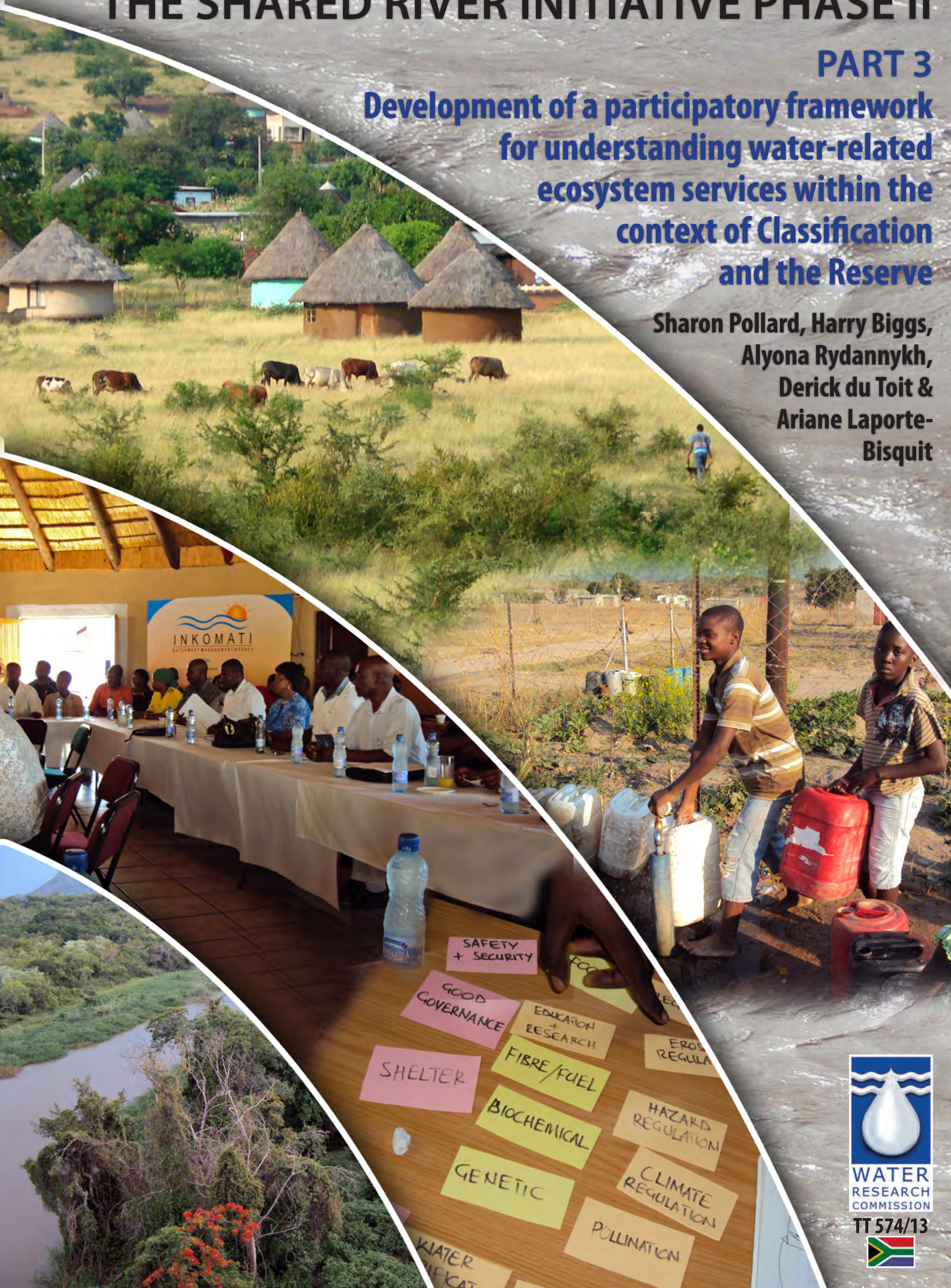
THE SHARED RIVER INITIATIVE PHASE II

PART 3

Development of a participatory framework for understanding water-related ecosystem services within the context of Classification and the Reserve

Sharon Pollard, Harry Biggs, Alyona Rydannykh, Derick du Toit & Ariane Laporte-Bisquit



WATER RESEARCH COMMISSION
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Water Research Commission

by

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Water Research Commission
Private Bag X03
GEZINA, 0031

orders@wrc.org.za or download from www.wrc.org.za

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PREFACE

Over the past decades, integrated water resource management (IWRM) has gained prominence as a powerful water management concept. It is an idea that promotes the equitable and sustainable management of a catchment by all who live and share its waters. The complexities of realising IWRM are emerging within the context of South Africa.

Emerging concerns regarding the sustainability of South Africa's water resources contend that despite world-acclaimed legislation, such as the National Water Act (NWA), the ecological condition of the country's river systems – a number of which are transboundary – continue to deteriorate.

On the one hand many recognise that at the very least, developments are taking longer than expected to take effect, and an 'implementation lag' is to be expected. On the other hand, with varying degrees of empathy or frustration, stakeholders express the view that government is unable, or even unwilling, to enforce legislation and water users, acting with impunity, take as much or pollute as they want.

There is much that can be shared and learnt between South Africa and its neighbours. The Lowveld river basins, for example, are all shared between neighbouring states. Each river-sharing neighbour faces a similar set of needs and challenges in its attempts to balance social development imperatives with management for resource sustainability. There is a clear need to harmonise management and decision-making within relevant institutions and between neighbours to ensure fair and effective policy implementation.

From these concerns has emerged an initiative known as the Shared Rivers Initiative (SRI), a transboundary project that aims to understand and effect change in the implementation of policies and legislations relevant to the wise use of the Lowveld river systems. The programme has been led by the Association for Water & Rural Development (AWARD) and is funded by the Water Research Commission (WRC).

Establishing the sustainability of Lowveld water resources

As part of Phase I of the Shared Rivers Initiative, AWARD undertook a preliminary assessment of the status of sustainability of the water resources of the Lowveld and the factors that constrain or contribute to this, in order to provide a grounding from which the project was able to design and implement real change. Investigations were carried out in six major river catchments (Levuvhu, Letaba, Olifants, Sabie-Sand, Crocodile and Komati), residing within the three Water Management Areas (WMAs), namely the Levuvhu/Letaba WMA, Olifants WMA and Inkomati WMA. The results of this study are captured in the report, *The Shared Rivers Initiative Phase I: Towards the sustainability of freshwater systems in South Africa* (WRC Report No. TT 477/10).

Phase 1 of the SRI raised some serious concerns. Of the Lowveld Rivers investigated, none met the Reserve requirements in terms of river flow. In fact, with the exception of the Sabie River, the situation was found to be generally worse than when the NWA was promulgated in 1998. In many cases, water quality also seemed to have deteriorated. However, some signs of a welcome turn-around were evident, certainly in the Crocodile Catchment which falls in the Inkomati Water Management Area, where new

Integrated Water Resource Management (IWRM) approaches driven by the Inkomati Catchment Management Agency and stakeholder partnerships were due to come online.

In the Phase 1 report the authors point out firstly that one does not 'implement the Reserve' but rather it is the collective plans for Integrated Water Resources Management (IWRM) that are together designed to achieve the desired outcomes, including equity and sustainability (through the Catchment Management Strategies, Pollard & du Toit 2008). Thus securing river systems is predicated on a 'bundle of strategies' that are collectively required to achieve sustainability. Furthermore, ensuring water in the river means bringing different stakeholders (e.g. agriculture, municipalities) along the river on board – each with their own planning frameworks driven by different factors (e.g. crop production and water supply). This also illustrates that time is needed to re-orientate users to a new unified goals of sustainability and equity and thus lags are to be expected. Moreover it highlights the importance of having a flexible and adaptive approach that embraces learning-by-doing. This moves water resources management into the world of complexity where multiple factors working at different scales render outcomes that are not always predictable.

That said, the Phase 1 report pointed to seven key areas where action is required to transform the degrading river systems. The key findings against which recommendations were made are:

1. A generally poor understanding of the Ecological Reserve and hence failure to change practices
2. The almost total lack of integration of water resources management and supply
3. Some degree of unlawfulness but more importantly, the weak regulation of unlawful use and poor legal literacy.
4. Some seemingly excessive lags in the implementation of the Reserve and emergence of sustainability discourse
5. Various examples of the emergence of, or lack of, self-organisation, leadership and feedback loops in adaptive action and management
6. Attendant dearth of skills, capacity, monitoring and legal literacy with some exceptions.
7. The importance of participatory and representative platforms for collective action: their functioning and contribution to IWRM

In May 2009 a working group convened to charter a way forward for a Phase 2 of the SRI. It was clear from the report that the vast geographic expanse of the study area, the scope and depth of issues at hand, and the need to include a basin-wise (international) perspective, that there was a need to focus the work in the second phase. The working group decided to limit the focus mainly to the Inkomati Water Management Area with the guiding focus of how to best support compliance with environmental water requirements within the evolving institutional environment.

Furthermore, the overarching theme of Phase 2 was that of sustainability and how it can be planned for and achieved over the coming decade. Based on this, Phase 2 was conceptualised as key themes suggested by Phase 1 that would support compliance with the EWRs. The operating assumption is that fundamental to addressing degrading systems is the recognition that the priorities for managing water have shifted where the concerns for sustainability and equity become paramount. Phase 1 pointed towards a situation where, if appropriately addressed, catchments can become units for sustainable water resource management that are both robust and responsive. Achieving this requires – at the outset – a 'shift in the discourse' such that sustainability and equity guide planning and implementation rather than being seen as simply a 'requirement of the Act'. The motivation for this is that, firstly, without adequate understanding of the concepts and language of sustainability (and the EWRs), there is unlikely to be meaningful progress in realizing its goals. This means that water managers and users need access to new concepts and reasoning associated with these new management priorities. Secondly, there is a strong need for learning associated with the use of new 'tools' that focus on the practicalities of achieving sustainability. In this case learning about the ecological Reserve and its provisions, is fundamental to building sustainability into water management practices. Thirdly, there is the requirement for a 'new shared discourse' for water management across all sectors. The challenge is to support institutions and multiple stakeholder platforms that can potentially develop and hold a collective discourse on sustainability and that realize adaptive management processes as crucial for managing in complex environments.

Given these challenges, Phase 2 set about by structuring the research process around three case studies each exploring different aspects of IWRM raised in Phase 1. The three cases form the basis for this report and are briefly introduced here, and dealt with in detail as Parts 1, 2 and 3 of this document.

Case 1: Collective action for improved water resources management

The research process of this case is to explore new ways of working by bringing stakeholders together to decide on collective actions that will halt the degradation of the lowveld rivers. The expectation in employing such an approach is that water users, with different stakes and views of how the resource should be managed, arrive at a strategic plan for protecting the resources of a specific catchment. Essentially this entails decentralisation and democratization of water management functions where various stakeholder groups are engaged in platforms for participation and decision making. These are commonly called multiple stakeholder platforms (MSPs). MSPs therefore give meaning to the decentralization process by providing spaces where stakeholders can be involved in processes of improving specific situations/conditions that adversely affect them.

The aim of this project action was to explore ways of moving beyond awareness raising to collective action which is defined as: ''the collective process of involving diverse stakeholders for resolving conflicts and advancing shared visions''. However as Phase 1 pointed out, planning forums and multiple stakeholder platforms in the lowveld are bedevilled by a sense of inaction and criticisms are levelled that "nothing ever happens". Almost always they lack a focus on sustainability (and specifically the Reserve).

This case completed a literature and policy review of collective action and drew on the key findings of the other cases in the project. The findings were used to develop a set of guideline principles for collective action. These included the fundamental importance of activities for collective action such as setting a vision, integration of policy and legislation to support collective action, and the importance of meaning making and learning in collective action processes.

Case 2: Building regulatory competence for addressing unlawful water use

Phase I identified that there is inadequate compliance monitoring and enforcement around environmental and water laws with the consequent poor compliance with legal requirements such as the Reserve. Critical deficiencies in the water-use license applications were also highlighted. These shortcomings have contributed to the perception that the "regulator cannot regulate" and that the "regulator lacks teeth". AWARD has observed factors that contribute to this include a lack of legal competence both in the private and public sector as follows: building legal cases around sustainability, poor and underdeveloped enforcement protocols for ensuring legal compliance with instruments such as the Reserve and a failure to attract and expose legal students (future lawyers and judges) to the water sector.

It can be argued that the twin mechanisms of compliance monitoring and enforcement, are the most important mechanisms to ensure legal compliance. Legal provisions, such as those under the NWA, generally give a government entity the authority to conduct inspections and carry out investigations. They provide the authority to impose sanctions, in either the administrative, judicial, or criminal forum, and require the violator to come into compliance with the law. These regulatory powers play a significant role in deterring unlawful activities. Better understanding challenges and shortcomings faced by the regulator when undertaking compliance monitoring of and enforcing the NWA and other environmental laws and providing constructive recommendations to address those challenges is essential to ensuring sustainable water resources.

Through a collaborative and co-learning process with regulators, multiple stakeholder platforms and law students, this component of the project sought to identify factors that constrain compliance with environmental water requirements and to collectively seek solutions to enable a better regulatory environment.

Case 3: Benefit sharing: understanding the intention of the Reserve and the benefits that an ecosystems goods and services approach provides

Findings of Phase I clearly demonstrated a weak grasp of the Reserve such that almost all stakeholders perceive that the benefits of measures associated with sustainability (such as implementation of the Reserve) accrue to *other* stakeholders whilst *they* (i.e. their sector) carry all the risks. This poses a serious obstacle to fulfilling the intentions of sustainability and equity of water resources through stakeholder participation. People indicated that if they comply, it is because of a legal obligation rather than because it is regarded as beneficial to them or future generations.

Given the aforementioned tendency to perceive the Reserve as risks (“to me”) and benefits (“to others”), the research process in this component set out to examine with stakeholders the benefits and risks associated with compliance (or non-compliance). This meant exploring benefit-sharing through a sound framework to help stakeholders understand the implications of meeting (or not) the environmental water requirements. The guiding questions were: What are the implications of not meeting the Reserve? Or phrased another way: What are the benefits for society of being compliant? As researchers, the question also arose as to how best these can be communicated to affect the kind of changes needed? Under Case 3 the issue of boundaries became important because such questions can be asked at the scale of users in a catchment (upstream-downstream ‘boundaries’ or boundaries between sectors) and between sovereign nations (commonly referred to as transboundary or international issues).

This case sought to focus specifically on the development of a framework and method for exploring the risks and benefits of meeting the EWRs with a focus on the Sand and Crocodile rivers of the Lowveld. This meant developing a solid conceptual and methodological basis through bringing together appropriate skills and expertise drawn from a trans-disciplinary group of scholars and practitioners involved in different aspects of water-related work.

Although the proposed framework was developed in relation to the Ecological Reserve it is not limited to this aspect of resource management alone. The project suggests that the benefits and risks of a Reserve scenario are a component of the broader Classification process which will have a number of Reserve scenarios – at least one for each class. This work therefore has application at this level as well as at basin-scale planning, across international boundaries.

Experience from other transboundary basins suggests that it is important to scope out and understand the full range of issues specifically related to international agreements and co-operation that need to be considered. Such issues are of high priority in the Incomati Basin where, amongst other things, EWRs are being considered in the formalisation of comprehensive water-sharing agreement between three sovereign states of Mozambique, Swaziland and South Africa.

Conclusion

The work presented in this three-part report has the potential to contribute to our knowledge of the policy-science-management-practice interfaces by adopting an integrated approach that seeks to track a policy intent such as environmental water requirements through to outcomes. It seeks to deepen the discourse on environmental water requirements, compliance and what these mean for society – both at a national and international scale. It is built on the recognition that ensuring water for future generations is the basis for a healthy and thriving society. Ensuring both provisioning and regulating services through Reserve compliance provides for benefits that impact on health and at the same time the economy. Demonstrating where the distribution of benefits lie is an important component of understanding the links between environmental water requirements (designed for the benefit of society) and economic well-being.

Although the project concentrated on the rivers under the jurisdiction of the Inkomati Catchment Agency, its findings have a wider application at the national and international scale especially in the light of needing to address sustainability of freshwater systems. Such efforts however cannot be tackled without the involvement of stakeholders. An important aspect of working within complex systems such as catchments is to identify the requisite simplicity and present this in a way that can be communicated to all concerned in a practical and tenable way. The impact is to be experienced as a shift in the language and discourse of water management towards more sustainable ways. By engaging all sectors through multiple stakeholder forums the intention is to gain recognition for integrated approaches and to emphasize the importance of sustainability in adaptive planning. To this end concept and competence development at all levels is central to implementing the recommendations set out in this report. The overarching aim of this report is therefore to provide the basis for shifting the discourse in water resources management towards more sustainable configurations.

Note on report format

This report is presented in three parts, each documenting the work done within the three cases summarised above. The decision to keep the work separate is based on the distinct nature of each of the case studies. It also recognises that legal research and referencing is different to the format used in scientific research. Presenting the report in three parts allows for the conservation of disparate methods and formats.

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EXECUTIVE SUMMARY

The work reported herein emerges from the SRI Phase I. results indicated that securing the Reserve (as a benchmark for sustainability) is predicated on a ‘bundle of strategies’ that are collectively required to achieve sustainability. The framework for this is Integrated Water Resources Management (IWRM) which in South Africa is given effect in the development of Catchment Management Strategies (CMS) for each of the Water Management Areas (which must view the catchment as a complex, linked socio-ecological system). One component of the CMS is related to water resources protection and includes the Reserve, Classification and Resource Quality Objectives. Specifically this work sought ways in which to understand the Reserve so that it has meaning and buy-in from water users and others through understanding the water-related ecosystem services that the Reserve delivers and the benefits people enjoy from these. This was because the SRI I work – which examined factors that enable or constrain meeting the Reserve in six transboundary catchments of the lowveld clearly demonstrated that almost all stakeholders perceive that the benefits of measures associated with sustainability (such as implementation of the Reserve) accrue to other stakeholders whilst they carry all the risks. This perception of the Reserve – which is quite contrary to the spirit and intent of the National Water Act 36 of 1998 (NWA 1998) – poses a serious constraint to fulfilling the spirit of the transformation to sustainability and equity of water resources through stakeholder participation.

Given this, the overall aim of the project which was to *develop and test a framework for the collaboration of catchment stakeholders in building a shared appreciation of the risks and benefits of meeting (or not) the ecological Reserve (EWRs) through an understanding of the associated water-related ecosystem services (WatRES)*.

The conceptual approach taken breaks from current approaches to valuing ecosystems services based on the idea that (financial) values can be assigned to, or reified in, certain ecosystems processes. Rather their value is seen as the emergent outcome of a process of valuing by stakeholders informed by, but not restricted to, best available science. Moreover we explore how ecosystems services institutions can be *designed* in context specific ways that build local ownership and provide contributions to livelihoods (i.e. poverty alleviation) in the context of catchments and IWRM.

Key principles of the proposed framework

The proposed framework (Figure 26) comprises a number of key principles, as follows.

Embedding WatRES within a wider IWRM context

Exploring and elaborating water-related ecosystems services needs to be embedded within a wider context of IWRM context for sustainability which, in South Africa comprises policy elements such as Classification, the Reserve and water use planning. In practical terms within the Inkomati WMA (the study site) this is being given effect through operationalising the Reserve through the development of real-time WRM tools. Catchments are part of wider-systems each with their own institutional norms and realities which need to be considered. These systems may extend across international boundaries.

Embedding WatRES within a complex, systemic and dynamic framing

The framework must be cognizant of the catchment as a complex (socio-ecological) system requiring a systemic and dynamic view:

- The ecosystem services (ES) provides the basis for understanding the links between so-called ‘ecological’ on the one hand and ‘social’ systems on the other (the latter includes politics, power and governance). The derived ES benefits support human well-being in multiple ways. Understanding benefits must be explicated with stakeholder. This recognises the role of ecosystem services in understanding catchments as complex socio-ecological (SES) systems.
- Secondly, a systems view means recognising that ecosystems services are linked in a relational way that varies in space and time and that is not always predictable (due to the influences of

varying drivers and feedbacks). Equally benefits of ES are likely to accrue to *different beneficiaries in both space and time* Thus changes in practice such as through a different management class of a river – or through non-compliance – are likely to change not just one but multiple ES or *bundles of ecosystem.* Moreover, areas of ES production and consumption may be different so that impacts of changes in practice can be felt downstream and differentially by different users. The international component of this must be considered so that it is sufficiently flexible and robust to support coherence at an international scale.

A process which is stakeholder-centered and attentive to learning for transformation
This complexity highlights the need for a stakeholder-centered process that clearly articulates the learning processes within a framework for participation. The involvement of stakeholders should be at the start of such work and support a process of collaborative social learning for collective action.

A process which is iterative and which combines qualitative and quantitative approaches
The framework must allow for different 'ways of knowing' that might be partial, divergent and qualitative or quantitative in nature. The critical point is to support an iterative process that brings these epistemologies together and seeks the possibility of the sum is greater than the parts.

This framework was then tested for the Sabie-Sand Catchment through a collaborative stakeholder-centered process. Stakeholders broadly comprised two groups: catchment residents and 'specialists' (participants whose field of expertise was linked in one way or another to ecosystem services). Action research was undertaken with both groups based on an iterative process that allowed for the incremental development of concepts regarding WatRES. Both groups developed models of WatRES through concept maps as a means to develop a systemic view to WatRES. This facilitated the inclusion of linkages, feedbacks, multiple drivers and benefits. This was complimented by spatial exercises to examine production and consumption, and potential scenarios under different management practices (including non-compliance). The two groups then worked together to produce collaborative conceptual models. Consideration was also given to developing these as the basis of a quantitative systems dynamic model.

A number of conclusions were reached through this process. Firstly, the need to consider the wider management context was beneficial in a number of ways. On the one hand it compelled the team to think into both policy and practice in practical ways. For example, the setting of conditions for stakeholder engagement through national policies with seemingly simple requirements such as '*evaluating (classification) options with stakeholders*' imposes huge conceptual and logistical parameters for the way in which such processes need to be undertaken in reality. On what basis will stakeholders be able to provide meaningful inputs and engage in evaluations? Therefore what is it that stakeholders need to know to do so? How will this 'knowing' be brought to the process? And so on. Equally, seeking coherence with the evolving management tools such as the real-time WRM system being developed by the ICMA also meant ensuring methodological and technical coherence. For example, any quantitative modelling that might be required for the development of scenarios needs to be compatible with the afore-mentioned WRM system. On the other hand, being able to assure stakeholders that this work was being undertaken as part of a broader process (i.e. not just as a research project) provided the grounding for a tenable relationship between the researchers and stakeholders and between the managers and stakeholders.

Simplifying or demystifying certain terms is essential. For example, the term *ecosystem services* is not easily understandable and helping stakeholders to understand important underlying concepts is critical to a coherent process (for example, differentiating a *final service* from the underlying (intermediate) *ecosystems services, processes and functions* helps to mitigate potential conceptual confusion that can confound participatory processes). Once again as we have eluded to elsewhere, there is a need to seek the *requisite simplicity* and no more or no less (Stirzaker et al. 2010).

The view of catchments as *complex SES* underpins a number of theoretical and practical principles (see Sections 3 and 4) that guided the framework. A question was: *Did this process support the view of catchments as complex systems*? That is the recognition of linkages between ES (land and water), feedbacks in the system, the role of multiple drivers and emergence as well as the dynamic nature of the production of ES and their consumption in space and time. Using concept maps participants named ES and benefits in a linked and relational way. The following comments are offered in this regard.

- Although the system boundary is artificial selecting appropriate scales of analysis is important so that studies and processes can be bounded as internal, external, or ignored (see below).
- Any understanding of water-related ecosystem services must involve and understanding of the wider SES system. In particular WatRES are inherently influenced by landcover and landuse, as well as other drivers which may be internal or external to the 'system'.
- In terms of developing a systemic view, participants were able to
    - develop a more systemic perspective of ESs using concept maps through noting the *links between ecosystem services, between terrestrial and terrestrial-aquatic ESs, and the links to drivers and benefits in their concept maps.* This also addressed the need to understand relationships between variables;
    - think about upstream-downstream linkages where the supply of ES may be disconnected from their consumption and hence beneficiation. The use of the visualization exercise – following from a process of first working with bundles of ES – was successful at supporting participants to think about spatial characteristics and discontinuities between the production and consumption of ES; and
    - start to understand drivers in the system and their linkages and impacts in space and time by including them in the concept maps.
- Changes in a management class or any other management action (e.g. water allocation plans) of a river are likely to change not just one but multiple ES – or bundles of ES, and participants did work with *bundles of ecosystem.*
- The benefits of ES are likely to accrue to *different beneficiaries in both space and time* and understanding this requires more time.
- Further time and tools are needed to support peoples' ability internalise the dynamic nature of the systems under consideration. Dynamic modelling with a user-friendly visual interface may offer such support.

This highlights the importance of time in the learning process. Whilst the process was designed to take account of stakeholder fatigue and the limits on peoples' time and was largely successful at achieving a balance, there were certain constraints which are discussed.

A useful outcome of the process was the recognition by stakeholders that not everyone needs to be involved in every step and at a certain point participants noted that they had sufficient understanding to endorse further work by a smaller task team. This suggests that if people arrive at an informed position through a process they trust that allows them to dialogue, then certain tasks can be taken up by others. Moreover, not everyone needs to understand details but they must understand and endorse key principles and the process.

Through the process of developing a systemic model of ecosystem services, participants began to appreciate that understanding the benefits associated with river flows (such as the Reserve) is a complex task; they also began to appreciate linkages in the system so that for example, a water quality issue in one area impacts on others elsewhere. Most importantly people began to understand that they are being asked to think and act transformatively and that despite the complexity, there is a way to work through this that allows them to be invoked meaningfully. It is stressed that the starting point for understanding WatRES must be with stakeholders and their conceptualisation of the benefits and risks: only then should quantitative models be developed and used. Equally stakeholders must be supported to understand that the dynamic and uncertain nature of complex systems such as catchments requires both adaptive planning and management.

We suggest that this approach allows people to value ecosystems services as an *emergent* outcome of a process of learning and collaboration (informed by, but not restricted to, best available science). This work has also explored how ecosystems services institutions can be designed in context-specific ways that build local ownership and provide contributions to livelihoods in the context of catchments and IWRM.

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LIST OF ABBREVIATIONS

ABM	Agent-Based Modelling
ARIES	Artificial Intelligence for Ecosystem Services
BBM	Building Block Methodology
BN	Bayesian Network
CM	Concept Map
CMS	Catchment Management Strategy
DLL	Dynamic Linked Library
DRIFT	Downstream Response to Imposed Flow Transformations
DSS	Decision Support System
DWA	Department of Water Affairs
EGS	Ecosystem Goods and Services
EGSA	Ecosystem Goods, Services and Attributes
EMC	Ecological Management Class
ES	Ecosystem Services
ESF	Ecosystem Service Footprint
ESP	Ecosystem Service Partnership
EWR	Environmental Water Requirements
FSR	Flow Stressor Response
ICMA	Incomati Catchment Management Agency
InVEST	Integrated Valuation of Environmental Services and Tradeoffs
IUA	Integrated Units of Analysis
IWRM	Integrated Water Resources Management
MC	Management Class
MEA	Millennium Ecosystem Assessment
MIMES	Multi-Scale Integrated Models of Ecosystem Services
NRM	Natural Resource Management
PES	Payment for Ecosystem Services
	Present Ecological State
PRESENCE	Participatory Restoration of Ecosystem Services & Natural Capital
ProEcoserve	Project for Ecosystem Services
RA	Resilience Alliance
RC	Reference Condition (natural condition)
RDM	Resource Directed Measures
REC	Recommended Ecological Category
SAPECS	Southern African Program on Ecosystem Change and Society
SD	System Dynamics
SDC	Source Directed Controls
SES	Social-Ecological System
SRI	Shared River Initiative
TEEB	The Economics of Ecosystems and Biodiversity
WatRES	Water Related Ecosystem Services
WMA	Water Management Area
WRCS	Water Resources Classification System

1. Introduction

This report constitutes Deliverable 11 (or EGS 3) of the Shared Rivers Initiative II (WRC project K5/1920). The SRI II project of AWARD has three sub-projects: legal aspects of IWRM (completed); collective action for IWRM; and Water-related Ecosystem Services. This deliverable falls under the third of these sub-projects entitled ***A framework for understanding the benefits of meeting environmental water requirements through elaborating the distribution of ecosystems goods and services (EGS).*** As noted in the proposal, the framework will be developed through:

a. A sound conceptual grounding through a review of the literature (EGS Del 1);
b. Collaboration with key stakeholders to test the framework, namely the Inkomati CMA, DWA regional office (Mpumalanga), DWA national, and SANParks (EGS Del 1 and 3);
c. The establishment of appropriate interface with existing frameworks and approaches to ensure coherence with existing approaches as well as institutions (EGS Del 2-submitted).

After consultation, the aim of this sub-project was redrafted to place greater emphasis on stakeholder participation as the 'backbone' of the framework. The aim is thus to:

> *Develop and test a framework for the collaboration of catchment stakeholders in building a shared appreciation of the risks and benefits of meeting (or not) the ecological Reserve (EWRs) through an understanding of the associated water-related ecosystem services*.

The conceptual approach taken breaks away from current approaches to valuing ecosystems services based on the idea that (financial) values can be assigned to, or reified in, certain ecosystems processes. Rather their value is seen as the emergent outcome of a process of valuing by stakeholders informed by, but not restricted to, best available science. Moreover we explore how ecosystems services institutions can be *designed* in context specific ways that build local ownership (stakeholding) and provide contributions to livelihoods (i.e. poverty alleviation) in the context of catchments and IWRM.

Rationale

The work emerges from the SRI Phase I. The Phase I research illustrated difficulties and successes (Box 1) with respect to this transformation to an integrated approach (IWRM).

Box 1: Summary of the major factors we pointed to the following issues and made key recommendations (see Pollard and du Toit 2011 for a full discussion)

1. A generally poor understanding of the Reserve and hence failure to change practices
2. The almost total lack of integration of water resources management and supply
3. Some degree of unlawfulness but more importantly, the weak regulation of unlawful use and poor legal literacy.
4. The importance of participatory and representative platforms for collective action: their functioning and contribution to IWRM
5. Some seemingly excessive lags in the implementation of the Reserve and emergence of sustainability discourse (see WRC/ DWA consultancy)
6. Various examples of the emergence of, or lack of, self-organisation, leadership and feedback loops in adaptive action and management (see Pollard and du Toit 2011)
7. Attendant dearth of skills, capacity, monitoring and legal literacy with some exceptions.

Analysis of results indicated that securing the Reserve (as a benchmark for sustainability) is predicated on a 'bundle of strategies' that are collectively required to achieve sustainability. The framework for this is Integrated Water Resources Management which in South Africa is given effect in the development of Catchment Management Strategies (CMS) for each of the Water Management Areas (which must view the catchment as a complex, linked socio-ecological system). The formulation of CMS is still in early stages of development in South Africa but in the SRI project site, one CMS has been developed for the Inkomati WMA.

Specifically this work (WatRES) it builds on the finding of the Shared Rivers Initiative Phase I. which sought to examine factors that enable or constrain meeting the Reserve in six transboundary catchments of the lowveld. This clearly demonstrated that almost all stakeholders perceive that the benefits of measures associated with sustainability (such as implementation of the Reserve) accrue to other stakeholders whilst they carry all the risks. This poses a serious constraint to fulfilling the spirit of the transformation to sustainability and equity of water resources through stakeholder participation.

