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Journal of Hydrology 639 (2024) 131522

Contents lists available at ScienceDirect

Journal of Hydrology

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

Research papers

# Engaging stakeholders to address a complex water resource management issue in the Western Cape, South Africa

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ARTICLE INFO

This manuscript was handled by Nandita Basu, Editor-in-Chief

Keywords:
Stakeholder engagement
Water user
Agent-Based Model
ARDI
South Africa

ABSTRACT

Engaging water users when developing water management plans is increasingly being embraced by a wide range of scientists in the water sector as imperative for dealing with present-day water resources challenges. However, the complexity presented by unique catchment situations makes it difficult to prescribe a 'one size fits all' solution to localised water resource challenges. South Africa is well-known for its population heterogeneity, which spreads into catchments, layering complexity in terms of water user types, needs and interests. This research presents a novel conjunctive use of classical and newly developed tools within a stakeholder engagement framework. This application of a suite of tools responds to the complex conflict of water user needs and interests in the Koue Bokkeveld catchment in the Western Cape Province of South Africa. We implement the Adaptive Planning Process, and the Actors, Resources, Dynamics, and Interactions approaches to unite conflicting stakeholders and develop a shared vision as the foundation for co-developing and negotiating a shared water management plan. We present the outcomes of a series of participatory workshops in which stakeholders developed a shared catchment vision. Stakeholders united around the vision and actively engaged in participatory Agent-based Model co-development with the research team. Increased attendance and active participation in the latter workshops demonstrate a positive progression in the engagement process. Outcomes of the stakeholder feedback evaluation validate increased participant satisfaction with the process. We then reflect on the practicalities of stakeholder engagement based on our experience. Learnings from this conjunctive application of approaches suggest that providing a conducive engagement platform, facilitation, and appropriate tools can enable conflicting water users to develop shared solutions collaboratively.

## 1. Introduction

Water scarcity is a significant problem in South Africa—low average rainfall results in limited water availability for human and environmental needs (DWAF, 2013). Specifically, more than half of the country's water resources are generated by high water yield areas that cover less than 10 % of the country's landmass (Nel et al., 2013), while water consumption, notably for irrigated agriculture, is high due to the water demand for commercial crops. Irrigation uses up 63 % of freshwater supply in the country (Baleta and Pengram, 2014). The situation has been exacerbated by recurring droughts (Wolski et al., 2017), increasing water demands and the escalating impacts of climate change. The threat of climate change is expected to worsen the problem by changing the dynamics of catchment processes related to vegetation cover, soil moisture (Li and Fang, 2016), and runoff, which will interact and produce unfavourable and disproportionate socio-economic and environmental consequences (Thomas et al., 2019). Southern Africa is already experiencing an increase in average temperature and precipitation variability, with a tendency towards more extended drought periods followed by more severe flooding (IPCC, 2022). This means that the existing strain on limited water resources will intensify, which calls for more rigorous efforts to manage ever-dwindling supplies to ensure that

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https://doi.org/10.1016/j.jhydrol.2024.131522

Available online 22 June 2024

all users have equitable access.

The evolution of water laws in South Africa post-independence was expedited by the increase in water demand, changes in the political landscape and the need for equitable access to water resources by all races (Backeberg, 2005; Tewari, 2009). Historically, the British government established the riparian rights principle, which was later adopted in the Water Act of 1956 (Backeberg, 2005). Under this Act, water rights were tied to land ownership (riparian owner). Riparian owners had unlimited access to water flowing through perennial streams and full ownership of the tributaries flowing through their properties. This resulted in downstream communities and ecosystems not having access to water. Irrigation Boards (IB) enforcing the riparian principle were established to manage irrigation water (Kotzé, 2023), with these Boards solely composed of white farmers who held land rights during colonial times.

Post-apartheid government reviewed water policy and implemented the National Water Act of 1998 (NWA) and Water Services Act (Act 108 of 1997). The NWA also protects the environment by establishing Environmental Water Requirements (EWR) that stipulate the amount of water needed to ensure that a river system remains functional and sustainable. Under the new NWA, the riparian principle was abolished and equity to water access is promoted to address inequality in water allocation (Levy and Xu, 2012). The NWA transformed IBs into Water Users Associations (WUAs) to encourage collectiveness in managing water resources and ensuring a reliable and equitable water allocation for existing commercial farmers and emerging black farmers. The move by the post-apartheid state aims to enable wider participation of historically disadvantaged individuals (black emerging farmers) in the commercial farming sector (Backeberg, 2005; Kotzé, 2023). Unfortunately, mistakes were made in the process of transforming IBs to WUAs. One of these mistakes was reappointing those who oversaw the IBs to chair the WUAs (Backeberg, 2005). This means that the legacy of IBs still endures in the WUAs, and therefore, still favours the interests of white commercial farmers (Kapangaziwiri et al., 2016; Kotzé, 2023).

The areas of focus for this study is a catchment in the Koue Bokkeveld (KBV) farming area in the Western Cape Province, which we will refer to throughout the paper as the KBV. The catchment has similar characteristics to those highlighted in the preceding paragraphs. However, there are very few subsistence farmers in the KBV, whereas the majority of farmers operate primarily commercial farms, either as family farms or sections of corporate farms that expand beyond the KBV. All farmers and landowners in the catchment are white. This might appear to be a relatively easier situation compared to other areas in South Africa, also considering the KBV does not feature the most stressed situation of inequity regarding water access. Nevertheless, the situation in the KBV is still a complex one, due to conflict between water users during dry periods. Furthermore, agricultural expansion and concomitant increases in water demand worsen the problem (Paxton and Walker, 2018). Farmers have built numerous dams and water transfer networks (intra- and inter-basin) to leverage the existing water resources for irrigation purposes. Unfortunately, these abstraction activities have led to the EWR not being met, threatening downstream riverine ecosystems and the various plant and animal species that depend on the river systems (Paxton and Walker, 2018).

Although homogenous it term of race, the study catchment features a small but diverse group of stakeholders. Farmers with private ownership of the land, and who are generally not open to interacting with outsiders about their activities, form the main part of this group. The farming sector itself is heterogeneous, characterised by a mixture of fodder, vegetables and export fruit production. Commercial farmers exist as either corporate or family-owned farms, all with access but unbalanced influence in the WUA. Upstream farmers have their own small reservoirs, while downstream users depend on surface water availability or willingness of upstream users to release water from private reservoirs. Some of these reservoirs are constructed off the river channel, potentially connected to other reservoirs in neighbouring catchments, while others are in the channel (Mantel and Hughes, 2023). Despite the small number of sources of inequity within KBV, our research considered it a meaningful situation to investigate, because it is possible to focus on water issues and hence reach a common language, and it might become a situation in other places as corporate farming takes over an increasing part of farming within SA, changing the conditions for water governance.

Besides the farmers, the KBV also includes "week-enders" (those who have holiday cottages) and lifestyle residents, both of whom have a positive attitude to environmental protection. These two user groups are also interested in domestic water supply from indirect groundwater supplies and the integrity of the natural landscape. Some of them have developed outdoor tourism-related businesses. Despite their environmental awareness, these two stakeholder groups tend to have no regulatory influence to ensure EWR satisfaction, as evidenced in the Inkomati satisfaction survey (Pollard & du Toit, 2012).

In addition, the KBV includes stakeholders with an interest in its ecology, such as non-governmental organisations (NGOs) and governmental agencies. This stakeholder group mainly plays a knowledge-broker and monitoring role in the basin. Their rationale is that, with hard evidence relating to the endemic fish populations (Ellender et al., 2017), it should be possible to influence farmers towards sustainable water use. These stakeholders work closely with all water users or landowners in the valley as they install monitoring systems and periodically disseminate findings. To their credit, a catchment coordinator with an ecology background has been stationed in the area to oversee the nature-based solution (Cohen-Shacham et al., 2016; Holden et al., 2022) efforts driven by the World Wildlife Fund (WWF) in collaboration with the Freshwater Research Center and the Western Cape Government.

The needs and constraints of these groups vary, as do their farming approaches and relations to water. They also feature diverse strengths, opportunities, and weaknesses. For example, corporate farmers have the capacity to mitigate risks on a larger scale and are more robust from a financial point of view, but they are dependent on both political support at the national level and the international market. Family farmers may have financial capacity and autonomy, but are threatened by corporate farmers, who have made the culture of gentleman's agreements for facilitating water releases obsolete. The KBV is thus a layered complexity of stakeholder needs, interests, water access and financial capacity. During the dry season, water shortages and the setting of EWRs at the catchment level make it difficult to reconcile competing interests. The KBV faces a formidable challenge in addressing the diverse needs of and varying water access by farmers while safeguarding the riverine ecosystem. The absence of a shared water management plan and an appropriate platform for collaborative management stems from these diverse and competing needs and constraints. In addition, they make it even more difficult to implement a more collaborative approach to water resource management. Consequently, water use disputes often end up in the courts.

