Ecosystem Services xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Ecosystem Services

journal homepage: www.elsevier.com/locate/ecoser

Strategic water source areas for urban water security: Making the connection between protecting ecosystems and benefiting from their services

Jeanne L. Nel [a,b,*], David C. Le Maitre [c], Dirk J. Roux [b,d], Christine Colvin [e], Janis S. Smith [c], Lindie B. Smith-Adao [c], Ashton Maherry [f], Nadia Sitas [c,g]

[a] Institute for Environmental Studies, Faculty of Science, Vrije Universiteit Amsterdam, De Boelelaan 1087, 1081 HV Amsterdam, The Netherlands
[b] Sustainability Research Unit, Nelson Mandela Metropolitan University, Private Bag X6531, George 6530, South Africa
[c] Natural Resources and the Environment, Council for Scientific and Industrial Research, P.O. Box 320, Stellenbosch 7599, South Africa
[d] Scientific Services, South African National Parks, Private Bag X6531, George 6530, South Africa
[e] WWF-South Africa, P.O. Box 23273, Claremont 7735, South Africa
[f] Centre for General Education, Durban University of Technology, P.O. Box 1334, Durban 4000, South Africa
[g] Department of Conservation Ecology, Stellenbosch University, Private Bag X1, Matieland 7602, South Africa

ARTICLE INFO

Article history:
Received 3 February 2017
Received in revised form 21 June 2017
Accepted 28 July 2017
Available online xxxx

Keywords:
Water towers
Ecological infrastructure
Catchment stewardship
Water resource management
Sustainable development goals
Knowledge co-production

ABSTRACT

Strategic water source areas are those areas that have a relatively high natural runoff in the region of interest, which is made accessible for supporting the region's population or economy. These areas contribute substantially to development needs, often far away from the source. This disconnect between ecosystem service supply and use means that the social-ecological impacts of development decisions in these areas may not be obvious to users and decision makers. We identified 22 strategic water source areas in southern Africa linked to major urban centers. We quantified the population size and economy they support, and their current levels of protection. We found that strategic water source areas form only 8% of the land area but contribute 50% of the runoff. When linked to downstream urban centers, these areas support at least 51% of South Africa's population and 64% of its economy. Yet only 13% of their land area is formally protected. We recommend using multiple strategies for the legal protection of these areas. Identifying strategic water source areas and their links to downstream users offers an opportunity for achieving synergy in spatial planning across diverse policy sectors, and enables new patterns of collaboration between government, business and civil society.

1. Introduction

Protecting water source areas to secure water supply is not a new concept. Protection of the Catskills water source area, which supplies water to New York City, is a well-known success story that has reported high returns on investment (Chichilnisky and Heal, 1998)[1]. Similarly, restoration and protection of the Tijuca Forest in Rio de Janeiro to protect the city's water supply dates back to the second half of the 19th century (Trzyna, 2014). The benefits of protecting water source areas stem from maintaining the capacity of ecosystems to regulate the quality and quantity of water over time (Brauman et al., 2007), which in turn provides ecosystem services to downstream users. In an urban context, ecosystem services from water source areas include provisioning services such as water for domestic and industrial uses, regulating services such as dilution of waste, and cultural services such as aesthetic, recreational, sense of place and identity associations (Cosman et al., 2012). These ecosystem services translate into benefits such as reduced water quality treatment costs and improved health, leading to an overall improvement of human well-being.

Water source areas often only occupy a small fraction of the land surface area but supply a relatively high amount of water to the surrounding region (Meybeck et al., 2001). Deterioration of water quality and quantity in water source areas can therefore have a disproportionately large impact on downstream users who are often a far distance away. This disconnect between source and use means that the full social-ecological impacts of development in these areas are often not apparent to decision makers or users. These impacts could be positive (e.g. restoration activities

* Corresponding author.
E-mail address: jnel4water@gmail.com (J.L. Nel).

[1] Exact values are a matter of debate (Kenny, 2015; Appleton and Moss, 2014; Sagoff, 2005).

http://dx.doi.org/10.1016/j.ecoser.2017.07.013
2212-0416/

Please cite this article in press as: Nel, J.L., et al. Strategic water source areas for urban water security: Making the connection between protecting ecosystems and benefiting from their services. Ecosystem Services (2017), http://dx.doi.org/10.1016/j.ecoser.2017.07.013

to enhance soil permeability or soil retention, protection of land), or negative (e.g. coal mining, over-abstraction of water by farmers, pollutants from intensive farming activities, or increased streamflow reduction from water-consuming non-native trees and timber plantations). Identifying important water source areas and making more explicit linkages between ecosystem service supply and use can mend this disconnect, and promote the protection of these areas. A recent global study by Harrison et al. (2016) appeals for increased attention to protecting upstream water sources for safeguarding water flows and enhancing water security. They showed that protected areas already offer good potential to safeguard water sources, with almost two-thirds of the world's population living downstream of protected areas.

Originally, important water source areas were identified based on water supply only, by locating mountain areas that supply disproportionate runoff compared to adjacent lowland areas (Meybeck et al., 2001). These areas are termed 'water towers', but stakeholders of this study prefered to use the term 'strategic water source area' (Table 1). The latter term links more explicitly to a geographical area, and uses 'strategic' to imply that it is not an exhaustive identification of all water source areas. In addition, we broaden the original definition of water towers by considering both water supply and human use factors. Strategic water source areas are thus those areas that have a relatively high natural runoff in the region of interest, which is made available for supporting the region's population or economy through water supply schemes.