People indicated that if they comply, it is because of a legal obligation rather than because it is regarded as beneficial to them or future generations. Simplistic approaches such as 'awareness raiding' or once-off workshops where people 'participate in decision-making' are known to be inappropriate in context such as the lowveld where socio-economic are extremely varied. In part this reflects the fact that the ideas framing the acts are sophisticated requiring a shift in the discourse and the way in which people understand the system (in the case the catchment). The challenge is to find new and innovative ways to support this shift. It is unreasonable and naïve to suggest that these simplistic once off processes do this- especially in environments such as the lowveld where there are high levels of illiteracy and attendant poverty which make decisions where benefits appear to accumulate elsewhere exceptionally difficult and unlikely. The classification process is a case in point. To date it has yet to be implemented although various informal trials have demonstrated the difficulties of meaningful participation in decisions that affect peoples' development trajectories so fundamentally.

Thus the challenge is to examine what these benefits and risks associated with compliance (or non-compliance) with the policy are. The questions that emerge are: *What are the implications of not meeting the Reserve*? Or phrased another way: *What are the benefits for society of being compliant*? As researchers, the question also arises as to how best these can be communicated to effect the kind of changes needed?

The Inkomati Catchment faces such challenges currently. Results of a recently-completed WRC project indicate that the ecological Reserve is not being met in all major rivers (the Sabie, Sand, Komati, Crocodile and Komati) and this situation appears to have worsened over the last decade. This has implications not only locally but also nationally and internationally for downstream users such as Mozambique. A case in point is that of the Sand River which is extremely stressed in South Africa – placing demanding challenges on water resources managers to meet legislative requirements – but is central to livelihoods through the goods and services that its water provide to the catchment. Moreover South Africa is committed to meeting international requirements through the Inco-Maputo Accord. This is currently being further developed through the PRIMA project and it is likely that the requirements for a Reserve for Mozambique will be added to the international volumes required. This in essence is a process of negotiated benefit-sharing.

Since such scenarios are globally apparent especially around common-pool resources as demonstrated by the Millennium Ecosystem Assessment, it is imperative that we find ways of describing and sharing the implications of water resource transformations.

Interestingly, in their summary of challenges facing ecosystem services assessments, de Groot et al. (2010) point to management needs stating that "To make better decisions regarding trade-offs involved in land cover and land use change, a systematic account of the relationships between ecosystem management and the ecosystem services and values that it generates, is needed (p.264)". As noted in the last deliverable, Classification in South Africa provides just such management challenges since it requires that stakeholders chose a management class based on- amongst other factors – an understanding of ecosystem services. Choosing a management class (and associated EWR) for a river – as required under the South Africa water resources classification system (DWAF 2007a) – is a key means of capturing stakeholder desires for the condition of the river and sets the scene for management and operational decisions. Helping to understand the outcomes of this management decision requires understanding the ecosystem services that the chosen class – and EWR – generates and to whom the benefits accrue. Thus this work directly addresses this challenge posed by de Groot et al. (2010) (as well as some of the others).

Since the project focuses on water-related ecosystem services, it will be referred to by the acronym **WatRES** for brevity.

This report provides a literature review of ecosystem services (Section 2), a draft framework (Section 4) and a broad outline of testing the framework (Section 5).

2. Theoretical framing of the work: A review of ecosystem services and well-being within complex systems

2.1. A brief overview of ecosystem services

2.1.1. What are ecosystem goods and services?

Humans benefit from a range of resources and processes that are supplied by natural ecosystems. Collectively, these benefits are known as **ecosystem services** – henceforth referred to as ES in this report – and include 'goods' such as clean drinking water and processes such as the decomposition of wastes. Like the term ecosystem itself, the concept of ecosystem services is relatively recent—it was first used in the late 1960s (e.g. King 1966, Helliwell 1969) and the concept of ecosystem services has been popularized by the UNEP's *Millennium Ecosystem Assessment* where it was used as the central organizing idea. Today the concept is increasingly replacing ideas such as endangered species (McAfee and Shapiro 2010) particularly since it has wider intuitive appeal to the layperson. Research on ES has grown dramatically within the last 15 years (e.g. Costanza et al. 1997, de Groot et al. 2002, Daily et al. 2000) as the following review will demonstrate.

There are a number of definitions of ecosystem services, the most commonly used being those of Costanza et al. (1997), Daily (1997) and of the MEA which is the most widely used (Box 2). All emphasise the benefits to humans which has been questioned on the basis of intrinsic value and commoditization of ecosystems (see later). Many people believe that ecosystems have value quite apart from any human interest in explicit goods or services; Farber et al. (2002) point out that humans are only one of many species in an ecosystem and hence the values they place on ecosystems may differ significantly from the values to other species or the maintenance (health) of the ecosystem itself.

More recently ecosystem services are being understood as the contributions that ecosystems make to ***human well-being*** and this will be the orientation adopted within the proposed framework (see Section 2.2). Also most scholars and practitioners accept the term '*services' to* encompass 'goods and services' as suggested by the MEA.

Box 2: Definitions of Ecosystem Services

Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al. 1997).

Daily (1997) states that "ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life". They maintain biodiversity and the production of ecosystem goods They maintain biodiversity and the production of ecosystem goods, such as seafood, forage timber, biomass fuels, natural fiber, and many pharmaceuticals, industrial products, and their precursors (Daily 1997).

The Millennium Ecosystem Assessment (2003) regards ecosystem services as "the benefits humans obtain from nature". They categorise these as *provisioning*, such as the production of food and water; *regulating*, such as the control of climate and disease; *supporting*, such as nutrient cycles and crop pollination; and *cultural*, such as spiritual and recreational benefits.

The focus on water-related ecosystem services and issues of boundary setting
In this project the focus is on water-related – or freshwater aquatic ecosystems – of catchments which are characterized by the predominance of water and include streams, rivers, lakes, wetlands, groundwater and estuaries. The emphasis of this work was on rivers and wetlands, reflecting the focus on the Reserve or EWRs for the project site i.e. the Sand River Catchment. Nonetheless it is suggested that the proposed framework is sufficiently robust to be applied to other aquatic ecosystems. Having said this, it is also recognised that ecosystems are linked (such as between rivers and floodplains, or groundwater-surface water) and that aquatic systems do not exist in a vacuum in the catchment but are linked to terrestrial systems. Many of the functions of wetlands are influenced by the relationships with the terrestrial environment (e.g. Wetzel 2001) so that, for example, the capacity of similar wetlands to modify nutrient loads is altered significantly by the surrounding landscape (pristine versus heavily developed) (NRC 2004). Equally boundaries are not static but may vary in space and time such as under flood conditions. Thus 'aquatic systems' refers to freshwater aquatic and related terrestrial ecosystems unless otherwise stated.

2.1.2. Understanding ecosystem structure and function as the basis for assessing ecosystem services

Ecosystem structure and function (Box 3) provide various ***ecosystem goods and services*** to humans that have value: for example, 'goods' such as drinking water or fish for food. The functioning of ecosystems (interaction of organisms and the physical environment) often provides for 'services' such as water purification, recharge of groundwater, flood control, and various aesthetic qualities such as pristine mountain streams or wilderness areas. Note that the MA considers all these benefits together as "ecosystem services" because of difficulties at times in differentiating some benefits as a "good" or a "service." They point out that also cultural values and other intangible benefits are sometimes forgotten when people refer to "ecosystem goods and services,"

The translation from ecosystem structure and function to ecosystem (goods and) services is given by an *ecological production function*, whilst the translation from ES to an (economic) value is given by an *economic valuation function*[1]. In some cases the structure of the ecosystem is valued directly by humans, without the intermediation of functions, goods or services. For example, people may value the existence of forests in their own right – as an intrinsic value – rather than because of any functions or ES that they might provide.

Box 3: Ecosystem Structure and function (from NRC 2004)

Ecosystem structure refers to both the composition of the ecosystem (i.e. its various parts) and the physical and biological organization defining how those parts are organized.

Ecosystem function[2] describes the collective interactions of the biota (e.g. primary and secondary production), mutualistic relationships, interactions between organisms and the physical environment (e.g. nutrient cycling, soil development, water budgeting). The net ***primary production*** in an ecosystem is determined by the number and kinds of plants present; the amounts of sunlight, nutrients, and water available; and the amount of this productivity used internally by the plants themselves

Despite the importance of intrinsic values, the identification of ecosystem structure and function is regarded as a reasonable starting point for the mapping of ES (NRC 2004). However the same authors make the point that mapping ES does not proceed linearly from system structure because for example, ecosystem structure alone is not an adequate predictor of say, biotic habitat services.

Production functions try to establish a relationship between ecosystem condition and the capacity to perform certain functions, although again, the natural variability of the system confounds simple inferences from condition. Classification of aquatic ecosystems (e.g. the HydroGeomorphic Method for wetlands and streams) is a starting point but do not purport to show direct inferences about ecological functions. So although describing the structure of an aquatic ecosystem now has relatively well-defined protocols (such as plant composition, water movement and soil characteristics for wetlands) assessing the **level of function** is exceptionally complex. Moreover another factor affecting the level of function is

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[1] Estimating the value of ecosystem services requires uncovering both the ecological production function and the economic valuation function

[2] Although a distinction is not always made, *ecosystem function* can be distinguished from *ecosystem process*. *Ecosystem process* refers to mechanistic processes such decomposition or resource use that are carried out by fauna and which regulate the observed level of *ecosystem function* such as nutrient cycling or primary productivity.

the inherent variability in terms of biological or physical composition so that whilst all wetlands for example may modulate water quality the significance of the process can vary depending on its size, location and type. Also time can influence the functions performed so that seasonal changes in the aquatic ecosystem (e.g. low-flows versus floods in rivers) for example, will influence its ability to perform certain functions.

The NRC go on to point out that the default response to this conundrum has been the development of generalized list of potential functions for broad categories of aquatic ecosystems, the scope of which varies and is continually evolving. They use the example of wetland functions which, in the 1970s, included:

- Production of plant biomass,
- Provision of habitat,
- Modification of water quality,
- Flood storage, and
- Sediment accumulation.

The list has now expanded to include:

- Global carbon cycles,
- Maintenance of biodiversity, and
- Global climate control.

In the absence of a universal approach (or even paradigm), the practical approach is to work from an evolving list of potential ecosystem functions (such as those of de Groot et al. 2002, or the MEA 2003) and evaluate the capacity of the system under consideration to perform each function. Essential to the process is incorporation of both spatial and temporal considerations in developing the ecosystem assessment. The NRC point out that a 'perfect taxonomy' may be less important than developing a consensus on an appropriate cumulative list of potential aquatic ecosystem functions, such as that of de Groot et al. (2000, 2002) who suggest that the cumulative list of ecosystem functions can be grouped into four primary categories[3]: (1) regulation, (2) habitat, (3) production, and (4) information (see Table 1).

[3] Note the categories for Ecosystem Services (1) Supporting. (2) Regulating, (3) Provisioning and (4) Cultural (see next section)

Table 1. Functions Natural and Semi-natural Ecosystems (Adapted from de Groot et al. 2002)

Functions	**Specific function**
Regulation	
Maintenance of essential ecological processes and life support systems. Includes those processes affecting gas concentrations, water supply, nutrient cycling, waste assimilation, and population levels	- Gas regulation - Climate regulation - Disturbance prevention - Water regulation - Water supply - Soil retention - Soil formation - Nutrient regulation - Waste treatment - Pollination - Biological control
Habitat	
Provision of suitable living space for an ecosystem's flora and fauna	- Refugium - Nursery
Production	
Provision of natural resources. Includes primary (autotrophic) and secondary (heterotrophic) production, and generation of genetic material and biochemical substances.	- Food - Raw materials - Genetic resources - Medicinal resources - Ornamental resources
Information	
Provide an opportunity for cognitive development and, as such, are functions that can be realized only through human interaction	- Aesthetic - Recreation - Cultural and artistic - Spiritual and historic - Science and education

2.1.3. Classifying Ecosystem Services

Like ecosystem functions, various typologies of ecosystem services have been developed and the list is continually evolving. For example, services are sometimes grouped into categories such as consumptive and non-consumptive, or direct and indirect (extractive and non-extractive), or intermediate and final. In some instances the issue of classification is polemic as scholars struggle to understand and distinguish the ends from the means. Some such as Wallace (2007) have called for a universal classification system but this has been strongly criticized by Costanza (2008) who asserts that such attempts aim at a gross oversimplification of an inherently nuanced field. As he points out, some ES may be intermediate in one case and final in another. He critiques Wallace's demand for a single classification and asserts that a pluralism of typologies better suites our uncertain world. With this in mind, a brief overview of the various typologies and their development follows.

Some such as (de Groot et al. 2002) have attempted to articulate the link between ecosystem functions and the derived goods and services. The Millennium Ecosystem Assessment (MEA) adopted a taxonomy of ecosystem services drawn from the de Groot et al. (2002) construct (*http://www.millenniumassessment.org/en /index.asp*). After considering a number of alternative schemes for grouping ecosystem services, the approach based on function was selected for use in the MEA. In this particular iteration, services are classified as provisioning, regulating, cultural, or supporting (see Table 2).

Table 2. The MEA framework

Services	**Comments and Examples**
Provisioning	
Food	production of fish, wild game, fruits, and grains
Fresh water	storage and retention of water for domestic, industrial, and agricultural use
Fiber and fuel	production of logs, fuelwood, peat, fodder
Biochemical	extraction of medicines and other materials from biota
Genetic materials	genes for resistance to plant pathogens, ornamental species, and so on
Regulating	
Climate regulation,	source of and sink for greenhouse gases; influence local and regional temperature precipitation, and other climatic processes
Water regulation (hydrological flows)	groundwater recharge/discharge
Water purification & waste treatment	retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	retention of soils and sediments
Natural hazard regulation	flood control, storm protection
Pollination	habitat for pollinators
Cultural	
Spiritual and inspirational	source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems
Recreational	opportunities for recreational activities
Aesthetic	many people find beauty or aesthetic value in aspects of wetland ecosystems
Educational	opportunities for formal and informal education and training
Supporting	
Soil formation	sediment retention and accumulation of organic matter
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients

Nonetheless, it is also recognised that the related four categories of supporting, provisioning, regulating and cultural services of the MA are not always appropriate (Seppelt et al. 2011). As work on ES has progressed and as scholars have tried to clarify and refine the concept in practice, the categorization of ecosystem services has received increasing attention. As noted, the conundrum centers on distinguishing the ends from the means, and groups of researchers have attempted to tackle this in different ways. If, as stressed by Fisher and Turner (2008), ecosystem services must have a direct relation to human well-being to be considered a service then, they argue, there is a need for a clear distinction between the ends (i.e. the service) and means if ecosystem services are to be operationalised. For example some authors distinguish between ecosystem ***functions***, ***services*** and ***benefits*** (de Groot et al. 2010, Haines-Young and Potschin 2010, Burkhard et al. 2010). Under this definition, nutrient cycling for example, is an ecological function, not an ecosystem service (Boyd and Banzhaf 2007). In keeping with the need for greater specificity, Boyd and Banzhaf (2007) introduced the term *final ecosystem services* which are components of nature directly enjoyed, consumed or used to generate human well-being. They suggest that most of the other components and functions of an ecosystem would then be intermediate products – or intermediate services. However they caution that the distinction between intermediate and final services is often subjective and observer-based and furthermore depends on the context and question at hand (Costanza 2008). Nonetheless, the point is made that attention to such distinctions is necessary when taking the concept forward.

To try to address this, Müller and Burkhard (2007) have proposed and tested (Burkhard et al. 2011) a framework which integrates the concept of ecological integrity as the base for the supply of regulating, provisioning and cultural ecosystem services. In other words, the concept of ecological integrity is the proxy for ecological function, although how precisely this advances the debate is somewhat unclear. Burkhard et al. (2011) state that "Ecological integrity means the preservation against non-specific ecological risks that are general disturbances of the self-organizing capacity of ecological systems. This self-organizing capacity is based on structures and processes in ecosystems, and appropriate indicators for their description have been defined and applied in several case studies (Müller 2005, Burkhard and Müller 2008)".

In contrast, Balmford et al. (2008) use the following terms to classify ES: "core ecosystem process" (e.g. production, decomposition, nutrient & water cycling), "beneficial ecosystem process" (e.g. biomass production, pollination, biological control, habitat and waste assimilation), and "benefit" (e.g. food, fresh water, raw, materials, energy and wellbeing).

Despite this, de Groot et al. (2010) point out that there is still significant debate regarding the distinction between ecosystem functions and services, and how to classify the services so as to quantify them in a in a consistent manner (e.g. Wallace 2007, Fisher et al. 2009). They point to the growing consensus that ecosystem services are generated by ecosystem functions which in turn are underpinned by biophysical structures and processes – called "supporting services" by the MEA (MEA 2005). Ecosystem functions are thus intermediate between ecosystem processes and services, as shown in Figure 1. Actual use of a good or service provides benefits (nutrition, health, pleasure, etc.) which can be valued in economic terms and monetary terms (but will not be the subject of this report).

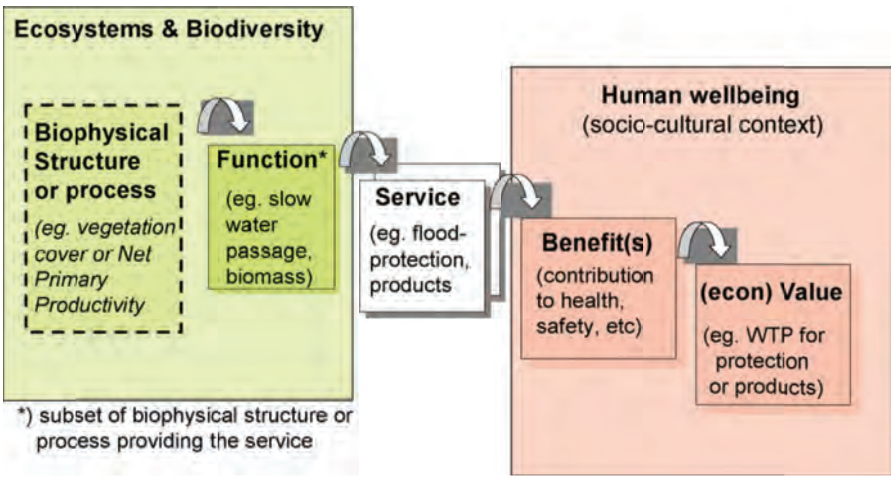

Figure 1. Framework for linking ecosystems to human wellbeing (from de Groot et al. 2010, adapted from Haines-Young and Potschin 2010)

In their summary of some of the major challenges confronting the study and assessment of ES, de Groot et al. (2010) point out that quantitative relationship between biodiversity, ecosystem components and processes and services is still poorly understood. They assert that to do this criteria and **indicators** are needed to comprehensively describe the interaction between the ecological processes and components of an ecosystem and their services, and provide examples of two types of indicators needed: state and performance indicators. *State indicators* describe what ecosystem process or component is providing the service and how much (e.g. total biomass or leaf area index) whilst *performance indicators* describe how much of the service can potentially be used in a sustainable way (e.g. maximum sustainable harvest of biomass or the effect of LAI on air-quality). In terms of this project, many of the indicators[4] would actually be developed as part of the dynamic modelling so that for example 'available freshwater' would be described and quantified using an appropriate measure or indicator (litres; m^3/ha; m^3/s).

2.1.4. The supply and consumption of ES

Land use and management affect the system properties, processes and components that are the basis of service provision and a change in these will affect the complete bundle of services provided by the (eco)system (de Groot et al. 2010). Likewise in the focus of this research project, land use and water use and management (e.g. classification- see later) will affect the delivery of the ecological Reserve (or EWRs) and hence the supply of ES. These factors are termed stressors by some (e.g. Brinson 1993) and drivers by others (for example in systems work).

Burkhard et al. (2011) also stress three related concepts which resonate with those used in the water sector: supply and demand and the heuristic of a footprint (which relates to the area required to generate a particular demand). They note that land use and related land cover modifications have a strong impact on ecological integrity and that such changes in ecological integrity lead to increasing or decreasing *supplies* of selected or bundles of ecosystem services on which humans depend. If the supply of ecosystem services is changed, the demands may not be met. They use the following definitions.

- **Supply** of ecosystem services refers to the capacity of a particular area to provide a specific bundle of ecosystem goods and services within a given time period. Here, capacity refers to the generation of the *actually used* set of natural resources and services. Thus, it is not similar to the *potential* supply of ecosystem services in a certain ecosystem, which would be the *hypothetical maximum yield* of selected optimized services.
- **Demand** for ecosystem services is the sum of all ecosystem goods and services *currently* consumed or used (this is different to water sector) in a particular area over a given time period. Up to now, demands are assessed not considering where ecosystem services actually are provided. These detailed provision patterns are part of the
- **Ecosystem service footprint** which (ESF, closely related to the ecological footprint's concept; Rees, 1992) calculates the area needed to generate particular ecosystem goods and services demanded by humans in a certain area in a certain time. Different aspects of ecosystem service generation are considered (production capacities, waste absorption, etc.).

The ESF recognises an important point- particularly in relation to rivers – which is that the origin and consumption of ES may be very different. This is even more true in a world of increasing complexity and

[4] See Deliverable 1

globalization. Consequently, the environmental impacts of ecosystem service generation are exported and leave a biodiversity and ecosystem service footprint elsewhere (Burkhard and Kroll 2010). Indeed, few approaches exist which deal with the relations between local demands and ecosystem service provision elsewhere (Seppelt et al. 2011) Finding an acceptable and equitable level of ecosystem service footprints and an appropriate balance of local ecosystem service supply and demand are important steps toward sustainability.

2.2. A brief overview of well-being

There have been many descriptions and definitions of human well-being but most agree that it includes basic material needs for a good life, the experience of freedom, health, personal security, and good social relations (Alkire 2002). Collectively, these provide the conditions for physical, social, psychological, and spiritual fulfillment.

Some of the same distinctions discussed previously regarding a distinction between the means and the end apply equally in the field of well-being. For example, Dasgupta (2001) views well-being as an end – as being experiential in what people value being and doing. The determinants of or means to this are sometimes expressed as *commodity inputs* many of which are provided by ecosystem services. Equally an enabling environment (environmental and social conditions) is also important determinants of or means to well-being. As with ecosystems services the plurality of terms applies to well-being where some elements can be both determinants and ends. For example, health can be both an end in itself or can be the means to experience (psychological) well-being.

Notwithstanding this, there is widespread agreement that well-being and poverty (or ill-being) are the two extremes of a multidimensional continuum (MEA 2005). In fact, the *World Development Report 2000/01* defined poverty as “the pronounced deprivation of well-being” (WorldBank 2001). Context and situation is central to understanding how well-being (or ill-being or poverty), is expressed and experienced (Prescott-Allen 2001). Work by Narayan et al. (2000) indicated five linked components which are now often used to describe well-being:

1. The necessary material for a good life (including secure and adequate livelihoods, income and assets, enough food at all times, shelter, furniture, clothing, and access to goods);
2. Health (including being strong, feeling well, and having a healthy physical environment);
3. Good social relations (including social cohesion, mutual respect, good gender and family relations, and the ability to help others and provide for children);
4. Security (including secure access to natural and other resources, safety of person and possessions, and living in a predictable and controllable environment with security from natural and human-made disasters); and
5. Freedom and choice (including having control over what happens and being able to achieve what a person values doing or being).

These five dimensions reinforce each other, whether positively or negatively.

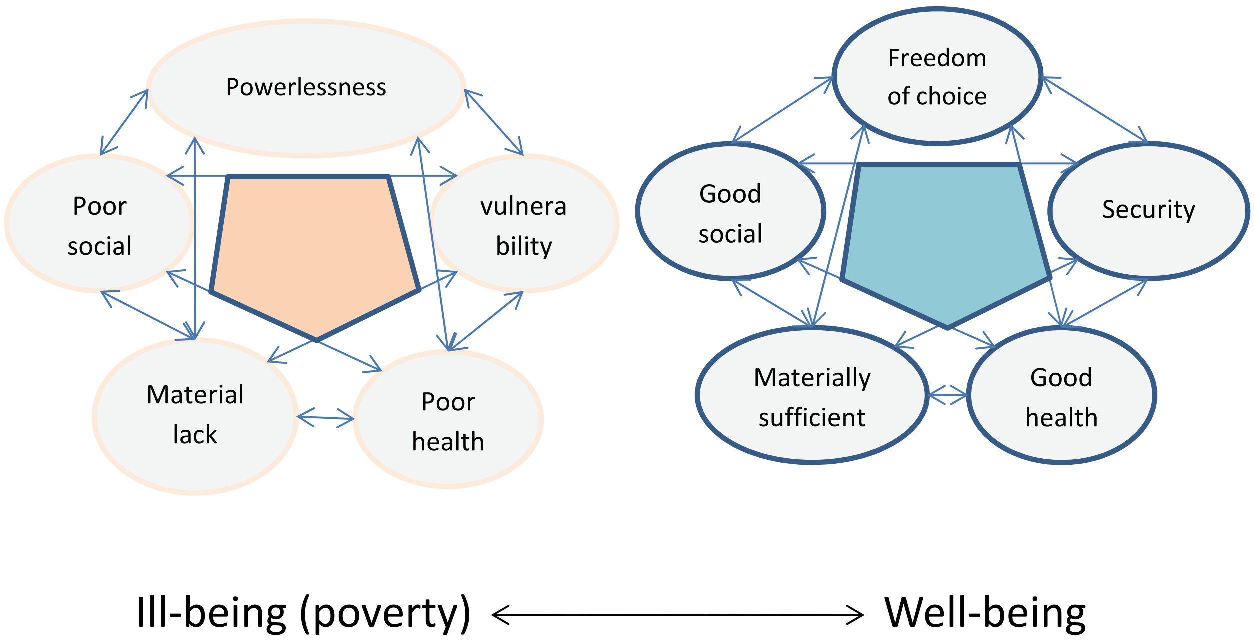

Figure 2. Key dimensions of well-being and ill-being (adapted from Narayan et al. 2000, MEA 2005)

This view indicates the links with another important concept, that of livelihoods[5] which has been reviewed elsewhere (Pollard et al. 2009). However the livelihoods framework also emphasises ecosystem services through a recognition of 5 capitals: natural, financial, social, human and physical. A livelihood that is resilient is understood to contribute to increased well-being.

The concept (or a set of concepts) of well-being has come to broaden the utilitarian vision of welfare as a measure of quality of one's life and GDP/GNP as a measure of society's progression. According to Eckersley (2006), a shift from 'wealth-producing economy' to 'health-creating society' was inaugurated by the recognition of the concept of sustainable development. It put together the requirements of economy growth with environmental sustainability and social basis of health and happiness. "The concepts of well-being and quality of life refer to evaluative judgements about selected aspects or the entirety of a life situation or life path, for an individual, group or society" (Gasper 2010).

2.3. The recognition of catchments as complex systems

The recognition of catchments as complex systems has a number of implications for WatRES, thereby establishing some important framework parameters, which are summarised herewith (see Pollard et al. 2007 for a detailed description).

Two interrelated conceptual frameworks underpin this work – systems thinking and complexity theory. Complexity theory is part of a wider body of systems thinking (see for example Von Bertalanffy 1972, Checkland 1981, Forrester 1992, Holland 1992) that arose as a critique to the reductionist approaches of

[5] A livelihood comprises the capabilities, assets, and activities required for a means of living; a livelihood is deemed sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities, assets, and activities both now and in the future, while not undermining the natural resource base (Scoones 1998).

the conventional scientific method, considered to be ill-equipped to deal with complex inter-dependencies such as those found in natural resources management (NRM). These foster a broader view of overall context, challenging conventional notions of optimization, 'maximum sustainable yield' and linear thinking (see for example Gunderson et al. 1995, Cilliers 1998, Levin 1999, Holling 2001, Folke et al. 2002, Gunderson and Holling 2002, Walker et al. 2002b, Folke 2003, Allison and Hobbs 2004, Walker et al. 2004, Walker and Salt 2006). Meppen and Bourke (1999) point out that conventional NRM unrealistically abstracts disciplinary interests from real-world complexity, a critique applicable to most single-discipline approaches.

Associated with systems thinking and complexity science is the evolution of systems approaches which attempts to view the world in terms of integrated systems, focusing on the whole, and the complex interrelationships among its constituent parts. As noted by Laszlo and Krippner (1998) this way of seeing is not an alternative, but a complement, to specialized views and incorporates the specialized perspectives as one aspect of a general conception. Important concepts contained in systems approaches include interdependence, holism and emergence, goal-seeking behaviour, feedbacks and regulation, hierarchy, differentiation, equifinality (alternative ways of attaining the same objectives (convergence) and multifinality (attaining alternative objectives from the same inputs (divergence). These concepts are reviewed by a number of authors (for example Forrester 1992, Cilliers 2000, Heylighen et al. 2007).
A related concept is that of resilience and South Africa's water law and classification system implicitly seeks to ensure resilience through establishing three management classes that are considered acceptable (see Table 3). The Resilience Alliance or RA (http://resalliance.org) has popularised the handling of complexity through the concept of *resilience.* A central tenet is the need to embrace variation as this absorbs shocks and confers resilience. Importantly, a focus on resilience shifts the attention from purely growth and efficiency to recovery and flexibility which allows for learning and adaptation. A number of attributes confer resilience including feedbacks, diversity, innovation, polycentric and overlapping governance, social capital, ecological variability, openness, and reserves (Walker and Salt 2006, Resilience Alliance 2007). In this study we were particularly interested in feedback loops and their potential for understanding systemic issues associated with NRM (Pollard and Du Toit 2011). Feedbacks, often because of operation at different scales, cause *emergence*. Feedbacks describe situations when the output from an event or phenomenon in the past will influence an occurrence of the same in the present or future (Holland 1999). *Resilience analysis* elucidates how linked social-ecological systems respond and adapt in the face of disturbance events such as changes in land-use (Walker et al. 2002a), and identifies the key social and ecological variables that determine the status of a system, as well as thresholds. This also helps develop strategies that will help systems to recover following disturbance.

The implications for WatRES fundamentally relate to the recognition of dynamics and uncertainty across spatial and temporal scales and a range of associated properties. In particular we emphasise:

- Boundary setting
- Spatial and temporal dynamism
- Linkages and interdependency
- Drivers (across scales)
- Feedbacks
- Emergence
- Thresholds
- Learning and adaptability

This means that catchments (as the focus of this work) are complex systems expressing the multiple, cross-scale and varying influence of drivers[6], the outcomes of which (in this case ES benefits) are inter-linked (inter-dependent) and vary in space and time (and to different beneficiaries), and hence display feedbacks, emergence and – at times – thresholds transitions and state changes (regime shifts). This requires a certain type of learning (learning-by-doing and for adaptability) and management (adaptive management). Each of these will be elaborated below as background to the process and tools required (of which system dynamics is one).

2.3.1. Boundary setting and system description

In the study of 'systems' it is recognised that the naming of a 'system' (such as a catchment) is simply as a model created to support understanding, and hence system boundaries are artificial. Nonetheless, the selection of boundaries is not arbitrary but rather designed to suite the purpose of the work (see Ulrich and Reynolds 2010) so that studies and processes can be bounded as internal, external, or ignored (see Allison and Hobbs 2004).

Given the focus on catchment water security and ecosystem services, and in keeping with South African water resource management approaches, the catchment – or some sub-unit thereof – is likely to represent the spatial boundary for work such as that envisaged within WatRES. Moreover both the Classification and Reserve determination processes require delineation of internal geographic sub-divisions (namely Integrated Units of Analysis and Resource Units respectively) with which consistency must be sought. In particular the Integrated Units of Analysis or IUAs have particular bearing (see Section 5.2.3) since under the Water Resources Classification System (DWAF 2007a), ecosystem services are to be determined for each IUA.

2.3.2. Linkages and interdependency

Examining the ES at a catchment scale means recognition of inter-linkages and dependencies – between ecosystem services themselves (land a water) and services and drivers. As stressed by the Millennium Ecosystem Assessment (2005), it's the connections between services and ecosystem processes that are, in the long run, often critical for the maintenance of ecosystem health and human well-being. This reflects the fact that changes in one ES are likely to have knock-on or cascade effects, reverberating in the production of other services and benefits.