In this situation, we have been involved in an action research project, under the leadership of Rhodes University, in agreement with the Western Cape Department of Agriculture, and funded by the Water Research Commission. This project aims to foster a participatory dynamic to help mitigate the current issues regarding water sharing, which becomes less and less sustainable under increasing droughts. In this paper, we describe our investigation regarding the suitability of using models in conjunction with a series of workshops with stakeholders concerned for the catchment to support a dialogue process towards a renewed governance of the basin. We do not focus on collaborative governance per se as this spans well beyond the scale of a series of workshops, but instead on stakeholder engagement towards renewed governance. Stakeholder engagement is potentially a move towards collaborative water governance by involving a larger set of stakeholders in these political choices, with the same limits met as in any participatory process (Barreteau et al. 2010).

Research and practice regarding water governance suggests that stakeholder engagement is the only way forward to handle challenges associated with the exploitation of a common pool of resources (Di Baldassarre et al., 2019; Galvez et al., 2019; Koebele, 2015; Palmer et al., 2022). Stakeholder engagement in environmental water management balances priorities of competing demands (Conallin et al. 2017). It also introduces more tacit and layperson knowledge (Richter et al., 2022), which in conjunction with natural science findings can generate more resilient outcomes. Establishing a common ground and a shared path between competing interests (Mott Lacroix et al., 2016) is central to successful water programs in areas such as the KBV. Even though proper evaluation over the long term is difficult, most studies report quite positive outputs.

In this research, we aimed to test various tools to assist farmers and other stakeholders in the KBV in negotiating a shared water management plan. With the choice of a participatory approach, some critical assessment is needed. Following Hassenforder and Ferrand (2024), we opted for a reflexive assessment. It is generally recommended that these tools are specifically suited to the case in which they are used (Miettinen and Virkkunen, 2005; Whitworth and De moor, 2003) and that a set of complementary tools are used instead of a single one (Kelly et al., 2013). We needed to provide tools and methods to better inform stakeholders of their interconnectedness and the consequences on the river and to develop their capacity to understand complexity and its consequences on possible pathways under global changes. As a result, we chose to develop a socio-hydrological approach (Sivapalan et al., 2012) and investigate interdependencies between water and human dynamics in the KBV. We applied the Adaptive Planning Process (APP) (Palmer et al., 2023) and the Actor, Resources, Dynamic and Interaction (ARDI) approach (Etienne et al., 2011) together with more classical hydrological modelling as a way to build on tool complementarities and tackle KBV specificities. The APP and ARDI were chosen for use during the stakeholder engagement process. APP was chosen for its ability to coalesce competing stakeholders towards a common purpose while ARDI is a method to engage a variety of stakeholders to develop land and water management plans. Both tools have been applied in South Africa (Etienne et al., 2011; Pollard et al., 2014, 2023) with positive outcomes. Classical ecosystem models, including hydrological models, were applied to provide information that stakeholders would need to produce a workable water plan. Therefore, we stress tested this association of approaches and tools to build collective understanding and capacity to discuss a shared water management strategy.

This paper reports on applying the APP and ARDI approaches to engage stakeholders in the KBV as an initial phase to build consensus and a collective understanding for the co-development and negotiation of a shared water management strategy. The approaches support the implementation of the companion modelling approach (Barreteau et al., 2013), in which stakeholders are actively engaged and collaborate in co-developing a model that represents their catchment system. The engagement is part of a larger ongoing project to assist stakeholders to develop a water management plan funded by the Water Research Commission (WRC) of South Africa. The other phases include workshops to co-develop models and to develop a water management plan (WMP) that will be collectively agreed upon and presented to the national water department. The reporting aims to demonstrate the approach, impacts and outcomes of engaging conflicting water resource users. Engagement typically involves the participation of stakeholders in active roles and decision-making regarding issues that affect them (Conallin et al., 2017). Given the complexity of the study area, an effective engagement strategy was crucial for bringing stakeholders into the same room, thereby enabling interaction and deliberation to identify a common vision for the catchment and to unpack the system's elements and their interactions. Additionally, the paper reports on the feedback provided by participants after the stakeholder workshops. Emphasis is placed on reporting the methodology and findings and their implications on future engagements. The discussions and conclusions focus on the robustness of the approaches, outcomes, and consequences on the project team and stakeholder groups.

## 2. Study area description

The KBV lies within the Western Cape Province of South Africa (Fig. 1). The catchment falls within the primary Olifants-Doring River catchment and accommodates one small town called Op-Die-Berg. Sub catchments E21G and E21H are the focal areas of this work. The town is an agricultural service centre, an Agri-village, which was established approximately 50 years ago (Vos, 2014). The total population of the Witzenberg local municipality in which the town and the KBV falls, was recorded as 142 466 in 2017 (including the 11 000 population of Op-die-Berg) (Witzenberg Municipality (WM), 2017). This local municipality's total population consists of 74 % coloured, 18 % black, and 8 % white. The languages spoken in the region are Afrikaans and English.

The KBV has a substantial rainfall gradient between the western (the Skurweberg) and eastern sides. As a result, water is piped via a vast sub-regional network of pipelines (Paxton et al., 2016). Farmers use a variety of water sources, including (1) surface water runoff from the Skurweberg, which is often piped to dams that would otherwise have small or low-yielding catchments, (2) Table Mountain sandstone aquifer boreholes that produce clean water, (3) shales on the valley floor that generate interstitial water that is of low quality, and (4) natural springs at the base of the mountains. Agricultural cooperatives (larger corporate farms) that have cultivated areas beyond the system's capacity have suffered the most from droughts and stand to lose the most. Due to their smaller size and greater flexibility, smaller individual farmers have been able to adapt far better to the extreme weather conditions between 2015 and 2017 because of lower water demand (Paxton et al., 2016).

The greater KBV region has the third-highest registered surface water use (20.9 %) in South Africa, indicating that it is a high water-use area. Irrigated agriculture is the primary land use in the study catchment (Tanner et al., 2022). The main crops grown in the area are deciduous (apples and pears) and stone fruits (peach, plum, and cherry) (Anchor Environmental, 2007; Vos, 2014). Citrus production is also on the rise. Agriculture has expanded to include potatoes, onions, and cucumbers (Vos, 2014). Irrigation constitutes 98 % of water use in the study catchment (DWAF, 2005). Irrigation water is stored in numerous farm dams. According to the Western Cape IWRM Action Plan (DEADP, 2011), 5–15 MCM/a of groundwater is abstracted in the KBV to supplement irrigation needs in dry periods. The most abstraction is sourced from the underlying water-rich Table Mountain Series during dry periods to supplement irrigation water supplied from these dams and rivers (DWAF, 2005; Vos, 2014). Arable land and water are limited

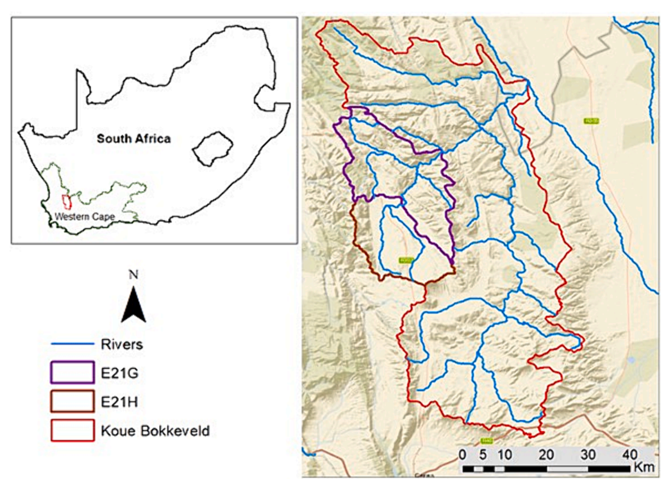


**Fig. 1.** The study area location showing the focal sub-basins that were identified for project implementation.

constraining future agricultural developments and the sustainability of current farming patterns. Around 11,500 seasonal and permanent workers are employed by the Greater Koue Bokkeveld Water User Association. The association is composed of individual water users who undertake water-related activities based on an agreed constitution, but these are barely effective (Madigele, 2018) due to the lack of well-established supporting structures such as Catchment Management Agencies (CMA).

## 3. Methodological approaches

For this research, a series of workshops were designed and implemented using a holistic participatory approach together with a suite of models to equip them. In this section, we first explain briefly the models developed, as these are the subject of other papers. Next, we focus on the methodology for stakeholder engagement in the workshops, and finally on the reflexive assessment, including the interview process. This work was conducted under the guidance and with the approval of the Rhodes University Ethics Standards for Human Subjects, with references (2022–5386–6678 and 2022–5900-7264). In line with the ethical requirements, the research team acknowledged their position as external stakeholders and the need to build legitimacy as credible facilitators (Barnaud and van Paassen, 2013). Throughout the engagements, the research team emphasised their non-neutral stance on the water management problem, making clear their interest in promoting sustainable and equitable water management.