While the concept of protecting water source areas is not new, recent global policies and planning requirements for sustainable development represent new opportunities for mobilizing businesses and governments around this issue. For example, the 2030 Agenda for Sustainable Development and associated Sustainable Development Goals (SDGs) call for achieving water access for all, while promoting the sustainable management of water resources (UN, 2015). SDGs 6 and 15 are particularly relevant to water source areas because they include explicit commitments to the protection and restoration of water-related ecosystems and their services (Griggs et al., 2013). The 193 countries that subscribe to the SDGs, including South Africa, need to establish national development plans on how they will contribute to these targets. Identifying strategic water source areas and their links to downstream users enables a more comprehensive assessment of different development options, and their impact on urban water. Global Aichi targets set by the Convention on Biological Diversity also offer a good policy opportunity for strategic water source areas. These targets strive to conserve ecosystems that are of particular importance for biodiversity and ecosystem services, through protected areas and other effective area-based conservation measures (CBD, 2010). Identification and incorporation of strategic water source areas into national protected area networks will make an important contribution toward CBD targets, but requires an expansion of the conventional focus of protected areas on terrestrial ecosystems to also prioritize freshwater ecosystems (Pittock et al., 2015) and ecosystem service provision (García-Llorente et al., 2016; Palomo et al., 2013).

Although strategic water source areas have been identified at a global level (Viviroli et al., 2007), application to national planning and decision making requires enhancing the spatial resolution of the global map and adding country-wide detail on water transfer schemes, access and use. The latter is especially important for arid and semi-arid countries, where inter-basin transfers are frequent, and thus water resources are used by more than just the lowland population of the surrounding basin. In this paper, we identify strategic water source areas for southern Africa at an appropriate scale for national planning. We focus on surface water resources, while recognizing that groundwater source areas should also ultimately be identified, particularly in areas with a high dependency on groundwater. We then link the identified strategic water source areas to the water supply systems of major urban centers, quantify the amount of urban water supplied by strategic water source areas, and relate this to the population size and economic value of each area. We assess current protection levels of strategic water source areas and conclude with generalized recommendations for incorporating this ecosystem service perspective into both sustainable development planning and protected area expansion elsewhere in the world.

2. Methods

2.1. Co-production of maps with stakeholders

Several maps of water source areas have been developed in South Africa over the years (Nel et al., 2011; Driver et al., 2005; Ross, 1961), with little or no traction in policy and decision making. To improve uptake, we used an iterative participatory process (*sensu* Nel et al., 2016) to co-develop the map of strategic water

Table 1
Key limitations of previous water source area maps and ways in which these were addressed.

Barrier to uptake	How we addressed this barrier
No acceptable common terminology for referring to these areas resulting in confusion, especially around terms too immersed in engineering-based solutions (e.g. 'water towers', 'water factories', 'high water yield areas')	Sought extensive stakeholder input on the collective name for these areas, as well as a definition. Later also sought consensus on names for each water source area
Broaden from a water supply focus only to include information of water access and use, particularly since some strategic areas are not necessarily those with the highest runoff	The initial map, focussing on water supply, was developed using natural mean annual runoff (MAR). Thereafter, national water resource planners and national demand data were consulted to identify gaps based on water demand by major urban development or economic nodes.
Mapping strategic water source areas using runoff data at catchment, or even sub-catchment, is too coarse because it is difficult to separate the actual source areas from the surrounding lowlands even if the sub-catchments are relatively small	Disaggregated catchment runoff data to $1' \times 1'$ resolution using a rainfall-runoff model, so that variability in runoff could be detected within sub-catchments
National water resource planners and engineers were reluctant to use runoff data that was not endorsed by their departments	Applied an adjustment factor to the $1' \times 1'$ data so that the runoff data matched that of the sub-catchment outlet in the data used by their departments
Previous maps were too detailed, with too many areas identified, making them difficult to apply in strategic, national-level planning	Focused on identifying the most strategic areas at a national level, rather than an exhaustive map of all water source areas. Water supply was mapped using percentage runoff relative to national runoff rather than catchment runoff, and water use focused on areas identified in the national development plan as major urban development or economic nodes.
Local scale delineations, rather than $1' \times 1'$ pixels, are preferred	Beyond the scope of this national scale work – needs attention at local scale

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source areas with key individuals and institutions involved in the governance of water resources in South Africa. We targeted over 50 end users from national and provincial government departments (water, development and conservation) and environmental non-governmental organizations, as well as local experts from researcher organizations and private consultancies. The co-production process built on work from Nel et al. (2011), and occurred over five years, from 2012 to 2016 (Fig. 1). Early in the process, stakeholders identified barriers to the use of previous water source area maps, which informed the co-development of methods used to map strategic water source areas (Table 1). Thereafter, we met regularly with stakeholders to iteratively review results at major milestones (Fig. 1), and to identify emerging opportunities for application of the outputs. We responded to several opportunities put forward by stakeholders from a range of different sectors. This included participation in a civil society and media campaign (the Journey of Water), and provision of materials (e.g. maps, principles and strategic objectives) tailored for national policies on water, infrastructure development planning, biodiversity and protected areas.