There are numerous implications of this.

- Firstly, since changes in a management class (see Table 3) of a river are likely to change not just one but multiple ES, the focus needs to be on *bundles of ecosystem* services deriving from the Reserve. Undoubtedly the challenges facing such an approach (the lack of production functions, the complexity of modelling this) mean that initially at least, certain ES will have to be prioritized. When modelling multiple services, the scale of data resolution needed corresponds to the most finely detailed ecosystem service model (Tallis and Polasky 2009).
- Secondly, this highlights the need to understand the *links between terrestrial and terrestrial-aquatic* ESs. Since landcover and land-use impact on the supply of ES (see Groot et al. 2010)

[6] These can be social, political, technical, or environmental in nature and external or internal to 'the bounded system'

these relationships need to be explicated. (Far fewer scholars have emphasized the water-use also impacts the supply of ES which must also be considered).

- Both of the above talk to the need to understand *relationships between variables*
- A third dynamic is between upstream-downstream linkages where the supply of ES may be disconnected from the provision of services. This means that the framework needs to be *spatially explicit*. This means understanding the location of production and the scale of distribution (see below).
- A fourth issue pertaining to interconnections is the ability to understand drivers in the system and their linkages and impacts in space and time (see Section 2.3.3).

2.3.3. Spatial and temporal dynamism

Further to the discussion above, there are a number of details regarding spatial and temporal dynamics that were considered for WatRES:

- Spatial dynamics – as noted, the *location and scale* of the provision of ecosystem services may be different to or disconnected from the scale and location of the beneficiaries.
- Equally there may be a *temporal disconnect* between provision and beneficiation or provision (e.g. generated in spring but realised in winter) or
- Temporal dynamics – there will be *temporal differences* in the production of ES (e.g. time (e.g. between seasons and years).

Because of the complexity this introduces, and given the context of semi-arid lowveld rivers in South Africa where low flows or flow cessation is the major issue (as opposed to floods), the initial focus was on dry-season (winter) provision of ES i.e. exploring the ES of base flows.

- The benefits of ES are likely to accrue to *different beneficiaries in both space and time*. Thus another important consideration for modelling is to be able to consider the provision of ES to different sectors in different parts of the catchment (spatially explicit in terms of supply and provision).

Given these considerations, any attempts tm quantitatively model WatRES would require the ability to handle spatially explicit data in terms of both supply and consumption and to different users.

2.3.4. Feedbacks

An examination of feedbacks is important to understand the complex and coupled nature of ES within complex systems. Feedbacks describe situations when the output from an event or phenomenon in the past will influence an occurrence of the same in the present or future. A *feedback loop* is the causal path that leads from the initial generation of the feedback signal to the subsequent modification of the event either as reinforcing (increasing the input) or balancing (reducing the input) loops. An examination of the nature of complexity and the role of feedbacks has underpinned some of the major theoretical shifts such as for example, in the field of economics (see for example Ormerod's (1997) critique of economics).

Feedbacks have been examined both in biophysical and social systems (e.g. networks of agents) but less attention has been paid to their emergence and role in the management of complex systems such as catchments, particularly within the context of water governance (Pollard and du Toit 2011).

2.3.5. Drivers (across scales)

Importantly the patterns that emerge of the system are influenced by a suite of drivers which may be within or 'external to the system of study. For example, the need to create cheap labour pools to service the mining industry (Beinart 2001) in South Africa during the apartheid regime resulted in an outmigration of men, greater livelihood insecurity and hence remaining families turning to marginal areas for food production (Pollard et al. 2008a). Resultant resource stripping in some areas would have influenced the supply of ES. As Cilliers (2000) stresses, this illustrates that in order to explore change in beneficiation, one needs to understand history, drivers and lags Also it is important to recognise that (a) drivers may be social economic, ecological or political in nature and (b) they are likely to change in space and time.

A number of tools exist to explicate drivers such as timelines and causal loop diagrams (see Pollard et al in prep). In complex systems, the '3-8 rule of hand[7]' is often used to identify critical drivers (see Allison and Hobbs 2004).

2.3.6. Emergence

Feedbacks, often because of operation at different scales, cause *emergence*; that is the feedbacks generate surprising new properties not predictable from the original components making up the system. A simple but effective example of emergence is the way in which words strung together make up a sentence with an emergent meaning, not directly evident from the meaning of the individual words. This unpredictability moves the study of SESs firmly into the world of complexity. In such systems an important example is that of self-organisation in management and practices where, as described by Pollard and du Toit (2011), (feedbacks) water-users collaborate around a resource issue (water shortages) and come to a management solution in a process of self-organisation. Such outcomes are not necessarily predicable from an original understanding of water-users per se but are rather an emergent property of that system at that time. Thus as Cilliers (1998, citing Lyotard (1984)) points out, self-organisation in social networks is not a designed characteristic but is rather emergent in response to contingent information in a dynamic way. Importantly features such as self-organisation are critical for issues such as sustainable resource management and need to be examined.

2.3.7. Thresholds

Drivers invariably vary in strength over space and time, producing different combinations of outcomes. At a certain range (called a threshold) in the values of these different drivers, systems can fundamentally change their nature, say from grassland to savanna, or from family to sibling kinship networks. In practice this usually takes place as a series of linked thresholds and system states, called a regime, and a regime shift follows (see amongst others Folke 2003, Scheffer and Carpenter 2003, Carpenter et al. 2001, Carpenter 2003). An example of a regime shift is the change in the nature of rivers in the lowveld from bedrock-influenced, higher-flow, and with lower human utilisation to lluvium-dominated, lower flow, and with higher levels of human abstraction. A series of interlinked thresholds is crossed in each of these

[7] where less than three means one has likely over-simplified the system and more than eight means that the critical drivers are hidden in an over-enumerated set of drivers

factors, leading to a different overall state. Essentially in a new state the rules-of-the-game – or underlying processes – change.

2.3.8. Stakeholder engagement, learning and adaptability

In deriving a systemic conceptualisation, or model, of the linked ES and benefits of a system – as is proposed through this framework it is important to recognise that this is merely an acceptable representation of reality – not the truth (Ison 2011). What one group of stakeholders may arrive at as a tenable depiction of the system of interest may be quite different to that developed by another group. The important point is that any such model is ultimately a heuristic to help people understand – collectively – complex systems and in this case, the potential outcomes of management decisions. We also know that stakeholders need to be involved in devising management options and actions because the success of a management decision – such as operationalising a management class for a river – *depends on the actions of the stakeholders*. For example, the lack of adherence of one individual to the conditions of their water use license can 'upset the apple cart' by shifting the system to another MC and rendering the system non-compliant. This is particularly true in under-resourced situations like South Africa where the regulator simply does not have the capacity to regulate at a micro-scale and hence relies on self-regulation (Pollard and du Toit 2011).

Given this background it is critical that stakeholders participate in the development of a model to understand what the Reserve delivers (or not) – namely the ecosystems services. Thus stakeholders need to be part of the process from the outset. This does not mean that the 'core' team does not prepare themselves adequately through a thorough understanding of concepts and even a prototype but that they are open to major changes in their own thinking so that they are not locked in to a trap of thinking they hold 'the truth'. It also requires that the team facilitates discussions through constructive probing and questioning (e.g. about relationships between variables) in a way that supports learning rather that setting up a dynamic between those that 'know' and those that 'do not'. This is also important in the context of South African water policy where the management classes and associated Reserve (EWR) are merely hypotheses that still need to be tracked and evaluated.

In this regard it is recognised that people are often brought into stakeholder processes without adequate conceptual orientation thereby immediately setting up power differentials (as is happening on the Olifants Classification). This has been termed by some as *symbolic violence*; a seemingly dramatic term but nonetheless one which emphasises that if people do not have the basic grounding they cannot participate. Thus we propose that under this framework, people are given the opportunity to become familiar with some of the key concepts.

2.3.9. Scenarios to envision futures

As noted, a systems view is not *the* truth – rather it is simply a model or heuristic of what is known about the system which, through representation and narrative, can suggest potential constraints, bottle necks, and feedbacks and in turn, enrich managerial responses and stakeholder dialogue. In this vein stakeholders need to be supported to envision consequences (e.g. switching from one MC to another or the implications of non-compliance). Any model needs to be sufficiently flexible to be able to consider such a *number of different WRM scenarios* (which could later extend to considerations of land-based actions and NRM decisions).

In South Africa, the main EWR methods explicitly consider scenarios as an outcome. DRIFT in particular emphasizes the production of scenarios to assist decision-making and given the efforts within EWR methods over the last decade as well as the clear links between this project and Reserve determination studies, coherence must be sought between these methods and approaches. A number of the authors of DRIFT have welcomed the opportunity and specifically the opportunity to consider feedbacks, a component that is not built into DRIFT (King and Brown 2012 pers comm.).

3. Institutionalising ecosystem services: An overview of related initiatives and projects

Substantial research effort is currently underway nationally and internationally on ecosystem services. Nonetheless, it appears that a coherent and integrated approach to operationalise the concept in planning, management and decision-making is still lacking (ICSU et al. 2008). Given this background, this project examined potential projects and initiatives that are important to consider in terms of their linkages details of which are given in Deliverable 2 and summarised herewith.

In particular, research related to freshwater aquatic ecosystem services in South Africa is situated within a particular institutional reality given by the National Water Act (1998), and relating specifically to water resources protection and management within the context of integrated water resources management. This review therefore starts with this background in order to frame the work. Within this context various operational efforts are underway many of which relate to IWRM in the Inkomati Water Management Area (WMA) into which the test study site, the Sand River Catchment falls and the review then addresses these. We then turn to specific projects that are examining ecosystem services, first within South Africa and then internationally. The review closes with a summary of points to consider in the current WRC project.

3.1. Integrated Water Resources management: Classification, the Reserve and RQOs

As outlined in deliverable 2, the WatRES project must be explicitly linked to integrated water resources management (IWRM) in South Africa for it to be contextually relevant (see NWA 1998, DWA 2007a, Pollard and du Toit 2007). Specifically IWRM comprises two key strategic areas that deal directly with water resources:

- Resource Directed measures (RDM) aimed at the protection of water resources as described in Chapter 3 of the NWA; and
- Source Directed Controls which deal with the allocation and authorisation of water use.

The former consists of three core areas with which WatRES has direct links:

- Classification of the water resource
- Determination of the Reserve (ecological and basic human needs) – or Environmental Water Requirements;
- Setting of Resource Quality Objectives.

In its entirety, the overarching process is classification, the outcome of which comprises the setting of a Management Class (MC), and the associated Reserve and Resource Quality Objectives (RQOs) by the Minister or delegated authority for every significant water resource (watercourse, surface water, estuary, or aquifer; DWAF 2007a). WatRES is firmly embedded within the classification process as outlined below.

The *Classification Process* involves determining the current class and then setting a desired MC with stakeholders (Table 3). The MC outlines the attributes required of different water resources by the resource custodian (DWA) and society and the extent to which they can be utilised. In other words, the MC of a resource sets the boundaries for the volume, distribution and quality of the Reserve and RQOs, and *therefore informs the determination of the allocatable portion* of a water resource for use. Clearly, this has considerable economic, social and ecological implications. Establishing the MC is a collaborative process. The MC outcome is binding on all authorities or institutions when exercising any power, or performing any duty under the NWA.

There are three classes, ranging from the minimally used to the heavily used (see Table 3 and Figure 3). A class of IV (poor) is not acceptable and measures must be taken to move the class to a III.

Table 3. Proposed water resource classes

Class I: Minimally used
The configuration of ecological categories of the water resources within a catchment results in an overall water resource condition that is minimally altered from its pre-development condition.
Class II: Moderately used
The configuration of ecological categories of the water resources within a catchment results in an overall water resource condition that is moderately altered from its predevelopment condition.
Class III: Heavily used
The configuration of ecological categories of the water resources within a catchment results in an overall water resource condition that is significantly altered from its predevelopment condition.

The procedure:
To determine the class of a water resource, the WRCS lays out a seven-step procedure or methodology for determining different classes of water resources that must be followed (Box 4). Details of these steps are given in Deliverable 1 and are important in terms of understanding the interface for the WatRES work.

Box 4: The 7-step procedure for determining different classes of water resources as laid out in the WRCS (DWAF 2007a)

Step 1: Delineate the units of analysis and describe the status quo of the water resource(s);
Step 2: Link the socio-economic and ecological value and condition of the water resource(s);
Step 3: Quantify the ecological water requirements and changes in non-water quality[8] ecosystem goods, services and attributes;
Step 4: Determine an ecologically sustainable base configuration scenario;
Step 5: Evaluate scenarios within the integrated water resource management process;
Step 6: Evaluate the scenarios with stakeholders; and
Step 7: Gazette and implement the class configuration.

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[8] This statement was originally included because the Department did not water to be used for the dilution of water quality issues. However recent questions on this suggest that this probably needs revision as the concern was conflated with the concept of ecosystem services (Prof. T. Palmer, UCWQM, Rhodes, 16th August 2012, pers. comm

The WRCS is quite unclear in some of the terminology used. For example, they introduce the term EGSA Ecosystem Goods, Services and Attributes (DWAF 2007b). The introduction of Attributes for example (to denote aspects such as biological diversity and scenic beauty) which is not consistent with terms used by other scholars and can be dealt with under current frameworks (see Deliverable 1).

Steps 2 and 3 have direct bearing on the ES work although the terms used in the WRCS documentation are less than helpful. For example,
Step 2 entails:
- *Selecting the ecosystem values to be considered based on ecological and economic data;*
- Describing the relationships that determine how economic value and social wellbeing are influenced by the ecosystem characteristics and the sectoral use of water;

Quite what ecosystem values are is unclear (although this seems to be part of the economic valuation as suggested in the WRCS volume 3, P. 64). Although unclear in the WRCs volume 1, it is in this step (i.e. Step 2 see above) that Ginsburg et al. (2010) have interpreted to involve the selection of the EGSA (see their Figure 4, P. 49).

Step 3c also has bearing for ES as follows:

> *Quantify the changes in relevant ecosystem components*[9]*, functions and attributes for each ecological category for each node.*

Other steps that have direct relevance for the ES work are as follows:

- Step 4 which requires the incorporation of planning scenarios (future use, equity considerations and existing lawful use);
  Step 5 which (a) notes that since the recommended MC, Reserve, RQOs, CMS and allocation schedule will impact on specific groups of people in different ways, what processes will guide decisions about who benefits and who pays the social and economic cost? And (b) requires the selection of a subset of scenarios for stakeholder evaluation; and
- Step 6 which includes the stakeholders evaluation of scenarios and agreement on a short-list.

Relationship between the WRCS and the Reserve determination
The process of determining a MC class has been preceded by Reserve Determination (ER) studies because of the urgent need to have such information prior to new licences or compulsory licencing – as required by the NWA. Thus some aspects of ER have incorporated elements that would routinely be part of the MC process (e.g. some socio-economic data) and the ER should be seen to be part of classification.

[9] Quite what an ecosystem component is also not adequately described. However the literature points to value consisting of the economic value of ES + intrinsic value (which is receiving more attention- See Section 2 of this report). Also although not explicit in the guideline (DWAF 2007a), it later becomes apparent that this is the part of the process where ES are dealt with: namely, **Types of Ecosystem Goods, Services and Attributes (EGSA) information required for the socio-economic component of the classification procedure.** This is accompanied by a table that lists certain EGS (named as EGSA), a description of the value and 'aspects' considered. It also mentions knock-on effects, presumably as a vague recognition of inter-linkages but this is unclear. The ES that are listed and the column entitled "aspects considered" (which also seems to list ES and ecosystem attributes) are somewhat confusing in terms of deriving a clear picture of ecosystem services.

There is also a process within the Reserve determination study called EcoClassification which is different to classification described above. The Ecological Classification process – refers to the determination and categorisation of the Present Ecological State (PES; health or integrity) of various biophysical attributes of rivers relative the natural or close to the natural reference condition (Kleynhans and Louw 2007). Emerging from this is a Recommended Ecological Category (REC). Until a classification process is undertaken, the REC is regarded as the preliminary Ecological Management Class (EMC) and ecological Reserve of a water resource.

The Classification process is s still in its early stages of implementation and is currently being undertaken in three WMA: The Olifants, the Olifants-Doorn and the Vaal. A summary of the Olifants process is provided in Deliverable 1. Classification for the Inkomati is likely to start in 2013 (B. Jackson, ICMA, August 2012 pers. com.).

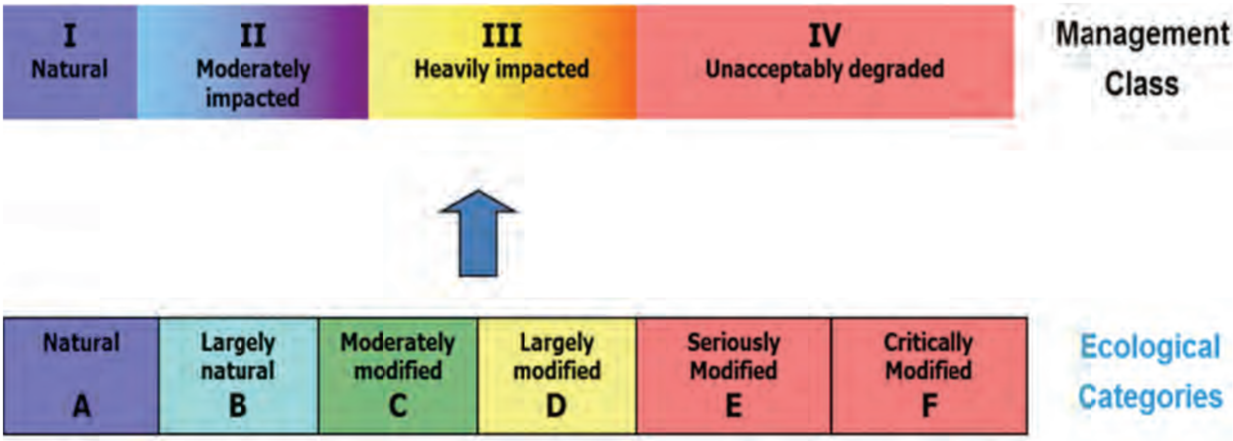

Figure 3 & Figure 4. Categories used by the WRCS and for the Reserve determination processes. The schematic indicates the relationship between the two (adapted from Pollard et al. (2007) and Palmer et al. (2004)).

3.2. Operationalising IWRM and the Reserve in the Inkomati

Sustainable use and management of scarce water resources has become impossible without the establishment of a flexible and adaptable operational Decision Support System (DSS) for the river systems. Two important initiatives of the Inkomati CMA (ICMA) are underway in this regard.

3.2.1. A real-time operational system for the Crocodile River (Inkomati Catchment)

The Incomati CMA is developing a real-time water resources operational system. Currently efforts are focused on a prototype for the Crocodile River which is considered to be the most stressed of all the Inkomati WMA rivers. The basis for the system is MIKE BASIN developed by DHI , which is billed as a flow forecasting and decision-support system. MIKE BASIN is an extension of ArcMap (ESRI) for integrated water resources management and planning, providing a framework for managers and stakeholders to address multi-sectoral allocation and environmental issues in river basins[10]. Between 2008 and 2009, Mike 11 (a river network model) was used to optimise water usage along the Crocodile River downstream of Kwena Dam and – taking into account the lateral inflows – the usage of water for irrigation was optimised while complying with downstream flow requirements. A new generation of GIS-based Mike Flood Watch has also been developed as a decision-support system for forecasting that integrates data management, monitoring, dissemination methodologies into a user-friendly environment (ESRI ArcMap GIS). The system can be used to import data from a range of source (DHI[11]).

The purpose is to develop a real-time operational model for the Crocodile catchment (medium and long-term water resources model (using a monthly time step)). As part of this work, a medium to long-term stochastic model is being developed under the name of WREMP, to interface with Mike 11 through the Mike Floodwatch framework to advise on when restrictions need to be imposed on users, and the degree of these restrictions. The DSS framework (Figure 4) is described in some detail by Cai et al. (2010). As they explain, the strength of the system lies in the information and its distribution, which can be in a number of formats – email, web publications or SMS – through the MIKE Floodwatch framework. Every attempt has been made to make the web page[12] as simple and self-explanatory as possible so that both the system set up by the consultants and other supporting information is added to provide a ‘one-stop’ system that can be used to support decisions in the Crocodile Catchment.

The simulation modelling process consists of (a) long term and (b) short term modelling systems. They are then incorporated to MIKE Floodwatch framework and – through its operation – are integrated to produce decision support information. The key objectives of the long term modelling approach (six months to two years) is to ensure that the Kwena Dam does not fail (storage dropping to such low levels that even basic requirements cannot be met) and that users get their required level of assurance. The Water Resources Modelling Platform (WReMP) which was developed in South Africa (Mallory et al. 2008), is being used for this purpose. The WReMP is a monthly time step model using stochastic outputs to generate probabilistic estimates of risk and reliability of supply from both the water user and resource perspective. The hydrological driver of the model is natural incremental inflows, which must be defined for every sub-catchment.

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[10] http://en.wikipedia.org/wiki/MIKE_BASIN
[11] http://www.dhigroup.com/upload/publications/mike11/Skotner_MIKE_FLOOD_watch.pdf
[12] http://crocdss.inkomaticma.co.za/Website/Index.html

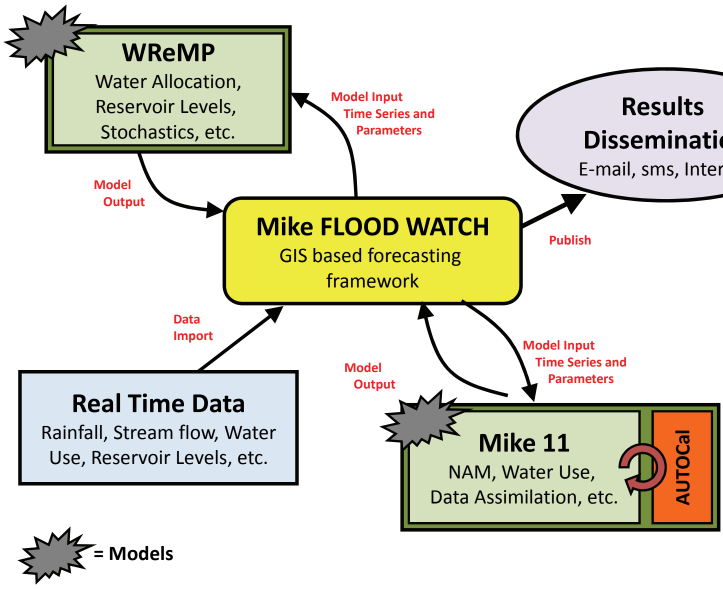

Figure 5. The DSS framework (DWA 2010)

3.2.2. A real time operating decision support system for the Sabie/Sand river system

This is a DWA project (WR 036) with the objective being to develop a real-time Decision Support System (DSS) for the Sabie/Sand system to assist managers in making the required releases from the Inyaka dam (and possibly other smaller dams) and impose restrictions timeously if necessary[13]. This DSS must include a system to monitor flows, water use and storage in major dams and provide a feedback loop to the catchment operator. The DSS must also be able to make annual allocations based on the state of storage and forecast flows in the system. The consultants (IWR) have proposed that the Sabie system be actively managed by means of releases from Inyaka Dam and the imposition of restrictions (if required) while the Sand River be managed passively by means of a proportional flow allocation.

3.2.3. Other related initiatives

Scanning the wider **global research and implementation** environment also highlighted a number of important initiatives with which links can be made or maintained. Some of these involve work in South or southern Africa and are summarised below:

- The Project for Ecosystem Services (ProEcoServ) is a global project funded by GEF developed to bridge the science-policy gap in environmental and natural resource management. It aims to mainstream ecosystem service information, tools, capacity and knowledge into natural resource management and decision making at local and national levels. The overall goal of the project is to better integrate ecosystem service information into national sustainable development planning. South Africa is one of four pilot sites. The South African component is led by CSIR (Dr Belinda

[13] Technical proposal by IWR to DWA September 2010

Reyers Dr Luthando Dziba), and SANBI (Ms Kristal Maze). The project is focusing on three scales: a national policy scale, a catchment management scale in the grassland biome (the Olifants east of Gauteng in the Witbank area); and a municipal planning scale. The work in Olifants falls internationally under the name AquaBase and is led by the University Maryland (Margaret Palmer).

- SAPECS: Although still in its early stages, the important linkages hinge around the discourse of complexity and the implications for management. Insights will be shared from WatRES – and from former WRC projects on complexity and socio-ecological systems (Pollard et al. 2008a, Pollard et al. 2012) – on experiences of operationalising complexity and systems approaches whilst insights will be gained on how other initiatives aim to engage these important concepts.
- PRESENCE is a North-South trans-disciplinary research collaboration between Wageningen University (WUR) and various South African Universities working with the restoration of degraded landscapes for poverty alleviation in Baviaanskloof. It is institutionally linked with the systems group at Wageningen University led by Dr. de Groot who has done extensive work on ecosystem services. Initially contacts have been made with one participant at the 2011 wetlands indaba.
- Wageningen also hosts the Ecosystem Services Partnership (ES-Partnership). The aim is to enhance communication, coordination and cooperation, and to build a strong network of individuals and organizations. WatRES is now a member of the ESP.
- There are a number of projects regarding the payment for ecosystem services (PES) that have been or are being conducted within South Africa. These are important because of considerations of how ecosystem services are assessed, mapped and valued. These include the Asset project (now complete) and ongoing work by Futureworks amongst others (see also deliverable 1). The importance of this process is the recognition that stakeholders often cannot afford much time in workshop processes and so offers an approach to quickly explicate and name ecosystem services.

Other important linkages are summarised in Table 4 and listed below.

Table 4. Projects and initiatives with direct implications for WatRES

Initiative	**Considerations for WatRES**
Riskoman	RISKOMAN has as one of the objectives, an improved hydrological understanding which will improve the inputs for quantitative modelling (see below)
Environmental flow approaches e.g. DRIFT	In terms of links to ES, the following are important with respect to DRIFT • Unlike other methods, it provides quantitative data on subsistence use of river resources which can be thought of as ecosystem services; • it can incorporate any relevant knowledge on the river; • it quickly and easily produces any number of detailed scenarios once the database has been populated; • each scenario provides detailed predictions of ecosystem change – which could incorporate ES – that can be used for goal-setting in monitoring programmes;
Framework for the evaluation of aquatic ES for RDM	Notwithstanding a number of concerns, the framework takes some important steps towards addressing the need for explicating ecosystem services in the classification process and any future work should seek to build on this.

3.2.4. Outcomes of exploring potential links with other related initiatives

DRIFT

DRIFT is a mature, widely-used and powerful tool for exploring the impact of changes in water regime on ecological indicators. Although DRIFT models can be implemented in Simile with no loss of fidelity, it is not recommended that Simile take over DRIFT modelling, since that would cut the project off from the excellent tools for managing large DRIFT models and for model analysis and optimisation which DRIFT provides. However, there are two avenues for interaction between Simile and DRIFT, both of which have been recommended to explore as they are consistent with the goal of achieving as much shareablility as possible within the modelling architecture. One is to develop a mechanism for converting DRIFT models into Simile format, in order to allow the models to be run within Simile, to be passed on to other modelling tools, or to be extended using Simile's capabilities (for example, to be made spatial). The other is to allow a DRIFT-compatible subset of Simile models to be converted into DRIFT format. This would allow DRIFT models to be developed within a graphical user interface, while benefitting from DRIFT's rich set of tools for model analysis. The feasibility of doing both jobs depends on how much work would be involved at the DRIFT end.

RECOMMENDATION
If technically possible, develop an interface to allow DRIFT models to be converted into Simile format.

RECOMMENDATION
If technically feasible, develop a translator for converting a DRIFT-compliant subset of Simile models into DRIFT format

Integration with MIKE

There is a clear existing commitment to the development of a DSS for water management based on MIKE; and a clearly-expressed need to incorporate a model of ecosystem services within this. There are, in principle, two ways that this can be achieved, given a Simile-based modelling core. One is to allow a Simile model, as a DLL (a binary Dynamic Linked Library) to be coupled to MIKE. This would be "close-coupling" – intimate interaction between MIKE and the model on a time-step-by-time-step basis. This approach would allow any Simile model, regardless of how complicated or disaggregated it were, to be linked to MIKE. The other is to generate a MIKE/ECO Lab template from the Simile model, which would mean that MIKE would see it as any other template. This could work for a subset of Simile models – those that conformed to the limitations of the ECO Lab template, which means that it would need to consist of a set of ordinary differential equations. There are uncertainties regarding the technical feasibility of both approaches (waiting to hear back from DHI on both methods). Additionally, the template approach is currently geared towards water characteristics (eutrophication, pollution): it is not clear whether it is limited to that, or whether a model of (terrestrial) ecosystem services could be used just as well.

RECOMMENDATION
If technically possible, develop an interface to allow Simile model DLLs to be run inside MIKE.

RECOMMENDATION

If technically feasible, develop a translator for converting an ECO Lab-compliant subset of Simile models into MIKE/ECO Lab's template language

3.3. Potential application and role of simulation modelling

Simulation modelling is an important tool used to study complex issues within the context of ecological systems. Many major research programmes develop models in order to integrate quantitative and/or qualitative data from different sources of information, test hypotheses and make predictions under different management scenarios. Most models are implemented based on conventional programming languages (i.e. Fortran and C:). However, there are increasing concerns about the problems related to this traditional method of modelling ecological systems (Reynolds and Acock 1997). The most important problems are the high level of efforts and skills needed to program the models, the lack of transparency, the lack of accessibility and the lack of reuseability of the models by other researchers (Muetzelfeldt and Massheder 2003). As a result, several approaches have been developed to overcome these problems. Currently, there is no specific approach which is widely adopted amongst researchers to simulate ecological systems.

The three main approaches that have been developed are as follows:

1) A Bayesian Network (BN) is a graphical model in which nodes represent variables and the edges between the nodes represent probabilistic dependencies amongst these variables. Therefore, a BN represents patterns of probabilistic dependence, or in other words, it defines relations between variables in terms of the conditional probabilities for each variable included in the network (Borsuk 2008). Moreover, these conditional probabilities can be specified using prior knowledge, model-based or data-based methods (Ben-Gal 2007). Consequently, BN facilitate reasoning under the uncertainties related to complex systems. However, the major limitations about the BN approach are that it is not well suited to incorporate feedbacks and represent temporal or spatial dynamics.

BN have been successfully applied to solve complex problems over a wide range of disciplines. Since BN was initially developed for research into artificial intelligence, it has been mainly been used in the fields of engineering and information technology. However, it is now used over a broader range of areas such as for financial market analysis, military applications, medicine and space shuttle propulsion systems. Moreover, it is increasingly applied in the fields of biology and ecology (Ben-Gal 2007). Finally, there are several software packages to develop models using a BN approach: Netica, Hugin, Analytica and DBLi.

2) Agent-based modelling (ABM) is a relatively new approach to model complex systems that involve human or institutional behaviour. ABM describes the observed world in terms of interacting and autonomous actors, referred to as agents (Macal and North 2010). Agents have behaviours that are characterised by certain rules and depend on the state of the environment, the state of the agent and its spatial location. Each agent is represented as an independent computerised entity capable of acting locally in response to stimuli or to interact with other agents. By modelling agent's behavior at the individual level, the behavior of the system as a whole emerges as a result of the diversity of agents, each behaving according to defined rules and interacting with each other and with the environment.

Moreover, the interactions of multiple agents give rise to global patterns and structures in the system that were not explicitly programmed into the model, sometimes even leading to self-organisation. Therefore, ABM corresponds to a “bottom-up modelling” approach (Borshchev and Filippov 2004).