### 3.1. Modelling suite

Implementing a suite of models is a way to deal with the complexity of the KBV to handle the various points of view of stakeholders and meet their expectations, which include information that can eventually be used to develop a water plan. Although each of the models implemented provided unique information to the catchment, the suite of models were also used to assess which tools/models would be most useful in water scarce and conflict prone catchments. Fig. 2 illustrates the various models that were implemented for the KBV and their interlinkages. Ad hoc models, including an agent-based model (ABM) a water balance model, and a decision support model (called the water sharing model), have been developed at the catchment and farm levels. These models are associated with classical hydrological models, including the locally developed and widely applied Pitman hydrological model (Hughes, 2013) and the Soil and Water Assessment Tool (SWAT + ) (Bieger et al., 2017). Pitman has been widely applied in water resource assessment in southern Africa, while SWAT has been used globally, including being

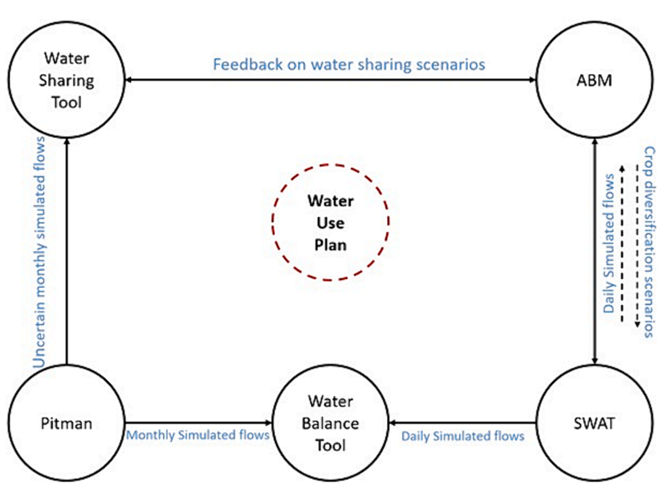


**Fig. 2.** The suite of models applied in the KBV towards achieving a shared water use plan.

coupled with an ABM (Khan et al., 2017).

ABMs (Ferber et al., 2004) have been applied worldwide to natural resources management in general (Bousquet and Le Page, 2004) and water resources management in particular (Berglund, 2015), including in South Africa by Farolfi et al. (2010). An ABM is used as a negotiation support tool together with the locally developed Water Sharing Model with Dams and Uncertainty (Pienaar and Hughes, 2017). The ABM and the Water Sharing Model simulations provide a workable basis for exploring various water management scenarios by stakeholders in negotiating and setting a water management plan. The Water Balance Tool (WBT) is another locally developed tool that operates at the farm level and can thus be deployed when operationalising the water management plan. All the models require the participation of stakeholders either in the development, implementation, and/or validation. Additionally, model development relied partially on data provided by stakeholders.

### 3.2. Stakeholder engagement

#### 3.2.1. Overall organisation of the workshops

The backbone of this association of tools and methods is a series of workshops that were implemented to facilitate engagement of stakeholders in co-developing the models. Three workshops, facilitated by the research team, were held between November 2021 and November 2022. The research team comprised researchers from Rhodes University (RU, South Africa), the Freshwater Research Centre (FRC, South Africa), the National Research Institute for Agriculture, Food and Environment (INRAE, France) and a professional workshop facilitator. The multidisciplinary team composition included expertise in ecology, hydrology, and computer and social sciences. Notably, the FRC has a long-standing relationship with farmers in the catchment as well as a resident catchment coordinator who handled the interpersonal pre- and post-workshop engagements with farmers. Invitations to the workshops were sent out to all water-users in the study area, specifically holders of water rights or their representatives. We invited this specific group because the entire study area is made up of private farms so there are no settlements or industry except those situated on farms and utilising the water rights of the farm owner. Other invitees included groups with interest in the ecology (e.g., the WWF) and development of the area.

In Workshop 1 we introduced the project to the KBV community and stakeholders, while in Workshop 2 we shared the methodologies and gathered baseline data using APP and ARDI for model development. Data from Workshop 2 makes up most of the outcomes reported in the results section. Workshop 3 was convened for sharing model prototypes, soliciting stakeholder feedback, and requesting additional data for improving model representations. Most of the outcomes reported in this paper relate to information gathered during Workshops 2 and 3, representing the foundational phase of our direct engagement with water users.

#### 3.2.2. Adaptive planning process (APP)

The Strategic Adaptive Management (SAM) approach instituted in the Kruger National Park, South Africa (Rogers and Biggs, 1999) emphasises consensus as a basis for designing a better future regarding ecosystem management. SAM is vital for bringing together stakeholders to identify shared values and goals and can be used to respond to contested water management spaces. SAM employs the Adaptive Planning Process (APP) as a foundational ground for stakeholder mapping. The APP specifies a set of actions that stakeholders engage in to discover common ground and develop an agreement (Palmer et al., 2023).

The project team implemented the APP, which is a forward-looking process vital for adaptive management (Palmer et al., 2023). The first phase of the APP involves stakeholders sharing their concerns regarding their space and the project. After concerns are recorded, stakeholders are encouraged to imagine a desired future, followed by collective crafting of a vision of their context with their concerns addressed. The concerns and elements of a desired future were categorised as Social, Technical, Economic, Environmental and Political (STEEP) (Pollard et al., 2014). The vision becomes the aim of the project process, and both the project team and stakeholders work towards achieving components of the collective vision. Once the vision is agreed on, stakeholders identify values and actions that contribute to attaining the vision. The values thus define a way of working together to underpin all engagements. Once a shared vision has been established through SAM/APP, the outcomes process provides input to frame the scenarios to be simulated by the ABM.

This part of our modelling suite approach is meant to ensure that stakeholders participate in the co-development of a water management plan, having a mutual understanding of the issues and a shared vision of the outcomes and opening their eyes to what the models will be about. More importantly, the values set the "rules of engagement" in a process that will likely be fraught with conflicts as stakeholders negotiate a workable plan for managing the scarce but shared resource.

#### *3.2.3. ARDI*

Participatory ABM design, such as companion modelling or other methods (Voinov and Bousquet, 2010), in complex, conflict-ridden spaces requires specific methods to elicit interacting entities and their coupled dynamics. The Actors, Resources, Dynamics, and Interactions (ARDI) method (Etienne et al., 2011) allows stakeholders to share mental models of the spaces they work or live in, thus allowing a progressive emergence of shared representation of the components of the shared system. Consequently, identifying actors, resources, dynamics, and interactions helps identify potential points of friction and contestation. The first step of the ARDI process is the identification of key actors, followed by a process to identify the critical resources associated with the key stakeholders identified in step one. The third step of the ARDI is to list the main dynamics (processes) that influence changes in the space (Etienne et al., 2011). Such processes can entail ecological dynamics such as water flow and vegetation seasonality, individual behavioural dynamics (e.g., farming decisions on plant selection or irrigation operation), or collective dynamics (e.g., joint investment in water collection infrastructure). The last step of the ARDI process involves eliciting interactions between users and resources (Etienne et al., 2011). This step takes more time because stakeholders develop a conceptual model (diagram) representing all the interactions associated with their territory, including monitoring, control, or operation. The stakeholders must determine and represent how each affects the resources and modifies the processes.

### *3.3. Stakeholder engagement assessment*

We refer here to the assessment framework developed by Hassenforder and Ferrand (2024). We collected the participants' demographic details using a registration on arrival approach, but only gathered information relating to names, email addresses, phone numbers and organisation. We used the information primarily to maintain communication with participants and to assess the number and composition of the participants at the workshops.

#### *3.3.1. Collecting reflections and feedback from stakeholders*

Stakeholder reflection enables the evaluation of the engagement strategy (Conallin et al., 2017). The reflection session was conducted using survey forms containing structured questions to guide the stakeholders to respond and a collective debriefing at the end of the session to share this feedback. The feedback assessed the impact of the process by evaluating if stakeholders felt the workshop was valuable, informative and engaging using a Likert scale as recommended by Hassenforder and Ferrand (2024). The feedback forms were anonymous as no information was collected through the form that could be used to identify individuals. Making the forms anonymous was done to ensure we received honest and impartial stakeholder feedback. The feedback was essential for gauging stakeholder satisfaction with the workshop process and participation experiences thus identifying potential issues that would need improvement in subsequent workshops.

The analysis focused on the outcomes of APP, ARDI and the reflection and feedback process. We implemented the approaches during the workshop and recorded the outcomes at every stage of the process. A similar method was followed for ARDI by Etienne et al. (2011). At the end of each workshop, the research team held a debriefing session where the workshop and capacity of the tools to gather the expected data were evaluated based on the workshop outcomes. Therefore, our stakeholder engagement evaluation was conducted *in itinere* as recommended by Hassenforder and Ferrand (2024). The results from the APP, ARDI and feedback from stakeholders are key indicators of the effectiveness of the engagement.

