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The ecological and economic benefits of investing in the rehabilitation and management of the Kluitjieskraal Wetland in the upper Breede River Catchment, South Africa

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Despite growing water quality issues in South Africa, there have been few assessments of ecological infrastructure (EI) investment focussed on water quality enhancement. The Kluitjieskraal Wetland in the upper Breede River Catchment was selected for such an assessment, given that it has been the focus of long-term rehabilitation and management interventions (including the control of invasive alien plants and the 'plugging' of drainage canals) and is strategically located immediately downstream of the Wolseley town and its wastewater treatment works. This paper reports on the ecological and economic outcomes of these interventions. The study demonstrates the application of an interdisciplinary assessment approach for investment in EI, which included stakeholder engagement, and an ecological, hydrological and economic assessment. Underpinning the study was a WET-Health and WET-Ecoservices assessment and a detailed WRSM2000-Pitman model configured for the wetland in a rehabilitated present-day scenario and for a degraded scenario without interventions. A key outcome of the interventions was an increase of 11 ha of wetland area (and associated vegetation and sediments) in contact with low to medium flows, thereby significantly increasing the wetland's capacity to assimilate nutrients. Based on the replacement-cost method applied in the study, the water quality enhancement benefits of the interventions were valued at 1 201 301 ZAR/a; considerably higher than the combined contribution of the other ecosystem services valued, namely, sediment retention and livestock grazing. While the functionality of the wetland has been significantly enhanced, the recovery of the vegetation from its historically disturbed state to a more natural state is limited to localized areas where species characteristic of Breede Alluvium Fynbos wetlands (including the Critically Endangered *Leucadendron chamelaea*) persist.

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INTRODUCTION

The concept of ecosystem services, defined as the benefits people obtain from ecosystems (MEA, 2023), is now well established globally and in South Africa (MEA, 2003; MEA, 2005; TEEB, 2010; Cumming et al., 2017; Kotze et al., 2021). Ecological infrastructure (EI) is a concept which builds on ecosystem services by explicitly drawing attention to the tangible asset base from which specific ecosystem services arise (Cumming, 2017). Ecological infrastructure thus refers to naturally functioning ecosystems that deliver services to people, with 'naturally functioning ecosystems' being ecosystems that have at least some of their natural ecological processes intact (SANBI, 2013; 2017). Ecological infrastructure is conceptualized as the nature-based equivalent of built infrastructure that can support, sustain, augment or in some cases substitute for built infrastructure (Cumming et al., 2017).

Wetlands are generally well-recognized for the multiple ecosystem services that they supply, particularly those relating to water quality enhancement (MEA, 2005; TEEB, 2010). Thus, wetland EI could contribute to supporting built infrastructure by mitigating point-source pollution, such as wastewater treatment works (WWTWs), and non-point-source pollution, which typically lacks infrastructure for treatment (Verhoeven et al., 2006).

Much has been written about the concept of investment in South Africa's ecological infrastructure (e.g. Cumming et al., 2017; Mbopha et al., 2021; Rebelo et al., 2021), including assessments of some specific EI investments (Marais and Wannenburgh, 2008; Crookes and Blignaut, 2019). However, the focus of these assessments has been predominantly on clearing of invasive alien plants (IAPs) and improved rangeland management, with few assessments having been conducted focussing on wetland EI for enhancing water quality.

The Kluitjieskraal Wetland in the upper Breede River Catchment was selected as a case study for such an assessment given that: (i) the Kluitjieskraal Wetland is one of few remaining intact portions of wetland in the valley floor of the upper Breede River Catchment; (ii) it has been the focus of long-term ecological rehabilitation and management efforts and interventions; (iii) the wetland is strategically located immediately downstream of a town and its wastewater treatment works; and (iv) the Breede River is the Western Cape's largest river and is well recognized as being strategically and economically important whilst facing combined environmental and economic threats as a result of declining water quality (Cullis et al., 2018).

This paper reports on the findings of an interdisciplinary study investigating the ecological and economic outcomes of these interventions. It further examines key current threats to what has been achieved thus far, to further inform and guide management. The study, which was supported by a stakeholder engagement process, included: (i) an ecological baseline description and ecological assessment; (ii) a hydrological assessment; (iii) an economic assessment; and (iv) the development of a management plan in consultation with stakeholders. This paper focusses particularly on the ecological and economic assessments of the study, but covers the other components in an attempt to provide context to the assessments and to ground them in the practical challenges, including how to sustain positive outcomes of ecosystem rehabilitation and management interventions in the face of multiple threats.

Study site description

The Kluitjieskraal Wetland (−33.432001°; 19.181449°) is located adjacent to the town of Wolseley (Fig. 1), which lies 80 km north-east of Cape Town, in the Western Cape Province of South Africa. The Wolseley area comprises a broad valley floor running in a north–south direction bounded in the west and east by Table Mountain Group (TMG) sandstone mountains. Immediately south of Wolseley is an extensive (2 747 ha) alluvial fan wetland which runs in an east-to-west direction across the valley floor, and which is further associated with the Breede River, now running on its southern margin. The Kluitjieskraal Wetland is 373 ha in extent and represents the last remaining intact area of this alluvial fan, with the rest of its historical extent having largely been converted to irrigated deciduous fruit orchards, with some return flows into the wetland (Fig. 1).

Rehabilitation of the Kluitjieskraal Wetland began in the late 1990s, when the wetland was in a highly transformed state with almost its entire area under pine plantations. In addition to the evapotranspiration effect that the pine trees were having on the wetland, artificial drainage canals designed to speed up water flow through the wetland were altering water distribution and retention in parts of the wetland (Fig. 2). The first step in the rehabilitation process was the complete clear felling of pine trees and cessation of the plantation forestry, as well as initial clearing of other invasive alien plants (IAPs) by the then-managers of the wetland, Mountain to Ocean (MTO) Forestry (Pty) Ltd. Further rehabilitation included: (i) the construction by Working for Wetlands of a flow-control weir and a series of earth 'plugs' in the former drainage canals (Fig. 2), designed to arrest the draining effect of the canals; and (ii) extensive and ongoing invasive alien plant control over a period of approximately 2 decades. These efforts were undertaken and funded by several different organizations, including the Western Cape Department of Agriculture's LandCare program, Breede-Olifants Catchment Management Agency (BOCMA), Wolseley Water Users Association, World Wide Fund for Nature (WWF) and the Western Cape Department of Environmental Affairs and Development Planning (DEA&DP).

Soils in the wetland are predominantly sandy, and vary across the wetland in terms of depth to the underlying cobble or silt-rich plinthic horizon (Fig. A1, Appendix). As is characteristic of an alluvial fan setting, multiple distributary channels are spread across the Kluitjieskraal Wetland. The three largest of these channels all arise in the town of Wolseley (Fig. 2), thus exposing the wetland to multiple sources of pollution, but also ample opportunity for the wetland to enhance the quality of water flowing through it, which will be elaborated on in the results of the assessment.

The wetland falls within Breede Alluvium Fynbos (as described by Mucina and Rutherford, 2006). This vegetation is listed as a threatened ecosystem type and has been subject to a high level of transformation, both overall (>60% lost) (Mucina and Rutherford, 2006) and in the wetland (as will be elaborated upon in the 'Results' section)

The Kluitjieskraal Wetland is state owned and, while no formal arrangements are in place for its use, the wetland is informally utilised for livestock grazing, with the wetland portions closest to the town of Wolseley being most intensively grazed. Other direct uses include occasional birdwatching, with the wetland being monitored as part of the Coordinated Waterbird Count (CWAC) programme.