2.2. Mapping strategic water source areas

Water supply was mapped using natural mean annual runoff (MAR). This was calculated from mean annual precipitation at $1' \times 1'$ spatial resolution (Schulze, 1997) using rainfall-runoff relationships (Scott et al., 1998; Pitman, 1996). This method allowed calculation of MAR at a much finer spatial resolution than previous data at sub-catchment resolution (Middleton and Bailey, 2009; Midgley et al., 1994), addressing a major stakeholder barrier to use of the previous maps (Table 1). The $1' \times 1'$ MAR data were summarized to sub-catchment resolution, and compared with sub-catchment hydrology based on gauged streamflow data (Middleton and Bailey, 2009). These data are widely used by water engineers in South Africa for planning and decision making at national and catchment level. The overall results showed that the datasets at sub-catchment level were very similar ($r^2 > 0.87$). We were therefore able to align the disaggregated $1' \times 1'$ data with Middleton and Bailey (2009), further facilitating the use of our outputs (Table 1). We did this by calculating, for each sub-catchment, the ratio of the Middleton and Bailey MAR to the summarized $1' \times 1'$ MAR. Each sub-catchment ratio was then applied as an adjustment factor to the associated disaggregated $1' \times 1'$ data, so that the $1' \times 1'$ disaggregated data matched that of the sub-catchment outlet in Middleton and Bailey (2009). The adjusted MAR data were categorized using thresholds that provided the percentage contribution of each category to total MAR of South Africa, Lesotho and Swaziland. For example, grid cells $\geq$420 mm·a^{-1} contribute the top 10% of the region's MAR, and grid cells $\geq$290 mm·a^{-1} account for the top 20% (Table 2). Similarly, we calculated categories for grid cells that account for the top 30%, 50% and 90% of MAR, together with the land surface area of each category (Table 2). Areas appropriate for catchment or local level planning can be identified in a similar way by using MAR relative to the total MAR for the catchment or local area of concern. Areas representing 50% of the MAR for South Africa, Lesotho and Swaziland were highlighted as potential strategic water source areas based on their water supply.

Water use was assessed using long-term (1:50 year) urban water yield. This is the measure of the volume and reliability of an urban supply that is used in national water resource planning in South Africa (Basson et al., 1994). It is the amount of water available from a water supply scheme determined from the stochastically estimated 1:50 year probability of the scheme being unable to supply that volume of water. Information was sourced mainly from the strategies developed by the national department of Water and Sanitation for the bulk water supply systems of South Africa (Appendix A), which supply several major urban centers (Fig. 2). We also included an assessment of water supply to the urban centers of Mthatha, Ladysmith and Newcastle (Fig. 2). Although these are not part of the bulk water supply systems shown in Fig. 2, they are important regional centers in South Africa that are solely dependent on water from strategic water source areas. In some of the water supply systems, several dams may operate as an integrated system for the entire supply area and it is therefore difficult to disaggregate water supply data to each urban center. Urban water yield was therefore summarized to the level of water supply systems rather than urban centers. We were also unable to disaggregate water supply data for the Vaal and Crocodile-West water supply systems (Fig. 2), and they were grouped to avoid double-accounting. The urban water yield of each water supply system

Table 2
Mean annual runoff classes used to distinguish strategic water source areas, which are considered to be those areas producing $\geq$135 mm per year. Relative contributions that each of these classes represents in terms of mean annual runoff and land surface area are also provided.

MAR range (mm·a^{-1})	% Regional MAR	% Regional land surface area
$\geq$420	10	1
$\geq$290	20	2
$\geq$220	30	3
$\geq$135	50	8
$\geq$60	75	19
$\geq$25	90	33

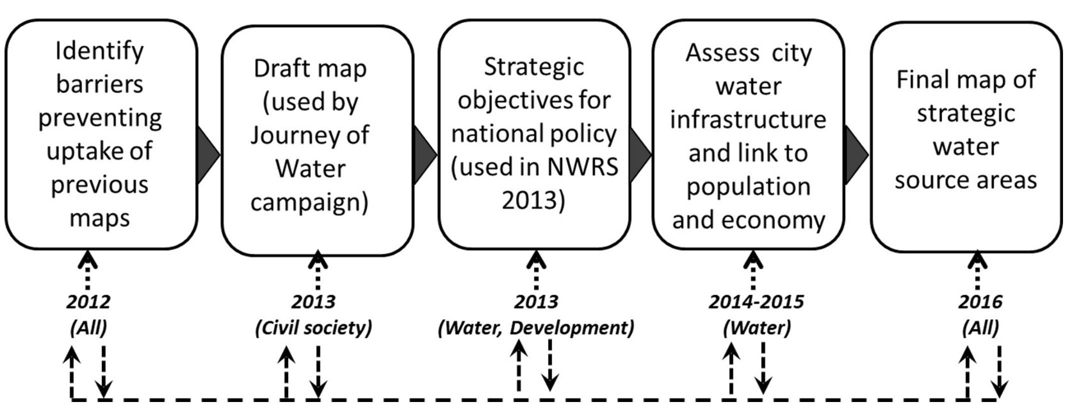

Fig. 1. Project timeline, showing major milestones (in boxes) and iterative stakeholder review process (dashed arrows). The information in brackets indicates the dominant sector of stakeholders with whom we engaged to accomplish these milestones.