## 4. Results

### *4.1. Overall stakeholder engagement*

Workshop 1 was organised by the WWF in South Africa, and the research leveraged this meeting to introduce the team and the proposed work. This workshop is thus not reported in the paper. Fourteen participants attended Workshop 2, and nineteen participants attended Workshop 3. Three of the participants were female. Most of the participants based in the study area were farmers and residents; the rest were government officials and NGOs (see Table 1 and Fig. 3). Two commercial farmers from a catchment 140 km to the south (the upper Breede River catchment) also attended Workshop 3 to observe the process, hoping to advocate for its implementation in their region, which is facing similar issues as the KBV. All attendees who lived in the study area were landowners or land managers attending on behalf of the landowners. These individuals were deliberately invited and prioritised for the engagement because of their influence and decision-making regarding water use in the catchment.

### *4.2. APP*

#### *4.2.1. Concerns*

The eliciting concerns process gathered a wide number of concerns from the stakeholders. The project team categorised concerns using STEEP. A summary of key concerns is provided in Table 2. Equity emerged under social concerns; this was expected because the catchment's key issue is the lack of equal access to water resources. Other social concerns like transparency and fairness also speak to water access issues prevailing in the catchment. Water storage was a key technical concern because farmers maintained that building larger dams could store sufficient water for the dry season. Measurement of water use emerged as a technical concern, highlighting possible overconsumption by some users and the need to track water use. Given local and global political and environmental shifts, stakeholders were worried about agriculture's economic value. Ecological concerns revolved around alien vegetation, soils, climate, water quantity and quality. A main concern was the lack of accessible information on expected climate change impacts on the farming region. Farmers opined that agriculture is dependent on water; thus, knowledge of water availability trends would be key to planning at the farm level. Knowledge of water quantity would be vital for determining what to grow and how much to grow.

#### *4.2.2. Visioning*

The visioning process collated multiple views of an imagined and ideal KBV for the stakeholders. Sustainability stood out as a key element of the imagined future. Stakeholders tied sustainability to balancing agricultural water use and economic benefit. Diversifying income streams away from dependence on water was highlighted as crucial for reducing pressure on water resources. Additionally, stakeholders envisioned a future where they all worked together effectively under a

**Table 1**
A distribution of participants that attended workshops 2 and 3.

| | Males | Females | Farmers | Residents | NGOs | Government |
|---|---|---|---|---|---|---|
| **Workshop 2** | 12 | 2 | 8 | 4 | 1 | 1 |
| **Workshop 3** | 16 | 3 | 10 | 4 | 3 | 2 |

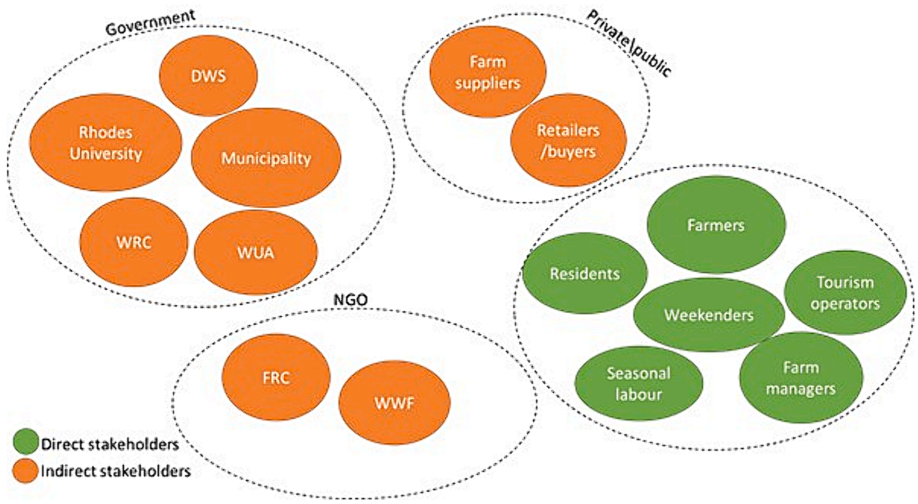


**Fig. 3.** A representation of the stakeholder groups present in the study area.

**Table 2**
Categories of concerns identified by the participants.

| Social | Technical | Economic | Ecological | Political |
|---|---|---|---|---|
| Equity | Water storage | Economic value of agriculture | Alien vegetation | Compliance |
| Transparency | Measurement | Eco-tourism value | Water quantity | Governance |
| Fairness | Consumption | Land value | Water quality | |
| Human impact | | | Climate | |
| Housing development | | | Soil | |

system of efficient cooperative governance. Embracing science and technology and ecosystem-based solutions were considered ideal for the future. The vision agreed upon by the stakeholders in the KBV is stated below:

- The Stakeholders working together to manage water resources sustainably and equitably with transparency and accountability in ways that balance social, economic, and environmental needs.
- Agriculture producing social and economic value through efficient, data-driven, scientific management practices and the adoption of technological and ecosystem-based solutions.
- A healthy, resilient ecological system with clean water flowing, even in summer.

### 4.3. ARDI

#### 4.3.1. A mapping of stakeholder attendees (workshops 2–3)

The mapping of stakeholders in the catchment resulted in two distinct groups of stakeholders: direct and indirect. Direct stakeholders are categorised as stakeholders that live and work in the catchment. Fig. 3 shows that direct stakeholders in the KBV include farmers, residents, and weekenders. Generally, direct stakeholder classes are based on activities that they perform within the catchment. Farmers in the KBV are large-scale commercial fruit farmers; some are smaller-scale family-owned farms. Residents live in the catchment and do not farm commercially, whereas weekenders are wealthy landowners who come in for short periods to vacation. Tourism operators are not a distinct group but farmers and residents who have diversified their business to increase income streams.

Indirect stakeholders depicted in Fig. 3 influence the catchments through policy implementation and supply of services. Three groups of indirect stakeholders are identified: government entities, non-governmental organisations (NGOs), and private/public institutions. Government institutions such as the municipality and Department of Water and Sanitation (DWS) implement land and water management policies. Related organisations, such as the Water Users Association and Water Research Commission, fall under DWS and provide technical support through research and oversee the implementation of water laws in the catchment. Although Rhodes University conducts independent research, it is listed as a government entity because it is a public university.

Non-governmental organisations operating in the catchment are interested in ecology and environments, therefore implementing environmental sustainability programs within the KBV. A strong working relationship exists between stakeholders – a significant synergy exists because environmental sustainability is a key objective interest for stakeholder groups. Private/public stakeholders include suppliers of farming implements and customers (local and international) who buy farming produce from the area. Some companies are privately owned, whereas government and quasi-government entities can also supply services and buy produce from farmers in the KBV. The stakeholder engagement process included almost all mapped stakeholders except the private/public indirect stakeholders and the seasonal labour.

#### 4.3.2. Identifying Resources, dynamic and interactions in the catchment

Table 3 lists the resources identified by the participants as occurring in the catchment. The listed resources include natural and human resources as well as artificial infrastructure. The category of natural resources includes resources vital for farming, such as water, soil, and sun. Fauna and flora are listed as resources supporting tourism activities.

**Table 3**
Resources and dynamics identified for representation in the model.

| Resources | Dynamics |
|---|---|
| Water | Irrigation |
| Land | Development of infrastructure |
| Irrigation infrastructure | Crop type |
| Crops | Inter-basin transfer |
| Groundwater | Water abstraction |
| | Storage of rainwater |
| | Climate change |
| | Environmental flows/reserve |
| | Expansion of agricultural land |

Human resources such as skills and knowledge are also listed as critical resources. Other physical artificial infrastructure, such as roads, are listed. The listed resources indicate that participants live in a fruit farming community. For example, bees are listed as a vital resource because they pollinate orchards during the flowering season.

The Interactions phase explored how stakeholders use the resources and modify the dynamics. For example, users abstracting water results in a shift in the available quantities. Stakeholders identified key resources as water, land, and crops. Fig. 4 illustrates some of the interactions between stakeholders and resources. Residents in the KBV abstract water for domestic use and cultivate small portions of land relative to the farmers. Other interactions between the stakeholders occur via the resources. For example, DWS water allocation rules impact the farmer's abstraction quantities, modify the land hectarage cultivated, and determine the type and quantity of crop that can be planted and harvested. Fig. 4 features some key interactions that were incorporated into the ABM and WST models.