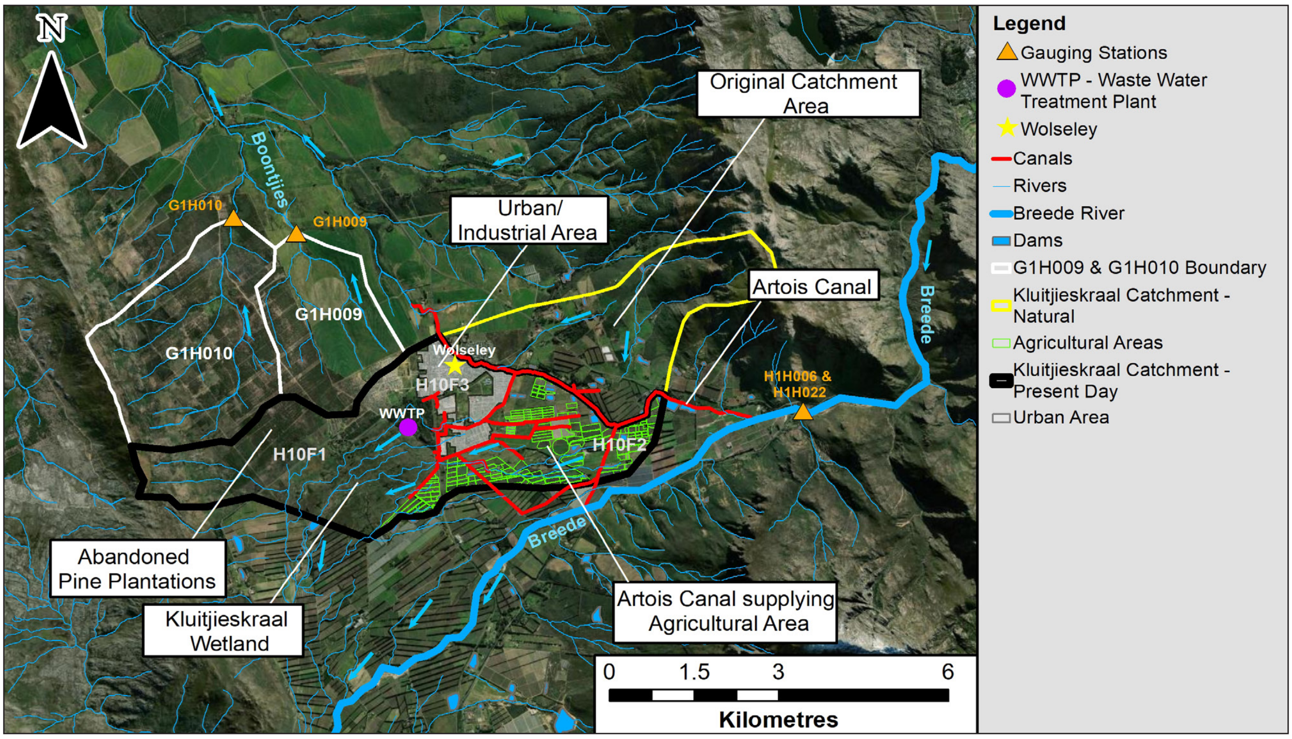

Figure 1. The Kluitjieskraal Wetland in relation to its catchment and the adjacent Boontjiesrivier catchment, with gauging stations

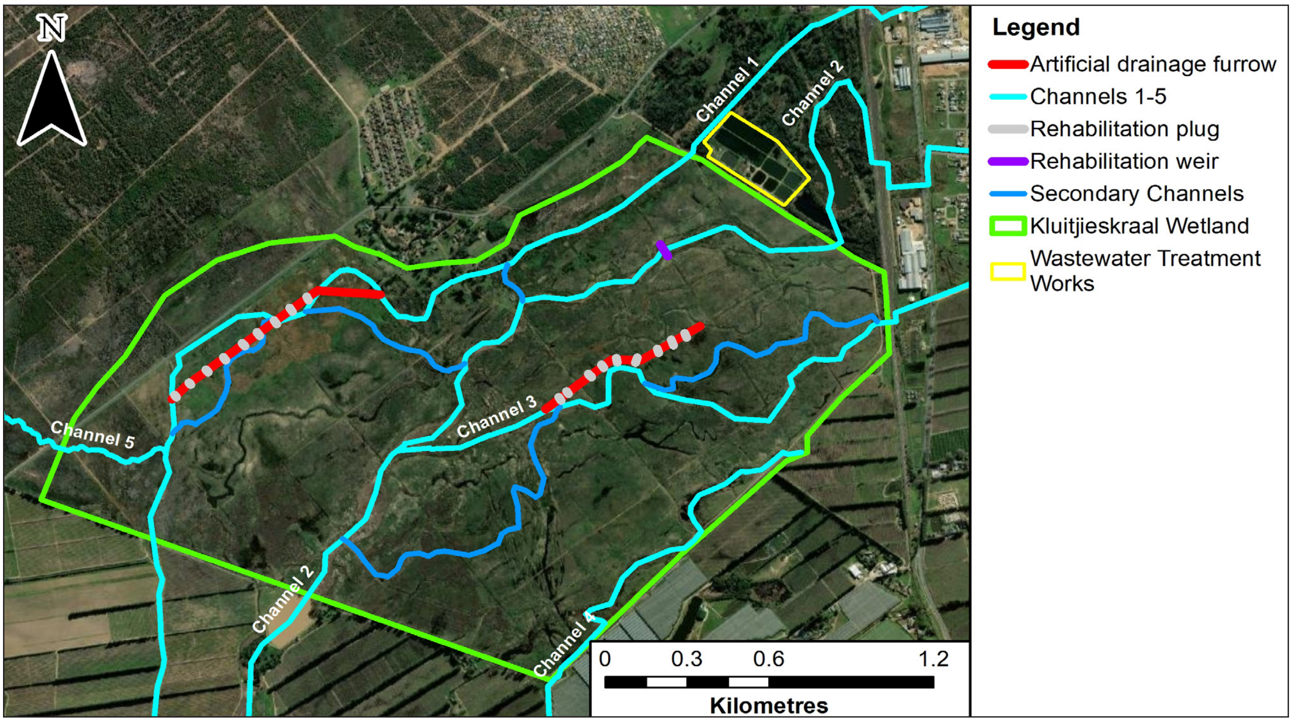

Figure 2. Kluitjieskraal Wetland, showing its primary flow channels and other key features

METHODS

Stakeholder engagement

At the commencement of the study the input of stakeholders on threats and opportunities for the Kluitjieskraal Wetland was solicited through a session in an Upper Breede Collective Extension Group (UBCEG) meeting. UBCEG is a platform where various governmental departments and non-governmental organisations meet to coordinate ecological infrastructure–related planning in and around the upper Breede River catchment. This platform was identified as an existing structure with exposure to many of the potential stakeholders in the area, making it an ideal starting point to begin gathering information pertinent to the study. The researchers undertook an information-gathering session at an UBCEG meeting wherein stakeholders had the opportunity to individually capture (on 'post-it' notes) their perceived threats and opportunities for the wetland.

This was followed by one-on-one discussions with some of the stakeholders from the platform. Additional stakeholders not present at the UBCEG meeting were identified through 'snowball sampling', which allowed for broader stakeholder connections to be identified and established through referrals from the initial stakeholders.

Towards the end of the study in September 2023, a broad stakeholder meeting was held in Wolseley to solicit feedback on key findings and recommendations from the study. This was led by a facilitator, A Gcanga, who has extensive experience in facilitating stakeholder processes in the water sector. The stakeholder meeting included municipal officials, the local councillor, provincial government officials, local civil society, technical experts, local water users and landowners. After presenting preliminary findings of the study and 'reflecting back' to stakeholders a synthesis of the key management issues facing the wetland, stakeholders had an opportunity to voice additional perspectives.

Hydrological assessment

The hydrological assessment involved configuring the WRSM2000-Pitman rainfall-runoff hydrological model (Pitman et al., 2015) for the wetland and all upstream catchment areas (Fig. 1). The WRSM2000/Pitman is a monthly-timestep hydrological model that considers long-term rainfall and measured streamflow data to determine the streamflow characteristics at different points of interest over a long simulation period (namely a 101-year monthly-timestep simulation). Long-term time series of monthly rainfall data and annual evaporation (distributed monthly) were the primary input datasets to the WRSM2000-Pitman model. Rainfall data originated from various sources, such as the South African Weather Service (SAWS), Agricultural Research Council (ARC) and the Department of Water and Sanitation (DWS). Rainfall measurement in this area started as far back as the late 1800s. The primary source of the rainfall data and evaporation data for the model developed originated from the *Water Resources of South Africa – 2012 Study* (WRC, 2015), also known as the *WR2012 Study*. The WR2012 rainfall data spans from the 1920 to 2009 hydrological years (October to September), and additional rainfall data from SAWS were used to extend the rainfall data, and therefore the simulation period of the model, to September 2021.

The WRSM2000-Pitman model also accounts for the changes in land- and water-use activities and their influence on wetland water availability over time. Upstream land- and water-uses for the Kluitjieskraal Wetland include extensive irrigated agriculture, farm dams, irrigation canals, urban-industrial developments and WWTW return flows.

The WRSM2000-Pitman model was configured using the 'Comprehensive Wetland' sub-module, which simulates not only the main channel but also lateral inflows to the wetland, while accounting for evapotranspiration of wetland vegetation on a month-to-month basis given the storage state of the wetland. Spatially measured data (such as would describe the main channel and lateral inflow catchment sizes), supplemented by data obtained from the wetland state description, were further used to configure the Comprehensive Wetland sub-module. Wetland description data used included the following: (i) wetland soil properties to estimate groundwater connectivity; (ii) plant species found in the wetland and their estimated annual water requirements; and (iii) expected changes in functional wetland area sizes due to rehabilitation.

Different configurations of the WRSM2000-Pitman model were developed to simulate the long-term annual average water balance of all wetland components. The scenarios developed considered different wetland rehabilitation states (in terms of IAP removal) and present-day (2020) versus future (2040) upstream land- and water-use development conditions. The simulations assume that the selected wetland's upstream development conditions (2020 or 2040) are already in place in 1920 and remain the same over the 101-year simulation period. The wetland is then exposed to the observed 101-year climatic conditions, generating altered inflow to the wetland given the selected (2020 or 2040) constant upstream development conditions. In other words, the changing quantitative water flows through the wetland are simulated over a long period to get the long-term statistical fluxes of water flowing through the wetland.