The programming language most commonly used for ABM is object-oriented programming since the concept of an object is similar to that of an agent. There are several tools available for ABM researchers such as SWARM, Repast, Netlogo and Mason. Furthermore, ABM can be applied over a wide range of disciplines. For example, researchers have used ABM to model agent behavior in the stock market (Arthur et al. 1997), the adaptive immune system (Folcik et al. 2007) or to understand the fall of ancient civilizations (Kohler et al. 2005).

3) System Dynamics (SD) approach is used to model complex dynamic problems by representing the observed world in terms of stocks (e.g. of material, money, population, knowledge) connected by flows and feedback loops. More specifically, the feedback concept is at the core of SD modelling (Scholl 2001). In this approach, diagrams comprising interacting feedback loops and circular causality are developed in order to conceptualise the structure of a complex and inter-related system. As explained by J. W. Forrester (1969), founder of the SD approach: “the complex system has a multiplicity of interacting feedback loops. Its internal rates of flow are controlled by nonlinear relationships. The complex system is of high order, meaning that there are many system states (or levels). It usually contains positive-feedback loops describing growth processes as well as negative, goal-seeking loops.”
SD modelling can be applied to an equally wide range of disciplines as agent-based modelling. There are several tools for SD modelling. More specifically, Stella was one of the first software packages developed and it captured widescale interest due to a very nice graphic user-friendly interface and a marketing program that targeted students and academics (Scholl 2001). A number of other software packages were developed since such as Vensim, Powersim, Madonna and Simile.

To summarise, BN, ABM and SD adopt different approaches to model complex systems. In the BN approach, the basic unit of analysis is the probabilistic dependencies between a set of variables in a system. On the other hand in the ABM approach, the basic unit of analysis is the resulting emergent behaviour of interacting and autonomous agents as a complex system. Finally, the unit of analysis in the SD modelling is the feedback loop.

The following paragraphs describe and compare five different modelling softwares that are being considered for potential future application in the WatRES project (see Table 5). Amongst the five softwares, there are two generic SD softwares: Vensim and Simile. In addition, three softwares specifically designed to model ecosystem services are also under consideration: InVEST, MIMES and ARIES.

Vensim

Vensim is an interactive visual modelling tool used to conceptualise, simulate and analyse dynamic feedback models (Vensim 1988). It provides a generic modelling environment to build simulation models based on stock and flow diagrams. Models are also developed diagrammatically and quantitative data is incorporated to produce a complete simulation model. Users can analyse the model throughout the building process in order to study the relationships between variables and their causes. Once the model is completed and simulated, the behaviour of the model can be examined thoroughly (Vensim website 2013).

Simile

Simile is a visual modelling environment which means that models are developed diagrammatically using an intuitive visual interface. Furthermore, the construction of a model in Simile entails a two-phase approach. The first phase consists of drawing a diagram which represents the different variables and relationships in the model (i.e. a concept map). In the second phase, the values and equations are inserted into the diagram in order to develop a quantitative model. However, it is also possible to construct a qualitative model instead by inserting conditional statements. Finally, the main difference between Simile and other SD modelling softwares is its capability to specify many instances of any part of the model which allows for spatially explicit formalisation. This feature is a major advantage as in most cases SD tools are not well suited for spatial modelling (Muetzelfeldt and Massheder 2003).

MIMES – Multiscale Integrated Models of Ecosystem Services

MIMES is a multi-scale, integrated collection of models that assess the impact of land use practices on ecosystem services and consequently the effect on human well-being under different management scenarios (Mulligan et al. 2010). It builds on the Global Unified Metamodel of the Biosphere (GUMBO) model (Boumans et al. 2002) in order to spatially model ecosystem services at various scales. MIMES uses correlative relationship between variables derived from the outcomes of five mechanistic submodels: Atmosphere, Lithosphere, Hydrosphere, Biosphere and Anthroposphere (Mulligan et al. 2010). The submodels are dynamically linked and are run along with geographic information system (GIS) data. Furthermore, these submodels are developed using the Simile modelling language.

InVEST – Integrated Valuation of Ecosystem Services and Tradeoffs

InVEST consists of a set of models aimed at quantifying and mapping the values of various ecosystem services by using ecological and economic production functions (Tallis and Polasky 2009). The aim of these models is to provide a better understanding of natural capital during decision making by visualizing the impacts of different management scenarios and determining potential tradeoffs between environment, economic and social benefits (Tallis et al. 2008). Furthermore, InVEST also contains a number of fixed model components which includes water pollution regulation, sediment retention for reservoir maintenance, biodiversity and more. For each model component, users can choose between a simple and a complex version as well as run the model using different data availability levels (Mulligan et al. 2010).

Finally, InVEST is accessible to non-programmers but it does require familiarity with ArcGIS as it runs in the ArcGIS ArcToolBox environment (Tallis et al. 2008).

ARIES – Artificial Intelligence for Ecosystem Services

ARIES does not rely on a collection of prebuilt models but is rather a modelling platform. Therefore existing ecological process models can be incorporated into ARIES. Moreover, several models have already been incorporated such as models for flood regulation, water provision, soil retention, carbon sequestration, etc. (Mulligan et al. 2010). However when specific ecological process models do not exist or are inappropriate for the context of the study, ad hoc models can be built and run in ARIES (ARIES website 2013). More specifically, ARIES builds ad hoc, probabilistic Bayesian Network models that are used to map the ecological, economic and social factors influencing ecosystem service provision and use (Villa et al. 2009). These probabilistic models allow users to express some level of uncertainty which is crucial for decision making (Mulligan et al. 2010). Furthermore, GIS data is also included to develop the maps of ecosystem service provision and use. Spatial ecosystem service flows are then simulated using an ABM approach in order to map service flow from ecosystems to people (Villa et al. 2009).

Table 5. Comparison between five modelling software: Vensim, Simile, MIMES, InVEST and ARIES based on criteria identified by this projects

	Modelling softwares				
Criteria	**Vensim**	**Simile**	**MIMES**	**InVEST**	**ARIES**
Represents spatial dynamics	Vensim is not well suited for spatially explicit formalisation	Spatial dynamics can be represented in Simile by modelling one spatial unit and then specifying many instances.	MIMIES models have a framework capable of studying various processes at different scales in space.	InVEST represents spatial dynamics	ARIES represents spatial dynamics
Represents temporal dynamics	Vensim is not well suited for temporally explicit formalisation	Simile is not well suited to represent temporal dynamics. However SimArc is a new software tool able to represent temporal dynamics by combining models constructed in Simile with ArcView GIS environment.	MIMIES models have a framework capable of studying various processes at different scales in time.	InVEST is not well suited to represent temporal dynamics. However, already existing process-based models that include temporal dynamics can be integrated with InVEST.	ARIES represents temporal dynamics
Deal with data-poor settings	Vensim can be used in data-poor settings	Simile can be used in data-poor settings	MIMES can be used in data-poor settings	For each model components in InVEST, a simple version can be applied in order to deal with low data availability	ARIES's probabilistic models are able to handle data-scare conditions
Handle feedback	Vensim develops dynamic feedback models	Simile develops dynamic feedback models	MIMES develops dynamic feedback models	It is unclear if InVEST can handle feedback	It is unclear if ARIES can handle feedback
Natural Resource Management experience	Yes	Yes	Yes	Yes	Yes

	Modelling softwares				
Criteria	**Vensim**	**Simile**	**MIMES**	**InVEST**	**ARIES**
Participatory modelling	Vensim's visual environment makes it suitable for participatory modelling processes	Simile's visual environment makes it suitable for participatory modelling processes	MIMES's visual environment makes it suitable for participatory modelling processes	InVEST was designed to facilitate stakeholder engagement in participatory modelling processes	An ARIES model can be developed in a participatory process as it is capable of accounting for different user's knowledge of the system
Capacity requirements	The skills requirements needed to develop a Vensim model are relatively light	The skills requirements needed to develop Simile models are relatively light	The skills requirements needed to develop MIMES models are relatively light	The skill requirements needed to develop InVEST models are relatively light	ARIES has a user-friendly interface requiring minimal data input

Desirable features for the core modelling platform

The following is a list of desirable features for the core modelling platform.

- intuitive, diagrammatic: to facilitate model construction, model transparency, stakeholder involvement in the modelling process;
- expressive: to allow the implementation of various classes of model (System Dynamics, agent-based, stochastic, spatial...);
- computationally efficient: to allow complex models to be run quickly, and rapid experimentation with simple models;
- scalable: to be able to handle very large models, both in terms of number of equations and degree of disaggregation;
- conceptually close to other peri-modelling activities (e.g. concept mapping, causal loop analysis, ecosystem services concepts): to reduce the "conceptual gap" between these other aspects and a corresponding model;
- allow for software integration with other modelling platforms (principally MIKE);
- allow for automatic conversion between the platform's native model-representation format and that used by other modelling systems (e.g. MIKE-ECO Lab; DRIFT; System Dynamics software): to obtain maximum leverage from available resources;
- support modular modelling: to allow submodel re-use;
- support links to external data sets and to files providing settings for alternative scenarios;
- allow customisation of the run-time user interface: to make it possible for people with no modelling experience to experiment with the models;

3.4. Harmonisation at an international scale

As noted below, boundaries are an important theme because such questions regarding the distribution of risks and benefits under compliant and non-compliant situations can be asked at the scale of users in a catchment (upstream-downstream 'boundaries' or boundaries between sectors) and between sovereign nations (commonly referred to as transboundary or international issues). The Inkomati WMA faces such challenges currently since non-compliance with the Reserve is widely evident (Pollard et al. 2010, Pollard and du Toit 2011). This has implications not only locally but also nationally and internationally for downstream users such as Swaziland and Mozambique – thus expanding the issues of benefits to a basin-wide scale.

Although beyond the scope of this project, it is important to consider widening the scope of WatRES to consider sustainability at the basin-scale, irrespective of political boundaries. Such issues are of high priority in the Incomati Basin where, amongst other things, EWRs are being considered through PRIMA project which will formalise a comprehensive water-sharing agreement between three sovereign states of Mozambique, Swaziland and South Africa. Each state is committed to determining national EWRs and this has raised a number of issues regarding 'up-scaling' these to a basin-wide commitment. The framework proposed must be sufficiently generic and robust to be applied at different scales (sub-catchment to basin) thus incorporating risks and benefits at an international scale. This would also require understanding the full range of issues specifically related to international agreements and co-operation. Although a thorough review of this is not possible currently, it will be undertaken as part of the new Resilim project (Resilience in the Limpopo Basin https://www.fbo.gov/spg) as the basis for future work.

4. Critical elements of the WatRES framework

4.1. A framework embedded within a wider IWRM context

The WatRES work is situated within a broader context which provides guidance and bounding for the work and hence is important to elaborate (see Section 3.2). Two important contextual developments frame the development of the WatRES framework, namely classification (which is a national endeavour) and the development of a real-time water resources management system for the Inkomati catchment into which the Sand River Catchment falls. Details are provided in Section 3.2 and are summarised below as important elements of the proposed framework.

4.1.1. IWRM in South Africa: Classification, the Reserve

As noted, the overarching context for water resources management in South Africa is that of integrated water resources management (IWRM) and thus WatRES must be explicitly linked to IWRM in South Africa for it to be contextually relevant (see NWA 1998, DWA 2007a, Pollard and du Toit 2007). It is noted above that the RDM component of IWRM has direct bearing as follows:

- Classification of the water resource
- Determination of the Reserve (ecological and basic human needs) – or Environmental Water Requirements;
- Setting of Resource Quality Objectives.

More specifically the classification process deals explicitly with ecosystem services whilst the Reserve is a composite amount of water that delivers various ecosystem services. In terms of links with current Reserve Determination studies, collaboration with the DRIFT as well as BBM/ FSR work, would be mutually beneficial. In particular DRIFT provides quantitative data on subsistence use of river resources (i.e. ecosystem services) and easily produces detailed scenarios with detailed predictions of ecosystem change – which could incorporate ES – that can be used for goal-setting in monitoring programmes.

Importantly, the classification of water resources of the Inkomati WMA will likely commence in 2013 (Mr. B. Jackson, ICMA, pers. comm. August 2012) making the development of a prototype even more relevant. This recognises that whilst a system is in place (based on the approach developed by Ginsburg et al. (2010) see below) and is being tested for the Olifants, the focus is on the economic valuation. One critique is that the assessment of ecosystem services is inadequate and it is this aspect that the WatRES project aims to address.

4.1.2. Operationalising IWRM through a real time operating decision support system

As noted real-time operational systems are being developed in the Inkomati (Crocodile and the Sand Rivers) for both the Crocodile and Sand Rivers. Any initiatives aimed at supporting IWRM, such as the WatRES work, need to seek coherence with the broader water resources management systems being developed. One such system is the ***real-time water resources operational system*** being developed by the Incomati CMA. This is essentially a decision-support system (as described in Section 3). Currently efforts are focused on a prototype for the Crocodile River which is considered to be the most stressed of all the Inkomati WMA rivers. To ensure coherency, discussion were held with the ICMA as requested by

Brian Jackson, the acting CEO for the ICMA. Given the flexibility of the evolving WatRES framework (and the system dynamic software) and the real-time system, this is entirely tenable.

Equally important is the **real time operating decision support system for the Sabie/Sand river system,** the main objective of which is to develop a real-time Decision Support System (DSS) for the Sabie/Sand system to assist managers in making the required releases from the Inyaka dam (and possibly other smaller dams) and impose restrictions timeously if necessary. One component of the spatial distribution of ecosystem services is to consider how infrastructure might move water- and hence the ES – around in the catchment. The real-time project has a good data base of infrastructure (including inter-basin transfers) within and into to or out of the catchment and secondly, this project is monitoring compliance with the current operating rules at a number of points (Dr. T. Sawunyama, IWR pers. comm. 8/9/12).

Section 3 (and Deliverable 2) also provides an overview of a number of associated initiatives focused on ecosystem services including for example Asset, Eco-futures, ProEcoServe, Presence, TEEB, Aquabase, Quest, Diversitas, Mimes and the ES-Partnership.

4.2. Recognition of catchments as complex systems

Complexity theory arose as a critique of linear causality and reductionist science asserting that not only has linear conventional thinking failed to chart a sustainable path but in many cases it has actually contributed to the problem (see synthesis by Walker and Salt 2006). This work takes a complexity approach by framing the systems with which we work (such as catchments) as complex systems where inter-linkages, feedbacks and emergence are central so that outcomes vary in space and time in ways that are not always predictable. The recognition of catchments as complex system has a number of implications for WatRES, thereby establishing some important requirements or parameters of the framework, which are summarised herewith (see Section 3 and Pollard et al. 2008b for a detailed description). A complex system can be distinguished from a simple one, albeit complicated, by a number of attributes. A complex system shows feedbacks (reinforcing or balancing) in its cause and effect relationships, which, usually because of operation at different scales, cause emergence (i.e. the feedbacks generate surprising new properties not predictable from the original components of the system). Almost all socio-ecological system can be shown to exhibit this complex behaviour and hence emergence. Ironically, complex systems often have only a few predominant drivers – it is the way these interact (and in particular the feedbacks) which produce the complexity. The drivers invariably vary in strength over space and time, producing different combinations of outcomes.

A central concept for sustainability is that of resilience, which lies at the very heart of sustainability. Resilience introduced by Holling in 1986, and further developed by the Resilience Network, is defined as "The capacity of a system to absorb disturbance and re-organise so as to retain essentially the same function, structure and feedbacks – to have the same identity (that is, to remain in the same system regime)." Many studies and initiatives focusing on sustainability and natural resource management now place particular emphasis on the concept of resilience and building the resilience of the socio-ecological system (see for example (http://www.resalliance.org). Within this context of uncertainty and change, we take a social learning approach to supporting the capacity for coping and adaptation particular with key stakeholders.

4.3. A stakeholder-centered process based on social learning processes

The complexity outlined above highlights the need for a stakeholder-centered process that clearly articulates the learning processes within a framework for participation (see IAP2, discussed in some detail in Deliverable 12). Both the constitution of South Africa and the National Water Act places specific emphasis on processes that engage stakeholders in planning and implementation. Flowing from the requirements of the NWA, stakeholders are involved in numerous aspects of IWRM including the development of the Catchment Management Strategy and in Classification (see Pollard and du Toit 2011, DWAF 2007a). For example, with reference to the Catchment Management Strategy, the NWA (Ch.2, Part 2) states: "*In the process of developing this strategy, a catchment management agency must seek co-operation and agreement on water-related matters from the various stakeholders and interested persons***".** In terms of classification the NWA (13 (4)) states that the Minister must "*invite written comments to be submitted on the proposed class or proposed resource quality.*"

Equally the Water Resources Classification System calls for participation stating that "*The procedures are to be applied as part of a consultative 'Classification Process'*, and further, that "*The Classification Process is not carried out in isolation, but is integrated within the overall planning for water resource protection, development and use. A key component of classification is therefore the ongoing process of evaluating options with stakeholders in which the economic, social and ecological trade-offs will be clarified and decided upon*". (DWA 2007a, Preface). Within this stakeholders must evaluate a subset of scenarios (Step 6). By implication this will include a process of understanding the costs and benefits of each of the scenarios and their associated suite of ecosystem services and benefits (as explicated in Step 3 of the process for example).

Given the imperative to involve stakeholders in decisions regarding their own futures, any framework needs to explicitly places processes that support stakeholder engagement at centre stage. This also recognises that compliance with the NWA and Reserve requirements are unlikely without the support of and buy-in from stakeholders. Evidence from the SRI I research indicated that even individuals (as opposed to large numbers of people) have the ability to tip the system from compliance to non-compliance through various actions such as over-abstraction/illegal abstraction or point-source pollution. Stakeholder-centered processes should be supported by formal, quantitative approaches so as to understand different scenarios of WRM practice (e.g. different water allocation plans, or changing a management class).

5. Developing and testing the proposed framework: A collaborative understanding of WatRES under different management scenarios

This section discusses the development and testing of the proposed framework for a collaborative understanding of **water-related ecosystem services** (WatRES) and the Reserve under different management classes (see Section 3). This was done with key stakeholders from the Sabie-Sand Catchment which forms part of the Inkomati WMA and hence falls under the ICMA. This is important because the Classification process for the IWMA is due to start in 2013. Thus processes developed under the auspices of SRI II are intended to support classification.

5.1. Overview of the proposed framework

Given the discussions of the previous sections a number of key principles framing the framework emerged. These are elaborated below.

5.1.1. A process which is stakeholder-centered and attentive to learning for transformation

Given the imperative to involve stakeholders in decisions regarding their own futures, the framework places processes that support stakeholder engagement at center stage. This also recognises that compliance with the NWA and Reserve requirements are unlikely without the support of and buy-in from stakeholders. Evidence from the SRI I research indicated that even individuals (as opposed to large numbers of people) have the ability to tip the system from compliance to non-compliance through various actions such as over-abstraction/ illegal abstraction or point-source pollution. Emerging from this principle therefore, the framework requirements are for a process that:

- is participatory;
- that builds on what people know;
- involves steps that are iterative allowing people to revisit concepts based on changes in their understanding through for example, engagement with others;
- is linked to 'real-life' practices or management actions (e.g. involvement in the Classification Process). Given the huge demand for stakeholder involvement in multiple issues, stakeholder fatigue can be mitigated somewhat by their involvement in practical actions aimed at change;
- must provide for a situation where people do not feel threatened by others deemed to be 'experts' or better informed. This is often an issue of power dynamics and perceived locus of power rather than who actually 'knows more'. In particular water-related ecosystem services are an emerging field and hence not the purview of any particular individual or group; equally adopting a systemic approach is new to many and so processes need to allow people to explore and learn in a constructive manner;
- aims to provide a collective understanding of WatRES for a specific area rather than simply an amalgamation of individual perceptions. Where possible consensus should be sought but should not be the overwhelming objective. Noting and accepting different opinions and understandings in an open and transparent way – are an essential part of (a) allowing people to see different perspectives from their own, (b) anticipating future areas of potential contention and in doing so, (c) allowing one to plan for this in an appropriate manner and (d)

identifying areas of critical research which can often be highlighted by contention and critique.

- The participatory process should aim to facilitate dynamic and productive discussions regarding the concept of water-related ecosystem services as dynamic (see next principle).

5.1.2. Central concepts: Embedding WatRES within a complex, systemic and dynamic framing

The proposed framework recognises that water-related ecosystem services are embedded in a wider, complex – and hence dynamic – socio-ecological system, in this case the catchment in question. This means recognising that both ES (production) and benefits (consumption) vary spatially across the catchment and in time. These vary as a function of biophysical factors, different flow and water quality regimes, landuse patterns and as a result of wider drivers such as governance and economic factors. This wider view highlights the systemic nature of the catchment and water-related ecosystem services. For example, earlier work on the Sand River catchment indicated the potential influence of some of these drivers (Pollard et al. 2008a). By adopting an approach that is *spatially and temporally explicit* and that explicates both *ES and benefits*, it is also recognised that the *production* (ES) and *consumption* (benefits) may be spatially and temporally distinct. In other words, a certain ES (water availability for food production) may be produced in a different sub-catchment to where it is enjoyed as a benefit (health). Adding to this complexity is the fact that the benefits are likely to *accrue to different groups* of people (sectors) differentially (i.e. in space and time). <u>The purpose of this framework</u> is to support stakeholders to develop an understanding of these complexities.

In summary therefore, the framing of the catchment as a complex system underpins a number of critical issues, namely:

- That the water-related ecosystem services are not static in space and time but rather are dynamic and varying. The dynamic nature reflects that:
    - water-related ecosystem services are linked; that is they cannot be assessed as independent factors (as is common in conventional assessment methods) but rather must be seen to influence interrelated ES
    - water-related ecosystem services are influenced by and influence other ES (e.g. terrestrial ESs) and landcover/landuse is central in this regard;
    - water-related ecosystem services are part of a wider system with influencing drivers that themselves vary in space and time (e.g. land-use practices);
    - moreover, critical feedbacks are likely to exist in the system and need to be identified.
- Equally, by the same rationale, the benefits derived from water-related ecosystem services will vary in space and time; by implication these will accrue differentially to different stakeholders (i.e. vary spatially and temporally);
- Changes in drivers and related ES will derive both benefits and dis-benefits (even if in the short-term) to different stakeholders both of which must be considered;
- Given this, the process is directed towards understanding how *ES and benefits* may be distributed in
    - space and time across the catchment and
    - under different management scenarios (e.g. management classes and classification);
- the production (ES) and consumption (benefits) may be spatially and temporally distinct;

- the benefits are likely to accrue to different groups of people (sectors) differentially.

5.1.3. A process which is iterative and which combines qualitative and quantitative approaches

In order to explore complex issues such as the impacts of different management scenarios (including non-compliance) in a way that includes stakeholders (see above), there is a need to develop a process that is iterative and that embraces 'different ways of knowing'. Theories of social learning for collective action (see Section 2.3.8) are important in that stakeholders (including 'specialists') do not know everything and might have different understandings of the same issue. Thus spaces need to be created for the process of *confronting, deconstructing and reconstructing* understandings and meanings and in this regard the following were tested:

- A key principle for this is to start with what people know, and hence the starting point for this process was through the concept of *Benefits* where people simply freelist benefits that they associate with the river in question.
- Terminology is important and whilst many may understand the term *ecosystem services*, many do not. Initially therefore such terms can be intimidating and constraining and alternatives need to be sought until people are comfortable.
- Allowing participants to work on their own initially provides a safe space free of peer review at too early a stage.
- The use of visual materials can support the conceptualisation of complex ideas.
- Only once individuals have had time to construct or make explicit their own views should they then interact in group work.
- Only once people are comfortable with the basics should the move be made to more complex ideas (e.g. defining relationships)
- Time must be allowed for discussion to allow for the above process.
- Allow for qualitative and quantitative information to be explicated and to be given value. For example, a farmer may describe a relationship between a water quality variable and food production but might not know the specific values. If these are needed they can be gathered at a later stage.

In complex systems such as those described under point 2, it is likely that some quantitative modelling will be required if different scenarios are to be explored. However it is critical that this is not the starting point but rather emerges out of a process where people are comfortable with the basics and trusting of the process so that one might work from a very open-ended and qualitative conceptualisation (or model) of ES and benefits to a model that is supported by quantitative data and can provide inputs to multiple scenarios. In this regard:

- Design a process that builds trust and understanding;
- Support participants to build a systemic conceptualisation of ES that is the starting point for further quantitative work (if required);
- Not everyone needs or will want to be part of the full process (i.e. qualitative – quantitative) but they do need to understand the basics and endorse the process

5.1.4. Linking the process to action and practice

As noted, stakeholders' interest are in participating in processes which are linked to 'action in the real world', and even then many participants, suffering from stakeholder fatigue, feel that time is wasted if they cannot see change (Pollard et al. 2008a). Thus any such participatory processes needs to be carefully crafted to indicate to participants the value of their participation and time (*why participate*), what is expected of them and how they might effect change in doing so. In the case of this project a link can clearly be made with the Classification process which sees stakeholders as central to decision-making (see Section 4.3) and by association, with support for compliance with the Reserve requirements. At an operational level, links have also clearly been made with the water-resources management systems being developed by the ICMA (see Section 3.2).

In both cases, key questions focus on the implications of different scenarios. In the case of Classification the implications of different classes are explored through the changes in ES and associated benefits (i.e. explicating the benefits derived under different management classes). Moreover, under each management class, a suite of water-related ecosystem services and benefits will pertain to the recommended Reserve for that class, and these need to be understood and monitored to ensure that the catchment vision is being achieved (see Pollard and du Toit 2011 for a full explanation of the catchment management strategy visioning process).

Given these critical elements, the emerging framework that was developed (Figure 5) was then tested with stakeholders/ residents of the Sabie-Sand Catchment and 'specialists' over six months.

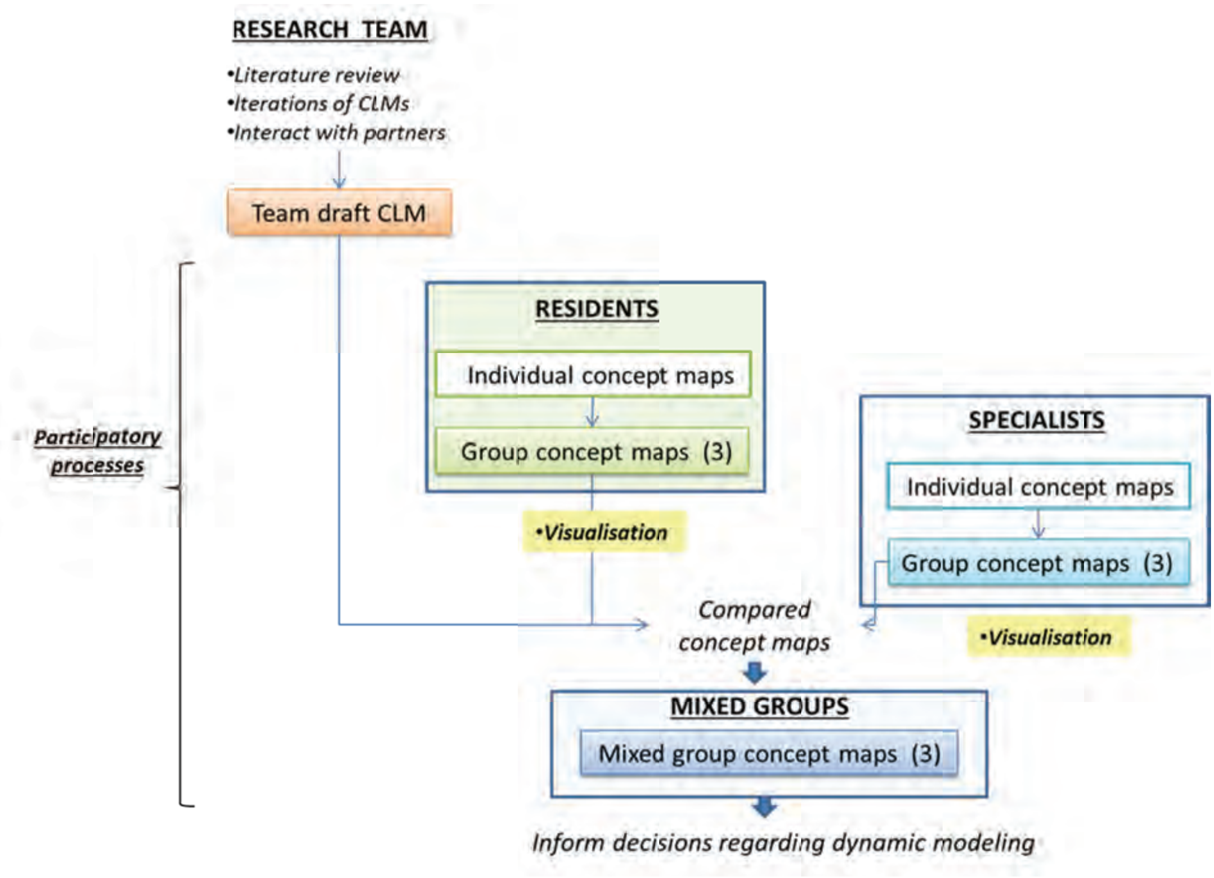

Figure 6. Overview of the key steps undertaken to test the proposed framework

In keeping with the aforementioned principles, the framework is based on a number of steps designed to build participants confidence and understanding – both of their own views but also of to have an appreciation of the views of others. Once these are explicated there is generally a tenable basis on which to move forward to developing a joint view or conceptualisation. Each of these steps is described in the following section.

5.2. Testing the framework: Preparatory work

The aim of the preparatory phase was to conduct a literature review of important concepts and approaches to the assessment of ES (see Section 2); to understand existing projects with potential linkages, thirdly to develop an initial conceptualisation of WatRES and benefits (as a concept map) by the core team so as to prepare ourselves for engagements with stakeholders and forth, to scope out the appropriate scale, units and stakeholders with which to work.

5.2.1. Literature Review

The literature review was conducted to explore various approaches to study the ES and human well-being (see Section 2). Key points emerging from the review are as follows:

- There seems to be an agreement on general definition of ecosystem services. One of the most commonly used is that of the Millennium Ecosystem Assessment (2005) which defines ecosystem services as "the benefits humans obtain from nature", conceptualised as four categories of supporting, provisioning, regulating and cultural services.
- These typologies appear to be easily understandable but can pose difficulties for operational purposes (Seppelt et al. 2011, Wallace 2007). Other conceptualisations include defining intermediate and final ES. However, there is no single classification of the ES and authors such as Costanza (2008) have suggested that the quest for a single system is inappropriate and that the categories used need to respond to the purpose of the study. Nonetheless a number of authors have drawn attention to the need for a clear distinction between ecosystem ***functions***, ***services*** and ***benefits*** so as to not conflate ecological function and service (de Groot et al. 2010, Haines-Young and Potschin 2010, Burkhard et al. 2010). Under this definition, nutrient cycling for example is an ecological function, not an ecosystem service (Boyd and Banzhaf 2007). Another useful conceptualisation has been the distinction of intermediate and final services. In this case intermediate services are similar to MEA's supporting services; final services are provided by intermediate and have direct effect on human welfare; and benefits are the endpoints that have direct effect on human welfare and that are to be valuated.
- Thus, it is also important to separate final services from benefits or a ***product consumed***. Example: recreation – benefit; fish landed – product consumed; fish population, surroundings, water body – final services (Boyd and Banzhaf 2007).
- As noted earlier, well-being has also received increasing attention. There is widespread agreement that well-being and poverty (or ill-being) are the two extremes of a multidimensional continuum and that components of well-being may be 'classified' of as the means and the outcomes depending on the context in question.

5.2.2. Preparation of an initial team model of WatRES and benefits edit

Given the context above, it is important to reflect the complexity of interrelation of different ecosystem components. Whilst systems modelling employs systems diagrams to conceptualise such complexity using quantitative data, concept maps (CM) help visualise the interrelationship between variables and how they might affect one another. The diagram consists of a set of variables connected together by arrowed links. Arrows represent the relationships between these variables that can go one or both directions or form a feed-back loop. A CM is particularly useful in proposing how a change of one factor may impact elsewhere or long-term consequences of such a change. Thus they offer useful initial conceptualisations that can be used as the basis for the development of subsequent influence diagrams.