### 4.3.3. *Stakeholder reflections and feedback (workshop 2–3)*

Figs. 5 and 6 illustrate the feedback responses given by stakeholders

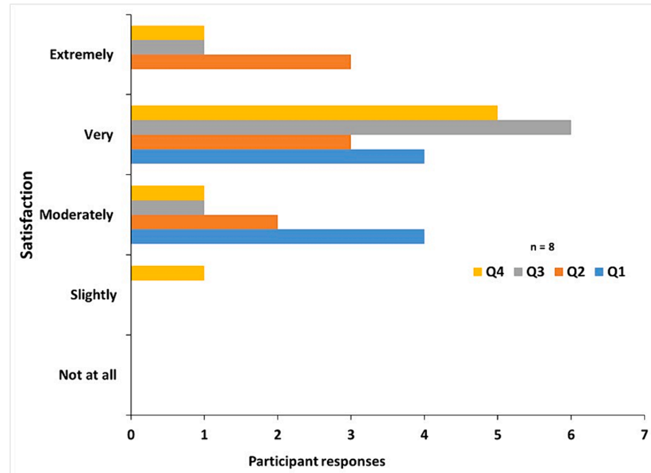


**Fig. 5.** Illustrated stakeholder feedback summary from the second workshop.

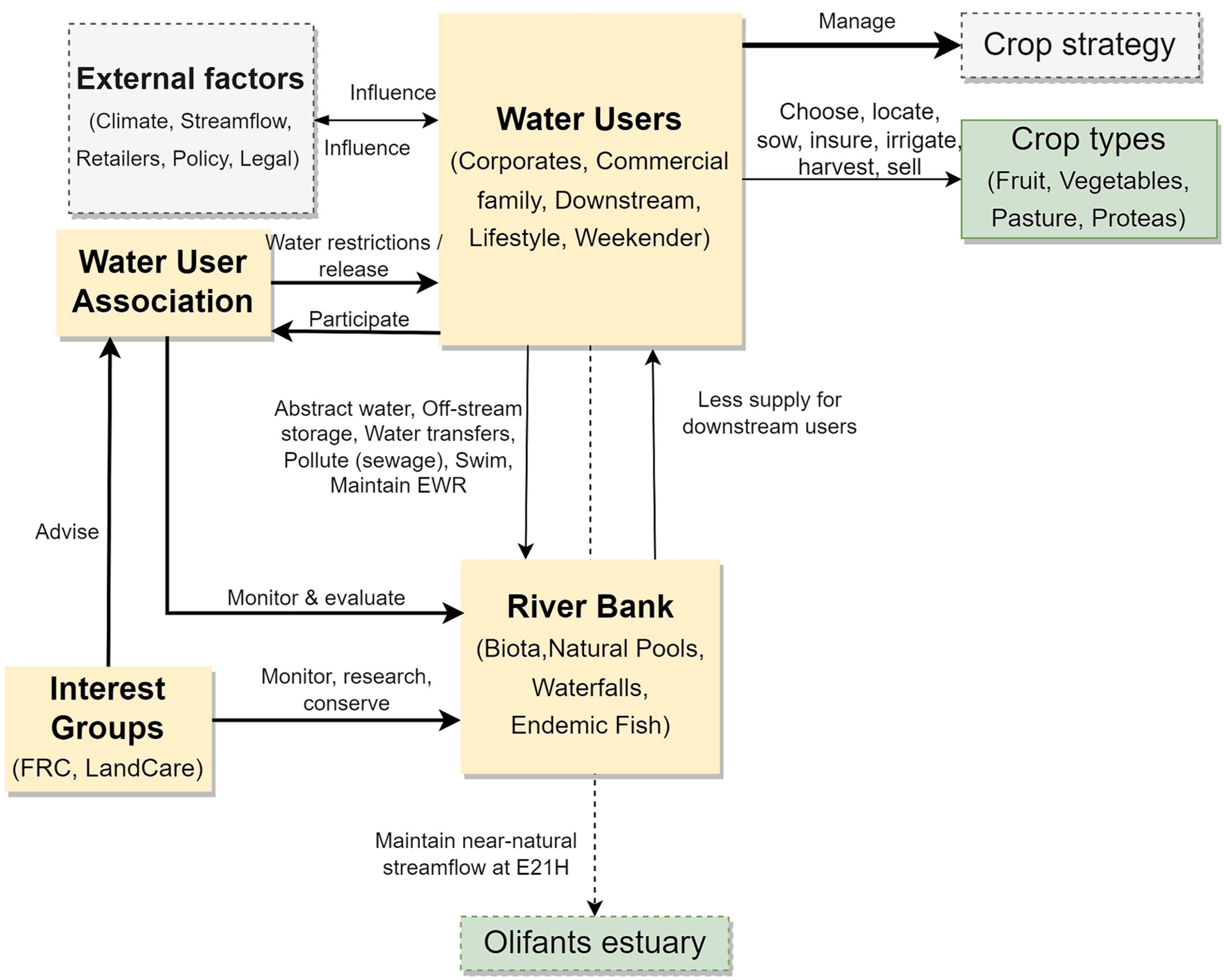


**Fig. 4.** A simplified representation of stakeholders' interaction with the key resources.

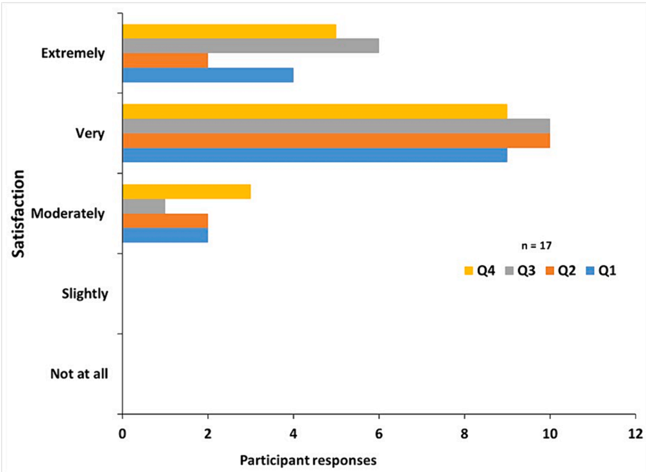


**Fig. 6.** Illustrated stakeholder feedback summary from the third workshop.

during the second and third workshops. The responses relate to the following questions posed to stakeholders:

Q1. How satisfied were you with the communication you received about the purpose and content of the workshop?
Q2. How satisfied were you with the information you received before the session about logistical arrangements?
Q3. How satisfied are you with the workshop structure and facilitation? (e.g., Was it engaging? Were there sufficient breaks? Was the pace good? etc.)
Q4. How valuable did you find the workshop today?

The outcomes indicate that stakeholders were moderately to very satisfied with the communication regarding the purpose and content of the first workshop. In Workshop 2, the number of attendees more than doubled, while satisfaction with pre-workshop communication improved significantly. The improvement in attendee numbers and satisfaction points to the efforts by the project team to improve communication prior to the workshop. A similar trend in increased satisfaction levels is noted for question two. However, when asked what could be done better after the first workshop, most participants did not respond. Only three participants responded, one used the section to compliment the process, stating, "*Very well organised*". Two other participants offered advice for improvement; one responded with "*More clarity on purpose/expected outcomes,*" while another recommended a "*Less ambitious conceptual integration!*". These comments were heeded by the team for planning of future workshops.

Regarding workshop structure and facilitation, most participants reported being either 'very' or 'extremely' satisfied. The high participant satisfaction with the workshop reflects the high-level planning and preparation that the team invested in before the workshop. In addition, the team engaged a skilled professional workshop planner and facilitator. Only one person in each workshop reported moderate satisfaction with the facilitation. For question four (Q4), most participants (~76 %) found both workshops more than 'very valuable', while less than 20 % said it was 'moderately valuable', while only one participant in the workshop found it 'slightly valuable'. Slightly better results were recorded in Workshop 2 than Workshop 3, in that no participant's response was below 'moderate' in terms of the value of the workshop.

Participants gave key feedback and were afforded opportunities to ask pertinent questions regarding the process and the model. They wanted to know if DWS would accept a water use plan emanating from the collective process, and fortunately, a DWS official was present to confirm that the plan would be recognised and should follow the template prescribed by the water department. Stakeholders appreciated the value of the models but were keen to know their transferability. The team advised that most of the models require technical expertise to operate. However, the water balance tool (Fig. 2) would be the more easily transferred tool to be used at the farm level when the water use plan is established. In general, stakeholders expected to interact with models and explore simulation scenarios instead of interacting with the conceptual model presented during the workshop. After interacting with the conceptual model, they proposed additional scenarios they would want to be represented, such as climate change, adding economic elements, and the possibility of adding more reservoirs to capture and store winter floods. The research team advised the stakeholders that they would investigate incorporating the scenarios but highlighted some limitations in data (some of which the farmers are not prepared to share) for input to the model, the model complexity and time.

## 5. Discussion

The discussion focuses on the methods used for stakeholder engagement, outcomes, stakeholder feedback, implications for water users and the broader aim of initiating an engagement towards developing a shared water management plan. It also gives an overview of the conceptualisation of the engagement process, including engagement team composition and preparatory work that occurred before interacting with stakeholders at workshops.