In summary the following steps were taken in modelling the flow scenarios:

Estimation of the local runoff conditions

Since there was no flow gauging upstream or downstream from the wetlands, a separate configuration of the WRSM2000-Pitman model was developed for the adjacent Boontjies River Catchment, which has 2 flow-gauging stations (Fig. 1). The changing upstream development of the two catchments (the forestry development) was also built into this model. The Boontjies River Catchment model was then calibrated against the observed streamflow (1983 to 2009) at the flow-gauging stations by adjusting the model's runoff generation parameters until the simulated streamflow time series for the gauges matched the gauged streamflow time series on a monthly and annual basis. The calibrated runoff-generation parameters for the Boontjies River model were then used as proxy for the local hydrology in the two wetland catchments. Using the Boontjies River's runoff-generating parameters for the Kluitjieskraal Wetland model means that the historical unit's natural inflow is assumed to be the same between the two areas for the 101-year period.

Develop scenario-based WRSM-Pitman model configurations

Different time slices (2020 and 2040) of wetland rehabilitation and upstream land-and water-use were developed for the Kluitjieskraal and Romansriver Wetlands to simulate long-term volume time series for all components of the wetland water balances.

Determine long-term nutrient removal fluxes

Long-term time series of wetland evapotranspiration were determined for economic analysis, which quantifies the access of wetland vegetation to nutrients over the long term.

Ecological baseline description and assessment

The ecological assessment was preceded by gathering existing relevant data, in particular the occurrence of any Red-Listed species and information relating to the ecological importance of the site for biodiversity conservation. Next, the boundary of the wetland and the main hydro-geomorphic units making up the wetland were mapped using an initial desktop assessment of current and historical imagery (1948). The mapping was refined following field assessment. In addition, a desktop identification of disturbance units within the wetland was undertaken as per recommendations of Macfarlane et al. (2020), which was also refined based on field observations. The field assessment was undertaken primarily over 3 days, from 27 February to 1 March 2023, which is in the dry season, but also included a wet-season visit on 11 June 2023 and visits in September 2023 to focus on identifying any IUCN Red-Listed plant species present (September being the peak flowering season in this vegetation zone).

The baseline field description included identification of hydrological zones, soils (organic or mineral), vegetation structure and dominant plant species, anthropogenic modifications – for example, artificial drainage channels and anthropogenic erosion sites – as specified in WET-Health (Macfarlane et al 2020). The field assessment was further informed by the requirements of WET-EcoServices (Kotze et al., 2021), noting evidence of the use of the wetland for livestock grazing. The field assessment included 18 sample points at what were identified as representative locations in the wetland's main disturbance units (Table A1, Appendix). At each of these sample points the following were recorded: dominant plant species; vegetation integrity score (on a scale of 0 [critically impacted] to 10 [pristine] as per the specifications of the vegetation component of WET-Health); soil morphology description based on soil colour (with reference to a Munsell colour chart) and texture (based on a qualitative field determination); water depth (either above or below the soil surface); and hydroperiod (temporary, seasonal or permanent), based on soil morphological indicators such as soil matrix chroma and the presence of mottles. In assessing the specific ecological contribution of the rehabilitation and management interventions, an approach was used based on the retrospective review applied by Kotze et al. (2019), which draws on multiple sources of relevant information. In the absence of a detailed pre-rehabilitation assessment, references were made to reports describing the site prior to and during rehabilitation, notably from Working for Wetlands (undated) and Land Resources International (LRI) (2005). Observations were also made of relevant trends, particularly in terms of the vigour with which IAP re-invasion occurred and of a broadly comparable site lacking similar rehabilitation and management interventions. While this comparable site did not constitute a negative control in the strict sense, some qualified inferences could nonetheless be drawn.

Economic assessment

The essence of the wetland valuation process is captured in the framework depicted in Fig. 3, which was applied by Marais et al. (2021).

In order to establish the necessary perspective for the valuation of a wetland, a brief introduction of the catchment feeding into the wetland is provided, highlighting the relation to the wetland and the surrounding geomorphic structures. This is followed by a detailed description of wetland function and performance in terms of the current status and expected future degradation or rehabilitation scenarios. Using the wetland description and catchment data, the hydrological functioning of the wetland is described in terms of the long-term internal water balances of the wetland as simulated by a calibrated rainfall-runoff model based on a WRSM2000-Pitman model (as set out in the assessment of the Vyeboom Wetland in Marais et al., 2021). The economic valuation for different options can then be determined from wetland scenario descriptions, water balances and basic assumptions on nutrient uptake rates.

The state of the wetland description sets out key attributes including the current hydro-geomorphic features, plant species, anthropogenic impacts, ecosystem services and demands of the wetland. This enables the formulation of potential outcomes relating to proposed rehabilitation options.

The economic valuation was informed by: (i) the scenario-based descriptions of the key function and performance differences of wetlands for each scenario, (ii) a rainfall-runoff hydrological model that simulates the long-term internal water balances to describe the interaction between water and the wetland vegetation, and

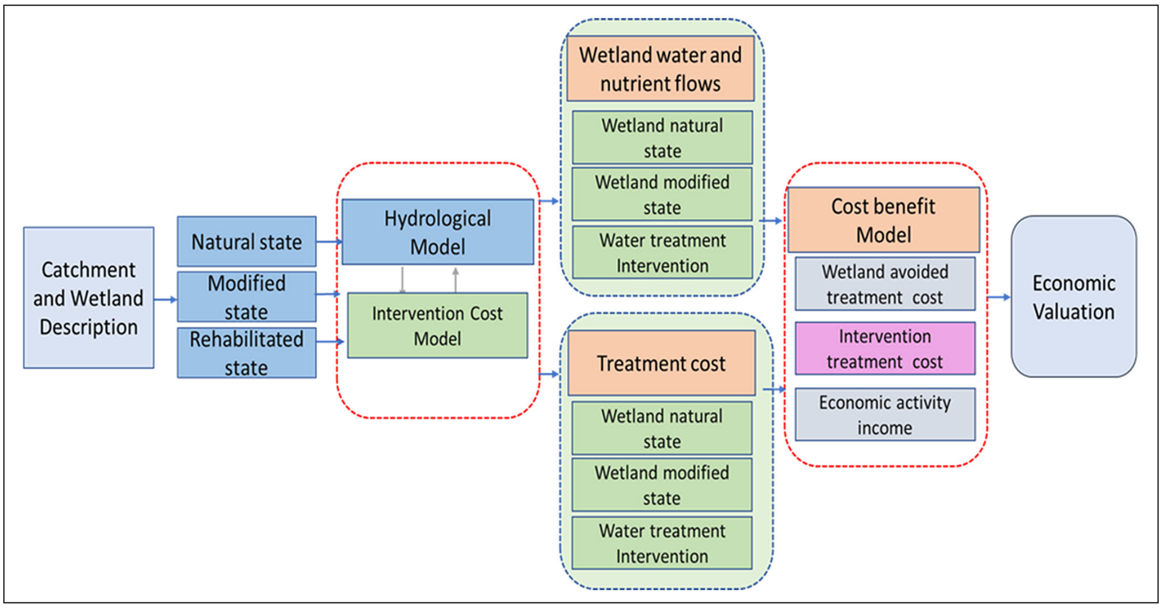

Figure 3. Wetland valuation study framework (from Marais et al., 2021)

Table 1. Key threats to the ecological infrastructure of the Kluitjieskraal Wetland

Key threat	Threat description
Landholder responsibility for management of the wetland and control of use	The principal party responsible for land management is largely absent and makes little contribution to key management needs such as controlling grazing and invasive alien plants, which are currently controlled by WWUA, BOCMA and other key stakeholders listed in the 'Introduction'.
Land invasion	Implications are greatest for the southern portions of the wetland, which are the most intact parts of the wetland and which are immediately adjacent to the land recently invaded for informal settlement in the local catchment of the wetland's Channel 5.
Pollution entering the wetland	Including: (1) discharge from the WWTW; (2) leaks/surcharging from the sewage pipeline feeding the WWTW; (3) inflows from informal settlements without proper sanitation; (4) urban stormwater runoff; and (5) irrigation return-flows from fertilized agricultural lands. Sources (1) to (3) could potentially lead to the wetland's assimilative capacity being overwhelmed.
Uncontrolled grazing	This applies particularly in the upper (northern) portions, which are closest to where livestock are kept each night.
Fire interval	Linked with the issue of uncontrolled grazing. The consequences for biodiversity are greatest where intact natural vegetation remains in the wetland, and for which the current fire interval is too frequent for reseeding species such as *Leucadendron chamelaea*.
Control of invasive alien plants (IAPs)	While currently the overall extent of IAPs in the wetlands is low as a result of sustained control efforts, a long-term IAP maintenance plan is required. In addition, specific actions are required to eliminate the emerging IAPs, notably *Melaleuca* species, in the wetland and prevent their spreading eastward through the wetland.