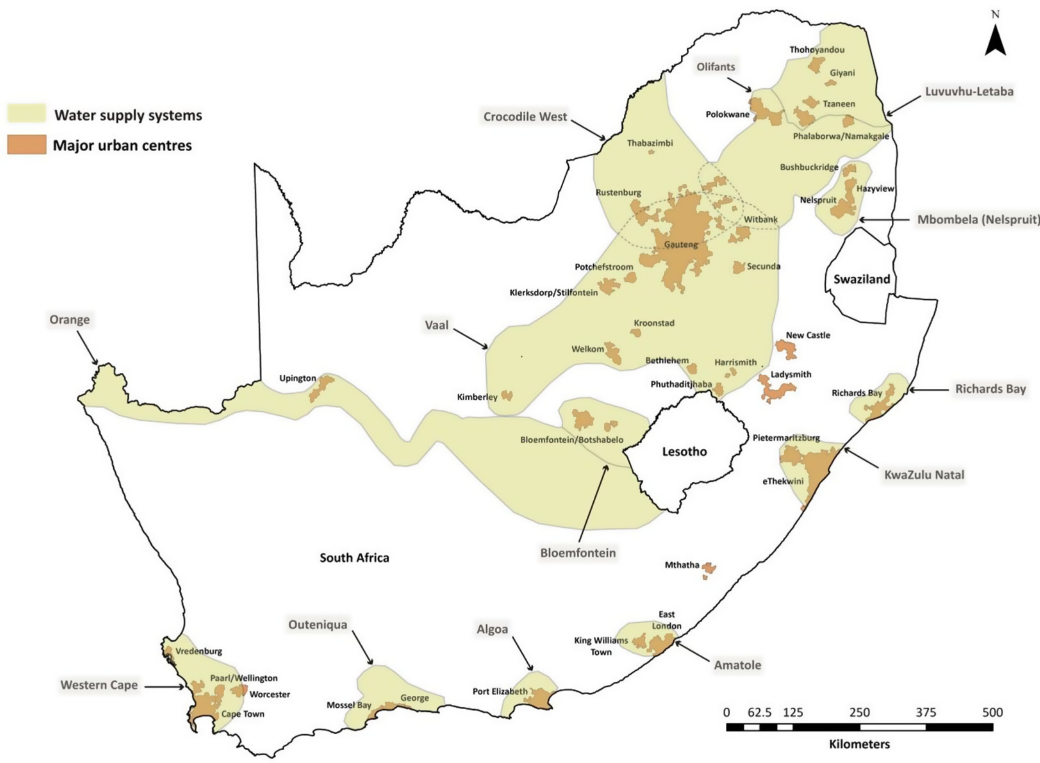

Fig. 2. Large water supply systems and major urban centres of South Africa (after DWA, 2013).

was quantified, and the dams and water transfer schemes linked to strategic water source areas were identified. The yield originating from strategic water source areas was calculated by summing the yield of dams and water transfer schemes linked to these areas. This was expressed as a percentage of the total water yield of each water supply system.

Based on the assessment of water use, we excluded the high MAR areas of the eastern coastal lowlands for consideration as strategic water source areas, because there was low demand for the water supply. We also added two water source areas that had not been identified in the initial mapping based on water supply alone, but which were considered by stakeholders to have high demand from urban centers of national importance (Upper Vaal and Waterberg), based on projected population and industrial growth in these two use areas (van Rooyen and Versfeld, 2010). These additional water source areas were delineated by adjusting the thresholds of the MAR categories for the respective catchments to include areas with MAR $\geq$75 mm. The adjustments were small and had little impact on the sensitivity of the resulting statistics (Table 2). The final map of strategic water source areas was developed by extracting the $1' \times 1'$ pixels and smoothing their boundaries.

2.3. Quantifying population size and economy linked to strategic water source areas

Population size of major urban centers for water supply systems in Fig. 2 were quantified along with their Gross Value Added (GVA) using the 2011 national population census data. These data have been disaggregated to small spatial units of ca. 5×5 km, which were based largely on administrative boundaries, infrastructure and land cover information (van Huyssteen et al., 2009). A list of the human settlements from van Huyssteen et al. (2009) that were used to describe each urban center is provided in the Appendix B. We estimated minimum population size of each water supply system by adding together the population sizes of its associated urban centers (Fig. 2). Similarly, the GVA of each water supply system was calculated by adding the GVA of its associated urban centers. The total population size and GVA of each water supply system was then multiplied by the percentage of urban water yield originating from strategic water source areas to estimate the extent of population and economy supported by strategic water source areas. We recognize that using the overall GVA as the measure, rather than a more detailed sectoral GVA analysis, can be seen as overstating the dependence of the economy on water. However, we would argue that if there was no water for the people who sustain that economy, then any economic activity would be constrained or curtailed. Using the GVA in this fashion provides an indication of the economic activity that is supported by water from strategic water source areas.

2.4. Protection levels of strategic water source areas

Protection levels of each strategic water source area were quantified in GIS according to the percentage of land area under formal protection. We used the protected areas GIS layer that has recently been used in South Africa's national protected area expansion strategy, which is a combination of protected areas used in the Protected Areas and Conservation Areas (PACA) Database (DEA, 2013) and the National Biodiversity Assessment 2011 (Driver et al., 2012). These protected areas can be state- or privately-owned, but all are formally protected by legislation. Protected area types include national parks, provincial and local nature reserves, forest nature reserves, wilderness areas, contract nature reserves, protected environments, mountain catchment areas, private nature reserves and world heritage sites (DEA, 2013). We classified these types according to two broad protection categories using the IUCN guidelines for protected area management categories (Dudley, 2008). Mountain catchment areas, private nature reserves and world heritage sites were classified as 'Category V-VI', and the remaining protected area types as 'Category I-IV'. Similar to the IUCN categories, Category I-IV protected areas generally have stricter controls over land use and biodiversity management than Category V-VI protected areas. The % area under formal protection was calculated for each strategic water source area, noting both the protection category and the ownership (state or private).