To assist an understanding of water-related ecosystem services (WatRES) in the Sabie-Sand Catchment, and for the purpose of operationalising the concept in the context of the given research, the core team of researches and experts produced a number of iterations of an initial CM of WatRES and benefits. This was critical in terms of framing the work and as preparation for the stakeholder interactions by providing a prototype CM by team for understanding drivers, variables, relationships and data needs. The last version (before the start of stage 1 interviews) is shown in Figure 6.

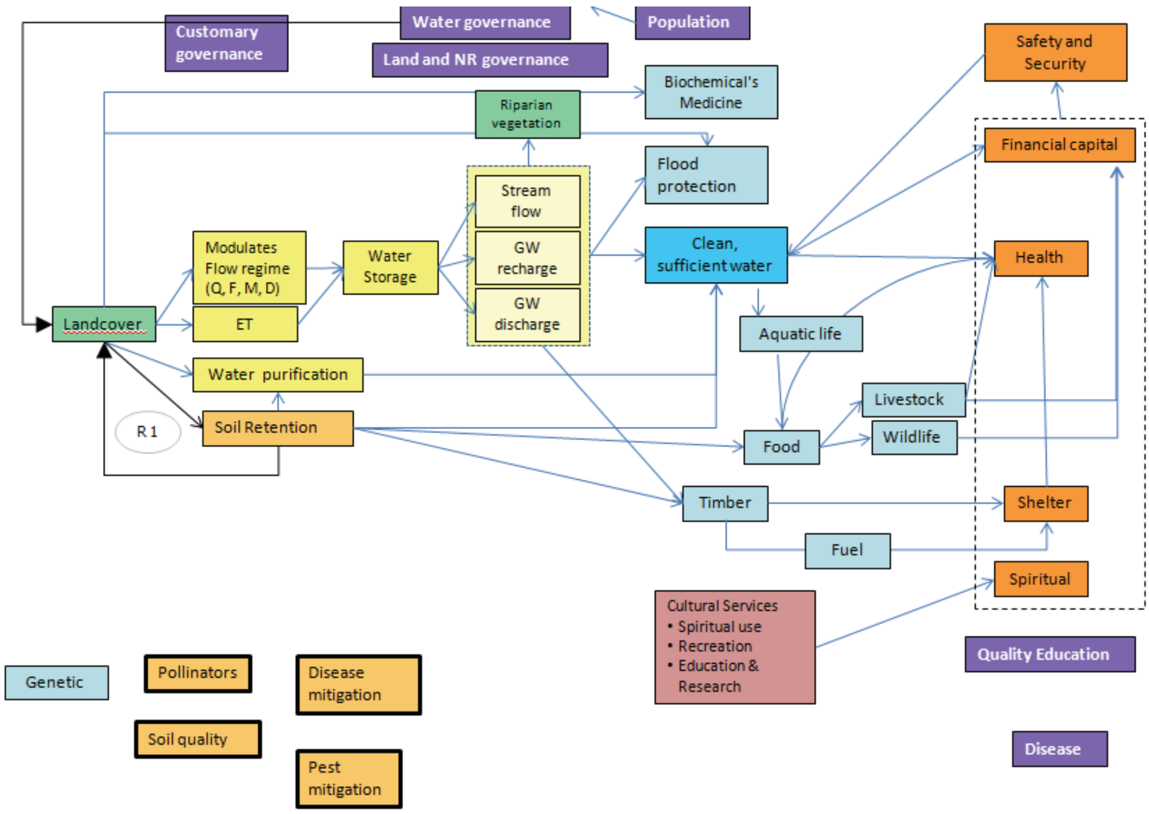

Figure 7. Draft conceptualisation of WatRES for the Sabie-Sand Catchment

A basic colour code was used as follows:

- Intermediate ES – green
- Final ES – blue
- Benefits (well-being) – orange
- Drivers (or dis-benefits) – red

This code was provided as guidance for CMLs during the participatory interviews and workshop.

5.2.3. Choosing the system boundary: the catchment and IUA boundaries

In order for the participatory process to support the upcoming classification process for the Incomati WMA, the classification process (DWA 2007[14]) was used as the basis for delineating the system boundaries and scales of analysis (see Section 3). The process requires the delineation of Integrated Units of Analysis (IUAs) within catchments. Given the focus on the Sand River Catchment at the broadest scale, attempts were then made to define IUAs. However, there is little practical guidance for this although a broad overview is provided such that the IUA delineation is primarily according to a number of socio-economic criteria and drainage region (catchment area) boundaries. It is suggested that ecological

[14] WRCS Guidelines, Vol 1 and 2 (Overview and the 7-step classification procedure; and Ecological, hydrological and water quality guidelines for the 7-step classification procedure) (DWA, February 2007)

information also plays a role. As part of understanding the practice guidance was sought through the Olifants Classification process which was underway at the time of this study, which apparently based the delineation on the following:

- Socio-economic zones
- Catchment area boundaries (drainage regions and water resource systems)
- Similar land use characteristics/land based activities
- Eco-regions and Geomorphology
- Ecological information
- Present status of water resources
- Stakeholder input

In reality their team members noted that sub-catchment boundaries were the most tenable since the hydrological modelling is core to the process.

In the case of this project the core team – together with specialists including hydrologists – examined all of the aforementioned features and selected three IUAs[15]. To the best of the core group's knowledge these three IUAs are fairly similar biophysically and socio-economically (Table 6).

[15] Note that although the SRC was the focus a number of stakeholders from the wider Sabie-Sand catchment requested involvement. This broader boundary was used in the visualization process (see below) and, given the emphasis on testing a method this was not considered to be a problem.

Table 6. General description of the Sand River Catchment IUAs used from Pollard et al. (2008a) and Ginsburg et al. (2010). PES – Present Ecological State.

	Landcover / landuse mosaic	Biophysical features	Socio-economic features
IUA 1	Upper Sand River. High proportion of flows generated in this IUA. Mainly forestry-conservation mix moving into rural settlements. State and communal land, Climate- MAP >1300 mm in mountainous west. MAE is ~1400 mm, decreases to	Great Escarpment and Lowveld; granite lowveld, Sour Bushveld, Northern Mistbelt Forest PES – Largely natural (B) and moderately modified © EIS – High + Moderate Aquatic biodiversity – Protected + Irreplaceable	Upper portion- in a state of flux between forestry and a move to conservation. Middle- mixed socio-economic profile; former bantustan areas thus high levels of poverty, female-headed households, poor literacy.
IUA 2	Mutlumuvi River. High proportion of flows generated in this IUA. Mainly forestry-conservation mix moving into rural settlements. State and communal land,	Great Escarpment and Lowveld: granite lowveld, Sour Bushveld, Northern Mistbelt Forest PES – Largely natural (B) and moderately modified © EIS – High + Moderate Aquatic biodiversity – Protected + Irreplaceable	Upper portion- in a state of flux between forestry and a move to conservation Middle- mixed socio-economic profile; former bantustan areas thus high levels of poverty, female-headed households, poor literacy.
IUA3	Includes confluence of Sand and Mutlumuvu. Middle region – communal land, lower portion-state and private conservation.	Lowveld: granite lowveld PES –Moderately modified © EIS – Moderate Aquatic biodiversity – Ecosystem maintenance + Protected Climate – semi-arid, low-lying areas MAP <500 mm, MAE ~1700 mm in the KNP	Middle- mixed socio-economic profile; former bantustan areas thus high levels of poverty, female-headed households, poor literacy. High earning conservation areas with tourism being a prominent feature.

5.2.4. Identifying stakeholders

Stakeholders were identified from previous work and included representatives of different sectors as well as organisations involved in water resources management or water use (Table 7).

Table 7. Sectoral representation. The sectors of municipality, mining and emerging farmers (from Sand River sub-catchment) did not attend

CATCHMENT and SECTOR
SAND SUB-CATCHMENT
Forestry (DAF)
Commercial agriculture (Water Use Association, Irrigation board)
Emerging farmers or schemes
Private tourism (SSW)
Conservation and tourism (KNP)
Interested parties and NGOs
Municipality
SABIE SUB-CATCHMENT
Commercial agriculture (Water Use Association, Irrigation board)
Emerging farmers or schemes
Interested parties and NGOs
Municipality
Mining
SABIE-SAND CATCHMENT
Water Resource Management
Department of Agriculture
Landcare
Traditional healers

5.3. Designing and testing participatory processes with stakeholders/residents

5.3.1. Methodology

The participatory process builds on the principles outlined in Section 4.3 and shown in Figure 5. Essentially the process consisted of three main engagements: that with stakeholders (later referred to as catchment residents), the second that engaged so-called 'specialists' and the third that allowed stakeholders and specialists to work together. The last two steps were combined into one workshop (Table 8, point 3) mainly to take into account specialist concerns regarding time commitments and also due to financial constraints (both of which are relevant outside of this research project).

Table 8. Stages of participatory process and summary of their testing

Process	Concepts introduced	Outcome:
Stakeholder engagement		
1) Individual interviews with stakeholders, some of whom are so-called 'specialists' (see above discussion on terminology).	The project conceptual grounds, classification and the Reserve, WatRES and benefits, links and feed-back loops;	Individual concept loop maps (CLMs)
2) Collaborative stakeholder/ residents (Workshop 1 with the same participants as at step 1;	links between different WatRES and benefits, spatial relations, difference between production and consumption of the benefits;	Group CLMs.
Stakeholder and specialist engagement + collaborative engagement		
3) Collaborative workshop between stakeholder/ residents and specialists (Workshop 2). and the developer of a modelling software; 6th-7th of February 2013; Venue: White River;	Reserve, benefits trade-offs between management classes and between different scenarios (compliance/ non-compliance);	A common CLM transferred into modelling software.

5.3.1.1. Stakeholder engagement: Individual interviews

The purpose of this step was to:

- support stakeholders to think about WatRES and benefits provided by the Sabie-Sand River and to think more broadly about the benefits of a healthy system;
- support stakeholders to conceptualise WatRES and benefits systemically (i.e. think about linkages, relationships and possibly feedbacks);
- do so in a non-threatening way (i.e. moderated by other participants perceived to 'know more').

Participants included forestry, commercial agriculture, emerging farmers, irrigation boards, tourism, interested and affected parties, DWA, the ICMA, Landcare, traditional leaders and Traditional healers (see Table 7).

The first stage of the participatory process was designed to meet stakeholders individually and to work with them to support their initial conceptualisation of water-related ecosystem services. In some cases participants came as a group but were nonetheless encouraged to work individually where possible. This comprised a series of 10 meetings in the course of which interviews were conducted with 21 people. Each hour long interview which, although fairly constrained in terms of time, was designed to take into account peoples' constraints of time and also stakeholder fatigue given that they had already been involved in various water-resource management processes.

Outline of the process:

- Introduction of context and purpose. Rapid background on IWRM context, specifically classification and the need for stakeholders to collaborate in decision-making process of different catchment sections (see Box 5).

Box 5: Outline of introduction

- Ask if the participant has heard about the Reserve. If yes, ask them to explain, if no – provide an explanation, for example: "Before allocating water for any other needs you have to allocate it for basic human needs, conservation and meeting international agreements. It is done in order to keep river functioning as a river system."
- Ask if the participant has heard about the Classification. If yes, ask them to explain, if no – provide an explanation, for example: "In 2013 Water Affairs will introduce a process of classification of Incomati catchment. Each sub-catchment within Incomati will be divided on parts and each part will be assigned a management class. There will be three management classes where Class 1 indicates pristine river and class 3 a 'working horse' river. Depending on the class, a Reserve will be defined for each part of a catchment. It is very important that the process of identifying management class involves all the stakeholders in order to ensure that the interests of each sector are represented. Our research has shown that stakeholders are often brought into processes without adequate briefing and are expected to participate meaningfully. Thus as part of a Water Research Commission project, we are developing an approach that supports stakeholder opinions and collaborative learning."
- Answer questions

- Participants provide a freelist of **benefits** on paper by responding to the question: "What are the benefits of a healthy, flowing Sabie-Sand River?" There is no specification as to whether or not they should answer from a sectoral perspective but if they ask, they are encouraged to do so. The research objective is not to understand sectoral conceptual models but rather to get people to start to think about benefits derived from healthy rivers. Because of this the status of 'healthy' is not defined nor is any reference made to the 'Reserve'.
- The facilitator then transfers each benefit onto individual coloured cards, checking that participant agrees if a point is paraphrased. At this point participants sometimes list not only benefits but also ecosystem services and drivers. In such cases and based on a knowledge of ES concept, each point is assigned to an appropriate coloured card depicting ES, benefits or drivers.
- Concept map development.
- Participants are then asked to think about how the benefits that they named are connected to each other, by asking
    - What impacts on that factor?
    - What does that factor/ card impact on?
- Participants then arrange the cards in a causal chain and narrate this.

- Different management scenarios: The session closes with a brief discussion on what participant thinks might happen to these system elements and linkages under different management classes: e.g. moving from Class II to Class III. The idea is to prompt thinking that these benefits are dynamic in time.

  At this stage only very superficial mention is made of the concept of ecosystem services as one which is distinct from benefits. Equally, the concept of compliance and non-compliance is not introduced at this stage, only the fact that ES will likely change under different management scenarios.

5.3.1.2. Collaborative engagement between stakeholders: Deepening understanding of WatRES

The aim of this step was to:

1. review the individual concept maps developed by stakeholders regarding water-related ecosystem services within the Sabie-Sand Catchment;
2. familiarize and/or build-on participants understanding with the concepts regarding water-related ecosystem services within the context of water resources management and protection in SA (Classification, the Reserve, Water Allocation Plans);
3. explore the distribution of ecosystem services
   a. spatially in a catchment (this happens at the scale of IUAs), and
   b. under different management scenarios
4. To support a collaborative and wider systemic conceptualisation between stakeholders.

The same stakeholders who attended the first stage were invited to the collaborative workshop which was held on the 22nd of October 2012 at Wits Rural Facility. Table 9 provides an outline of the activities.

Table 9. Agenda and activities of the stakeholder collaborative workshop

1	Session 1: Introduction and Background - Welcome and introduction - Context and background and plans for the day
2	Session 2: What has been done? - Review individual CMs - Review WatRES and benefits - Review links between WatRES and benefits - Consensus
3	Session 3: Group Work: Develop a common picture of WatRES and Benefits in the Sabie-Sand Catchment - Group work - Sharing of information - Agreement on general picture, relationships and the narratives
4	Session 4: Explore the spatial distribution, relative abundance and connectedness (linkages) - Group work on visualising ES distribution - Plenary- seeking agreement and coherence
5	Session 5: Deliberation of WatRES and benefits under different management scenarios
6	Session 6: Reflection and close

In session 2, the results of the data analysis described in the previous section including Figures 10-12 and the 'Top 5' lists of ES and benefits (Box 6) were presented to the participants with an explanation. Participants then reviewed their CMs which they produced during the interview process and made adjustments. During this discussion the participants got familiarised with the linkages between ecosystem services and benefits (as described in table 12).

The group work followed a similar process to that described above for individual participants but participants now had access to new ideas through the review of their individual concept maps where they were invited to think about what they might add or change.

When tasked to work collaboratively (Session 3) the participants were then divided into two groups of 4 and 5 people each. They we asked to develop a collaborative CM for a 'healthy flowing Sabie-Sand river system' showing ES, benefits, drivers and relationships between them. Both of the groups used the lists of 'Top 5' ES and benefits as a guidance but made some changes. For example, group 1 separated cultural benefits from spiritual and group 2 renamed 'safety and security' into 'stability and security'. A number of additional elements were also added by both groups.

Session 4 introduced the concept of *spatial variation* for which a visualisation process was designed. This activity was part of an endeavour to develop and test a collaborative, visual simulation tool to assist multi-stakeholder decision-making process.Initially an adaptation of the Water Allocation Game (WAG; see www.award.org.za) was employed but was considered to be (a) too complex in its process and (b) difficult to adapt for the purpose of multiple variables and hence abandoned in favour of a simple visualisation exercise which was used in two exercises:

1) Spatial representation of production and consumption of key ES and benefits. During the first visualisation exercise participants worked in the same groups (see Figure 7). They were asked to consider a generalised 'healthy, flowing Sabie-Sand River catchment'. Out of the presented 'Top 5' lists of ES and benefits the groups had to choose two or three ES and all the benefits that apply to them according to the group's opinion. They were then given a base map of the catchment and 'marbles' of different sizes and colours to represent each of the selected ES and benefits. They were asked to represent where the chosen ES are produced and where the associated benefits are consumed and by whom. They indicated relative amounts per IUA, ranking them
   - None = 0 marble
   - A little = 1 marble
   - Some = 2 marbles
   - A lot = 3 marbles

   Participants recorded information on a datasheet. Thereafter all the marbles were reintroduced onto the map according to the information from the datasheet. The participants were then able to compare with other groups the different spatial distributions and relative amounts of ecosystem services and benefits over the catchment area.

2) The second exercise, conducted in plenary with a facilitator, indicated the links between a range of ES and benefits. This also facilitated discussions regarding different scenarios. The second visualisation exercise was completed in one group with all the participants working together. A bundle of ES and benefits from the 'Top 5 list' was put on the map and the linkages between them were drawn. After several test cause-and-outcome questions (e.g. 'If clean water in this IUA goes from 3 to 1 how will it affect the benefits downstream?') the group was presented two degradation cards (where a hypothetical case was introduced) The degradation card described a change in the catchment and the participants were asked to reflect on how this change could affect the water management and residents of the catchment. The marbles on the map was mostly managed by a facilitator but when the participants were explaining their ideas they were using marbles for illustration.

In the course of this exercise the group discussed spatial and temporal linkages between the ES and benefits and reinforced an understanding of a common interdependence of IUAs. The participants also touched upon indirect linkages between the elements of the catchment. For example, it was mentioned that economic benefits of the tourism areas also include the food imported from local villages, cleaning services, transportation from the airport to the tourist's final destination.

After completing the data sheets, the groups re-introduced all the discussed ES to each IUAs. The two groups came together to share their results and discuss what the configuration and relative amounts of ES production mean for the management of the catchment as a whole.

Figure 8. Group of participants working on the first visualization exercise

5.3.2. Results of interactions with stakeholders/residents

5.3.2.1. First step: Individual interviews

A total of 18 CMs were developed by stakeholders (of 21 stakeholders, 4 farmers worked together).

The figures below are the two examples of the individual CMs. They differ in depth of the content as well as in the number of links and feed-back loops drawn. In the first diagram (Figure 8) the space is divided in accordance with a conceptualised causality and a colour code; most of the elements have multiple connections; and most of the connections are looped. The second diagram (Figure 9) represents an approach where the connections are predominantly linear.

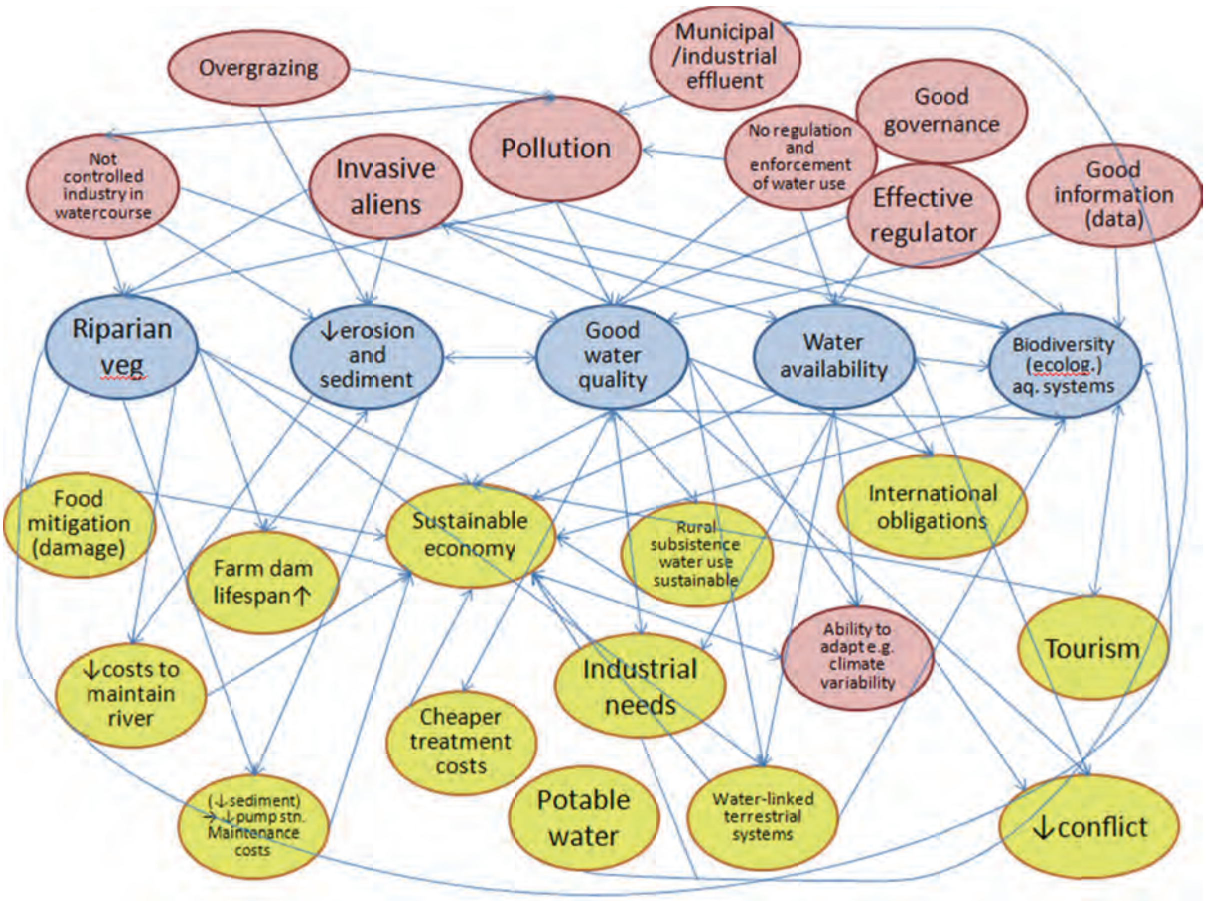

Figure 9. Example of an individual CM showing feedbacks and complex relations

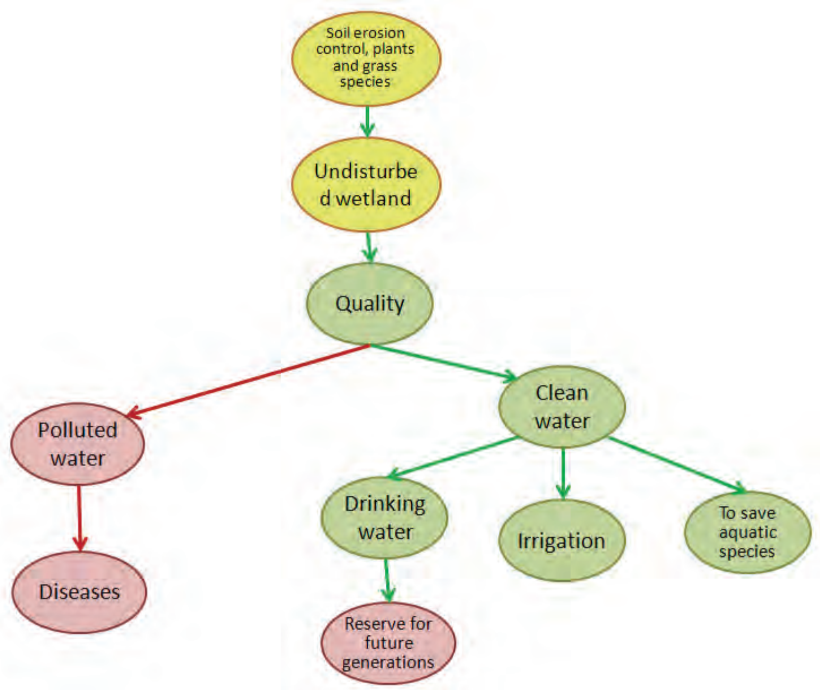

Figure 10. Example of an individual CM with linear connections

The analysis was conducted on data from the individual CMs. This was because of the need to present a synthesis of their results at the subsequent workshop.

For the purposes of analysis, all the elements of the CMs were listed and divided into two categories namely 'cause' (a preliminary listing of drivers) and 'outcome' (i.e. ES, benefits). Some 102 causes and 168 benefits were named. The items from 'outcomes' list (first list) were then grouped into categories (second list), based on the researchers' understanding of the roles of these elements as intermediate ES, final ES or benefits from ES (drivers were left out of the analysis at this stage). In total 15 categories of intermediate ES, 15 categories of final ES and 17 categories of benefits were developed. For the purposes of this step, the intermediate services were not analysed further. A second aggregation of the categories of final ES and benefits was undertaken which resulted in 10 categories of final ES and 9 categories of benefits (third list), as shown in Tables 10 and 11 of final ES and benefits respectively.

Table 10. The (final) ecosystem services (ES) identified by individual participants. The categories (3rd column) represent a range of ES that were considered to be sufficiently similar to be grouped

Detailed list of final ES	Incidence	Grouped (3rd) list of ES	Incidence
Clean water	16	Clean water	16
Domestic use	9	Domestic use and subsistence	13
Communities	4		
Potable drinking water	12	Potable drinking water	12
Agriculture	2	Agriculture	12
Farming	2		
Food production	8		
Healthy aquatic life	7	Healthy aquatic life	8
Aquatic migration	1		
Biodiversity	7	Biodiversity	7
Wildlife	7	Wildlife	7
Flood mitigation	2	Flood mitigation	3
Flooding river	1		
Livestock farming	3	Livestock farming	3
Industrial needs	1	Industrial needs	1

Table 11. The benefits derived from water-related ecosystem services (ES) as identified by individual participants. The categories (3rd column) represent a range of benefits that were considered to be sufficiently similar to be grouped

Detailed list of benefits	Incidence	Grouped (3ed) list of benefits	Incidence
Economic benefits	12	Economic benefits	16
Jobs creation	2		
Increased farm dam lifespan	1		
High standard of living	1		
Health	10	Health and disease mitigation	16
Disease amelioration	1		
Disease outbreak	4		
Cultural	3	Cultural and Spiritual	13
Recreation	6		
Spiritual	4		
Disease amelioration	1		
Disease outbreak	4		
Tourism	9	Tourism	9
Safety and security	3	Safety and security	4
Social development	1		

International relations	3	International relations	3
Reserve for future generations	1	Reserve for future generations	1
Ability to adapt	1	Ability to adapt	1
Political	1	Political	1

Figures 10, 11 and 12 indicate intermediate and final ES, and benefits from the ES respectively and their incidence as named by participants.

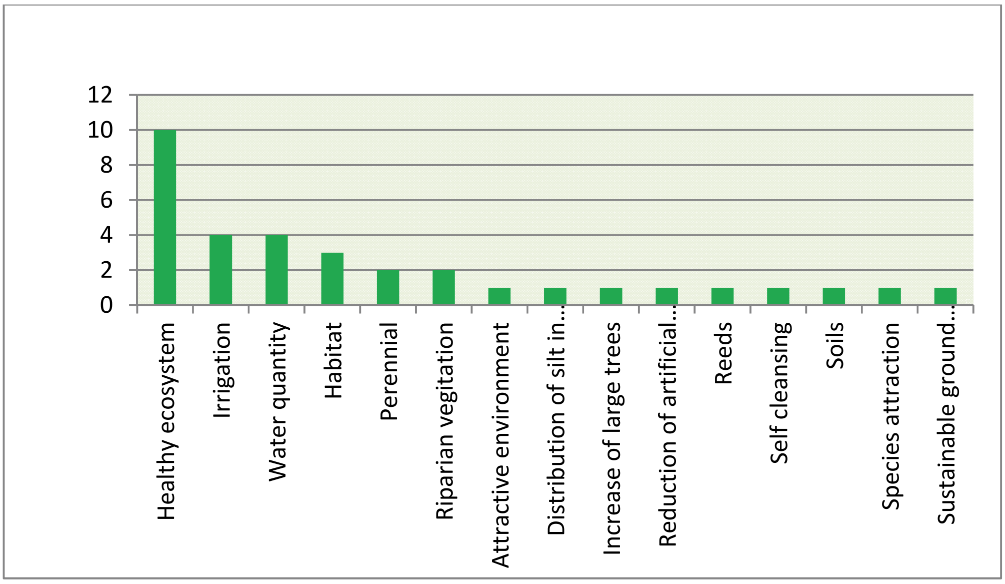

Figure 11. Incidence of intermediate ecosystem services (grouped into categories) as named by individuals

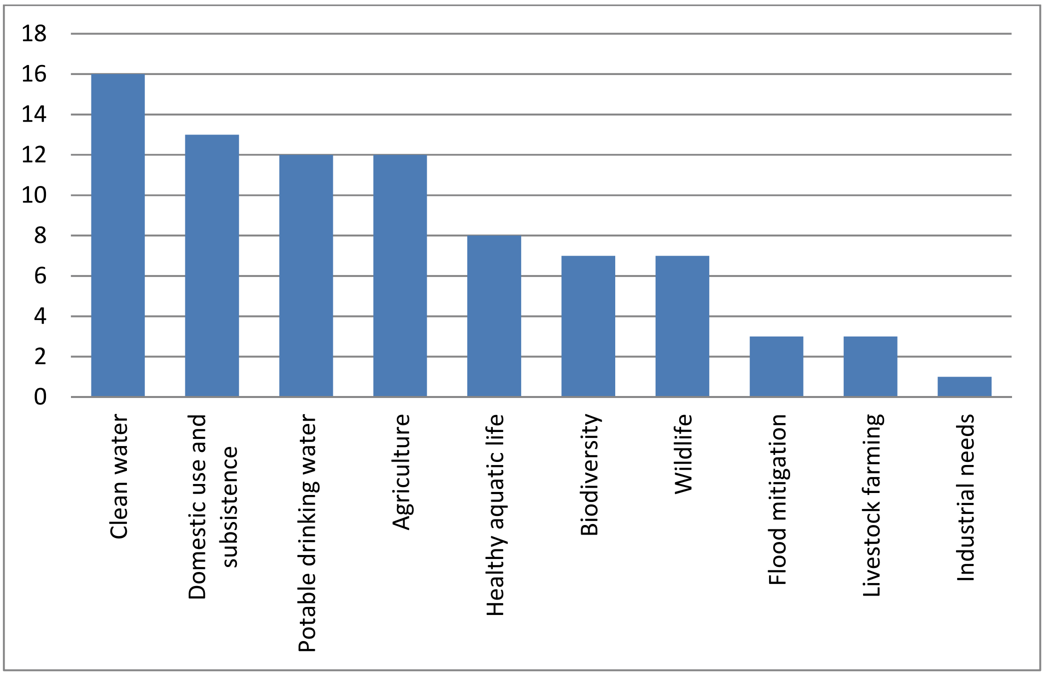

Figure 12. Incidence of final ES (grouped into categories) as listed by individual stakeholders (n=82)

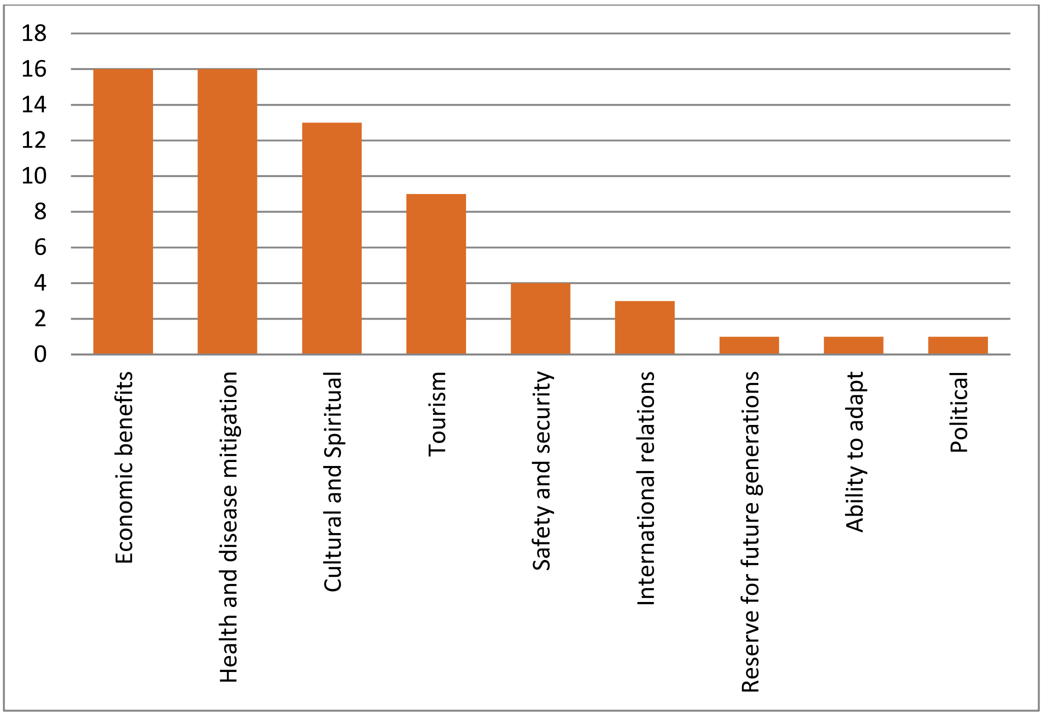

Figure 13. Incidence of benefits (grouped into categories) as listed by individual stakeholders Note the economic benefits include savings made through healthy ecosystems (n=70)

When considering benefits, all the participants named '***clean water'*** or '***good water quality'*** as a central element of a healthy Sabie-Sand river system. In terms of 'economic' benefits a number of participants named benefits that comprised savings rather than wealth creation. For example, savings made on health measures, waste water treatment and river rehabilitation through maintaining health ecosystems. Interestingly, some of the participants demonstrated broader system thinking and mentioned the importance of sustainable development in time ('ability to adapt', 'future generations') and the consequences for the neighbouring countries ('political', 'international development'). Quite a lot of participants mentioned disease outbreak (mostly caused by *E.-coli*) as a consequence of inadequate water quality.