(iii) a simple water quality model which is based on the difference in nitrogen and phosphorus assimilation capacity of intact and degraded wetlands, and which was applied and described in the assessment of the Vyeboom Wetland (Marais et al., 2021).

To derive the economic value of the wetland, an indirect-use-value method is used, with reference to the 'minimisation of replacement costs' approach (Grossman, 2012). The nutrient abatement model is the key driver for the evaluation, although the ability of wetlands to retain sediment, and provide grazing for cattle, was also incorporated into the assessment.

The monetary value difference between the current state view and that expected if degradation would continue provides useful justification for budgets associated with rehabilitation interventions.

RESULTS

Key outcomes of the stakeholder engagement process

As described in the Methods, the study and the management plan which it informed were both supported by a stakeholder engagement process. This included an initial group meeting, one-on-one discussions with individual stakeholders, and a final multi-stakeholder workshop.

The main direct contribution of stakeholder engagement to the results is reflected in Table 1, which synthesises key threats to the wetland as identified by participants. In addition, the engagement yielded valuable information on historical changes in the wetland. This included both land-use (notably plantation forestry in the wetland, which was withdrawn) and IAPs in the wetland, together with management and rehabilitation interventions (which were undertaken by many different stakeholders). The engagement yielded information conveyed orally by some of the stakeholders as well as internal reports shared by some stakeholders (e.g. the Working for Wetlands rehabilitation plans for the wetland).

Stakeholder input also helped shape the plausible scenarios used in the economic assessment, by contributing to the identification of relevant threats, opportunities, and management actions. Overall, however, the stakeholder process was not designed as the primary data source for the study; core data were drawn from field assessments and existing sources such as long-term flow records from the Boontjiesriver catchment.

The primary purpose of the stakeholder engagement process was to support the development of a management plan for the wetland, designed to identify a mutually beneficial, resilient and sustainable path in the face of competing land-use/management choices. The baseline assessment and initial engagement served as the basis for developing a preliminary management plan, which was presented at an in-person meeting to stakeholders. This gave participants an opportunity to provide feedback, ensuring that the final plan reflects a diversity of perspectives and seeks to balance competing land-use and management interests.

Due to resource constraints, the extent of stakeholder engagement was limited. Thus, while most key institutional stakeholders were reached, some groups – such as informal livestock users operating without formal representation – were underrepresented. This is acknowledged as a limitation in terms of both the depth and reach of the engagement process.

Hydrological assessment of the wetland

A detailed WRSM2000-Pitman Model was configured for the Kluitjieskraal Wetland for the Rehabilitated Present-Day Scenario (Fig. 4). The values in boxes in Fig. 4 are the long-term (101 years) average annual flow (million m³/a) for the indicated routes.

Four scenarios were simulated for the Kluitjieskraal Wetland. The present-day scenarios simulate the variable hydro-climatic and wetland inflow conditions for 1920 to 2020, if the upstream land- and water-use conditions were at the 2020 development level from the start of the 101-year simulation period. The 2040 scenarios simulate the same hydro-climatic and wetland conditions as the present-day scenarios but with 2040 development conditions. Rehabilitated versus degraded scenarios mainly refer to conditions where the IAPs are either removed or left to grow back, respectively. The upstream land- and water-use conditions for the different wetland scenarios are provided in Table 2.

The long-term wetland water balance for the different scenarios (Table 3) shows that, although the wetland inflow changes with the different scenarios, the long-term average annual rainfall and evaporation from the surface of the wetland area does not change greatly. However, over the long term the monthly evaporation fluctuates with the storage state of the wetland and could be close to zero in times of drought when the wetland store is empty. Most of the inflow to the wetland occurs in the winter months during higher rainfall and lower evaporation periods, while wetland vegetation takes a few summer months to dewater the wetland through evapotranspiration and outflows at depth. Figure 4 shows that inflows from the WWTW constitute 21% of the 1.79 Mm³/a of total inflows to the wetland, and during the dry season these flows contribute to sustaining some portions of the wetland in a much wetter state than would naturally be the case.

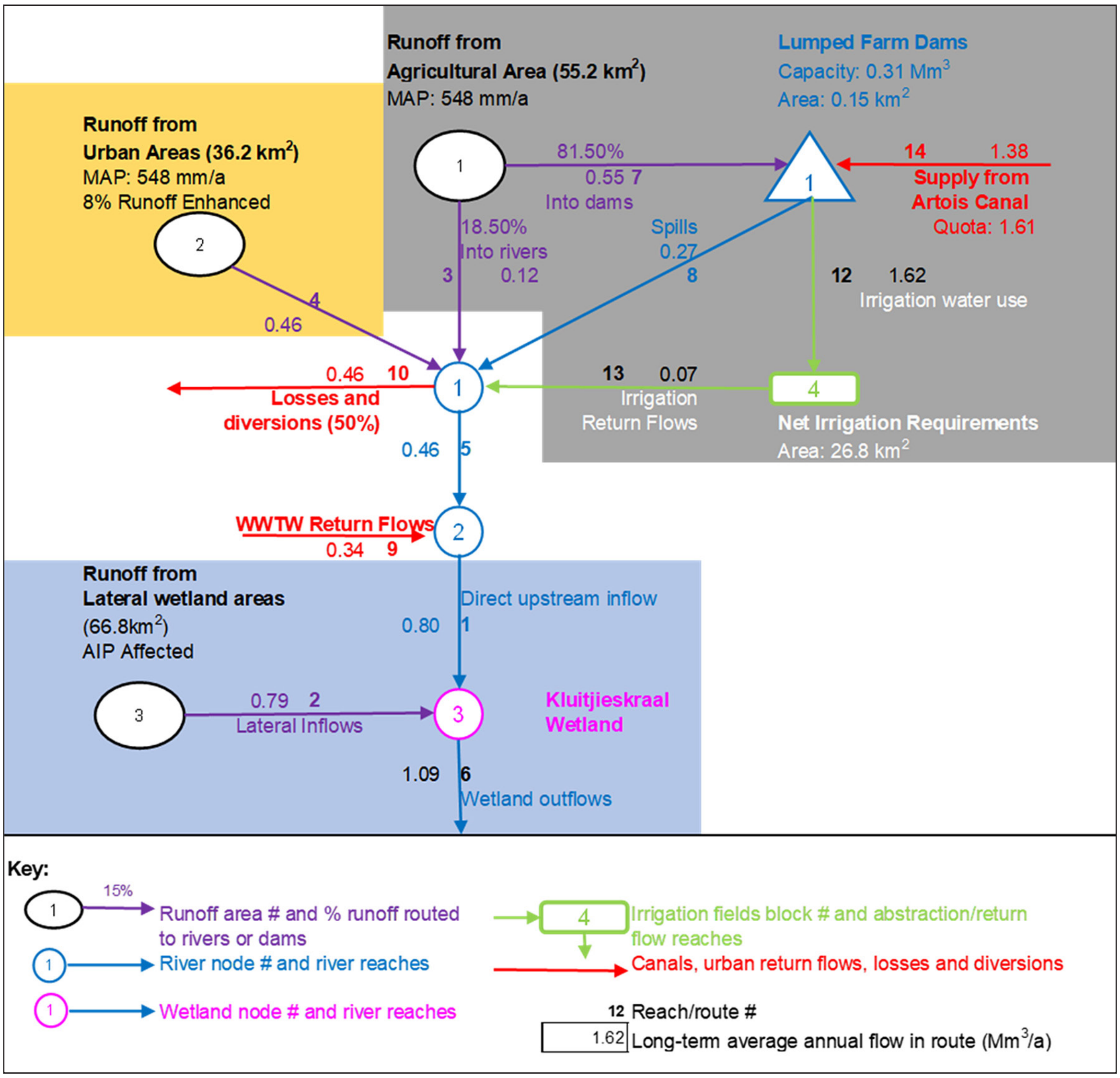

Figure 4. Kluitjieskraal Wetland network diagram for the Rehabilitated Present-Day Scenario

Table 2. Parameters for the comprehensive hydrological wetland module for the Kluitjieskraal Wetland

Parameter	Scenario			
	Rehabilitated Present-Day	**Degraded Present-Day**	**Rehabilitated 2040**	**Degraded 2040**
Wetland area (km^2)	1.27			
Wetland capacity ($10^6 m^3$)	1.27			
River bankfull capacity ($10^6 m^3$ per month)	0.04	0.05	0.04	0.05
Contribution to wetland after bankfull	0.80			
Spill back to river after wetland full	1.00			
MAP (mm/a)	548			
MAE (mm/a)	1 022	1 208	1 022	1 208