3. Results

Twenty-two strategic water source areas were identified in South Africa, Lesotho and Swaziland (Fig. 3). Collectively, these areas contribute 50% of the region's water supply from 8% of the land surface area (Table 2). When strategic water source areas were linked to water supply systems and their associated urban centers, we were able to show that they support at least 51% of South Africa's population and almost 64% of the country's economy (Table 3). These results are underestimates of the true population and economy supported by strategic water source areas, as we only considered major urban centers within water supply systems, and have not taken into account other smaller towns that may share the same water sources. The Maloti Drakensberg, Northern Drakensberg, Southern Drakensberg and Boland are extremely important for urban water security. Together, these four strategic water source areas contribute to most of the population and economic support from strategic water source areas (43% and 56% respectively; Table 4).

The participatory co-production process facilitated uptake of the strategic water source areas into the policies of a range of different sectors. Although the exact extent of use has not yet been exhaustively quantified, compelling evidence of policy uptake exists in development planning (DEA, 2014), national water resource planning (DWA, 2013) and civil society programs (Colvin et al., 2013). Formal policy uptake in the biodiversity sector has yet to be realized, but the maps are being applied by provincial conservation authorities to identify synergies between biodiversity conservation and water, as well as to contest mining applications in individual strategic water source areas. Participating protected area managers are interested in using the map products to make a case for the inclusion of certain areas in South Africa's protected area network; however formal incorporation has yet to occur.

Only 13% of all strategic water source areas are formally protected (Table 4), with an estimated 7% of this protection occurring in Category I-IV protected areas. Three of the 22 strategic water source areas have >50% of their area protected, but most of this protection stems from Category V-VI protected areas. There are no strategic water source areas with >50% protection in Category I-IV protected areas. The Upper Vaal strategic water source area has no formal protection at all, and four others have <1% formally protected (Upper Vaal, Maloti Drakensberg, Upper Usutu, Eastern Cape Drakensberg, Amatole). Protection of strategic water source areas by Category I-IV protected areas is achieved mainly with state-owned land (88% state c.f. 12% private), while Category V-VI protection is shared more equally between state-owned (40%) and private (60%) protected areas.

4. Discussion

4.1. Strategic water source areas and their links to downstream users and economy

The southern African region is characterized by a highly variable climate and rainfall, which is reflected in the uneven distribu-

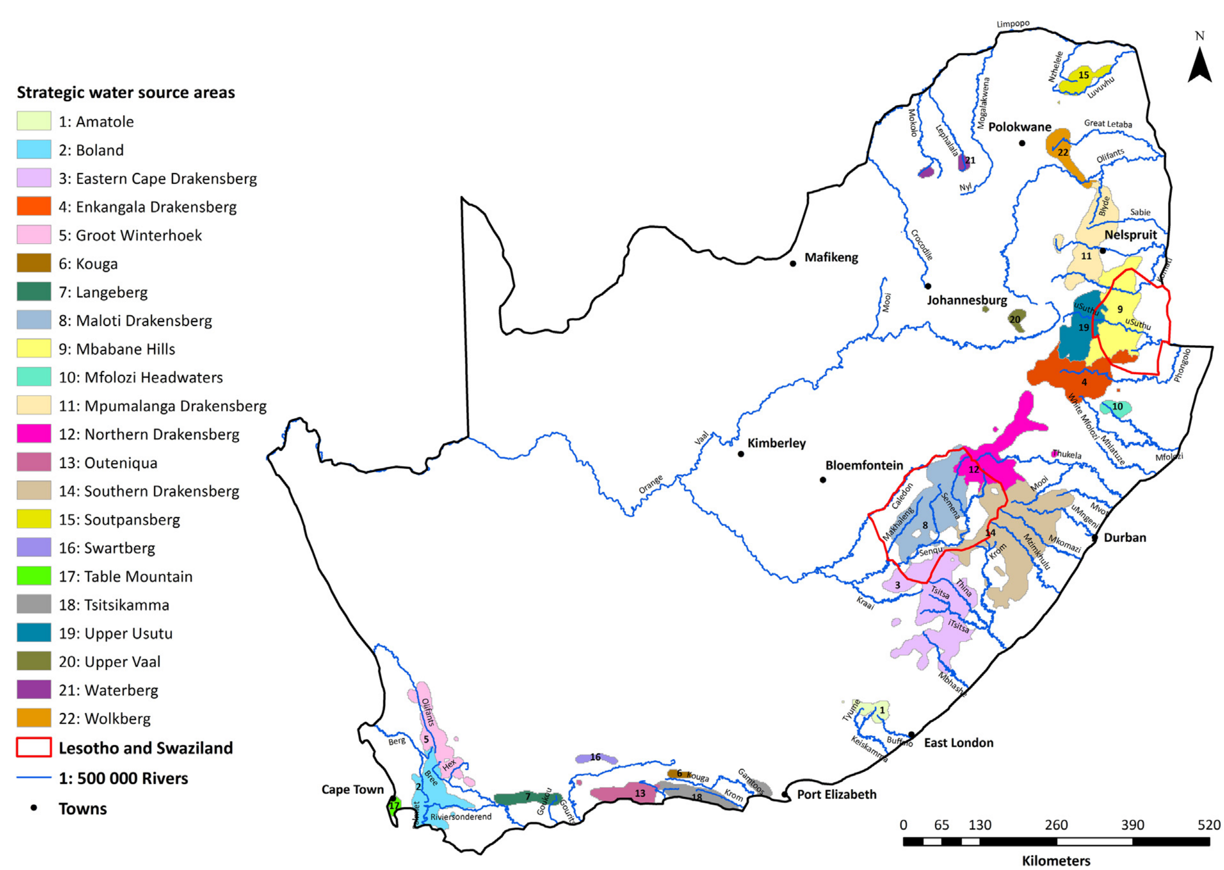

Fig. 3. Strategic water source areas identified at a national scale in South Africa, Lesotho and Swaziland.

