g. HDI 1).

Although the HDI does not explicitly include the state of water resources in its assessment of a nation's development, it is fair to assume that good quality and well distributed water resources might be a feature underpinning some of the dimensions of the HDI (e.g. life expectancy, per capita income, education; UNDP 2019). Therefore, despite indicating a transition up the HDI, South Africa's score of 0.705 potentially indicates more intensive red loop management of water resources nationwide. Viewing the Cape Town crisis through the RL-GL lens demonstrated how a solely red loop managed system can lack resilience to external pressures (i.e. climate change). Other nations have, however, demonstrated that red loop social-ecological systems can be sustainable; Sweden for example (Cumming et al., 2014). Although, this is yet to be demonstrated for the management of water resources specifically. In the Cape Town example, the re-integration of green loops into the system helped alleviate the crisis, and could potentially increase resource resilience by reinstating missing social-ecological feedbacks. It would be interesting to see if these findings are supported by other case studies, perhaps for the management of water resources in HDI category 1 and 4 countries. Additionally, analysing different water users (i.e. agriculture, industry) in the Cape Town scenario (or elsewhere) using the RL-GL model would be beneficial to gain a broader picture of the complex relationships between water supply and its consumers. To conclude, we strongly advocate the use of the RL-GL framework when analysing social-ecological dynamics. We have shown that it can be an effective tool to illustrate water resources challenges and can facilitate the implementation of policies or management practices to improve sustainability and resilience. In addition, we provide a novel application of the RL-GL framework to the management of water resources and demonstrate its utility in a context outside of the fields of ecology and conservation.

4. Conclusions

- Our analysis demonstrates how the novel application a social-ecological framework (RL-GL) to water resources issues can potentially improve sustainability and resilience;
- This pilot study on a water resources system also contributes another example application of how the RL-GL framework can be used to visualise and identify detrimental, missing feedbacks in social-ecological systems;
- The South African example presents how the re-introduction of feedbacks can change behaviour to promote more sustainable water use and management practices; and
- Our article provides a conceptual, interdisciplinary approach to water resources management which should be applied more broadly and validated through empirical work.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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