Table 3. Long-term water balance components for the Kluitjieskraal Wetland

Element	Sub-element	Kluitjieskraal Wetland				Romansrivier Wetland
		Scenario				
		Rehabilitated Present-Day	**Degraded Present-Day**	**Rehabilitated 2040**	**Degraded 2040**	**Rehabilitated Present-Day**
		Long-term annual average flow (x $10^6 m^3$/a)				
Inflow:	Direct inflow	0.80	0.80	0.92	0.92	0.16
	Lateral Inflows to wetland store	0.79	0.78	0.79	0.78	0.00
	Total inflow	1.59	1.58	1.71	1.70	0.16
Minus abstraction		0.00	0.00	0.00	0.00	
Minus evaporation from wetland		1.11	1.19	1.11	1.19	0.16
Plus rainfall on wetland		0.61	0.56	0.61	0.56	0.10
Total outflow		1.09	0.95	1.21	1.07	0.09
Gains(+)/losses(–) & % of inflow:		−0.5 (−31%)	−0.63 (−40%)	−0.5 (−29%)	−0.63 (−37%)	−0.07 (−44%)

Table 4. Landcover in the Kluitjieskraal Wetland under the Rehabilitated Present-Day Scenario and under a projected scenario lacking the rehabilitation and management interventions described in the main text

Landcover types	Rehabilitated Present-Day Scenario		Degraded Present-Day Scenario	
Deep flooding from impoundments	1.2 ha	0.3%	1.2 ha	0.3%
Natural / minimally impacted	77.0 ha	20.6%	11.2 ha	3.0%
Semi-natural (undrained)	229.0 ha	61.4%	16.0 ha	4.3%
Semi-natural (drained)	10.5 ha	2.8%	21.3 ha	5.7%[a]
Dense infestations of invasive alien plants	9.0 ha	2.4%	277.1 ha	74.3%
Eroded areas (and heavily degraded lands)	0.5 ha	0.1%	0.4 ha	0.1%
Infilling (from the road and hardened management tracks in the wetland)	6.0 ha	1.6%	6.0 ha	1.6%
Artificially wetter areas (from sustained releases from Wolseley town into the wetland during the dry season)	39.9 ha	10.7%	39.9 ha	10.7%
Total area	**373 ha**	**100%**	**373 ha**	**100%**

[a]Under the projected scenario without rehabilitation, the semi-natural (drained) is also densely infested with IAPs

Key ecological outcomes in the wetland because of rehabilitation/management interventions

Although historically much more extensive, dense infestations of IAPs are currently limited in the Kluitjieskraal Wetland, as are other landcovers generally associated with loss/high transformation of habitat (Table 4). Instead, most of the wetland currently comprises semi-natural vegetation (Table 4). Even in the Rehabilitated Present-Day Scenario, minimally impacted vegetation is very limited in extent, as reflected in the fact that 61% of the 18 sampling points in the wetland scored <6/10 in terms of vegetation integrity (Table A1, Appendix). This semi-natural vegetation is strongly dominated in the wettest portions of the wetland by the wetland pioneer species *Typha capensis* and in the higher lying less-wet portions by pioneer terrestrial species such as *Seriphium plumosum* and *Cynodon dactylon* (Table A1).

The most prominent outcome of the rehabilitation/management interventions in the wetland has been the drastically reduced extent of IAPs relative to projections without rehabilitation/management interventions (Table 4). This assumption is based on the existing considerable extent of IAPs in the broadly comparable area immediately west of the wetland and on the aggressiveness with which regrowth was observed to occur within Kluitjieskraal Wetland when there was an extended lapse in IAP maintenance from about 2010 to 2019. This further underscores the need for continued sustained efforts in IAP management.

The second key outcome relates to influence of the drainage canals in the Kluitjieskraal Wetland. Through a series of earth 'plugs' constructed within these drainage canals (see Fig. 2), much of their negative draining effect has been neutralized, increasing wetland water levels, such that the area of wetland which is in contact with low to medium flows is estimated to have increased from 61 ha to 72 ha. Where flows through this additional 11 ha portion (which constitutes 3% of the wetland area) were previously confined to a single drainage canal, they are now spread more diffusely through emergent vegetation, mainly *Typha capensis*. Thus, a key ecological outcome of the rehabilitation is an additional 11 ha of 'high contact' flow with emergent vegetation and supporting wetland soils, thereby significantly increasing the capacity of the wetland to assimilate nutrients, pathogens and toxicants.

A substantial reduction in the cover of IAPs has also removed the flow reduction effect that these plants were having and has allowed natural/semi-natural vegetation to re-establish dominance in the wetland. In localized areas, mainly in the southern portions of the wetland (fed by inflowing Channel 5, shown in Fig. 2), native indigenous species characteristic of Breede Alluvium Fynbos wetland (including *Leucadendron corymbosum* [VU] and *Leucadendron chamelaea* [CR]) now dominate, and such vegetation can be described as being in a near-natural state. The remaining areas of the wetland are strongly dominated by disturbance-favoured indigenous species, notably *Typha capensis*, which is likely to have occurred naturally in the wetland to only a limited extent. The dominance of disturbance-favoured species is likely to have been influenced by the historical disturbance created by pine plantations, altered seasonality of flows, increased nutrient loads, and a high grazing pressure from livestock, with the first of these factors occurring throughout the wetland, and the remaining three factors being most intense in the wetland's northern portions.

Thus, while the functionality of the wetland has been significantly enhanced overall because of the rehabilitation and management interventions, the recovery of the vegetation to a higher or climax natural state has been limited to localized areas (notably that fed by Channel 5: see Fig. 2). Six Red-Listed plant species were recorded within these natural areas, including the Vulnerable *Aponogeton angustifolius*, Critically Endangered *Leucadendron chamelaea*, Vulnerable *Leucadendron corymbosum*, Endangered *Monopsis variifolia* and *Monsonia speciosa* and Vulnerable *Skiatophytum tripolium*. No Red-Listed plant species were recorded in the semi-natural wetland areas. However, they support a diversity of permanently saturated/flooded habitats and associated obligate wetland plant species (e.g. *Cyperus fastigiatus*), and provide valuable habitat for avifauna, including the Regionally Endangered African Marsh Harrier (*Circus ranivorus*) and the Endangered Black Harrier (*Circus maurus*).

Economic valuation

The economic valuation, which was informed by an initial rapid assessment of the supply and demand of 16 ecosystem services (Fig A1, Appendix 1), is structured on a particular scenario which incorporates the most prominent outcomes of the rehabilitation/management interventions discussed above. As elaborated in the preceding section, in the absence of IAP control measures, the wetland is very likely to have reverted to a state dominated by IAPs. Therefore, the basis for a 'do nothing' scenario would be to assume that 80% of the wetland becomes dominated by IAPs.

This observation was simulated by the hydrological model as it considers IAPs as a separate, discrete landcover amongst various vegetation options, allowing IAP scenarios to be modelled. Given the greater evapotranspiration loss of water under IAP cover, there would be a shrinkage in extent of the core wetland area that provides high contact with throughflows. Based on this consideration it is estimated that the current 72 ha of wetland in high contact with throughflows could be diminished to between 55 and 65 ha. This situation is expected to take 15 to 20 years to manifest if the IAP invasion is left uninhibited.

Given that the predominant IAP, *A. saligna,* is a nitrogen-fixing plant, it is expected to enrich the wetland soil and sediment with nitrogen, and it is assumed that where it replaces reeds/bulrushes, nitrogen would be assimilated less effectively from the wetland water flow. Nevertheless, the rhizosphere environment associated with IAPs is assumed to remain suitable for denitrifying bacteria. Considering these factors, it is assumed, based on the findings of Chamier et al. (2012) and Peterson et al. (2020), that the effectiveness in assimilating nitrogen in the area where IAPs are present will be reduced to about 85% of the level achievable relative to wetland under more natural bulrush/reed vegetation. For phosphorus, we have no evidence to argue for any significant change in effectiveness, so the effectiveness of phosphorus assimilation is assumed to remain at levels similar to the area under bulrush/reed vegetation.

The IAP infestation, if not actively managed, is expected to start slowly at first but to expand at an increasing rate until it reaches about 80% coverage of the wetland by 2043. The total annual loss in wetland benefits (which can be viewed as the cost of the management opportunity to prevent such benefit losses) is then expected to be about 1 233 000 ZAR/a. The contribution of water quality enhancement to this total benefit loss is by far the most dominant contribution at 98%. It is important to note that this estimated loss is an annually repetitive amount which would justify an annual expense of similar quantum to either reduce the infestation or keep it at bay. It was estimated that an investment in the clearing of IAPs would be considered acceptable if the capitalised cost (discounted to perpetuity) of such an initiative would be less than 6.1 million ZAR.

By allowing for future demographic growth of the Wolseley townships, it is possible to generate a comparative economic valuation for the year 2040 at higher water demand levels. Assuming the same IAP infestation prevention scenario was projected to the year 2040 demands, it would result in a potential total annual wetland benefit loss of 1 340 000 ZAR/a, with a capitalised value of R6.6 million.

Key threats to the wetland

Based on the preceding results and on the issues raised by stakeholders, 6 key threats to the wetland were identified (Table 1). If not adequately addressed they threaten to undermine wetland function, with the associated economic costs, including undermining the environmental and economic benefits of past rehabilitation/management efforts.