In terms of ecosystem services, unlike the CM of the core team, factors such as soil retention, climate, flow regime, water storage were almost never named. Land use practices are mentioned by some of the participants. The underlying drivers of 'good water quality' were mostly identified as anthropogenic factors such as pollution and governance.

The lists of final ES and benefits were planned to be used on a collaborative workshop during the group visualisation exercises. For the sake of convenience it was decided to define five ES and five benefits with the highest incidence and present them for the groups to work with. The resulted 'Top 5' categories are given in Box 6.

Box 6: 'Top 5' bundle of ES and benefits as listed by participants

'Top 5' ecosystem services:

- Clean water;
- Potable water;
- Domestic use and subsistence;
- Aquatic life;
- Agriculture.

'Top 5' benefits from ecosystem services:

- Economic;
- Health and disease mitigation;
- Tourism;
- Cultural and spiritual;
- Safety and security.

In order to understand how the participants link these ES and benefits to each other, the most commonly mentioned relations were calculated. Table 12 shows the numbers of incidence between the 'Top 5' ecosystem services and the associated benefits. In Table 12, the cells coloured in green show the highest frequency at which ecosystem services directly impacted on benefits.

Table 12. Frequency at which the 'Top 5' Ecosystem services had an impact on benefits. High, medium and low frequencies are represented respectively in green, blue and yellow.

	'Top 5' Ecosystem Services				
Impact on Benefits	**Clean water**	**Potable water**	**Domestic use and subsistence**	**Agriculture**	**Aquatic life**
Health	5	5	5	2	
Cultural and spiritual	4				1
Recreation	4		1		
Economic benefits	3	1		5	1
Tourism		1		1	3
Safety and security	1		1	1	1
Ability to adapt	1				
International relations		2			
Reserve for future generations		1			

5.3.2.2. Second Step: Collaborative stakeholder workshop

The main outcomes of the collaborative workshop were as follows:

1) The participants had a chance to reflect on their personal CMs and had developed first **collaborative CMs** of WatRES (two group CMs were produced).
2) During the first visualisation exercise the participants, working in two groups, had considered **distribution of production and consumption** of ES in Sabie-Sand and their relative amounts in each IUA.
3) During the second visualisation exercise the participants, working all together, had discussed **linkages between ES and benefits**, their spatial relations and change under different management scenarios.

5.3.2.3. Collaborative concept maps

Figures 13 and 14 show the collaborative CMs produced by both of the groups.

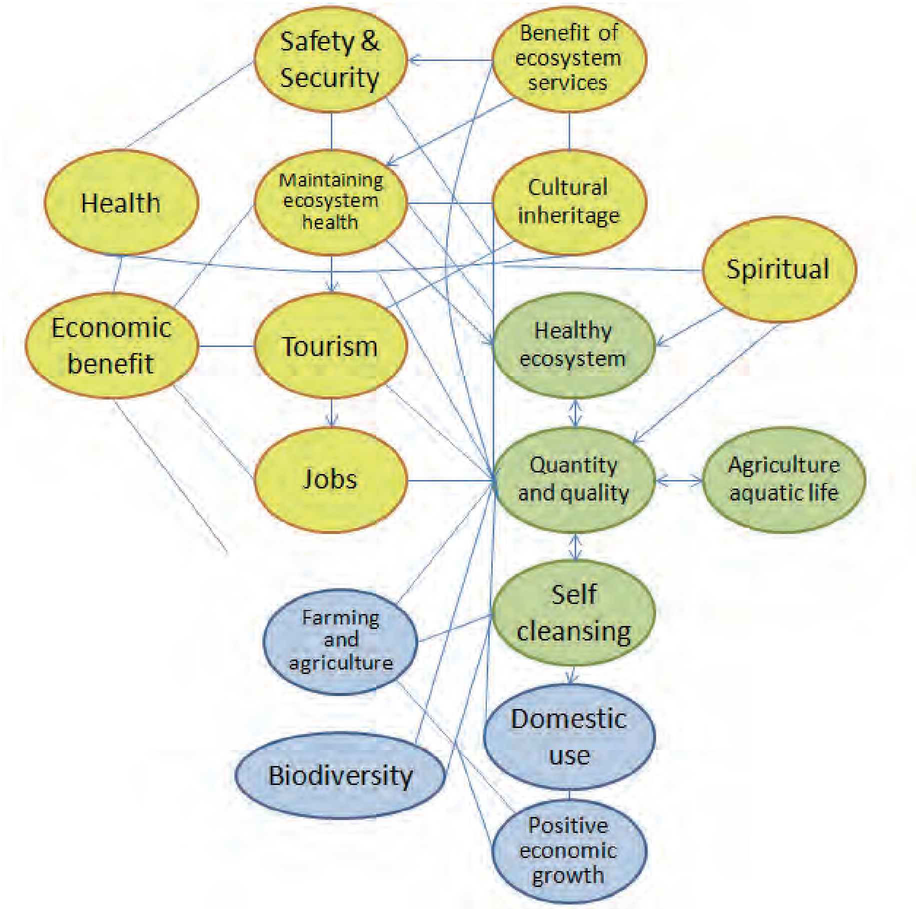

Figure 14. Collaborative CM produced by Group 1

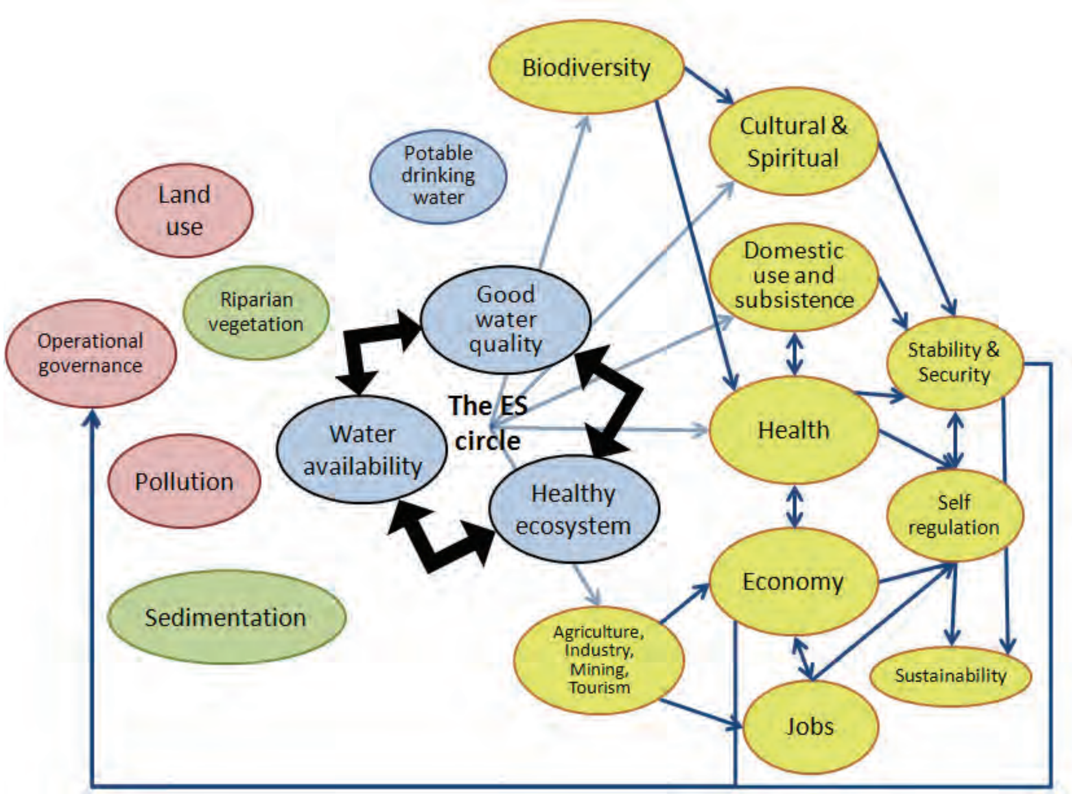

Figure 15. Collaborative CM produced by Group 2

In plenary each group presented their CMs and asked each other questions. As outlined above, the term 'cultural and spiritual benefits' was discussed: group 2 chose to use more generic categories and view spirituality as a form of culture; on the other hand group 1 stressed that cultural and spiritual practices form significantly different linkages to other elements of a system, namely tourism.

5.3.2.4. Distribution of ES production and the consumption of benefits

Table 13 provides the outcome for the visualisation exercise. Both of the groups chose to analyse ES of clean water with all five of the benefits and ES of agriculture with economic and safety and security benefits. Group 2 had time to analyse an additional ES – 'domestic use and subsistence use'.

Table 13. Data from the two groups indicating the distribution of ES production (blue) and the consumption of associated benefits (pink). '3' = 'a lot', '2' – 'some', '1' – 'a little', '0' – 'none'.

	Group 2				Group 1			
Ecosystem service/ Benefit	IUA1	IUA2	IUA3	Outside	IUA1	IUA2	IUA3	Outside
Clean water	3	1	2	0	3	2	2	1
Economic	3	3	2	3	1	3	3	3
Tourism	3	1	3	3	3	1	3	2
Health and disease mitigation	2	3	1	3	0	3	1	3
Cultural and Spiritual	2	3	2	0	3	1	2	0
Stability/Safety and Security	1	3	3	3	3	3	1	3
Domestic use and subsistence (water for)	3	2	1	0				
Health and disease mitigation	2	3	1	0				
Cultural and Spiritual	2	3	2	0				
Agriculture (water for)	3	2	1	0	3	3	0	3
Economic	2	3	1	3	3	3	0	3
Stability (Food security)/Safety and Security	2	3	1	3	3	3	0	3
Health and disease mitigation	0	3	0	3				
Tourism	2	0	0	0				

It can be seen that the weights allocated by different groups vary significantly. This came up on the plenary and an agreement was reached on most of the positions.

- For example, the benefit of 'Stability/Safety and Security' for an ES of 'Clean water' is rated '3' and '1' in IUA1 by group 1; and '1' and '3' in IUA3 by group 2. After discussion it appeared that one reason related to differences in understanding of the category name: group 1 interpreted this as food security whilst group 2 took a political interpretation and went so far as to replace 'safety' with 'stability'. A further reason was that group 1 assigned '3' to IUA1 thinking of this IUA as an important *source* of safety and security of the catchment. They noted that the group had confused the production of ES and consumption of ES-related benefits.

As noted, the two groups came together to discuss what the configuration and relative amounts of ES production mean for the management of the catchment as a whole and reached a number of conclusions:

- The consumption of a particular ES often depends on its production mainly in another IUA.
- Externalities and the notion of 'outside of the catchment' – group 2 mostly considered Mozambique as a downstream neighbour but group 1 mentioned the importance of considering the whole nation or society as a beneficiary of certain activities in the catchment.

5.3.3. Discussion

In this final section we reflect on the development and application of the WatRES methodology and its application to planning for sustainability in water resources management.

5.3.3.1. Evaluation by participants

The participants were asked to fill in a reflection form. It consisted of four questions regarding the workshop:

- What was easy to understand?
- What was not easy to understand?
- What I know that I did not know before?
- What working in a mixed group means to you?

The points of interest that arose from these reflections are the following:

- Visualisation was mentioned several times both as a helpful and a confusing tool.
- It was mentioned that the idea of ES and benefit is easy in principle but unclear in details (for example, is biodiversity an intermediate service, a final service or a benefit?).
- Some disagreed with the category of 'safety and security'. It can be illustrated by how Brian Jackson put it during one of the discussions:

"We took out "safety and security" and called it "stability and security" and "self-regulation". Self regulation is about people and ecosystem. Stability is sustainability. I don't like "safety and security" cause it's a different department and it will be confusing."

- The confusion around the category of 'cultural and spiritual' benefits was mentioned. During the CM exercise, one group said cultural and spiritual benefits can be crudely collated to 'cultural' because spirituality is just one side of human cultural life. The other group looked at the practical implications of such a division and decided that while cultural benefits may be linked to tourism, spiritual benefits are sacred and should not be linked to tourism.
- Some participants mentioned that they have learned the importance of water in various aspects of people's lives and the links between the benefits.
- The absence of representatives of such important sectors as mining and municipalities was mentioned.
- The work in mixed group was noted as important, informative and mind-opening. For some of the participants it was a rare opportunity to meet other stakeholders in the catchment. Many participants expressed appreciation of the differences and commonalities in everyone's values. It can be illustrated by the following quote from the evaluations:

"People value water resources differently based on their work or where they live in the catchment but in many cases these different people can agree on a lot of common values."

5.3.3.2. Evaluation by team on methodology

<u>First stage: Individual interviews</u>

Overall the session was successful in achieving its aims in the following ways:

- The participants demonstrated an understanding of the purpose of the project and the question that was asked ("What are the benefits of the healthy flowing river system?").

- The participants did not seem to be constrained by more 'knowledgeable' colleagues or facilitators and felt free to ask questions and express their views.
- The participant's vision of the catchment developed within the session. It can be proved by comparing the list of the benefits that they were asked to write down in the beginning with the diagrams. Many of the participants mentioned that the systems thinking exercise provoked them to notice the bigger picture.
- The research team was able to learn new information from the interviews (for example, the forest practices, the *E. coli* distribution).
- The individual CMs that were produced during the first session provided information that was later analysed and used in the further process.
- Despite a couple of exclusions where the interview extended beyond the declared topic, the planned hour was enough to achieve the desired results.

However, there are a number of issues that need to be taken into consideration in the next stages of the work:

- The sectors were underrepresented: municipality and emerging farmers from Sand sub-catchment were absent. Possibly this could be arranged if more time was given to the organisation of the meetings.
- Usually one hour was enough to reach the desired results although the stage of drawing the links could take longer and sometimes had to be interrupted. Thus it is unclear whether the results would be significantly different if we spent more time with the participants.
- As another consequence of time limitation is a possibility that the given time might be enough to only explore one side of participants' vision of the problem. For example, Brian Jackson produced a complex CM that had no food production in it. When he was asked of the reasons, he said he was concentrated on exploring the links between the factors he put down on the paper in first minutes and did not have enough time to think about other important areas.
- It is possible that facilitation was influencing the depth and direction of the analysis that the participants were performing in their CMs.
- Sometimes participants got confused when their own understanding of the question seemed to contradict with the vision of the sector they represented. For example, Harry Biggs and Rina Grand-Biggs admitted that a part of their diagrams was produced from their personal perspective and other part – from the perspective of the organisation that they represented. It did not make a difference for data analysis but may potentially result into inconsistency of the information provided.
- Some of the participants tent to include a lot of examples of corruption and pollution into their interviews. Even though such stories provide details of the situation in the catchment, some of them might appear to be distractive and need to be interrupted.
- If some of the benefits may stay not mentioned it does not mean they are not perceived as important. As Winners Mashego put it:

"They knew these benefits, but the way they were considering them was different. Some people say we use water for drinking and forget washing. But it's also a main benefit, we should put it in."

Second stage: Collaborative stakeholder workshop

Twelve people including emerging and commercial farmers, representatives of Department of Agriculture and interested parties cancelled their attendance in the morning of the workshop. Out of nine people who attended the majority were experienced participants of multi-stakeholder meetings.

The groups were small and facilitators made sure to engage everyone into a discussion. Nevertheless, one of the groups was more reluctant to contribute and relied on one leader. Plenary opened space for a discussion among all the stakeholders where they were asking each other questions and exchanged information. For example, Brian Jackson explained his idea of 'operational governance'.
As group work showed, the concept of ES and benefits seemed to be understood in general by all the participants. But there was still quite a lot of uncertainty in details. For example, Group 2 could not establish what category to put 'biodiversity' in.

The categories of ES and benefits were rather broad and it was sometimes problematic for participants to agree what the categories mean and how they differ from each other. For example, during the first visualisation exercise both of the groups tend to think that 'clean water' and 'drinking water' are essentially the same. Confusion arose around the category of agriculture: participants had different opinions on whether it includes private farming, livestock and forestry or not.
The condition of 'healthy flowing Sabie-Sand river system' tends to create some confusion.

5.4. Designing and testing for the collaborative conceptualisation between stakeholders and specialists

As noted in Section 5.3 the participatory process consisted of three main engagements (1) the first with stakeholders (later referred to as catchment residents), (2) the second with so-called 'specialists' and (3) the third that allowed stakeholders and specialists to work together. The last two stages were combined into one workshop (see Table 8) so as to accommodate concerns regarding time and finances. This section focuses on the last two steps.

The workshop was designed to bring together the aforementioned residents, involved in the first stage, and 'specialists' from various disciplines in order to develop a collaborative understanding of the benefits of water-related ecosystem services (WatRES) and well-being in the Inkomati using the Sand River Catchment as a test case. The workshop objectives were:

1. To further build-on catchment resident understanding with the concepts regarding water-related ecosystem services (WatRES) within the context of water resources management and protection in South Africa (Classification, the Reserve, Water Allocation Plans)
2. For specialists to elucidate collaboratively their understanding of WatRES and benefits and to co-construct a joint concept map of these
3. To develop an acceptable, collaborative concept map (with residents, specialist and core team) based on the previously-developed draft concept maps [regarding WatRES within the Sabie-Sand Catchment]
4. To describe the nature of the relationships between variables
5. To consider feedbacks in the system, especially between areas in the catchment (e.g. the IUAs)
6. To explore the distribution of ecosystem services and associated benefits
    a. spatially in the catchment
    b. under different management scenarios
7. To explore the use of system dynamic modelling within the context of WatRES.

5.4.1. Methodology

An outline of the workshop's activities is given in Table 14. The workshop opened with a session for the specialist which essentially covered the same steps that the catchment residents had been taken through (see Section 5.3).

Table 14. Major activities of the two-day workshop

	Session	
1	Session 1: Introduction and overview of theories on ecosystem services and human well-being	
2	Session 2.a): 'Specialist' conceptualisation of WatRES and their inter-linkages	Session 2.b): Revision of catchment resident conceptualisation of WatRES
3	Session 3: Collaborative understanding between the two groups: catchment residents and specialists	
4	Session 4: Working towards a common systemic view of WatRES	
5	Session 5: Understanding the distribution of WatRES – where these are produced and enjoyed	
6	Session 6: Understanding quantitative system dynamic modelling	
7	Session 7: Reflection and Evaluation	

Table 15 provides a list of participants and indicates the variety of sectors and disciplines represented by the residents and specialists. However the local municipalities, community leaders and mining sector did not attend.

Table 15. Participant representation at the workshop

Stakeholder group
Department of Agriculture, Forestry and Fisheries
Commercial Agriculture (Lima Rural Development)
Private Tourism (Sabie-Sand Game Reserve)
Conservation and tourism (SANParks)
ICMA and projects: Water Resource Management
Department of Agriculture
Specialist group
Southern Waters (Ecological Research and Consulting)
University of Kwazulu-Natal (Hydrologist)
PhD student in Hydrology (University of Kwazulu-Natal)
Hydrologist (IWR Water Resources)
Institute of Water Research (Rhodes University)
Institute for Poverty, Land and Agrarian Studies (University of Western Cape)
Conservation (Mpumalanga Tourism and Parks Agency)
Conservation (SANParks)
Department of Water Affairs

Inkomati Catchment Management Agency
NGO (Association for Water and Rural Development)

5.4.1.1. Session 1: Introduction and overview of theories on ecosystem services and human well-being

During this session, background information about the procedure for classifying water resources according to the National Water Act (1998) was presented to the specialist group. They were also introduced to the framework developed, described in Section 4. In order to facilitate resident engagement in the process, it is important to build a shared understanding of the catchment system (socio-ecological system). In the case of this project, specialists were introduced to the theories of ecosystem services and their relation to human well-being (see Section 2).

5.4.1.2. Session 2a: 'Specialist' conceptualisation of WatRES and their inter-linkages

The aim of this session was:

- to explore WatRES and their benefits as well as their linkages, relationships and feedbacks;
- to work collaboratively with specialists from different disciplines to develop a common understanding of WatRES and their inter-linkages.

Activity 1: Production of individual concept maps

For the first activity, the specialists were given 45 minutes to create individual concept maps of WatRES and their benefits. This exercise was carried out as described for stakeholders in Section 5.3.1.1, comprising:

- the identification of benefits:
- the identification of underlying WatRES:
- the development of concept maps to explore inter-linkages.

To ensure coherency with the methods used for the stakeholder data, the data for the individual interactions were analysed in some detail. This involved categorising the ES and benefits and examining the frequency of listing. An analysis of inter-linkages was also undertaken in order to examine the most common linkages conceptualised between ES and benefits.

Activity 2: Production of group concept maps

Thereafter, the participants were separated into three groups (five people per group) and given 45 minutes to develop a collaborative concept map (see Figure 15). First each participant briefly presented their individual concept map to the other members of the group; then, based on this, they collectively drafted a new list of benefits, discussed the underlying factors for each benefit and developed a joint concept map.

Less time was spent on analysing these maps and data than for the individual interactions mainly because participants did not manage to complete the exercises to their satisfaction due to time constraints.

Figure 16. Participants working in groups to produce a concept map of WatRES

5.4.1.3. Session 2b: Revision of catchment resident conceptualisation of WatRES

The aim of this session was to review with the catchment residents their conceptualisation of the WatRES concept maps that they had undertaken at the previous workshop (see Section 5.3).

5.4.1.4. Session 3: Collaborative understanding between the catchment residents and specialists

The aim of this session was to:

- compare the different concept maps produced by the residents, specialists and core team in order to identify commonality and divergence;
- facilitate interaction and discussion between stakeholders and specialists so as to develop a common understanding of WatRES and their inter-linkages.

The process started with a plenary session where the six concept maps constructed by the different groups were displayed: two resident's concept maps (Figure 13 and 14), three specialists' concept maps (produced in session 2a, Figure 18 and 19) and one core team concept map (produced by AWARD's researchers, Figure 6). Whilst observing the different concept maps, they were asked to think about the following questions:

- What is novel for you? What is similar with your concept map?
- What would you add? Or take away? (from your map)
- Which factors would you name differently on your map?

This was followed by a general discussion when participants were encouraged to share points of interest or observations they made.

5.4.1.5. Session 4: Working towards a common systemic view of WatRES

The purpose of this session was to:

- work collaboratively towards a joint systemic view of WatRES and their inter-linkages by focusing on water quality and water quantity;
- specify the nature of the relationships and feedbacks in the Sabie-Sand River catchment.

Activity 1: Production of a collaborative concept map focusing on water quality and quantity
In the first activity, the specialists and residents worked together in three mixed groups to develop a collaborative concept map within their group. During the exercise, a list of benefits and ecosystem services, gathered from the six concept maps presented earlier in the plenary session, was shown on a projector. This list was provided as a reminder of the ES and benefits that had been named and that could be considered. Participants were asked to consider the previous concept maps and discuss any new factors or linkages as well as commonalities but with a specific focus on the two ecosystem services of water quality and quantity because most participants had agreed that they were central to a healthy river system. While constructing their concept maps, the participants had to think more rigorously about the narrative of the relationships as well as the language used to describe these. At the end of the exercise, the facilitator chose one of the concept maps to be presented and participants were invited to comment and critique this.

Less time was spent on analysing these maps and data than for the individual interactions mainly because participants did not manage to complete the exercises to their satisfaction due to time constraints and because much of the focus was of a different nature (i.e. on understanding water quantity and quality).

Activity 2: Core team synthesis of concept maps
The final activity for this session was carried out by the core team of researchers from AWARD. Based on the discussions generated during the previous activity and the different concept maps produced, the core team worked together towards a common conceptualisation of WatRES and rationalization of the relationships. They worked during the evening of the 6th February. However, the maps were so divergent that this proved difficult and finally one map was selected for discussion the following day.

5.4.1.6. Session 5: Understanding the distribution of WatRES

The aim of this session was to explore the distribution of WatRES and consumption of their benefits:

i. spatially in the Sabie-Sand catchment;
ii. under different management schemes

This activity which tested a collaborative, visual simulation tool to assist multi-stakeholder decision-making process was carried out as described in Section 5.3.1.2. In this case the participants selected only two ecosystem services out of the five most commonly named ecosystem services and benefits defined from previous workshops, also referred to as 'Top 5' list (see Box 7).

5.4.2. Results of interactions with specialists and stakeholders

5.4.2.1. Individual conceptualisation of ES and benefits

A total of 15 concept maps (CM) were produced individually by the specialists. Out of these, the arrangement of ecosystem services and benefits in one of the concept maps was unclear and difficult to interpret and so only 14 CMs were analysed.

Tables 16 and 17 provide a list of all the ecosystem services and benefits mentioned in the 14 individual concept maps in order to show how these were named by the specialists. These were then grouped into categories based on the researcher's understanding of ES and benefits and the role of each of these: 13 categories of ES (including 4 sub-categories) and 10 categories of benefits (including 3 sub-categories). Due to time constraints, there was insufficient discussion regarding the conceptual difference between ecosystem services and benefits. Thus, some factors that were listed by the specialists as ecosystem services when technically they are benefits and vice versa. For example, drinking water was sometimes listed by the specialists as a benefit. However, drinking water is actually an ecosystem service and a benefit it provides is health. In such cases and where deemed appropriate they were re-categorised by the team. Also due to the lack of a defined colour code in most individual concept maps, the determination of a variable as either an ES or benefit had to be made by the research team on the same basis. The frequency of listing was then analysed.

The main categories of ES included water quality, water quantity, water for basic human needs, sufficient groundwater reserves, flow characteristics, water for food production, water for animals, biotic biodiversity, habitat diversity, intact riparian vegetation, mitigation, supporting functions and processes, and the 'healthy' state of the ecosystem.

Table 16. List and frequency of ecosystem services named in individual specialist's concept maps

<table>
<tr><th>List of Ecosystem services</th><th>Frequency</th><th colspan="2">Categories of Ecosystem services</th><th>Frequency</th></tr>
<tr><td>Clean/safe water</td><td>1</td><td colspan="2" rowspan="5">Water Quality</td><td rowspan="5">12</td></tr>
<tr><td>Clean water</td><td>3</td></tr>
<tr><td>Water quality</td><td>5</td></tr>
<tr><td>Good water quality</td><td>1</td></tr>
<tr><td>Fresh water</td><td>2</td></tr>
<tr><td>Resource availability (quantity)</td><td>1</td><td colspan="2" rowspan="5">Water Quantity</td><td rowspan="5">6</td></tr>
<tr><td>Water availability</td><td>1</td></tr>
<tr><td>Water quantity</td><td>2</td></tr>
<tr><td>Enough water</td><td>1</td></tr>
<tr><td>Enough water for migration of fish species</td><td>1</td></tr>
<tr><td>Groundwater quantity & quality</td><td>1</td><td colspan="2" rowspan="4">Sufficient Groundwater Reserves</td><td rowspan="4">4</td></tr>
<tr><td>Groundwater</td><td>1</td></tr>
<tr><td>Soil water</td><td>1</td></tr>
<tr><td>Water storage</td><td>1</td></tr>
<tr><td>Environmental flow</td><td>1</td><td colspan="2" rowspan="6">Flow Characteristics that Mimic Natural Conditions</td><td rowspan="6">6</td></tr>
<tr><td>Dry season flow</td><td>1</td></tr>
<tr><td>Wet season flow</td><td>1</td></tr>
<tr><td>Sustained flow</td><td>1</td></tr>
<tr><td>River flow</td><td>1</td></tr>
<tr><td>Flow at surface</td><td>1</td></tr>
<tr><td>Drinking water</td><td>1</td><td rowspan="4">Potable Drinking Water</td><td rowspan="7">Water for Basic Human Needs</td><td rowspan="7">7</td></tr>
<tr><td>Drinking water (clean & sustained)</td><td>1</td></tr>
<tr><td>Drinking/cooking with household treatment</td><td>1</td></tr>
<tr><td>Clean drinking water (humans)</td><td>1</td></tr>
<tr><td>Domestic use</td><td>1</td><td rowspan="3">Domestic Use & Subsistence</td></tr>
<tr><td>Enough water for humans</td><td>1</td></tr>
<tr><td>Subsidence</td><td>1</td></tr>
<tr><td>Food</td><td>3</td><td colspan="2" rowspan="11">Water for Food Production</td><td rowspan="11">18</td></tr>
<tr><td>Food production</td><td>5</td></tr>
<tr><td>Dryland & other small scale farming</td><td>1</td></tr>
<tr><td>Farming</td><td>2</td></tr>
<tr><td>Agriculture</td><td>1</td></tr>
<tr><td>Cropping activities</td><td>1</td></tr>
<tr><td>Water for agriculture production/consumption</td><td>1</td></tr>
<tr><td>Water for smallholder agriculture (surplus product)</td><td>1</td></tr>
<tr><td>Irrigation</td><td>1</td></tr>
<tr><td>Fisheries</td><td>1</td></tr>
<tr><td>Fuel</td><td>1</td></tr>
<tr><td>Drinking water for wildlife</td><td>1</td><td colspan="2" rowspan="3">Water For Animals</td><td rowspan="3">3</td></tr>
<tr><td>Clean drinking water for animals</td><td>1</td></tr>
<tr><td>Enough water for animals</td><td>1</td></tr>
<tr><td>Biodiversity</td><td>4</td><td rowspan="4">Biodiversity</td><td rowspan="4">Biodiversity</td><td rowspan="4">8</td></tr>
<tr><td>Natural parks/environment</td><td>1</td></tr>
<tr><td>Wildlife</td><td>1</td></tr>
<tr><td>Medicinal plants</td><td>1</td></tr>
</table>

Aquatic biota	1	Aquatic BD	
Existence of specific "habitats" which support different cultural or spiritual activities	1	Habitat Diversity	1
Vegetation cover	1	Intact Riparian Vegetation	7
Vegetation	2		
River vegetation	1		
Riparian vegetation	2		
Riparian matrix	1		
Erosion control & water attenuation	1	Mitigation	10
Waste removal	1		
Disease control/ clinical services	1		
Disease control (including sanitation)	1		
Flood amelioration	1		
Flood control	1		
Flood mitigation	2		
Drought mitigation	1		
Drought prevention	1		
Ecosystem service natural rainfall and runoff	1	Supporting Functions & Processes	14
Ecosystem services instream natural water purification	1		
Water cleaning	1		
Maintenance of freshwater dependent biodiversity	1		
Runoff processes	1		
Sediment transport & erosion	1		
Sedimentation	2		
Nutrients	1		
Infiltration	1		
Groundwater recharge	2		
Evaporation	2		
Continuation of ecological processes	1	Ecosystem State	10
Ecological	1		
Healthy river system	1		
Healthy environment	2		
Healthy functioning ecosystem	1		
Support Sabie River health	1		
Riverbank condition	1		
State of wetland	1		
Aquatic Ecosystem	1		

The main categories of benefits included cultural and spiritual, health (human and animal), safety and security, economic (local, national and transboundary), tourism, recreation and aesthetics, social well-being, livelihoods and shelter (see Table 17). Tourism was separated from recreation because of its distinctive importance in the lowveld.