### *5.1. Preparation for the stakeholder engagement workshops*

The stakeholder engagement process benefited from collaborating partners with long-standing relationships with the farmers in the KBV and the inclusion of a professional workshop facilitator. Using these individuals and existing communication structures and goodwill, planning workshops, and achieving good attendance was easier. Team composition is key to the success of engagement activities, and we strongly believe that the involvement of experienced social scientists enriches the engagement and its outcomes. However, interdisciplinary research teams are challenging because individuals generally lean towards their disciplinary approaches; hence, adopting a transdisciplinary approach was necessary. Routine team meetings were essential to forming and maintaining a shared understanding as the project evolved.

Stakeholder mapping prior to engaging stakeholders is vital and has significant implications for the evolution of the engagement process. The team had access to a wealth of information about the KBV stakeholder activities, issues, behaviours, and relations. The information was provided by the collaborating partners, highlighting the importance of building meaningful research teams. We used the stakeholder information to craft an engagement process and mechanism that suited our stakeholder group. Consequently, we held a well-attended workshop and maintained good attendance throughout, making significant progress for the team. The progress is bound to the research team composition and the existence of champions within the stakeholder group. Some farmers and government stakeholders with significant social capital were key in canvassing support for the engagement activity. These influential individuals were identified as champions because they demonstrated a concern for the collective good and rallied other stakeholders to adopt a similar standpoint. Therefore, initial stakeholder mapping should identify such individuals and research teams must prioritise them in pre-engagement activities; their buy-in can determine the success or failure of the engagement activity.

Inviting many non-decision makers can result in a larger stakeholder group, thus making engagement more difficult. Engagement in such spaces should ideally prioritise the key stakeholders who influence resource utilisation and have decision-making power (Conallin et al., 2017). For example, attending farm managers could not make a final decision in real time without consulting farm owners. This resulted in ambiguity in the engagement process wherein present stakeholders became sceptical about the finality of outcomes agreed on without other key stakeholders. Unfortunately, this adds pressure to the research teams to reassure present stakeholders of the value of the process regardless of the absent key stakeholders and to follow up on those who were absent. It is generally unlikely to always have all necessary stakeholders in the room (Gaynor, 2014); therefore, contingencies must be made to ensure the engagement process does not stall. In fact, the absence of more powerful stakeholders does not always lead to unfruitful participatory processes because showing the result of the participatory work may give a common voice to less powerful stakeholders (Paget et al., 2016). Nevertheless, more engagement work must be done to ensure absent stakeholders participate in the process. The stakeholder engagement space can be chaotic, requiring the research teams to be adaptive (e.g., the research team had to visit farms after the workshops to gather more data because participants could not attend a workshop spanning more than a day). Additional engagements outside the planned workshops occur consistently through a project team member based in the study area, who acts as a liaison.

### 5.2. Engaging stakeholders using the APP and ARDI approaches

In areas where resources are contested, a shared vision becomes the overarching goal for a set of objectives (Palmer et al., 2023) based on an agreed set of values. A vision should highlight the issues and concerns; thus, the 'eliciting concerns' step allowed stakeholders to speak out about what was important to them. This is a vital step in crafting the specific issues for inclusion in the vision. A shared vision becomes a basis for collaboration and commitment. The visioning process indicated a strong desire by the stakeholders to maintain the region's economic viability. Consequently, the visioning feedback also indicates a firm understanding of the role of the ecosystem. A provincial government agricultural department participant remarked that farmers (the most critical stakeholder) are environmental stewards and have strong bonds with their land and environment. The South African Protected Areas database (DFFE, 2023) indicates that almost 80 % of the E21H subcatchment is a nature reserve, which is being expanded, demonstrating farmers' commitment to environmental sustainability (Xoxo et al., 2023).

The vision outcome in the KBV speaks to the shared priorities of the stakeholders. It is a consistent signpost of why they are involved in the engagement process and what they wish to achieve. Hence, stakeholder commitment to engagement has been strong, as shown by the participation in the ARDI process and thereafter. More participants attended the second and third workshops, which drew individuals from different catchments. Through their actions, stakeholders in the catchment have exhibited a commitment to the process (e.g., farmers who were unwilling to share data initially indicated during the third workshop that they were willing to share their data). Therefore, the initial engagements built relationships and galvanised stakeholders towards the shared vision. Pollard et al. (2023) used a similar process in the Crocodile and Olifants Catchments in South Africa and reported that the visioning exercise was a key mediating device in contested spaces if accompanied by benchmarks for achieving the vision.

The catchment's characteristics listed in Table 3, pertain to farming, indicating that farming is the major economic activity in the area. In particular, the listed dynamics highlight some concerns highlighted during the APP session, e.g., the value of crops, alien species invasion, water quantity, and related water restrictions. The listed dynamics are key for representation in the system models. The approach used to gather the information ensures that the participants who are the target users of the simulation models are included in the development of the models. Therefore, model representations were constructed based on the participants' information and feedback, fostering a sense of involvement, ownership, and legitimacy for the simulation outcomes. A legitimate participatory process of model co-development is vital in spaces where the model outcomes are used to discuss and plan the shared use of contested common pool resources. The conjunctive use of engagement approaches in this research enabled stakeholders to develop a basis and space for collaboration despite competing interests and needs.

### 5.3. Stakeholder feedback

Participants gave valuable feedback on what can be improved in workshop facilitation and increasing the value of the workshops. One participant highlighted "*Clarity over what will be achieved*", while another remarked, "*Shorter, punchier explanations of the modelling process. Too much time on vague concepts*". The participants' feedback reflects that better science communication is needed. The participants' reflections also highlight the difficulty of distilling scientific concepts for a non-scientific audience. A potential language barrier could have impacted the delivery of concepts; it may be necessary to consider more active translation from English to Afrikaans during workshops following the suggestion of Rangecroft et al. (2021). The following reflection from a participant supports the previous aspect "*Some more clarity was required on the last session with the stickers, language challenges, understanding the terminology*".

Participants were eager to get to the outcomes of the models; they wanted to get to the business of actual interaction with simulation models. While the project team was aware of the participants' enthusiasm, they remained cautious about taking participants through the necessary co-modelling stages until the simulation models' output was well understood and validated. The participants demonstrated confidence in the process and validated its usefulness by requesting the water department for surety that they would adopt the outcomes of the process. The team interpreted this as an acknowledgement by the stakeholders that the workshops can indeed culminate in a workable water management plan.

### 5.4. Outcomes and sustainability of the process

#### 5.4.1. Stakeholder engagement

Engagements thus far indicate that the approach adopted has yielded some positive outcomes. The feedback indicates increasing levels of satisfaction from one workshop to another. An increase in attendance also ensued. Notably, farmers who were initially unwilling to have DWS officials involved in the process later accepted this, adding legitimacy to the process. Raising the question of legitimacy was vital and will require stakeholders and the project team to collaborate more strongly towards developing a workable water management plan.

Additionally, stakeholders increased ownership of the process (e.g., participants became more willing to share some data to improve model accuracy). During Workshop 3, they suggested elements and scenarios that could be added to the model. Such stakeholder-led developments signify that participants have transitioned from a passive to an active role. This outcome is key to the sustainability of the engagement process.

However, key questions still need to be addressed as the process unfolds. While farmers have made a big step in sharing data, they are still unwilling to share data on irrigation water uses and schedules because of possible irregularities in water use. Without these, the research team must rely on various estimation methods.

#### 5.4.2. Capacity to generate WMP

The continued absence of corporate farmers is a problem for other stakeholders who perceive this group as a significant water user with a stake in the water issues. Although representatives of corporate farmers have attended workshops, the process requires stakeholders with decision-making powers to negotiate the water use plan. While the research team can provide the data and information required to develop the WMP and assist the water users to establish the plan, the users have to collectively agree on water sharing scenarios. The agreed WMP is then implemented by the WUA.

*5.4.3. Step towards WUA*

The lack of a dedicated efficient WUA, pointed out by some participants, could be seen as a limitation of the process as there is no one to take it forward. However, these workshops have also generated an opportunity to discuss this situation regarding WUA and might push towards a re-emergence of such an organisation. The positive feedback from the government participants regarding the process is encouraging but there was no direct push to expedite the process from the authorities. Therefore, the move to set up a more efficient WUA remains open. Unfortunately, as the WUA is a local water users' body, it is not the legitimate role of the research team to have a direct influence in its governance.