DISCUSSION

Sustained clearing of IAPs in the wetland has resulted in the greatest overall effect on the structure and functioning of the Kluitjieskraal Wetland, of all of the management/rehabilitation interventions. Without the control of IAPs, much of the wetland, including the remaining fragments of natural vegetation, would likely have become highly infested with IAPs. This would have severely compromised the natural vegetation fragments and led to the demise of many of its indigenous wetland-dependent species, including 6 Red-Listed species. Thus, the intrinsic value of the wetland for biodiversity conservation would have been substantially diminished.

A further key consequence of a high IAP infestation of the Kluitjieskraal Wetland would be the increased evapotranspirative loss of water from the wetland, thereby diminishing the wetland's outflow volume. Based on the hydrological assessment, this was estimated to be approximately 130 million L/a less outflow. Placing an economic value on this water loss is problematic using the replacement-cost method applied in the study. However, it is informative to view this water volume from a production perspective, where the estimated difference in evapotranspirative water loss between the two scenarios was calculated to be adequate to irrigate approximately 22 ha of fruit orchards annually (based on current general irrigation levels for orchards).

Based on a meta-analysis of 21 different sites in the south-western part of the country (including the Kluitjieskraal and Romansrivier Wetlands), Crookes and Blignaut (2019) showed that the average annual cost to clear multiple species of IAPs was 289 USD/ha per annum (2017 values), with a variance of ± 550.6 USD/ha per annum. If one (conservatively) ignores the purchasing power devaluation of 289 USD, while assuming a current exchange rate of 18.84 ZAR/USD, the equivalent opportunity cost of non-restoration would amount to 5 445 ZAR/ha per annum. If this value were to be applied to 80% of the total area (298 ha) of Kluitjieskraal projected to become infested in the absence of clearing, it would translate into an opportunity cost of 1 298 000 ZAR/a. Water purification services were not included in the assessment of Crookes and Blignaut (2019), which focussed particularly on water quantity–related benefits of clearing IAPs. This suggests that if the water quantity–related benefits were to be added to valuation of the Kluitjieskraal undertaken in this study, they may potentially be a similar order of magnitude to the water purification/quality–related benefits assessed in this study.

The structure and functioning of the Kluitjieskraal Wetland has also been significantly positively affected by the intervention of adding 'plugs' into the former drainage canals, which has successfully spread flows more diffusely through emergent wetland vegetation and associated sediments. This has increased the area of wetland in contact with low flows by 11 ha. While only making up 3% of the wetland extent, this 11 ha constitutes a 15% increase in the 'high contact' area of the wetland, thereby significantly increasing the capacity of the wetland to assimilate nutrients, pathogens and toxicants. The detention of sediment further promotes the detention of nutrients and toxicants, given that many of these, notably phosphorus, are sediment-bound (Wiener and Grenfell, 2024). In economic terms, by far the greatest contribution of spreading/detention of flows and sediments has been to the enhanced assimilation of nutrients and pathogens by the wetland. Based on a replacement-cost economic assessment applied in this study, it was estimated that without the rehabilitation/management interventions, the annual loss in terms of water purification amounts to approximately 1.2 million ZAR/a. This amount was determined based on what it would cost using a treatment works to replace the nutrient assimilation capacity of 11 ha of highly functional wetland, which is the area of functional wetland that would likely be lost in the absence of rehabilitation/management interventions. The current demand for water purification by the Kluitjieskraal Wetland is high, and likely to grow even if the WWTW is well managed, given the projected human population growth of Wolseley, especially within informal settlements, as captured in the 2040 scenario applied in the study.

As was found for the Vyeboom Wetland (Marais et al. 2021) and the Papenkuils Wetland (Reuther et al. 2021), the economic contribution of the Kluitjieskraal Wetland to water quality enhancement was considerably higher than for the other ecosystem services assessed. For Kluitjieskraal, these other benefits that have been significantly enhanced by the rehabilitation/management interventions (but have contributed much less in economic terms) include sediment trapping and grazing. The economic importance of wetlands, specifically for water quality enhancement, is further emphasized in a study by Turpie et al. (2010) where the average value of the water treatment service provided by Western Cape wetlands was estimated as 14 350 ±12 385 ZAR/ha per annum (2010 values). Turpie et al. (2010) argue that these values are high enough to compete with the alternative land uses that threaten their existence, and that wetlands should be given considerably more attention in land-use planning and regulation. The present study confirms this evaluation and the authors agree with the Turpie et al. (2010) conclusion.

Preventing the advanced infestation of the wetland by IAPs (eucalypts and *A. saligna*) is assumed to have a positive effect in terms of sediment trapping and erosion control. Although these trees accumulate greater aboveground biomass than the natural/semi-natural vegetation, this increases the fire intensity and likelihood of groundfires (Chamier et al., 2012). When dense infestations are killed in a fire, extensive bare ground results before the next generation has established, as observed at the Kluitjieskraal Wetland and highlighted generally by Chamier et al. (2012). In the upper Breede River Valley, livestock grazing is primarily of herbaceous vegetation. In natural and semi-natural areas, herbaceous vegetation generally predominates. However, in dense infestations of eucalypts and *A. saligna*, the indigenous herbaceous vegetation is strongly suppressed.

A notable exception to the generally positive effect of the interventions on ecosystem service delivery is flood attenuation, which appears not to have been improved by the rehabilitation/management interventions. Although the lateral spreading of flows by the plugging of the drainage furrows has contributed positively to flood attenuation, this has likely been largely offset by the lower surface roughness and higher level of wetness of the wetland in its current rehabilitated state relative to a degraded state densely infested with IAPs. A lower surface roughness of the vegetation potentially decreases the capacity to detain and laterally spread flood waters (Adamus et al., 1987) while an increased level of wetness would generally reduce flood storage because of the water already present in a wetland when it receives stormflows (McCartney et al., 1998).

The results of the Kluitjieskraal Wetland assessment demonstrate how different interventions vary in their relative contribution to specific ecological outcomes and corresponding economic value. Thus far, the interventions to prevent the drainage of the wetland by plugging the former drainage canals have substantially enhanced the wetland's capacity to improve water quality but have not contributed to any meaningful improvement in vegetation integrity, as these interventions have primarily favoured the opportunistic pioneer and competitive *Typha capensis*. While this species assists greatly in water quality enhancement, it appears to supress any establishment of the less competitive species characteristic of wetlands of Breede Alluvium Fynbos. As shown by Cowden et al. (2014) for a channelled valley bottom wetland in KwaZulu-Natal, South Africa, and by Galatowitsch and Van der Valk (1996) for native sedge meadow wetlands in North America, rehabilitation interventions may result in a significant improvement in the hydrological condition of the wetland, but competitive invasive species may have a potentially strong constraining effect on vegetation recovery. Furthermore, if wetlands are re-wetted with nutrient-enriched water, then the negative effect on native vegetation may be considerable (Verhoeven et al., 2006), and this is likely to be particularly relevant to fynbos wetland areas with their naturally low nutrient levels.

In contrast, interventions in the Kluitjieskraal wetland to control IAPs have contributed considerably to enhancing the integrity of the remaining natural vegetation areas characteristic of wetlands of Breede Alluvium Fynbos, but have been relatively less important in terms of enhancing the wetland's capacity to enhance water quality through enhanced spreading of flows. Even so, based on the research of Chamier et al. (2012) and Petersen et al. (2020), preventing infestation by IAPs is likely to have had some positive effect in terms of water quality. For the purposes of the water quality model used in the Kluitjieskraal Wetland, a conservative approach is taken, with a moderately diminished effectiveness in nitrogen assimilation assumed. However, the results reported by Chamier et al. (2012) and Petersen et al. (2020) suggest that this negative effect may potentially be greater, but further investigation is required to confirm this.

The discussion above demonstrates this study's use of multiple sources of evidence, including proxies and other relevant studies, to derive a first-level quantitative assessment. While this appears to be adequate to inform management practice, it has revealed some specific gaps where further research would be useful to add detail and increase granularity. The most important potential further research would be to directly compare the assimilation of nutrients by the wetland with natural/semi-natural herbaceous vegetation to that by a wetland which is densely invaded by invasive alien trees. Given the contrasting nitrogen dynamics of invasive legumes compared to native fynbos riparian/wetland vegetation (Crous et al., 2019), a significant difference is anticipated.

CONCLUSION

Fundamental to the overall success of the rehabilitation interventions and the achievement of multiple ecological outcomes in Kluitjieskraal Wetland has been the combination of different types of intervention aimed at different wetland aspects. On the one hand, had the interventions focussed on IAP clearing alone, the enhancement of the wetland's capacity to improve water quality is likely to have been significantly less. On the other hand, had the interventions focussed only on deactivating the drainage canals then the contribution to maintaining the intact area of Breede Alluvium Fynbos would have been significantly less. However, by including both complementary forms of intervention, significant contributions have been made, both in terms of the wetland's contribution to water quality enhancement and to maintenance of biodiversity.