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Table 3
Population size and Gross Value Added (GVA) of urban centers within the water supply systems assessed, based on downscaled national population census data for 2011 (van Huyssteen et al., 2009). The % water supply from strategic water source area was used to determine the population and economy supported by each strategic water source area. Urban centers of each water supply system are shown in Fig. 2. Further detail on urban water yield of water schemes within the water supply system is provided in Appendix A. A list of van Huyssteen et al. (2009) human settlements used to define each urban center, along with its associated GVA and population size, is given in Appendix B.

Water supply system[a]	Population size	GVA of urban centres (million USD)[b]	% water supply from strategic water source areas	Population size supported by strategic water source area	GVA supported by strategic water source areas (million USD)[b]	Associated strategic water source areas[c]
Vaal and Crocodile West	15 822 873	47 445	67	10 601 325	31 788	Maloti Drakensberg (57), Northern Drakensberg (18), Upper Usuthu (2), Upper Vaal (0.5), Enkangala Drakensberg (0.4)
Western Cape	4 296 292	13 922	98	4 210 366	13 643	Boland (97), Table Mountain (1)
KwaZulu Natal	4 365 310	12 269	98	4 278 004	12 024	Southern Drakensberg (98)
Algoa	1 149 873	2 836	89	1 023 387	2 524	Tsitsikamma (41), Kouga (23), Maloti Drakensberg (25)
Bloemfontein	729 419	1 790	70	729 419	1 790	Maloti Drakensberg (100)
Amatole	686 524	1 755	92	631 602	1 615	Amatole (92)
Polokwane	516 386	1 012	58	299 504	587	Wolkberg (58)
Richards Bay	437 356	1 001	30	131 207	300	Northern Drakensberg (20), Mfolosi headwaters (10)
Luvuvhu-Letaba	694 187	988	96	666 420	948	Soutpansberg (41), Wolkberg (55)
Mbombela (Nelspruit)	772 924	975	100	772 924	975	Mpumalanga Drakensberg (100)
Outeniqua	263 792	664	97	255 878	644	Outeniqua (97)
Mthatha	211 896	360	100	211 896	360	Eastern Cape Drakensberg (100)
Ladysmith	286 232	369	100	286 232	369	Northern Drakensberg (100)
Newcastle	427 034	491	100	427 034	491	Northern Drakensberg (80), Enkangala Drakensberg (20)
Total strategic water source areas				24 525 198	68 058	
Total for South Africa	51 755 034	114 536				

[a] The Orange water supply system (Fig. 2) is not included; although the Orange River has its source is in a strategic water source area, these water resources are fully utilized before reaching this supply system.
[b] Based on a 6-month average exchange rate of 14.2 South Africa Rand to the US Dollar.
[c] Numbers in brackets represent the percentage of the urban center's total water supply from each strategic water source area.

Table 4
Percentage of South Africa's population size and Gross Value Added (GVA) supported by each strategic water source are together with respective levels of protection.

Strategic Water Source Area	Total area (km2)	% Contribution to SA population size	% Contribution to SA GVA	% Area in Category I-IV		% Area in Category V-VI		Total% area protected
				State	Private	State	Private	
Amatole	1 589	1.2	1.4	0.9	0.0	0.0	0.0	0.9
Boland	6 229	8.1	11.8	7.7	1.8	18.3	16.6	44.4
Eastern Cape Drakensberg	16 313	0.4	0.3	0.8	0.0	0.0	0.0	0.8
Enkangala Drakensberg	8 652	0.3	0.3	0.6	5.3	0.0	0.4	6.4
Groot Winterhoek	5 491	–	–	4.0	1.3	14.8	36.6	56.6
Kouga	476	0.5	0.6	0.1	0.3	76.6	3.5	80.4
Langeberg	2 100	–	–	11.3	0.4	7.0	19.1	37.8
Maloti Drakensberg	12 231	19.4	25.8	0.3	0.0	0.0	0.0	0.3
Mbabane Hills	10 385	–	–	5.1	0.0	0.0	0.2	5.2
Mfolozi Headwaters	1 145	0.1	0.1	4.6	0.0	0.0	0.0	4.6
Mpumalanga Drakensberg	8 687	1.5	0.9	8.2	0.2	0.0	5.6	14.0
Northern Drakensberg	8 923	6.9	8.3	8.0	0.2	0.0	0.2	8.3
Outeniqua	2 947	0.5	0.6	28.8	0.0	0.0	0.0	28.8
Southern Drakensberg	20 462	8.3	10.5	10.3	1.0	0.0	0.0	11.4
Soutpansberg	2 329	0.5	0.4	1.7	0.0	0.0	0.0	1.8
Swartberg	747	–	–	0.0	0.0	52.5	8.1	60.7
Table Mountain	483	0.1	0.1	35.9	0.0	0.0	0.0	35.9
Tsitsikamma	3 390	0.9	1.0	30.1	0.1	0.0	0.0	30.3
Upper Usutu	6 017	0.6	0.8	0.0	0.0	0.0	0.5	0.5
Upper Vaal	835	0.2	0.2	0.0	0.0	0.0	0.0	0.0
Waterberg	838	–	–	3.9	11.2	0.0	2.6	17.7
Wolkberg	2 747	1.3	1.0	16.3	0.0	0.0	0.1	16.4
Total	123 018	50.7	63.9	6.4	0.8	2.3	3.4	12.9