## 6. Conclusion

The KBV case study presented in this paper demonstrates a successful initial engagement with stakeholders in a resource-contested area using a variety of approaches. Complexity drives the conjunctive use of approaches in the absence of a single tool that responds to heterogeneous issues raised in the study area. The study fortifies the approaches used to engage stakeholders and highlights a participatory approach that attempts to place stakeholders at the centre of identifying the issues that need resolving, how they can be resolved and their role in solving local issues. Following the socio-hydrology principles, the engagement establishes a space and platform to evaluate the co-evolution of coupled human-water systems and thereafter negotiate the issues and conflicts. The paper highlights the importance for research teams to establish a stakeholder engagement framework tailored to the location, closely monitor the engagement process through stakeholder feedback and reflect on the process for continual improvement to occur. The outcomes demonstrate that the approach united stakeholders and galvanised them around a shared vision. Stakeholders built significant trust and confidence in the process and appreciated the potential value of the outcomes. Therefore, in areas where users contest water resources, we emphasise the importance of the research teams' role in providing a platform, facilitation, and appropriate tools to enable stakeholders to develop solutions collaboratively. The research provides valuable insights on how stakeholder engagement evolved in a South African farming area, closed off to outsiders but facing conflicts in times of water scarcity. Outcomes can be extrapolated to the many other farming regions in the country facing similar issues.

## CRediT authorship contribution statement

**David Gwapedza:** Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Olivier Barreteau:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Sukhmani Mantel:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Bruce Paxton:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Bruno Bonte:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing. **Rodney Tholanah:** Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing. **Sinetemba Xoxo:** Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing. **Stefan Theron:** Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing. **Sakikhaya Mabohlo:** Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing. **Lucy O'Keeffe:** Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing. **Karen Bradshaw:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Jane Tanner:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

## Declaration of competing interest

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

## Data availability

Data will be made available on request.

## Acknowledgements

The authors would like to acknowledge the contribution of stakeholders in the KBV to this work. We particularly acknowledge Rudolph Roscher and Shelley Fuller for their assistance with stakeholder engagement efforts. The Water Research Commission (WRC) project manager Dr Eunice Ubomba-Jaswa and the WRC reference group members were particularly supportive of this research. We also thank the editor and reviewers that contributed to the improvement of the manuscript.

This work was supported by the WRC ([grant number C2020/2021-00607]; the NRF Research Grants: International SA / France (PROTEA) [Grant number 138137]. The Oppenheimer Memorial Trust (OMT) provided postdoc funding for the lead researcher who is the first author.

## References

Anchor Environmental Consultants., 2007. Cape Regional Estuarine Management Programme. Olifants Estuary Management Plan: Situation Assessment. Draft Report: Part 1.

Backeberg, G.R., 2005. Water scarcity and institutional reform in southern africa. Water Int. 24, 116–125. https://doi.org/10.1080/02508069908692147.

Baleta, H., Pengram, G., 2014. Water as an input in the food value chain. Understanding the Food Energy Water Nexus. WWF-SA, South Africa. Wwf-Sa 32.

Barnaud, C., van Paassen, A., 2013. Equity, power games, and legitimacy: Dilemmas of participatory natural resource management. Ecol. Soc. 18 https://doi.org/10.5751/ES-05459-180221.

Barreteau, O., Bots, P.W.G., Daniell, K.A., 2010. A framework for clarifying "participation" in participatory research to prevent its rejection for the wrong reasons [online] URL: Ecol. Soc. 15 (2), 1 http://www.ecologyandsociety.org/vol15/iss2/art1/.

Barreteau, O., Bousquet, F., Étienne, M., Souchère, V., d'Aquino, P., 2013. Companion Modelling: A Method of Adaptive and Participatory Research. Companion Model. https://doi.org/10.1007/978-94-017-8557-0_2.

Berglund, E.Z., 2015. Using Agent-Based Modeling for Water Resources Planning and Management. J. Water Resour. Plan. Manag. 141, 04015025. https://doi.org/10.1061/(asce)wr.1943-5452.0000544.

Bieger, K., Arnold, J.G., Rathjens, H., White, M.J., Bosch, D.D., Allen, P.M., Volk, M., Srinivasan, R., 2017. Introduction to SWAT+, A Completely Restructured Version of the Soil and Water Assessment Tool. J. Am. Water Resour. Assoc. 53, 115–130. https://doi.org/10.1111/1752-1688.12482.

Bousquet, F., Le Page, C., 2004. Multi-agent simulations and ecosystem management: A review. Ecol. Model. 176, 313–332. https://doi.org/10.1016/j.ecolmodel.2004.01.011.

Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. Nature-based solutions to address global societal challenges. *IUCN: Gland*. Switzerland 97, 2016–2036.

Conallin, J.C., Dickens, C., Hearne, D., Allan, C., 2017. Stakeholder Engagement in Environmental Water Management, Water for the Environment: From Policy and Science to Implementation and Management. Elsevier Inc. doi: 10.1016/B978-0-12-803907-6.00007-3.

DEADP. 2011. Status quo report: The Olifants/Doorn WMA. Western Cape IWRM Action Plan. Cape Town, South Africa, 287–311.