The study demonstrates the application of an interdisciplinary approach for the local-scale assessment of the outcomes of investment in EI, which included the engagement of stakeholders and the management planning process. As described earlier, the same approach and methods were applied in the Vyeboom assessment (Marais et al., 2021). However, whereas the Vyeboom Wetland assessment related to the loss of ecosystem services which would be averted as a result of the interventions planned (but not yet implemented, by Working for Wetlands) at the time of the assessment, the Kluitjieskraal assessment was of interventions already implemented, some over 20 years ago. This much longer history of the Kluitjieskraal site, together with a greater degree of engagement with stakeholders and management planning, has provided a richer and deeper basis on which to draw lessons from the case. Furthermore, the economic valuation model suggests that the replacement cost for lost ecological infrastructure is high enough to motivate for significant formal protection and maintenance of wetland EI in the Breede catchment.

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AUTHOR CONTRIBUTIONS

Dr Donovan Kotze: study conceptualization, data collection and fieldwork, sample taking, data analysis, interpretation of results, writing of the initial draft, revision after review. Mr Bennie Haasbroek: hydrological modelling, interpretation of hydrological modelling results, reporting on hydrology modelling findings and conclusions. Dr Daniel Marais: economic modelling, interpretation of economic modelling results, reporting on economic modelling findings and conclusions. Mr Malin Govender: methodology of the study, data collection and project administration – management, planning and coordination responsibility for the research activity, reporting, review, proofreading and editing. Mr Theo Fischer: methodology of the study, integration of study components, data validation, review of the initial draft. Mr Phil McLean: project steering committee, editing. Mrs Annabel Horn: conceptualisation of the study, project steering committee, key stakeholder forum management, editing.

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APPENDIX

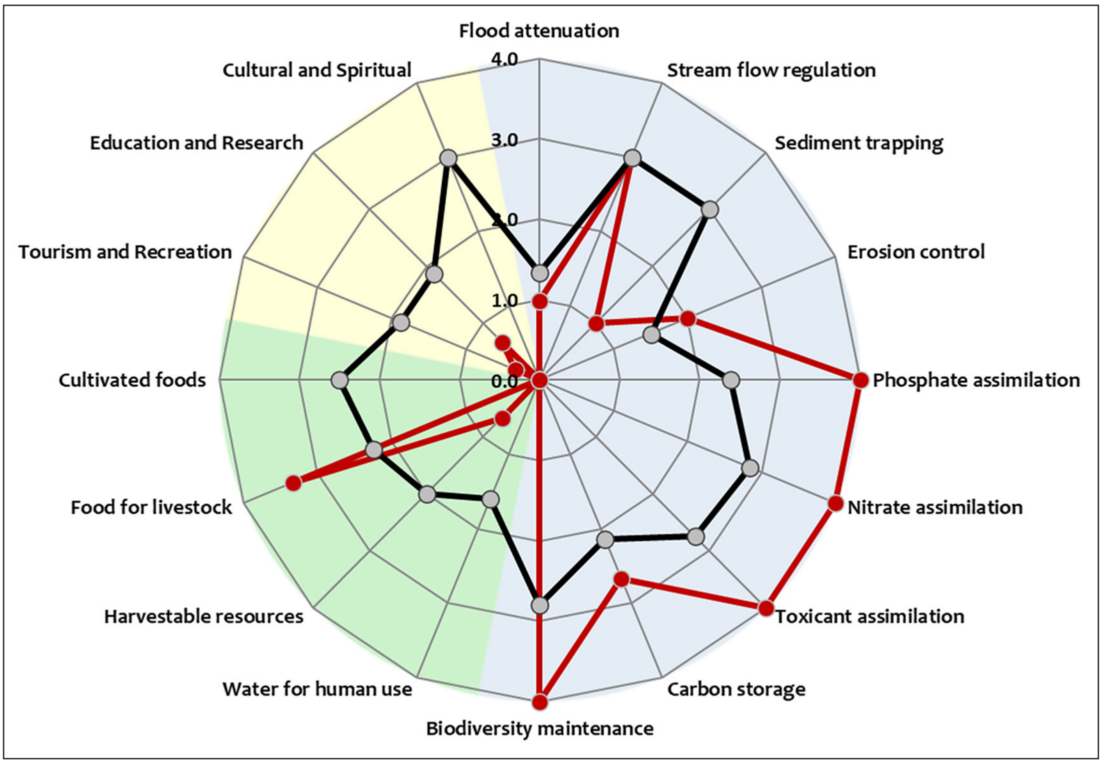

Figure A1. Ecosystem supply (black line) and demand (red line) scores (0 to 4) for the Kluitjieskraal Wetland in its current state

Table A1. Vegetation and soil morphology information recorded on 27/28 February 2023 for 18 sampling points located within the Kluitjieskraal Wetland

Point No.	Latitude and longitude	Dominant plant species	Other plant species	Vegetation integrity score (0–10)[1]	Soil description	Water depth (cm) (+above and –below)	Hydro-period
1	−33.42721; 19.173135	*Seriphium plumosum, Athanasia trifurcata*	*Ficinia indica, Tribolium uniolae, Pennisetum macrourum, Melaleuca parvistaminea, Acacia mearnsii*	2.5	0–20 cm: 10YR5/3 loamy sand; 10–30 cm: 10YR 6/2 with few yellow mottles, sandy loam; 30–50 cm: 10YR5/4 with few orange high contrast mottles; 50–75 cm: 10YR 5/8 hard silty sandy loam; 75–85 cm: 10YR6/5 with few yellow and grey mottles, silty sandy loam; 85–95 cm: 10YR 6/6 hard silty sandy loam; 95–120 cm: 10YR 6/6 hard silty sandy loam with few light grey mottles. Profile moist throughout	Dry	Temporary (transition to non-wetland)
2	−33.427644; 19.173497	*Typha capensis*	*Juncus effusus*	1	0–15 cm: sulphidic black muck; 15–30 cm:2.5Y4/3 fine sandy silty loam; 30–50 cm: 2.5Y6/5 with few low contrast grey mottles	40	Permanent/ Semi-perm
3	−33.428234; 19.172535	*Juncus effusus*	*Eleocharis limosa, Juncus lomatophyllus, Persicaria* sp.	3	0–10 cm: sulphidic black muck; 10–50 cm: 2.5Y5/2.5 silty sandy loam	35	Permanent/ Semi-permanent
4	−33.432173; 19.167371	*Restio capensis Ficinia indica, Tribolium uniolae, Helichrysum* sp.	*Leucadendron corymbosum, Seriphium plumosum, Cliffortia juniperina, Passerina corymbosa, Athanasia trifurcata, Acacia longifolia, Ischyrolepis* sp., *Leucadendron chamelaea*	7.5	0–15 cm: loamy sand 10YR6/4; 15–25 cm: loamy sand 10YR7/6; 25–35 cm: slightly silty sandy loam 10YR6/8; 35–60 cm: slightly silty sandy loam 10YR6/7; 60–70 cm: coarse sandy loam 7.5YR7/6 with few dark brown silty mottles and black nodules up to 8 mm; 70–80 cm: coarse sandy silty loam, hard with few low contrast greyish yellow mottles and many red brown nodules; course sandy silty loam, hard 7.5YR6/6 with abundant yellow grey and red mottles; 90–105 cm: hard coarse silty loam 5YR7/1 with abundant yellow and red mottles and few dark brown nodules; 105–140 cm: hard coarse sandy silty loam 7.5YR5/5 abundant bright red and yellowish grey mottles; 140–150: as above but yellowish grey mottles constitute the matrix.	Dry	Non-wetland
5	−33.434348; 19.166011	*Eragrostis planiculmis*	*Acacia longifolia, Conyza albida, Ficinia indica*	2	0–15 cm: loamy sand 10YR6/3; 15–30 cm: 7.5YR6/4 loamy sand with few low contrast greyish yellow and orange mottles; 30–40 cm: 7.5YR6/2.5 loamy sand with low contrast yellow mottles; 40–60 cm: 7.5YR6/2.5 loamy sand with abundant yellowish grey and olive mottles; 60–80 cm: 7.5YR4/5 loamy sand; 80–90 cm: 7.5YR7/4 loamy sand; 90–110 cm: 7.5YR7/4 loamy coarse sand with fine gravel; 110–115 cm: 7.5YR6/3 loamy coarse sand; 115–125 cm: 7.5YR6/2 moderately hard sandy silty loam with abundant yellow mottles	Dry	Temporary
6	−33.434289; 19.167153	*Merxmuellera stricta, Cynodon dactylon*	*Watsonia meriana, Seriphium plumosum, Tribolium uniolae, Juncus capensis, Pentameris* sp., *Cyperus tabularis, Acacia longifolia*	6	0–10 cm: 10YR3/1 fluffy (humic) sandy loam; 10–20 cm: 7.5YR6/3 loamy sand; 20–40 cm: 7.5YR6/2 loamy sand with orange root channel mottles; 40–50 cm: 7.5YR7/2.5 loamy sand (sand particles predominantly grey but some red brown); 50–70 cm: 7.5YR7/4 loamy sand; 70–80 cm: 7.5YR6/3 loamy sand with low contrast yellow mottles; 80–90 cm: 7.5YR7/1.5 sandy loam; 90–100 cm: 10YR6/2 hard sandy silty loam with abundant yellow mottles and few dark brown nodules; 100–120 cm: as above but slightly harder	Dry	Temporary
7	−33.435089; 19.168594	*Typha capensis; Carpobrotus edulis* (higher lying non-flooded areas)	*Psoralea* cf. *affinis, Persicaria* sp., *Erhata calcynia, Athenasia trifucata, Cliffortia strobilifera, Cyperus fastigiatus, Zantedeschia aethiopica*	5	0–5 cm: 7.5YR3/1 muck; 5-25 cm: 7.5YR6/1.5; 25–50 cm: 10YR6/1 sandy loam with medium contrast yellow mottles	40	Semi-permanent
8	−33.43152; 19.169273	*Typha capensis*	*Cyperus fastigiatus*	3	0–8 cm: 7.5YR3/1 slightly sulphidic muck with live roots; 8–40 cm: 10YR4/1 sandy silty loam, soft, with few olive mottles, slightly sulphidic; 40–60 cm: 10YR6/1 sandy silty loam with abundant yellow and olive mottles	30	Permanent/ semi-permanent
9	−33.430086; 19.171694	*Typha capensis*	-	2	0–25 cm: Fibrous (2) organic slightly sulphidic; 25–40 cm: 2.5Y5/1 slightly sulphidic silty loam, soft with harder but easily broken crumbs; 40–50 cm: 2.5Y3.5/1 silty loam with some small charcoal fragments; 50–70 cm: 2.5Y4/1 loam with abundant yellow and orange mottles	-5	Semi-permanent