tion of water resources (Middleton and Bailey, 2009). It is therefore not surprising that half of the water in South Africa, Lesotho and Swaziland stems from only 8% of the land surface area. This is similar to the finding by Meybeck et al. (2001) on the relative land area of water towers. The resulting statistics were very compelling – that half of South Africa's population and well over half its economy is supported by water from strategic water source areas. This engaged the attention of national politicians and decision-makers and greatly strengthened the rationale to protect this small proportion of land.

Mapping the supply and use of provisioning ecosystem services made explicit the connections and benefits of these areas to downstream users and economies. With cities around the world growing rapidly and placing urban water resources under increasing pressure, protecting strategic water source areas offers an ecosystem-based approach to managing water resources beyond the usual built infrastructure (Schoeman et al., 2014). The assessment highlighted the benefits of strategic water source areas to downstream users and economies. It allowed stakeholders to co-produce the concept of strategic water source areas as 'ecological infrastructure' – the nature-based equivalent of built or hard infrastructure from which ecosystem services flow, and on which a great deal of built infrastructure for water services and water security depends. Stakeholders were able to use the concept of ecological infrastructure to engage with high-level politicians and decision makers in their own organizations. Here we highlight three examples from different sectors of planning in South Africa: development planning, water resource planning and civil society. The development planning sector in South Africa focuses strongly on infrastructure development. Implementation of South Africa's national infrastructure development plan is guided by 18 multi-billion US Dollar 'strategic integrated projects', which include large-scale investments in energy, transport, bulk water and mining (PICC, 2012). The strategic water source areas concept and maps were the main driving force behind a submission of a proposal for a 19th strategic integrated project, which focuses on an ecosystem-based management approach to water security (DEA, 2014). In addition, the environmental impact of different development options for the existing 18 'strategic integrated projects' is currently being assessed, and the impact on strategic water source areas and their benefit flows have been considered in several of these early assessments. Knowing the location of strategic water source areas and their beneficiaries allows the impacts of future development options to be assessed in a more equitable and comprehensive manner, a goal that is strongly aligned to the SDGs and associated national integrated development plans. In the second example from the water sector, the map of strategic water source areas was one of only four maps incorporated into South Africa's National Water Resource Strategy (DWA, 2013). This is the five-year strategy that guides the cross-scale implementation of national water policy, and one to which catchment level strategies align. The final example targeted civil society, resulting in a non-governmental conservation organization launching a dedicated program on stewardship in water source areas, using the map and its statistics as a starting point (Colvin et al., 2013). The program includes a civil society campaign (the Journey of Water) aimed at raising awareness of the links between managing strategic water source areas and the water security of cities. This has become a regular event in a different source area each year, and combines media, popular celebrities, scientists and high-profile decision makers (Colvin et al., 2013). It has also seeded the establishment of a dedicated position in an environmental law firm (CERa, 2016), that is using the strategic water source areas as an advocacy tool for improved coal mining decisions that take into account the impact on water resources (CERb, 2016).

4.2. Protection of strategic water source areas

The low levels of formal protection of strategic water source areas are alarming given their pivotal role in the country's water supply. Protected areas are increasingly under pressure to demonstrate their value to society both in their surrounding landscapes and more generally (Cumming, 2016; Watson et al., 2014). Mapping the benefits that flow via ecosystem services within and beyond protected area boundaries provides one mechanism for doing this (Palomo et al., 2014). However, prioritizing land for conservation based on its potential for providing ecosystem services, especially to beneficiaries outside of protected area boundaries, is a relatively new idea. Lagging management and funding models will have to adapt. For example, South African National Parks (the largest conservation authority in South Africa, responsible for managing its 19 National Parks) generates approximately 85% of its operating revenue through conventional conservation offerings such as tourism and wildlife sales (Roux et al., 2015). An option to generate revenue for ecosystem services from beneficiaries outside these parks would offer welcome funds for maintaining ecological infrastructure such as strategic water source areas, e.g. clearing water consuming, non-native trees (Le Maitre et al., 2016).

In the above sense, strategic water source areas can be viewed as common pool resources, which might be best maintained through co-management arrangements between public and private stakeholders (Carlsson and Berkes, 2005). Through pooling their resources and coordinating their actions, stakeholders are more likely to balance the costs of maintaining the benefits derived from ecosystem services. A level of complexity is added where strategic water source areas are shared between countries, for example South Africa and Lesotho. Transaction costs, risk sharing and conflict resolution are some of the factors that will have to be considered in setting up a coherent network of multinational actors for governing strategic water source areas (Carlsson and Sandström, 2008). The UN convention on the protection and use of transboundary water courses has relevance here (UN, 1992), although countries in the southern African region are not signatories.