Table 17. List and frequency of ES benefits named in individual specialist's concept maps

<table>
<tr><th>List of Benefits</th><th>Frequency</th><th colspan="2">Categories of Benefits</th><th>Frequency</th></tr>
<tr><td>Cultural values</td><td>2</td><td colspan="2" rowspan="5">Cultural & Spiritual</td><td rowspan="5">8</td></tr>
<tr><td>Cultural</td><td>3</td></tr>
<tr><td>Cultural uses</td><td>1</td></tr>
<tr><td>Spiritual/cultural</td><td>1</td></tr>
<tr><td>Value of knowing "pristine" river exists (incl. spiritual & wilderness experience)</td><td>1</td></tr>
<tr><td>Health</td><td>5</td><td colspan="2" rowspan="5">Health</td><td rowspan="5">9</td></tr>
<tr><td>Good health</td><td>1</td></tr>
<tr><td>Human health</td><td>1</td></tr>
<tr><td>support living with HIV</td><td>1</td></tr>
<tr><td>Combating HIV/AIDS</td><td>1</td></tr>
<tr><td>Improved livestock health</td><td>1</td><td colspan="2">Animal Health</td><td>1</td></tr>
<tr><td>Safety</td><td>1</td><td colspan="2" rowspan="7">Safety & Security</td><td rowspan="7">12</td></tr>
<tr><td>Security</td><td>1</td></tr>
<tr><td>Water security</td><td>2</td></tr>
<tr><td>Food security</td><td>5</td></tr>
<tr><td>Food security & household income</td><td>1</td></tr>
<tr><td>Household food security</td><td>1</td></tr>
<tr><td>Poverty alleviation</td><td>1</td></tr>
<tr><td>Economic</td><td>2</td><td rowspan="9">Local</td><td rowspan="13">Economic Benefit</td><td rowspan="13">14</td></tr>
<tr><td>Employment</td><td>1</td></tr>
<tr><td>Water-related formal employment</td><td>1</td></tr>
<tr><td>Non-agric. & informal economic activities</td><td>1</td></tr>
<tr><td>Economic development</td><td>1</td></tr>
<tr><td>Employment opportunities</td><td>1</td></tr>
<tr><td>Employment</td><td>1</td></tr>
<tr><td>Job creation</td><td>1</td></tr>
<tr><td>Healthy local economy</td><td>1</td></tr>
<tr><td>Socio-economic benefit for RSA</td><td>1</td><td rowspan="3">National</td></tr>
<tr><td>Access to markets</td><td>1</td></tr>
<tr><td>Commodity based trade</td><td>1</td></tr>
<tr><td>Energy/electricity</td><td>1</td><td>Transboundary</td></tr>
<tr><td>Tourism</td><td>4</td><td colspan="2" rowspan="2">Tourism</td><td rowspan="2">5</td></tr>
<tr><td>Wildlife economy</td><td>1</td></tr>
<tr><td>Recreation</td><td>3</td><td colspan="2" rowspan="4">Recreation & Aesthetics</td><td rowspan="4">7</td></tr>
<tr><td>Entertainment</td><td>1</td></tr>
<tr><td>Recreational & aesthetics</td><td>1</td></tr>
<tr><td>Aesthetics</td><td>2</td></tr>
<tr><td>Social well-being</td><td>1</td><td colspan="2" rowspan="4">Social Well-Being</td><td rowspan="4">4</td></tr>
<tr><td>Well-being living</td><td>1</td></tr>
<tr><td>Social</td><td>1</td></tr>
<tr><td>Skills development & upliftment</td><td>1</td></tr>
<tr><td>Healthy livelihoods</td><td>1</td><td colspan="2" rowspan="3">Livelihoods</td><td rowspan="3">5</td></tr>
<tr><td>Rural livelihoods</td><td>1</td></tr>
<tr><td>Livelihoods</td><td>3</td></tr>
<tr><td>Shelter</td><td>1</td><td colspan="2" rowspan="2">Shelter</td><td rowspan="2">2</td></tr>
<tr><td>Construction material</td><td>1</td></tr>
</table>

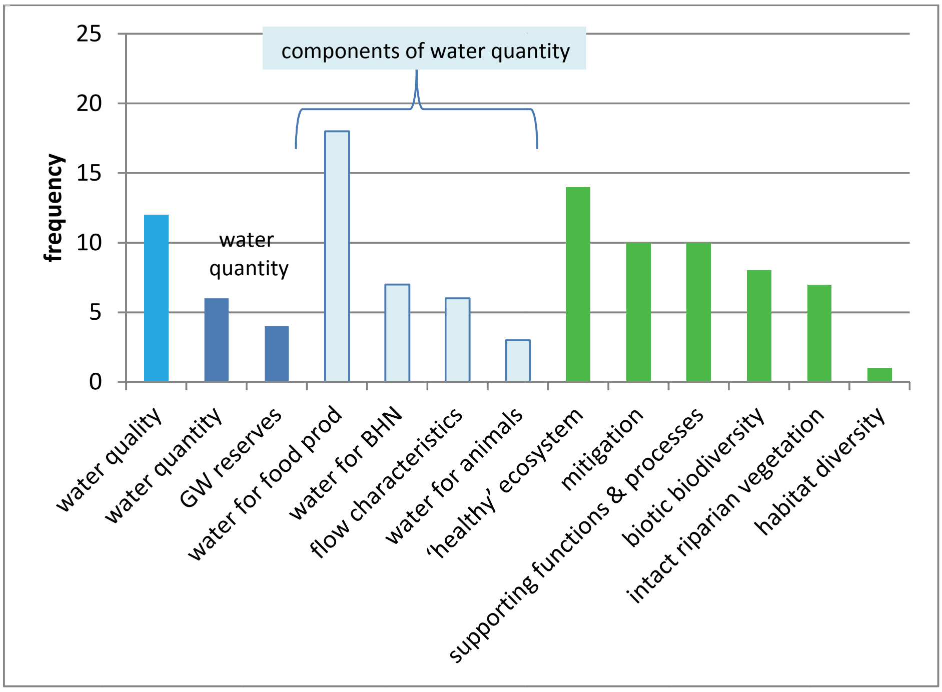

Figure 17. Incidence of final ES (grouped into categories) as listed by individual specialists (n=106)

Participants named a number of factors that relate to, or are part of, the broader category of ES named '*water quantity'* which includes both surface water and groundwater. Included in this (see Table 16) was water (availability) for food production, to meet basic human needs, for animals and for the environment (certain flow characteristics).

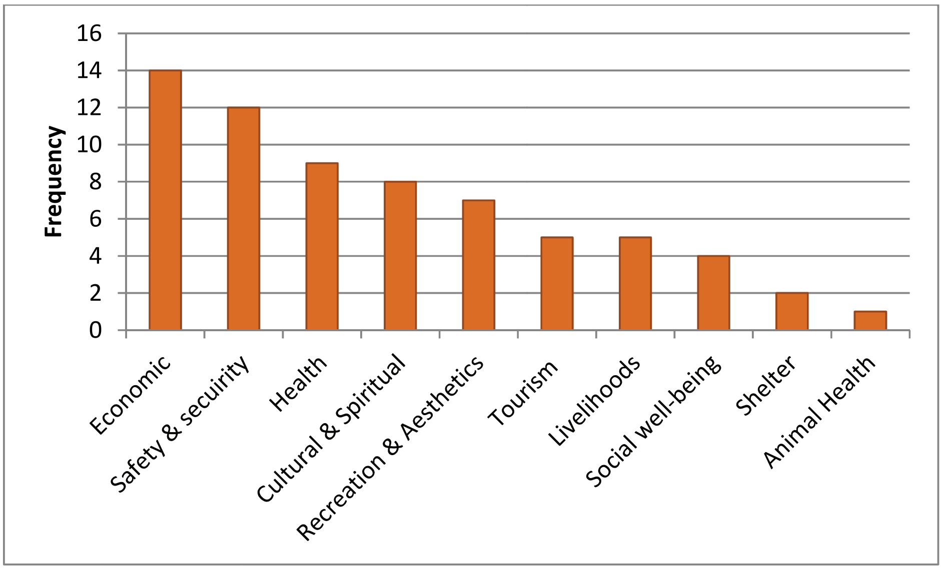

Figure 18. Incidence of benefits of ES (grouped into categories) as listed by individual specialists (n=67)

Based on the information provided in the above tables, the five categories of ecosystem services and benefits with the highest frequencies were determined (see Box 7).

Box 7: 'Top 5' bundle of Ecosystem services and Benefits

'Top 5' ecosystem services:

- Water quality;
- Water quantity (available in surface flow and groundwater)
  - o for production;
  - o for basic human needs;
  - o for animals.
- Healthy ecosystems;
- Mitigation;
- Function and process;

'Top 5' benefits from ecosystem services:

- Economic
- Safety & security
- Health
- Cultural & Spiritual
- Recreation & Aesthetics
- Tourism

The linkages between the priority ecosystem services and benefits were analysed and the direction of the link was taken into consideration during the analysis. In other words, a distinction was made if an ecosystem service was impacted *by* a benefit or *impacted on* a benefit. Table 18 shows the frequency at which an ecosystem service directly impacted on a benefit.

Table 18. Frequency at which the 'Top 5' Ecosystem services had an impact on benefits. High, medium and low frequencies are represented respectively and green, blue and yellow.

	'Top 5' Ecosystem services				
Impact on Benefits	**Water for Production**	**Water quality**	**Ecosystem state**	**Mitigation**	**Function and process**
Economic benefit	4	2	1		
Health	2	2	2	1	
Tourism		2	1		
Recreational and aesthetics		2			
Safety and security	1	1		1	1
Cultural and spiritual		1			
Livelihoods			1		

5.4.2.2. Production of group concept maps

Two groups of specialists produced concept maps with a specific colour coding (Figure 18 and 19).

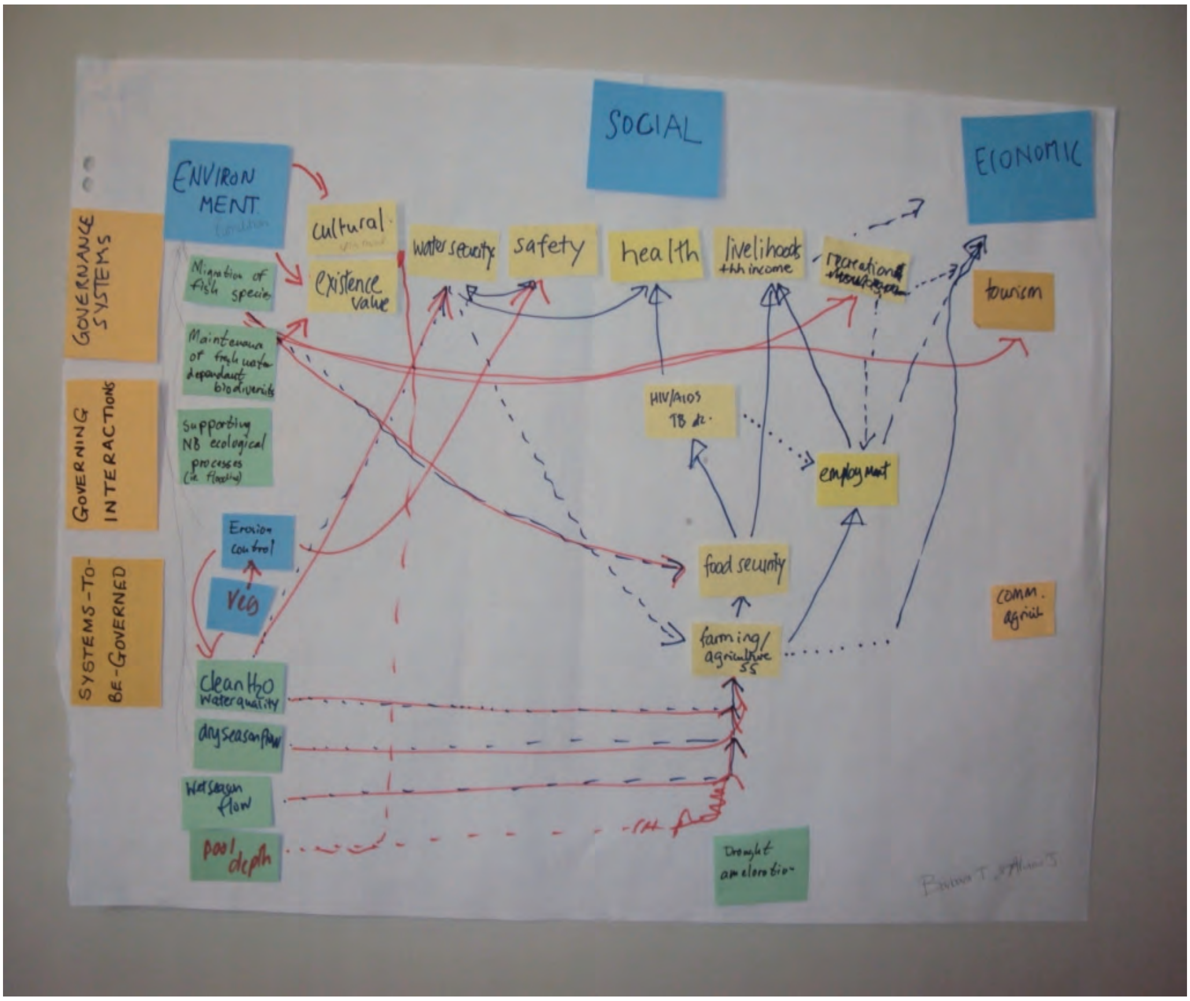

Figure 19. Concept map of WatRES and their inter-linkages produced by a specialist group. The themes, drivers, ecosystem services and benefits are represented respectively in blue, orange, green and yellow. Vegetation and erosion control belong to ecosystem service.

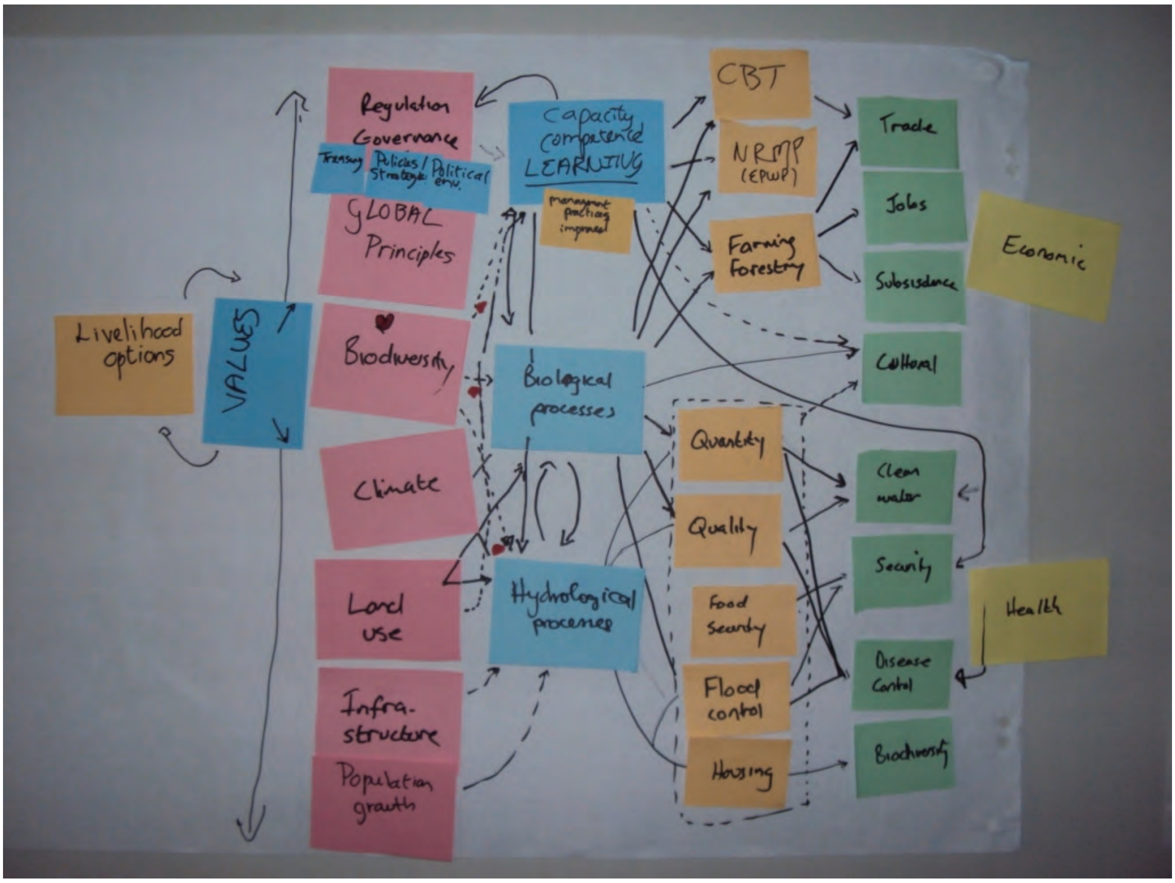

Figure 20 Concept map of WatRES and their inter-linkages produced by a specialist group. The drivers, processes, ecosystem services and benefits are represented respectively in pink, blue, orange and green. The benefits were grouped into two overarching categories: economic and health (yellow).

In Figures 18 and 19, the different factors are arranged according to a conceptualised causality. Most elements are connected through multiple linkages and feedback loops. Both concept maps successfully represent some of the key ecosystem services (i.e. water quality, flood control, drought amelioration) and benefits (i.e. jobs/employment, cultural, health, safety and security). Furthermore, the two groups included drivers (e.g. land use and governance) and processes (i.e. hydrological and biological processes) into their concept maps.

5.4.2.3. Collaborative understanding between catchment residents and specialists

When comparing the six concept maps from the different groups, the following points of commonality were discussed:

- In general, the concept maps shared much: the concept maps represented linkages between similar key benefits, ecosystem services and drivers (as mentioned above). More specifically, the two concepts of water quantity and quality were found to be central to the functioning of a healthy river system. These features were consequently used as a common starting point for the next activity.

- Overall, the concept maps were fairly generic in their conceptualisation of WatRES and benefits, particularly those of the specialists (i.e. none of the concept maps were specific to the Sabie-Sand River). Although there is a need to focus more specifically on the site of interest, starting with a generic concept map is an important first step to make explicit people's worldviews. It was felt that the visualisation exercise in session 3, would help the participants take into consideration specific characteristics of the Sabie-Sand River catchment by exploring the distribution of both the production and consumption of ecosystem services within the catchment area.
- In most concept maps, there are grouped themes that can be broken down into smaller sub-models that are linked to each other (e.g. biophysical functions, intermediate ecosystem services, final ecosystem services). This point is noteworthy when considering transforming these concept maps into a system dynamic model.

During the general discussion, the participants had a tendency to focus their attention on the process rather than discussing the differences and similarities between concept maps. The participants made the following comments on the process:

- It is important to have participants from various disciplines working in small groups in order to share and understand different worldviews. On the other hand, when working with a multidisciplinary team it can be difficult to attain a common agreement. Therefore, the high transaction costs and energy required during this process should also be taken into consideration.
- The focus on the benefits as a starting point reduces potential conflict because people naturally share a common perception of the benefits from a healthy flowing river.
- One participant suggested a different approach for this exercise which consisted of writing an essay about what are the benefits from a healthy flowing Sabie-Sand river. It is likely that through the narrative of the essay more similarities will be expressed than through a diagram.

5.4.2.4. Working towards a common systemic view of WatRES

Outcome for Activity 1: Production of a collaborative concept map focusing on water quality and quantity

The focus of this exercise was on water quality and quantity. The three concept maps produced by the mixed groups are shown in Figures 20-22. Because of the progress the group had made in terms of describing the relationships between variables, the facilitators used the concept map shown in Figure 20 as an example for discussion. The participants argued that this concept map (see Figure 20) was not specific enough to describe the Sabie-Sand River catchment system. Furthermore, they questioned if this concept map would be representative of each Integrated Unit of Analysis (IUA) and hold for each management scenario. They recognised that it was very difficult to grasp the complexity of this river system and therefore modelling could be a useful tool at this stage. Through the use of modelling, it would be possible to move from a generic representation to one that models unique systems and include quantitative information. The facilitators stressed that this model needs to be informed by stakeholder's perception and the linkages need to be co-constructed. Thus before running the model, they need to identify and agree on the nature of the relationships. This information is crucial to be able to construct a model that will help people to meaningfully understand the complexity of the system so as to understand the consequences under different management scenarios.

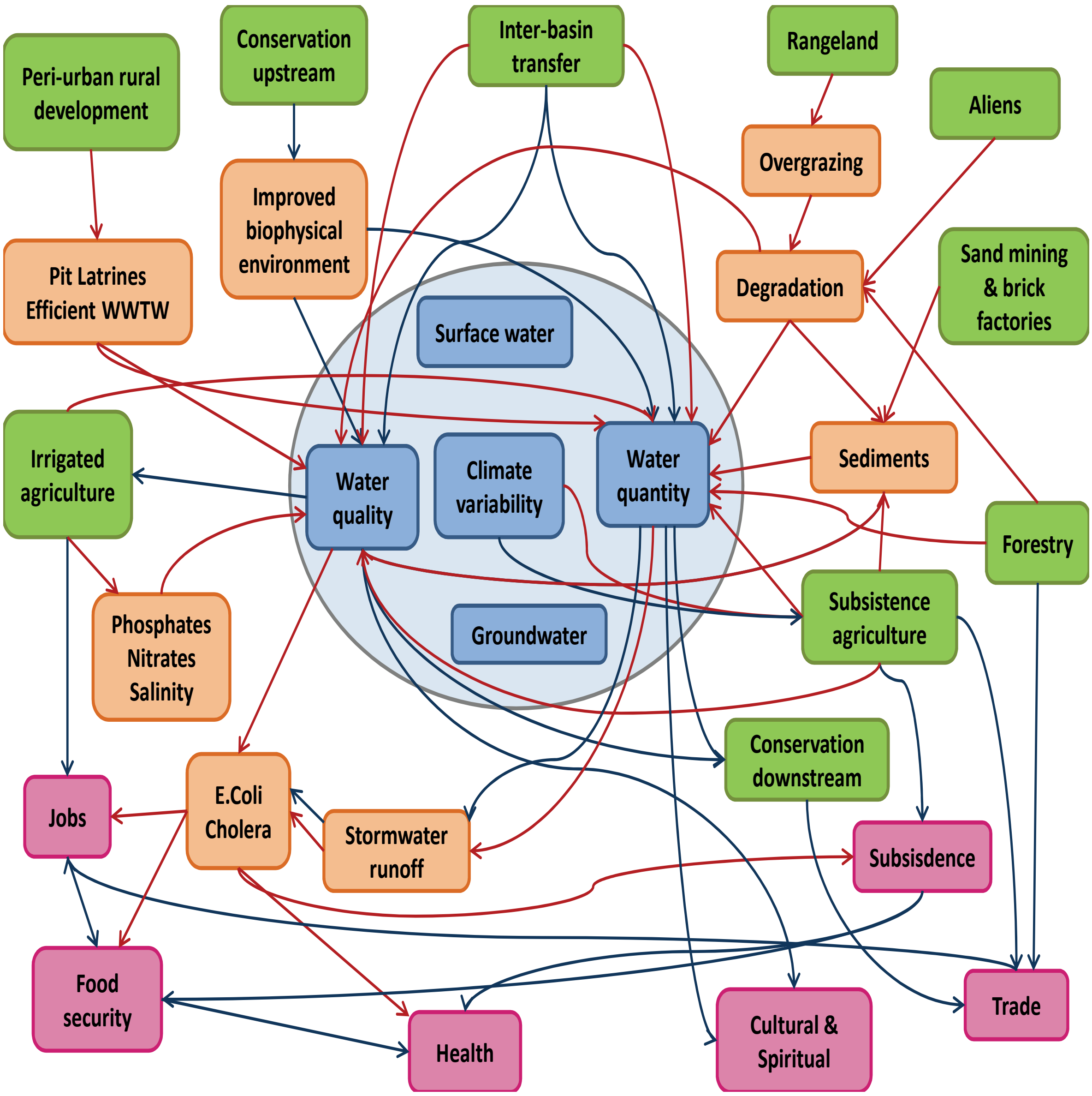

Figure 21. Concept map of WatRES and their inter-linkages produced by 1st 'mixed group'. The drivers, ecosystem services and benefits are represented respectively in green, blue and pink. The dis-services (except for improved biophysical environment) are shown in orange.

In Figure 20, the ecosystem services related to the hydrological system were placed at the centre of the concept map: water quality, water quantity, surface water and groundwater. When the group presented their concept map, they explained that water quantity was defined according to *frequency, duration, timing and volume*. As for water quality, the various factors influencing it were named as *temperature, pH, microbial load and nutrients*. The '*dis-services'* named by the group included: degradation, sediment, stormwater runoff, *E. coli* and cholera, pit latrines and waste-water treatment plants. In fact this list represents a combination of processes, ES, ecosystem state and drivers.

Coloured arrows were used to describe the type of linkages within the concept map: blue arrows for a positive effect and red arrows for a negative effect. For example, water quality has an impact on irrigated agriculture activities through salinity so that if water salinity is high then it will have a negative impact on irrigated agriculture activities.

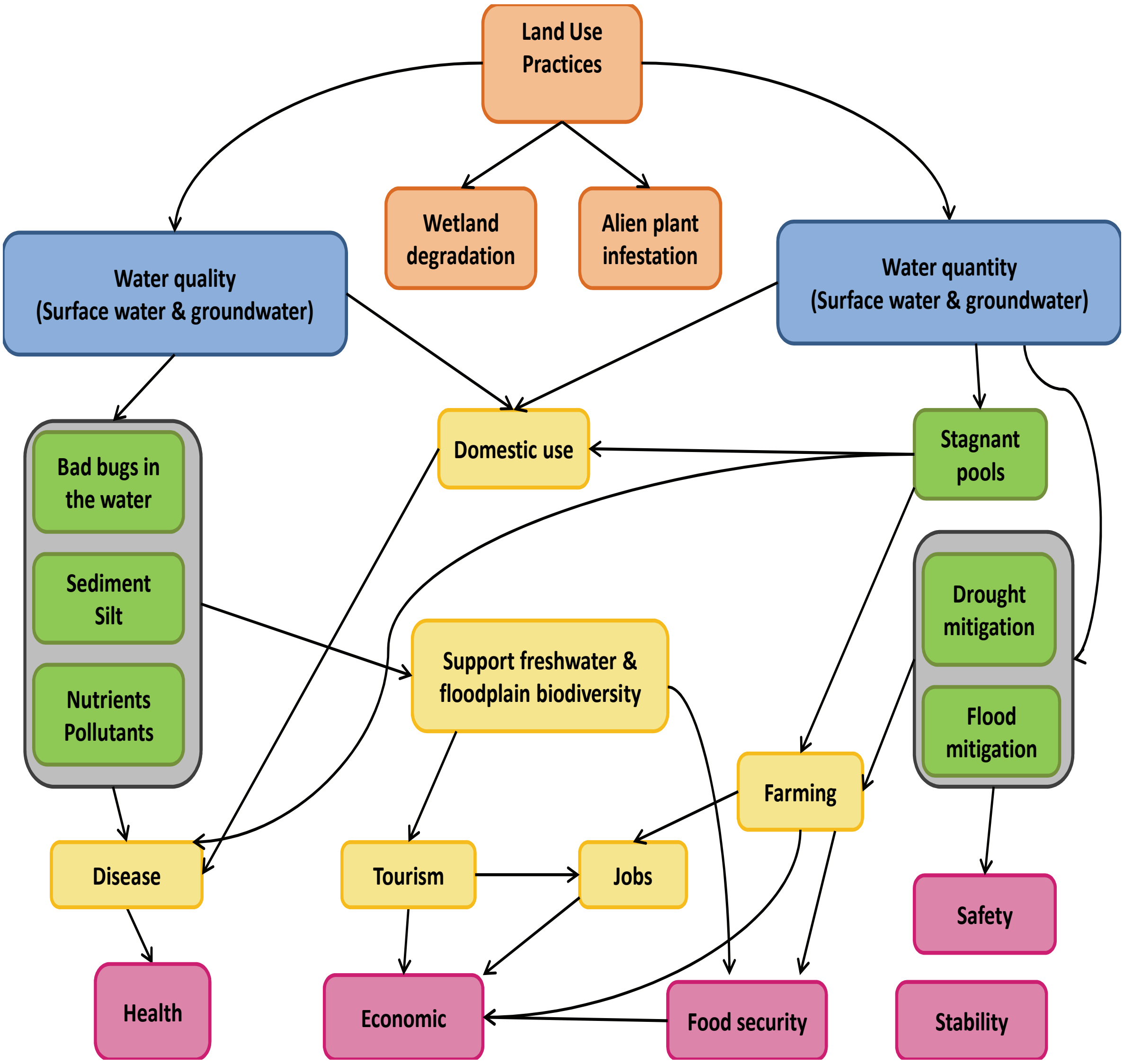

Figure 22. Concept map of WatRES and their inter-linkages produced by 2nd 'mixed group'. The concepts of water quality and quantity, intermediate ecosystem services, final ecosystem services, drivers and benefits are represented respectively in blue, green, yellow, orange and pink.