[1]Vegetation integrity was scored on a scale of 0 (critical condition with no native vegetation remaining) to 10 (pristine) based on the guidance given in WET-Health (Macfarlane et al., 2020)

Table A1 Continued. Vegetation and soil morphology information recorded on 27/28 February 2023 for 18 sampling points located within the Kluitjieskraal Wetland

Point No.	Latitude and longitude	Dominant plant species	Other plant species	Vegetation integrity score (0–10)[1]	Soil description	Water depth (cm) (+above and −below)	Hydro-period
10	−33.429589; 19.173212	*Typha capensis*	*Pycreus nitidus*	3	0–5 cm: 10YR4/2 sandy loam; 5–20 cm: 10YR5/2 sandy loam; 20–30 cm: 10YR5/2 sandy loam with yellow and dark grey low contrast mottles; 35–50 cm: 2.5Y 6/3.5 slightly silty sandy loam with few orange mottles; 50–72 cm: 2.5Y6/4 silty coarse sandy loam; 72–80 cm: 7.5YR5/6 with abundant dark grey and olive mottles, hard silty loam with embedded coarse sand particles; 80–85 cm: 7.5YR3/1 sandy silty loam with bright orange high contrast mottles and red-brown nodules; 85–110 cm: 7.5YR5/2 with very abundant orange and yellow mottles and red-brown nodules and fine gravel up to 3 mm	Dry	Seasonal
11	−33.428789; 19.174165	*Typha capensis*	*Zantedeschia aethiopica*	2	0–15 cm: Fibrous (2) organic; 10YR 5/2 very soft silty sandy loam; 30–50 cm: 2.5Y6/3.5 silty fine sandy loam; 50–60 cm: 2.5Y6/5 silty sandy loam, runny	−1	Permanent/ semi-permanent
12	−33.430587; 19.172571	*Phragmites australis*, *Typha capensis*	cf. *Melaleuca quinquenervia*	2	0–5 cm: 10YR3/1 loam; 5–20 cm: 2.5Y5/1.5 silty loam; 20–30 cm: 10YR6/1.5 silty loam with few orange mottles; 30–40 cm: 10YR5/2 fine sandy silty loam with many orange and yellow mottles; 40–75 cm: 10YR4.5/1 samdy silty loam; 75–95 cm: 10YR5/2silty coarse sandy loam getting courser with depth; refusal (feels like bedrock but more likely 'well bedded' cobbles?)	−70	Seasonal
13	−33.427614; 19.180638	*Phragmites australis*, *Xanthosoma* cf. *roseum*	*Zantedeschia aethiopica*, *Typha capensis*, *Persicaria* sp., *Pennisetum clandestinum*	3	0–20 cm: 2.5Y4/2moderately fibrous (4) organic; 20–40 cm: 2.5Y4/2 slightly silty moderately fibrous organic; 40–50 cm: 2.5Y4/2 organic sandy silt, slightly sulphidic, with abundant living roots; 50–60 cm: 2.5Y4.5/2 sandy loam; 65–80 cm: 2.5Y6/2 sandy loam; 80–100 cm: similar to above but little retrieved.	4	Permanent/ semi-permanent
98	−33.431784; 19.185291	*Typha capensis*, *Psoralea usitata*, *Pennisetum macrourum*	*Mentha aquatica*, *Juncus effusus*, *Athenasia trifucata*, *Conyza scabrida*, *Senecio* sp., *Carpobrotus edulis*	6	0–5 cm: 10YR 4/1 sandy loam; 5-20 cm: 10YR5/2 silty sandy loam with few orange mottles; 20–30 cm: 10YR 5/2 silty sandy loam with few dark brown mottles; 30–50 cm: 10YR4/3 fine sandy silty loam; 50–60 cm: 10YR 5/3 sandy silty loam; 60–70 cm: 10YR5/3 sandy silty loam cm: 70–80 cm: 10YR5/5 sandy silty loam; 80–100 cm: 10YR6/6 silty sandy loam with many low contrast grey brown mottles	Dry	Seasonal
14	−33.430597; 19.187163	*Phragmites australis*, *Juncus effusus*	*Ludwigia palustris*, *Juncus lomatophyllus*, *Typha capensis*, *Mentha aquatica*, *Cyperus fastigiatus*, *Passerina corymbosa*, *Conyza albida*, *Cynodon dactylon*, *Isolepis prolifera*	6	0–15 cm: 10YR 3/1 silty loam; 15–20 cm: 10YR4/0.5 clayey silty loam; 20–30 cm: 10YR5/1.5 sandy loam; 30–60 10YR5/2 loamy sand; 60–80 cm: 2.5Y6/2.5 loamy sand; 80–100 cm: 2.5Y6/4 sandy loam	5	Permanent /semi-permanent
15	−33.427636; 19.190218	*Eragrostis planiculmis*, *Pennisetum macrourum*	*Schoenoplectus* sp., *Isolepis* sp., *Carpobrotus edulis*, *Conyza albida*, *Cynodon dactylon*, *Athanasia trifurcata*	6.5	0–10 cm: 10YR 4/2 fine sandy loam with lo contrast mottles; 10 cm: refusal (cobbles?)	dry	Seasonal
16	−33.428138; 19.186533	*Typha capensis*, *Phragmites australis*	*Mentha aquatica*, *Cyperus fastigiatus*	6	0–20 cm: 10YR2/1 mixed fibrous and amorphous organic; 20–30 cm: 2.5Y4/0.5silty sandy loam; 30–50 cm: 2.5Y5/1 silty sandy loam; 50-60 cm: 2.5Y6/5 sandy silty loam (sticky) with abundant yellow and grey mottles; 60–80 cm: 2.56/1 cm: sandy sticky silty loam with abundant yellow mottles	-25	Permanent /semi-permanent
17	−33.435503; 19.189389	*Typha capensis*	*Nymphaea nouchali* var. *caerulea*, *Paspalum scrobiculatum*, *Alisma plantago-aquatica*	6	0–20 cm: mucky dark grey silty loam; 20–39 cm: 2.5Y 5/1.5 sandy loam; 39 cm: refusal	10	Permanent /semi-permanent
18	−33.435134; 19.189815	*Typha capensis*, *Mentha aquatica*	*Cyperus denudatus*, *Cyperus congestus*, *Zantedeschia aethiopica*, *Pycreus polystachyos*, *Paspalum urvillei*, *Cynodon dactylon*	6	0–15 cm: 10YR2/1 organic silty loam; 15–25 cm: 10YR3/1 fluffy silty loam with charcoal fragments; 25–45 cm: 10YR 3/0.5 silty loam; 45–60 cm: 10YR5/1 sandy loam; 60–80 cm: 10YR 3/0.5 fluid loamy sand (little retrieved); 100–120 cm: 10YR5/1 loamy coarse sand	−70	Permanent /semi-permanent

[1]Vegetation integrity was scored on a scale of 0 (critical condition with no native vegetation remaining) to 10 (pristine) based on the guidance given in WET-Health (Macfarlane et al., 2020)