Category I–IV protection, with more stringent requirements on human activities, is currently achieved in strategic water source areas using mainly state-owned land. Purchase of additional state land can be an expensive strategy for protecting strategic water source areas, and new protection mechanisms need to be considered. One alternative is through stewardship arrangements, broadly referring to actions that aim to "achieve sustainability in natural resource management, contribute to conservation priorities, and curb environmental degradation that threatens societal well-being" (Barendse et al., 2016). In South Africa, stewardship is strongly associated with biodiversity conservation agreements on private land, but elsewhere stewardship is also associated with good land and catchment management practices, sustainability in agri-environmental systems, management of wilderness areas, and market-linked incentives such as certification schemes for responsible harvesting of certain commodities (Barendse et al., 2016). Stewardship agreements could offer an affordable way of legislating conservation mandates for strategic water sources areas. An obvious link is for protected area managers to partner with the non-governmental organization program on stewardship programs in these areas.

4.3. Replication elsewhere

For regions elsewhere in the world, a stronger emphasis may be needed on future water supply and use. In the southern African region, we focused mainly on the current situation for two reasons. First, the location of high rainfall, high-yielding catchments and therefore the location of the strategic water source areas is not expected to shift dramatically under climate change (Engelbrecht et al., 2013). Downscaled predictions of climate change impacts on rainfall in the southern African region indicate a likely increase in the intensity and frequency of storm events and a reduction of annual rainfall in the west (Engelbrecht et al., 2013). The expected increase in the frequency of storm events further strengthens the call to protect these mountainous areas from land use activities that cause erosion, particularly along the eastern escarpment which has highly erosive soils (Le Roux et al., 2008). Second, 98% of the surface water resources in South Africa are already allocated to meeting human and environmental needs (DWA, 2013). This means that future water supply cannot be sourced from new geographic areas, but rather through alternative strategies such as water demand management, re-use and desalinization.

Viviroli et al. (2007) provide a global overview of regions in the world that are likely to have potential for similar ecosystem service mapping. We suggest that countries, especially those in regions identified by Viviroli et al. (2007), develop maps of strategic water source areas using this ecosystem service perspective. Apart from the methods used here, we offer five broad recommendations stemming from this southern African case study.

First, embed the development of the map and supporting information in a stakeholder engagement process that targets specific end users. Co-produced terminology, definitions, approaches, map design and management guidelines greatly supported direct uptake of these maps by the targeted stakeholders. Second, identify strategic water source areas at a scale that provides an appropriate level of detail for the targeted stakeholders. The mapping exercise is not about comprehensive mapping of all water source areas, but rather about mapping those areas that are considered strategic at the level of planning that is being targeted. The value of the regional maps produced here was that it did not have exhaustive water source areas and could be communicated and assimilated quite easily by national politicians, planners and decision makers. It is theoretically possible to derive a hierarchy of strategic water source areas appropriate for finer levels of planning (e.g. local authority or catchment scale) by classifying MAR in a similar manner relative to this smaller planning region. Third, assess both water supply and use by identifying water infrastructure linked to strategic water source areas. While earlier ecosystem service mapping approaches focused mainly on mapping potential supply, the importance of access and use of these services is now more widely acknowledged (Dearing et al., 2014; Tallis et al., 2008). If we had focused on strategic water source areas with the highest MAR only, we would have missed some lower runoff source areas which are linked to important national development nodes. Fourth, the assessment of benefit flows from strategic water source areas should be extended to a range of water use sectors beyond just urban users (e.g. agriculture), which is a future endeavor of the work reported here. Lastly, conserving upland strategic water source areas, while a very important tool, should not be misinterpreted as a silver bullet for conserving freshwater biodiversity. It is but one tool in a whole catchment approach that should draw on many place-based conservation mechanisms (Abell et al., 2007), including ensuring ecological functioning and representation of biodiversity in the lowland areas. Unlocking the full potential of strategic water resource areas ultimately requires managing these upland areas, as well as addressing severely impacted lowland areas (Pittock et al., 2015).

5. Conclusions

Several global examples exist of single water source areas that are protected for urban water security. There are few, if any, examples of how these areas are mapped and incorporated collectively into development planning. The ecosystem service mapping approach we used here highlighted the importance of these areas for supporting people and the regional economy. The resulting map and statistics allowed us to engage with sectors beyond conservation, such as water and national development planning. The map and its explicit links to downstream users enable a more comprehensive assessment of the consequences and equitability of future development options in strategic water source areas. This presents a potentially powerful tool to 'upscale' the focus on individual water source areas. The use of the strategic water source area map in considering the potential impacts of infrastructure development in South Africa has been promising. However, strategic water source areas have alarmingly low levels of formal protection in the southern African region. Broadening the conservation toolbox to a range of legally-binding protection mechanisms for sustainable development on private land is urgently needed to enable new patterns of collaboration across government, business and civil society.

Acknowledgements

Maps of strategic water source areas were developed iteratively over a period of approximately four years, between 2011–2016. Funding for the work over this time was provided by: Worldwide Fund for Nature (WWF), Global Environment Facility (GEF), United Nations Environmental Program (UNEP) through the Project on Ecosystem Services (ProEcoServ), Swedish Development Agency (Sida) through SwedBio, the Water Research Commission (WRC) and the Council for Scientific and Industrial Research (CSIR).

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecoser.2017.07.013.

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Please cite this article in press as: Nel, J.L., et al. Strategic water source areas for urban water security: Making the connection between protecting ecosystems and benefiting from their services. Ecosystem Services (2017), http://dx.doi.org/10.1016/j.ecoser.2017.07.013