Department of Water Affairs and Forestry, South Africa., 2005. Olifants/Doorn Water Management Area: Internal Strategic Perspective. Prepared by Ninham Shand (Pty) Ltd in association with Jakoet and Associates, Umvoto Africa, FST and Tlou and Matji, on behalf of the Directorate: National Water Resource Planning. DWAF Report No P WMA 17/000/00/0305.
DFFE, 2023. South Africa Protected Areas Database (SAPAD_IR_2022_Q3_01). Pretoria, South Africa.
Di Baldassarre, G., Sivapalan, M., Rusca, M., Cudennec, C., Garcia, M., Kreibich, H., Konar, M., Mondino, E., Mård, J., Pande, S., Sanderson, M.R., Tian, F., Viglione, A., Wei, J., Wei, Y., Yu, D.J., Srinivasan, V., Blöschl, G., 2019. Sociohydrology: Scientific Challenges in Addressing the Sustainable Development Goals. Water Resour. Res. 55, 6327–6355. https://doi.org/10.1029/2018wr023901.
DWAF., 2013. National Water Resource Strategy. Water for an Equitable and Sustainable Future. (Department of Water Affairs and Forestry, Pretoria. https://www.dwa.gov.za/nwrs/NWRS2013.aspx.
Ellender, B.R., Wasserman, R.J., Chakona, A., Skelton, P.H., Weyl, O.L., 2017. A review of the biology and status of Cape Fold Ecoregion freshwater fishes. Aquat. Conservat. Mar. Freshwat. Ecosyst. 27 (4), 867–879.
Etienne, M., du Toit, D.R., Pollard, S., 2011. ARDI: A co-construction method for participatory modeling in natural resources management. Ecol. Soc. 16 https://doi.org/10.5751/ES-03748-160144.
Farolfi, S., Müller, J.P., Bonté, B., 2010. An iterative construction of multi-agent models to represent water supply and demand dynamics at the catchment level. Environ Model Softw. 25, 1130–1148. https://doi.org/10.1016/j.envsoft.2010.03.018.
Ferber, J., Gutknecht, O., Michel, F., 2004. From Agents to Organizations: An Organizational View of Multi-agent Systems 214–230.
Galvez, V., Rojas, R., Bennison, G., Prats, C., Claro, E., 2019. Collaborate or perish: water resources management under contentious water use in a semiarid basin. Int. J. River Basin Manag. 18, 421–437. https://doi.org/10.1080/15715124.2019.1634083.
Gaynor, N., 2014. The tyranny of participation revisited: International support to local governance in burundi. Community Dev. J. 49, 295–310. https://doi.org/10.1093/cdj/bst031.
Hassenforder, E., Ferrand, N., 2024. Evaluating a participatory process. In: Transformative Participation for Socio-Ecological Sustainability - around the CoOPLAGE Pathways, QUAE. HAL Open Science, pp. 122–130.
Holden, P.B., Rebelo, A.J., Wolski, P., Odoulami, R.C., Lawal, K.A., Kimutai, J., New, M. G., 2022. Nature-based solutions in mountain catchments reduce impact of anthropogenic climate change on drought streamflow. Communications Earth & Environment 3 (1), 51.
Hughes, D.A., 2013. A review of 40 years of hydrological science and practice in Southern Africa using the Pitman rainfall-runoff model. J. Hydrol. 501, 111–124. https://doi.org/10.1016/j.jhydrol.2013.07.043.
IPCC, 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability Contribution of Working Group II to the IPCC Sixth Assessment Report. Synth. Rep. IPCC SIXTH Assess. Rep. 1–36.
Kapangaziwiri, E., Kahinda, J.M., Dzikiti, S., Ramoelo, A., Cho, M., Mathieu, R., Naidoo, M., 2016. Validation and verification of lawful water use in South Africa : An overview of the process in the KwaZulu-Natal Province Validation and verification of lawful water use in South Africa : An overview of the process in the KwaZulu-Natal Province. Phys. Chem. Earth 0–1. https://doi.org/10.1016/j.pce.2017.12.002.
Kelly (Letcher), R.A., Jakeman, A.J., Barreteau, O., Borsuk, M.E., ElSawah, S., Hamilton, S.H., Henriksen, H.J., Kuikka, S., Maier, H.R., Rizzoli, A.E., van Delden, H., Voinov, A.A., 2013. Selecting among five common modelling approaches for integrated environmental assessment and management. Environ. Model. & Softw. 47, 159–181. doi: 10.1016/j.envsoft.2013.05.005.
Khan, H.F., Yang, Y.C.E., Xie, H., Ringler, C., 2017. A coupled modeling framework for sustainable watershed management in transboundary river basins. Hydrol. Earth Syst. Sci. 21, 6275–6288. https://doi.org/10.5194/hess-21-6275-2017.
Koebele, E.A., 2015. Assessing Outputs, Outcomes, and Barriers in Collaborative Water Governance: A Case Study. J. Contemp. Water Res. & Educ. 155, 63–72. https://doi.org/10.1111/j.1936-704x.2015.03196.x.
Kotzé, P., 2023. Water policy is hindering agricultural transformation, study shows. Water Wheel 22, 22–25. https://doi.org/10.10520/ejc-waterb-v22-n1-a5.
Levy, J., Xu, Y., 2012. Review: Groundwater management and groundwater/surface-water interaction in the context of South African water policy. Hydrgeol. J. 20, 205–226. https://doi.org/10.1007/s10040-011-0776-4.
Li, Z., Fang, H., 2016. Impacts of climate change on water erosion: A review. Earth-Science Rev. 163, 94–117. https://doi.org/10.1016/J.EARSCIREV.2016.10.004.
Madigele, P.K., 2018. Efficiency of common-pool resource institutions: focusing on water users associations in South Africa. Environ. Dev. Sustain. 20, 825–840. https://doi.org/10.1007/s10668-017-9912-1.
Mantel, S., Hughes, D., 2023. Farm Dams in Southern Africa: Balancing Environmental and Socio-Economic Sustainability. IntechOpen. https://doi.org/10.5772/intechopen.113930.
Miettinen, R., Virkkunen, J., 2005. Epistemic Objects, Artefacts and Organizational Change. Organization 12, 437–456. https://doi.org/10.1177/1350508405051279.
Mott Lacroix, K.E., Xiu, B.C., Megdal, S.B., 2016. Building Common Ground for Environmental Flows using Traditional Techniques and Novel Engagement Approaches. Environ. Manag. 57, 912–928. https://doi.org/10.1007/s00267-016-0656-8.
Nel, J., Colvin, C., Maitre, D. Le, Smith, J., Haines, I., 2013. Defining South Africa's Water Source Areas 1–30.
Paget, N., Daniell, K.A., Rubio Zuazo, A., Barreteau, O., 2016. Environmental information sharing: a means to support the legitimization of oyster farmers' stewardship over water quality management in NSW. Australia. Nat. Resour. Forum 40, 21–36. https://doi.org/10.1111/1477-8947.12092.
Palmer, C.G., Fry, A., Libala, N., Ralekhetla, M., Mtati, N., Weaver, M., Mtintsilana, Z., Scherman, P.-A., 2022. Engaging society and building participatory governance in a rural landscape restoration context. Anthropocene 37, 100320. https://doi.org/10.1016/j.ancene.2022.100320.
Palmer, T., Tanner, J., Akanmu, J., Alamirew, T., Banadda, N., Cleaver, F., Faye, S., Kabenge, I., Kane, A., 2023. The Adaptive Systemic Approach : catalysing more just and sustainable outcomes from sustainability and natural resources development research. River Res. Appl. 1–15 https://doi.org/10.1002/rra.4178.
Paxton, B., Dobinson, L., Kleynhans, M., Howard, G., 2016. Developing an Elementary Tool for Ecological Reserve Monitoring in South Africa' s Freshwater Ecosystem Priority Areas (FEPAs): A Pilot Study in the Koue Bokkeveld.
Paxton, B., Walker, J., 2018. Appendix A - Synthesis Report. Freshwater Research Centre. Cape Town, South Africa.
Pienaar, G.W., Hughes, D.A., 2017. Linking Hydrological Uncertainty with Equitable Allocation for Water Resources Decision-Making. Water Resour. Manag. 31, 269–282. https://doi.org/10.1007/s11269-016-1523-3.
Pollard, S., du Toit, D., 2012. Shared Rivers Initiative. Phase 1: Towards ecosystems sustainability. WRC No. Report Water Research Commission, South Africa.
Pollard, S., Biggs, H.C., Du Toit, D.R., 2014. A systemic framework for context-based decision making in natural resource management. Ecol. Soc. 19.
Pollard, S.R., Riddell, E., du Toit, D.R., Retief, D.C., Ison, R.L., 2023. Toward adaptive water governance: the role of systemic feedbacks for learning and adaptation in the eastern transboundary rivers of South Africa. Ecol. Soc. 28 https://doi.org/10.5751/ES-13726-280147.
Rangecroft, S., Rohse, M., Banks, E.W., Day, R., Di Baldassarre, G., Frommen, T., Hayashi, Y., Höllermann, B., Lebek, K., Mondino, E., Rusca, M., Wens, M., Van Loon, A.F., 2021. Guiding principles for hydrologists conducting interdisciplinary research and fieldwork with participants. Hydrol. Sci. J. 66, 214–225. https://doi.org/10.1080/02626667.2020.1852241.
Richter, I., Roberts, B.R., Sailley, S.F., Sullivan, E., Cheung, V.V., Eales, J., Fortnam, M., Jontila, J.B., Maharja, C., Nguyen, T.H., Pahl, S., Praptiwi, R.A., Sugardjito, J., Sumeldan, J.D.C., Syazwan, W.M., Then, A.Y., Austen, M.C., 2022. Building bridges between natural and social science disciplines: a standardized methodology to combine data on ecosystem quality trends. Philos. Trans. r. Soc. B Biol. Sci. 377 https://doi.org/10.1098/rstb.2021.0487.
Rogers, K., Biggs, H., 1999. Integrating indicators, endpoints and value systems in strategic management of the rivers of the Kruger National Park. Freshw. Biol. 41, 439–451. https://doi.org/10.1046/j.1365-2427.1999.00441.x.
Sivapalan, M., Savenije, H.H.G., Blöschl, G., 2012. Socio-hydrology: A new science of people and water. Hydrol. Process. 26, 1270–1276. https://doi.org/10.1002/hyp.8426.
Tanner, J., Mantel, S., Paxton, B., Slaughter, A., Hughes, D., 2022. Impacts of climate change on rivers and biodiversity in a water-scarce semi-arid region of the Western Cape. South Africa. Front. Water 4. https://doi.org/10.3389/frwa.2022.949901.
Tewari, D.D., 2009. A detailed analysis of evolution of water rights in South Africa: An account of three and a half centuries from 1652 AD to present. Water SA 35, 693–710. https://doi.org/10.4314/wsa.v35i5.49196.
Thomas, K., Hardy, R.D., Lazrus, H., Mendez, M., Orlove, B., Rivera-Collazo, I., Roberts, J.T., Rockman, M., Warner, B.P., Winthrop, R., 2019. Explaining differential vulnerability to climate change: A social science review. Wiley Interdiscip. Rev. Clim. Chang. 10, 1–18. https://doi.org/10.1002/wcc.565.
Voinov, A., Bousquet, F., 2010. Modelling with stakeholders☆. Environ Model Softw. 25, 1268–1281. https://doi.org/10.1016/j.envsoft.2010.03.007.
Vos, E., 2014. Land Cover Change and Its Effect on Landscape Function in the Koue Bokkeveld. South Africa. Stellenbosch. Stellenbosch University (MSc Thesis).
Whitworth, B., De moor, A., 2003. Legitimate by design: Towards trusted socio-technical systems. Behav. Inf. Technol. 22, 31–51. https://doi.org/10.1080/01449290301783.
Witzenberg Municipality., 2017. Amended integrated development plan 2017 – 2022. [Online]. Available:https://lg.treasury.gov.za/supportingdocs/WC022/WC022_IDP%20Final_2022_Y_20220624T110705Z_ajami.pdf. (Accessed 5 August 2021).
Wolski, P., Hewitson, B., Jack, C., 2017. Why Cape Town's drought was so hard to forecast? [Online]. Cape Town: UCT Climate Systems Analysis Group. Available: https://theconversation.com/why-cape-towns-droughtwas-so-hard-to-forecast-84735 (Accessed 22 June 2020).
Xoxo, S., Tanner, J., Mantel, S., Gwapedza, D., Paxton, B., Hughes, D., Barreteau, O., 2023. Equity-Based Allocation Criteria for Water Deficit Periods: A Case Study in South Africa. Lect. Notes Bus. Inf. Process. 474 LNBIP, 137–155. https://doi.org/10.1007/978-3-031-32534-2_11.