In Figure 21, land use practices were identified as the key driver influencing water quality and water quantity. Furthermore, water quality was described as connected to *bad bugs in the water, sediment, silt, nutrients and pollutants*, and water quantity was described as connected to *stagnant pools, drought mitigation and flood mitigation.*

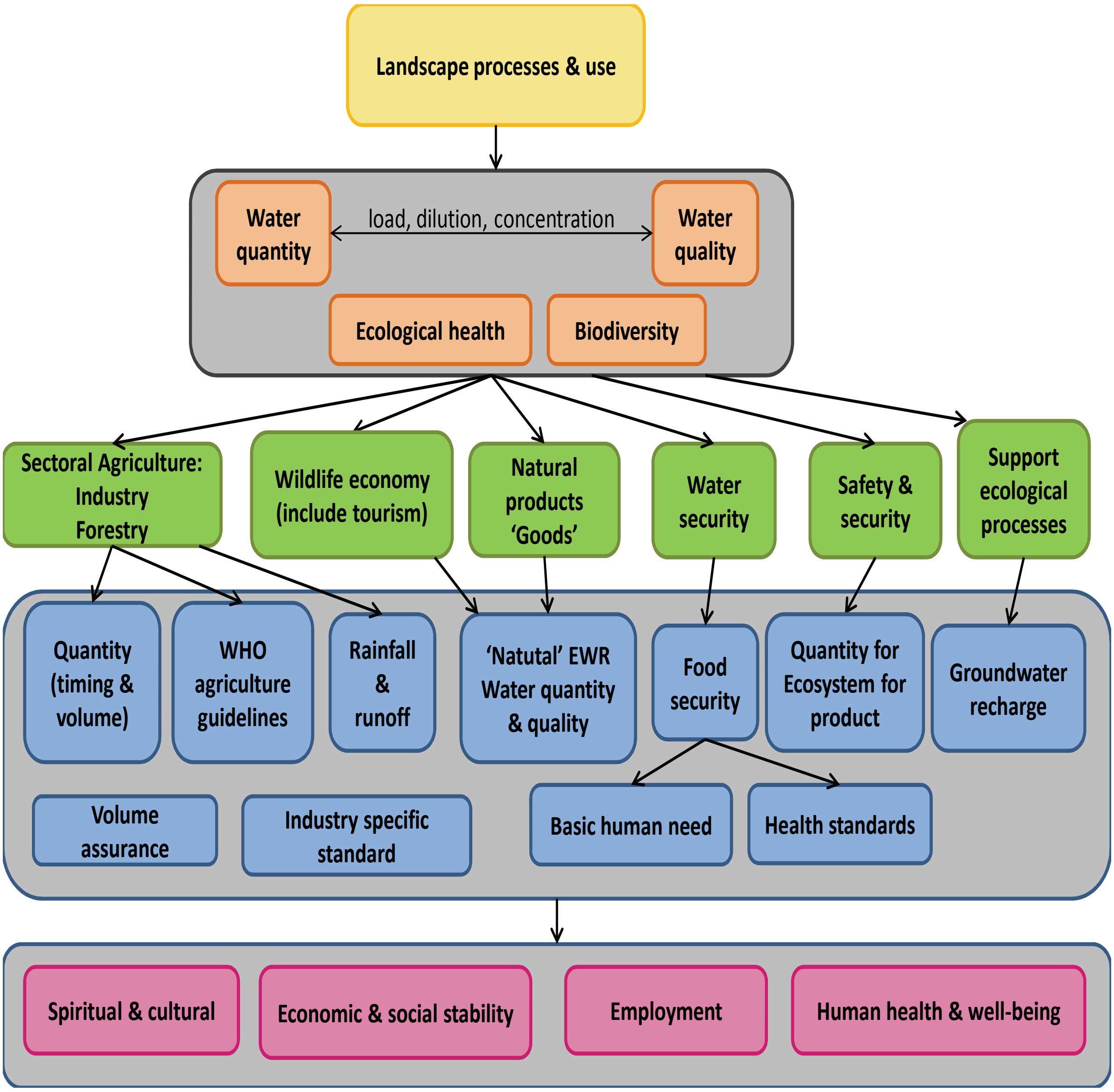

Figure 23. Concept map of WatRES and their inter-linkages produced by the 3rd 'mixed group'. The drivers, ecosystem services, intermediate benefits and final benefits are represented respectively in yellow, orange, green and pink. The causal links from the intermediate to the final benefits are represented in blue.

Similarly in Figure 22 land use practices were also identified as the key driver influencing water quality and quantity. Moreover, water quality and water quantity were described as being interconnected and influencing each other through *load, dilution and concentration*. In comparison to the previous concept maps, the concept map in Figure 22 is the only one to explicitly distinguish between intermediate and final benefits.

The facilitators ended the workshop by asking the participants the following question: would you endorse a "task team" to further develop the concept map into a more detailed and robust map, based on what has been done here?" The purpose of this question was to ask the participants if they would be satisfied to hand over their work to a team of specialists at this stage, or would they prefer to be further involved in the process. Most participants suggested that they would feel comfortable handing over their work to a "task team" at this stage. They felt that they had made their contribution and were sufficiently informed to be able to evaluate the output. One participant did raise the issue of trust as he would be satisfied to hand over their work as long as he could trust the "task team" with it.

Outcome for Activity 2: Core team synthesis of concept maps and the need for differential detail

Initially, the core team had intended to produce a single concept map gathering all the comments and suggestions from the previous activities. However, given the work this would entail and the huge differences in CMs, they decided to take a different approach using one of the maps as an example (see above).

Instead, the discussion focused on the need for different levels of detail for different stakeholders and purposes. This recognises that not everyone needs to know all the information to the same level of detail. Consequently, they suggested four different levels of complexity:

1) Level 1 consisted of a high level summary of the catchment system that might be needed by a policy maker for example. It describes in broad terms the overarching factors and their linkages such as land use practices, ecosystem services and benefits.
2) Level 2 consisted of a concept map with a similar amount of detail to those produced by the previous activities such as those of the mixed groups (see Figure 20-22). At this level, the different benefits and ecosystem services needed to be identified and some of the relationships might be described, even if only qualitatively.
3) In level 3, the benefits and ecosystem services were unpacked in order to show the exact ecosystem services in more detail. For example the link water quality – food production may be further named as salinity levels – winter vegetables. Once this is done, the nature of the relationship can be described even if only qualitatively (e.g. increased salinity- decreased vegetable production). Since these ecosystem services must be clearly articulated and their values determined, the people involved at this level need to have a sufficient level of ecological knowledge, also referred to as *eco-literacy*.
    - This raised the concern about the level of eco-literacy on ecosystem services needed by the catchment residents in order to be able to engage in the process. To address this issue, AWARD has purposefully not used the language of ecosystem services during the first stages of working with residents. Instead, they started by getting the residents to think about the benefits derived from a healthy river. They worked around the resident's understanding of benefits to support an initial conceptualisation of WatRES.
4) The final level was be the conversion to a full rigorous and scientifically specified version of WatRES and their benefits, resulting in a complex, quantitative model.

Further discussion also involved understanding the distinctions between types of ecosystem services, and the underlying functions, processes and state variables. To illustrate this, the benefit identified as health was unpacked as follows (Figure 23):

- The first step consisted of thinking about what underlies **health**. Water-related diseases, such as *E. coli* infection or cholera were identified to impact on health. However, *E. coli* and cholera do not represent ecosystem services per se but are examples of types of diseases or infections (or dis-services). Therefore, the final ecosystem service provided by the river to help combat these diseases was identified as **disease mitigation**.

- The next step was to determine what underlies **disease mitigation**. The participants identified three intermediate ecosystem services that affect the river's ability for disease mitigation: **natural purification processes**, **flushing** and **dilution**.
  - A resident pointed out that dilution as an ecosystem service does not apply to the Sabie-Sand river system because it has a low flow. Furthermore, flooding in the Sabie-Sand river generally causes *E. coli* from the rural villages and towns to be disseminated into the river. Consequently, the intermediate ecosystem service known as dilution and flushing were found to depend on the volume of water in the river. In addition, all the participants agreed that the three identified ecosystem services required healthy ecological processes.

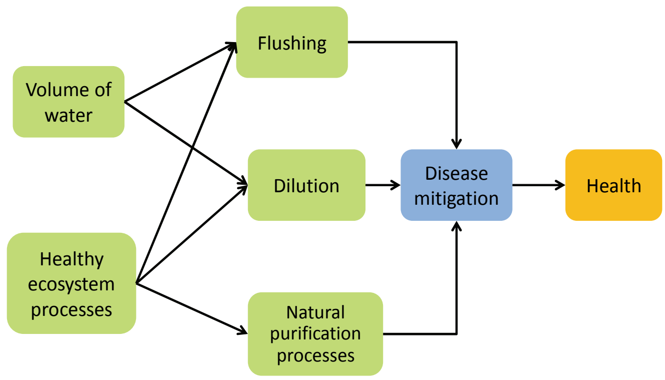

Figure 24. Ecosystem services influencing health. The benefits, final ecosystem services and intermediate ecosystem services are represented in orange, blue and green respectively.

5.4.2.5. Understanding the distribution of WatRES

An example of the type of outcome from the visualisation exercise is shown in Figure 24. To help interpret the map, the different marbles have been labelled to the corresponding ecosystem services and benefits. During the exercise, the participants spent a lot of time discussing the definition of the different ecosystem services and benefits. For example, one group carefully distinguished between the two benefits for tourism and economy by defining economy as excluding any contribution from tourism activity.

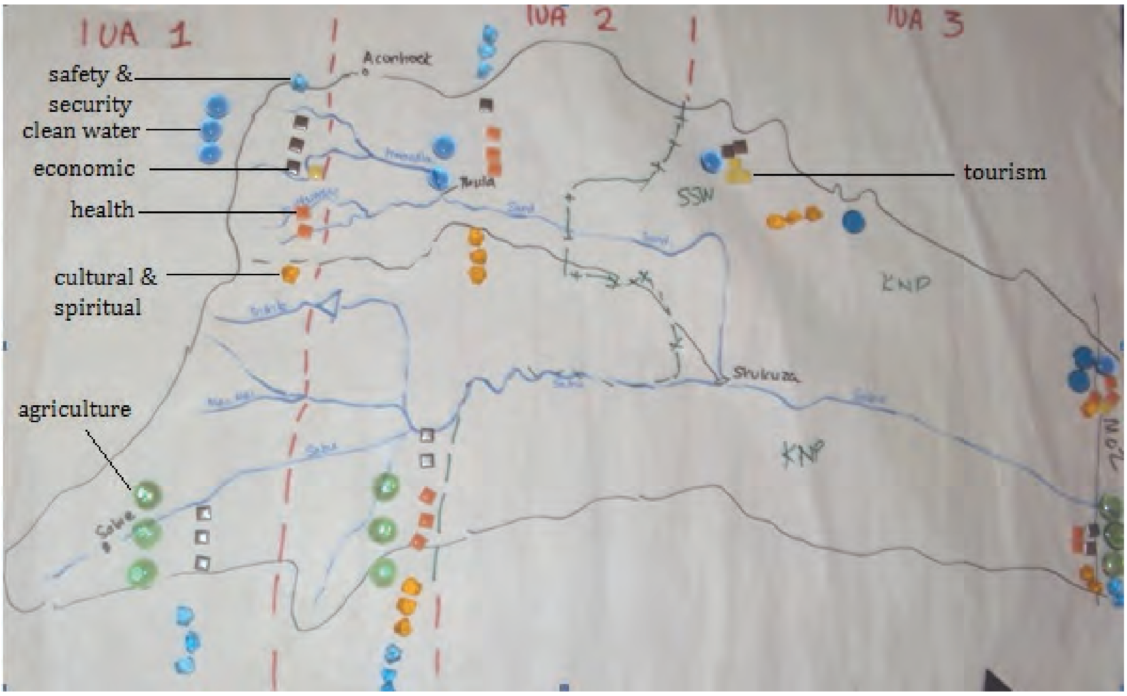

Figure 25. An example of the outputs from the exercise regarding the Spatial distribution the ecosystem services and associated benefits in the Sabie-Sand River catchment.

In Figure 24, the **production of clean water and agriculture** and the consumption of their associated benefits have been spatially distributed over the three IUAs as well as to the border area of Mozambique. The production of clean water was considered to be highest in IUA 1 (3 marbles = 'a lot') in comparison with IUA 2 (2 marbles = 'some') and IUA 3 (1 marble = 'a little'). Furthermore, Table 19 comprises the data sheet information of all the groups for the visualisation exercise (Figure 24 corresponds to the data sheet information from Group 1 in Table 19). When comparing these results, every group had estimated that the highest amount ('a lot') of clean water was produced in IUA 1 due to the high rainfall in IUA 1 and the low inputs from tributaries further downstream in the Sabie-Sand river.

As another example, each group identified **health** as a benefit provided from **clean water**. In every group (see Table 19), health was estimated to be enjoyed 'a lot' in IUA 2 because of the high human population density, whereas in IUA 1 and IUA 3, the relative amount for which health was consumed/enjoyed varied between 'some' and 'none'. Consequently, although clean water is mostly produced in IUA 1, the consumption of clean water for health is in IUA 2.

Table 19. The four mixed group's data sheet information on the spatial distribution of the ecosystem services and associated benefits in the Sabie-Sand River catchment as well as outside the catchment (meaning Mozambique). The ecosystem services are represented in blue and the benefits in pink. For each ecosystem service and benefit: '3' stands for 'a lot', '2' stands for 'some', '1' stands for 'a little' and '0' for 'none'.

Group 1

Ecosystem service/benefit	IUA 1	IUA 2	IUA 3	Outside
Clean water	3	2	1	1
Health	2	3	0	3
Cultural & spiritual	1	3	3	1
Economy	3	1	2	0
Tourism	1	0	3	1
Safety & security	1	3	1	2

Agriculture	3	3	0	3
Health	0	3	0	2
Cultural & spiritual	0	3	0	2
Economy	3	2	0	2
Safety & security	3	3	0	2

Group 2

Ecosystem service/benefit	IUA 1	IUA 2	IUA 3	Outside
Clean water	3	1	2	1
Health	2	3	1	2
Cultural & spiritual	3	3	3	0
Tourism	2	1	3	0
Economy	1	2	0	0

Group 3

Ecosystem service/benefit	IUA 1	IUA 2	IUA 3	Outside
Clean water	3	1	1	0
Health	1	3	1	0
Cultural & spiritual	2	0	3	0
Tourism	2	0	3	0
Economy	3	2	3	2
Safety & security	1	3	1	2

Agriculture	2	3	0	0
Health	1	3	1	2
Cultural & spiritual	1	2	0	2
Tourism	1	0	0	0
Economy	3	3	0	2
Safety & security	2	3	0	2

Group 4

Ecosystem service/benefit	IUA 1	IUA 2	IUA 3	Outside
Clean water	3	2	1	1
Health	1	3	1	2
Cultural & spiritual	3	2	2	1
Economy	1	2	2	1

Agriculture	3	3	0	2
Health	1	3	0	0
Cultural & spiritual	1	2	0	0
Economy	3	3	0	2

In addition, the participants discussed the consequences of changing clean water production in IUA 1 on health and other associated benefits throughout the catchment such through a change in water and land-use practices. For example if less clean water was produced in IUA 1, this would have a negative impact on (a) commercial forestry in IUA 1 leading to a reduction in economic benefits, (b) on the rural population in IUA2 through impacts on health and (c) on the conservation areas in IUA 3 thereby impacting on tourism.

In conclusion, the key points from this visualization exercise were:

- Ecosystem services and benefits need to be clearly defined in order to appropriately study their spatial distribution.
- It is important to recognize that there can be a disjunction between where an ecosystem service is produced and where its benefit is consumed/ enjoyed.
- It is important to understand the potential consequences and knock on effects from changes in the production of an ecosystem service.

5.4.3. Understanding quantitative system dynamic modelling

The aim of this session was to understand how system dynamic modelling can

- provide a bridge from a conceptual representation of WatRES and their inter-linkages to one in which scenarios can be explored through a quantitative model
- represent complex systems with spatial disaggregation and feedback loops

Dr Muetzelfeldt of Simulistics gave a brief presentation on the use of system dynamic modelling in the context of WatRES and their inter-linkages. More specifically, he introduced the option of using the Simile software as a platform for system dynamic modelling for this particular project. The Simile software was developed by Dr Muetzelfedelt and two of his colleagues: Dr Taylor and Dr Massheder.
When developing Simile, he attempted to address the following existing problems with modelling:

- Issue of accessibility
- Issue of transparency
- Issue of handling complex systems

Introduction to SIMILE

First, Dr Muetzelfeldt gave a brief introduction regarding Simile within system dynamic modelling approach. Simile is a visual modelling environment which means that models are developed diagrammatically. Consequently, Simile is accessible to non-programmers as it does not require one to be familiar with a programming or simulation language. Furthermore, the construction of a model in Simile entails a two-phase approach. The first phase consists of drawing a diagram which represents the different variables and relationships in the model (i.e. a concept map). In the second phase, the values and equations are inserted into the diagram in order to develop a quantitative model. However, it is also possible to construct a qualitative model instead by inserting conditional statements. Finally when running a simulation of the model, the results can be displayed in different forms: graph, data table, lollipop diagram and more.

Models constructed in Simile are based on four key symbols of System Dynamics:

1) A stock (also referred to as compartment) represents the amount of a defined substance (i.e. water or money) which is controlled by flows in and flows out.
2) A flow arrow represents a process that contributes to an increase or decrease in the amount of substance present in a compartment.
3) A variable represents any quantity with a constant value or a calculated value in function of other quantities in the model.
4) An influence arrow visually represents which quantity is used to calculate the value of another quantity in the model

Simile in the context of WatRES

Dr Muetzelfeldt presented his first attempt at converting a concept map (AWARD's core team concept map was used) of WatRES into a running model in Simile (see Figure 25). In this model, the different ecological components (drivers, intermediate ecosystem services, final ecosystem services and benefits) were visually separated by enclosing them in an envelope each. Furthermore, the linkages between drivers, ecosystem services and benefits as well as the feedback loops were visually represented by flow or influence arrows in the model.

In general, the ecosystem services were represented as stocks with flows in and out but only a few were represented as variables. Dr Muetzelfeldt explained that ecosystem services were represented as stocks or variables depending on how quickly they respond to changes in the system. More specifically, if an ecosystem service changes quickly over a short period of time then it is represented as a variable whereas if it changes slowly over a long period time then it is represented as a stock.

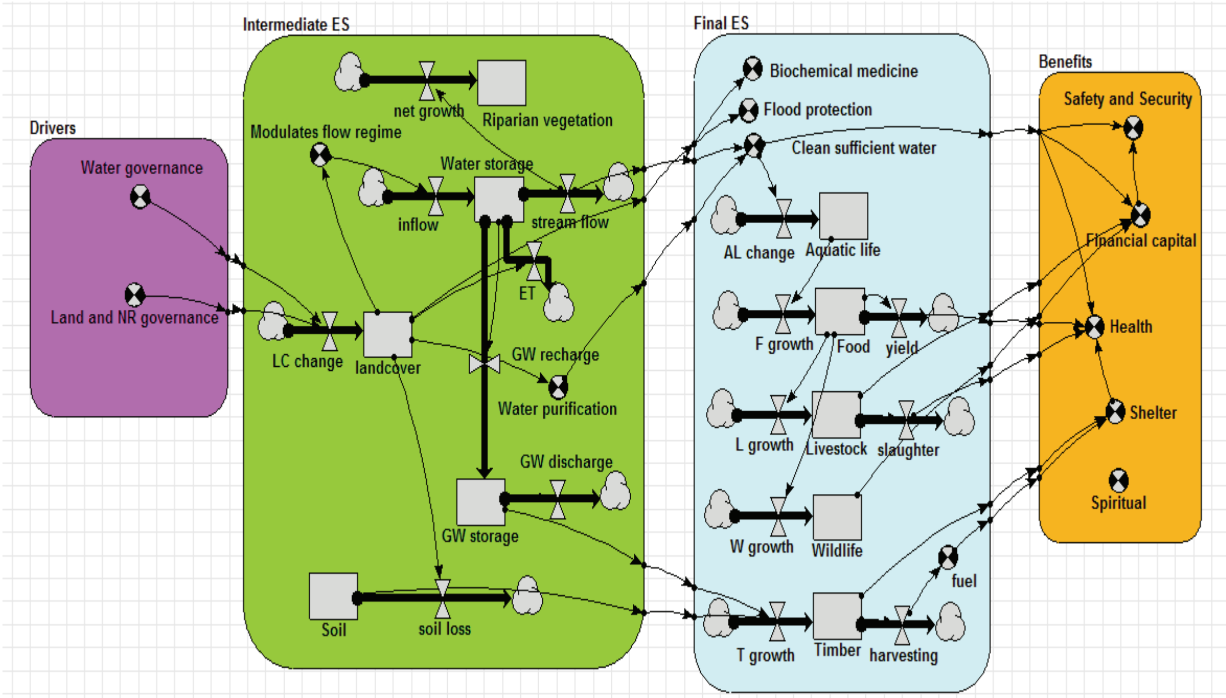

Figure 26. Simile model of WatRES and their inter-linkages based on AWARD's core team concept map. The drivers, intermediate ecosystem services, final ecosystem services and benefits are represented respectively in pink, green, blue and orange.

In terms of dealing with spatially differentiated data, Dr Muetzelfeldt explained three different options for spatially modelling WatRES and their benefits in the Sabie-Sand catchment. The approach to be adopted depends on the extent to which the WatRES and benefits in the three IUAs are similar or different. These approaches are described below:

- The three IUAs can be represented by one model with three instances if all the IUAs can be represented by the same model structure and components but only differ in terms of values.
- If each IUA is unique and distinct than the IUAs can be represented separately by different sub-models. However, this approach becomes complicated and time consuming if there is a large number of IUAs.
- The three IUAs can be represented by sub-models containing conditional statements if the IUAs differ only slightly in their WatRES and benefits.

5.4.4. Reflection and Evaluation of the workshop

To close, the participants were asked to reflect on the workshop through reflecting on either one of the following questions:

I. What did you learn from today's process that you did not "know" before?

II. What was valuable? What was not valuable or challenging?

The points of interest that arose from these reflections are shown in boxes 8 and 9.

Box 8: What did you learn from today's process that you did not "know" before?

- About the co-creation of knowledge
- Understanding the various ecosystem goods and services and their linkages
- It is important to classify our rivers
- Learnt novel activity-based process to draw together people with disparate knowledge /expertise on focused task
- I expanded knowledge and register of technical/biophysical aspects (e.g. debates about flow/dilution and quantity)
- The process of constructing a map like this was a first time for me. It is certainly more complicated than I imagined and highlights my own 'single-minded' or focused contribution – very inadequate. It also made me realize the importance of ensuing stakeholder buy-in
- Most important I realized that one should have an adequate and diverse group of participants in a process like this
- Involving stakeholders from the beginning of the process is important in decision making. Team work is important I learnt how interrelated the activities that affect water resources are and how complex the relationship is
- EGS is very complex
- EGS is a key aspect to consider in classification
- Process of starting with individual ideas and moving outwards to group work was daring but interesting. Concern that radical, often transformative ideas, get left out so that the whole group is comfortable with what is produced or more dominant ideas are re-produced. The individual exercise slightly counteracts this but not completely

Box 9: What was valuable?

- Learning to discriminate between services and benefits
- Learning to identify intermediate and final benefits
- Experiencing a new integrative process and realizing how difficult these are to engage with
- Interplay of the general and the specific
- Experiencing the depth of discipline and practice, language and thinking
- Multidisciplinary approach
- Sharing worldviews – getting all on the same page
- Exposure to disciplines beyond one's own knowledge
- Varied approaches of different people to the same issue and a way of consolidating
- Everyone had the opportunity to participate
- Seeking connections between benefits that had never been thought before
- Thinking as a team rather than as individuals
- Sharing and learning from 'specialists' – learning the jargon and abbreviations
- Exposure to process improved understanding of stakeholder engagement process
- Valuable to see conceptual models done in previous sessions. I found similar themes in most

of them suggesting to me shared understanding in most of us
- Very valuable to interact with the specialists

What was not valuable or challenging?

- Trying to grasp what was being asked
- Trying to balance own understanding with group facilitation
- Not clearly articulated from the start as to the level of detail required
- There may be more processes/ways to approach this—clustering vs. detail
- How to cope with tiredness
- Time constraints – not much time for inclusive participation
- I am still unclear about how the concept maps produced in this manner feed into the classification process. I think this is important to understand to increase stakeholder 'buy-in' for the process
- I did not find the framing of the questions very helpful in focusing the mind in the 3 mapping exercises
- Simpler, shorter intro with clearer guidelines for approach – it's a bit difficult to follow if you are new to it
- The terminology was diverse – there is a need to establish a common base/ground
- Need to clarify 'systemic approach'
- Hesitation to take the diagrams as 'complete' given pressurised environment of production
- Second map – first struggled with language because rather technical but soon as I understood relational process (links), language was no longer a problem

At the end of the second day of the workshop (7th February), the participants were asked to complete the following statement: "The most important things for me were…." The main comments and reflections are summarized in Box 10.

Box 10: "The most important things for me were…."

- Engaging/interacting with stakeholders and specialists from various disciplines and to be exposes to their expertise and worldviews
- Working collaboratively in groups to produce concept maps
- The relationships created with other stakeholders
- Multidisciplinary approach and co-learning opportunity
- Realising (once again) how differently people think (e.g. which end of a "problem"/ "concept" they start from) and consequently how difficult it is to a build a coherent concept map in a short time period
- Importance to involve locals/residents from the catchment and representatives from the different sectors
- Insight into stakeholder engagement and team-based cooperative knowledge building processes
- Important to frame/define ecosystem services and benefits before starting with

conceptualisation process, otherwise stakeholders might not share common understanding
- Learning about the complexities, links and relationships between ecosystem services and benefits and how this plays out in a particular context
- Understanding the consequences of changes in ecosystem services due to human activities from one area of the catchment to another
- Conceptual model development is always useful as an environmental scientists but to do this interactively was very useful
- Experiencing system analysis and working through the barriers and difficulties. The
- Focusing on relationships and developed this way of thinking into a model
- Understanding system dynamics modelling
- Ability to learn the use of Simile model and how to interpret it in a stakeholder engagement process
- To envisage the translation of a concept map to a model
- Insight into taking a complex view of system and transforming that into a valid predictive model – new and daunting idea

5.5. Discussion

Much of the overall discussion, and in particular comments regarding the framework as a supportive process for stakeholder engagement and learning, is given in the following section. However here we elaborate some of the specific issues pertaining to the outcomes of this process.

A key challenge for the project was to support a systemic view of WatRES through the use of concept maps. To our knowledge there has been no systemic conceptualisation of ecosystem services and some issues warrant mention. Even for those familiar with this tool the process was somewhat difficult in that the team suffered from similar conceptual difficulties as have been expressed in the literature regarding the distinction of ES from underlying function and process (see Section 2.1.2). Thus while the focus might be on ES and benefits, it is challenging to limit the conceptual model to these factors alone. Interestingly, residents of the catchment – drawn from diverse backgrounds- fared better than specialist who are possibly constrained by their own disciplinary field and belief in "correctness" (see similar comments by (Hong and Page 2004). In this regard specialists often lapsed back to developing detailed biophysical models. Thus bounding the concept maps to a focus on ecosystems services can be difficult and needs good planning and facilitation.

It was also found that due to time constraints, there was insufficient discussion regarding the conceptual difference between ecosystem services and benefits. Thus, some factors that were listed by the specialists as ecosystem services when technically they are benefits and vice versa. For example, drinking water was sometimes listed by the specialists as a benefit. However, drinking water is actually an ecosystem service and a benefit it provides is health. Another example drawn from Figure 20, relates to the '*dis-services'* named by the group included: degradation, sediment, stormwater runoff, *E. coli* and cholera, pit latrines and waste-water treatment plants. In fact this list represents a combination of processes, ES, ecosystem state and drivers. Some participants wanted a more detailed description of these at the start of the workshops. However it is the teams' opinion that a more iterative process with more contact sessions will allow for such concepts to be developed rather than trying to do this at the start and potentially constraining peoples' thinking through formal definitions.

Whilst a great degree of commonality existed between stakeholders and specialists, there were certain notable differences. Stakeholders highlighted the *savings made through healthy ecosystems* – an issue never mentioned by specialists (see Section 5.3). Interestingly, some of the participants demonstrated broader system thinking and mentioned the importance of sustainable development in time ('ability to adapt', 'future generations') and the consequences for the neighbouring countries ('political', 'international development'). A number of participants mentioned disease outbreak (mostly caused by *E.-coli*) as a consequence of inadequate water quality. Unlike the CM of the core team, factors such as soil retention, climate, flow regime, water storage were almost never named. Land use practices were mentioned by some of the participants. The underlying drivers of 'good water quality' were mostly identified as anthropogenic factors such as pollution and governance.

It was clear from the literature review and the development of the CM by the core team (see Figure 6) that landcover and land use are critical starting points for elaborating water-related ecosystems services. In other words, WatRES cannot be understood without thinking about landcover and the impacts. This point and the aforementioned factors should be highlighted with stakeholders during the process if they are to achieve adequate conceptual scaffolding for the process.

Attempts to get to the heart and specifics of water-related ecosystems services were somewhat frustrated by the generalizations that emerged with regard to water quantity and quality. Equally much of the literature simply refers to these same factors which are *composite ecosystem services* that do little to help one understand a particular system. For example, participants would state that 'good water quality is linked to health'. The facilitator had to probe this by questioning *what* it was about water quality that was linked to *which* aspect of health. It is felt that once one moves towards the development of semi-quantitative and quantitative models this will be addressed as participants are required to describe specific relationships.

Understanding benefits proved to be an invaluable starting point. In keeping with Narayan et al. (2000) work from 23 countries participants' conceptualisation of benefits represented the five linked components: material for a good life, health, safety, social relations and freedom. Again, the named benefits could themselves be conceptualized as intermediate or final benefits depending on the context. This is not problematic but simply underscores the plurality of meanings that different people may have.

Finally, the visualisation exercise helped participants to move from the somewhat more generic conceptualisation to take into consideration specific characteristics of the study site (Sabie-Sand River catchment). It was effective in allowing them to think not only about bundles of ecosystem services but also allowed then to explore the distribution of both the production and consumption of ecosystem services within the catchment area. This then led to fruitful discussions on scenarios.

6. Conclusions and recommendations

This section discusses the outcomes of the work within the context of the overall aim of the project which was to *develop and test a framework for the collaboration of catchment stakeholders in building a shared appreciation of the risks and benefits of meeting (or not) the ecological Reserve (EWRs) through an understanding of the associated water-related ecosystem services*. This reflection is done against the overall framework developed for the purposes of the project. Additionally comments are provided on recommendations for further use.

6.1. Key principles of the proposed framework

The proposed framework (Figure 26) was elaborated in detail in Section 4 and is summarised below for the purposes of this discussion.

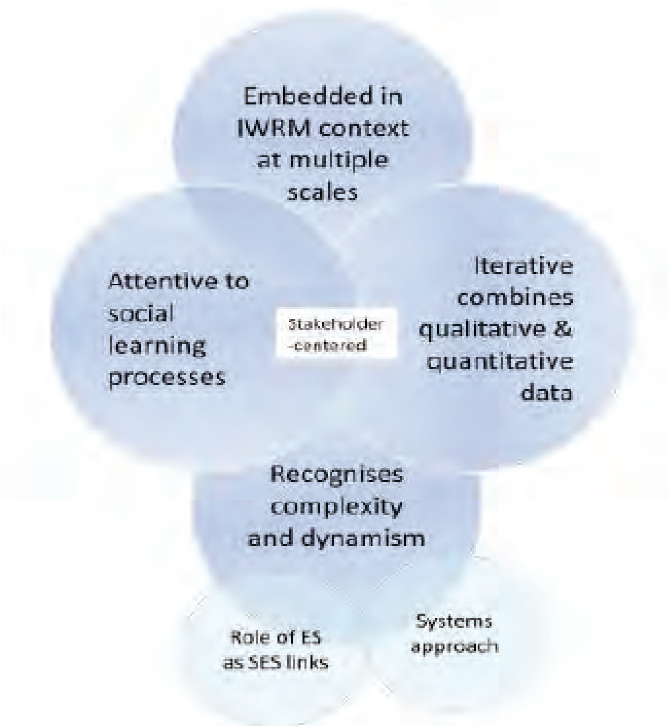

Figure 27. Schematic summarising the key principles of the proposed framework (see Section 4)

Embedding WatRES within a wider IWRM context.

Exploring and Elaborating water-related ecosystems services needs to be embedded within a wider context of IWRM context for sustainability which, in South Africa comprises policy elements such as Classification, the Reserve and water use planning. In practical terms within the Inkomati WMA (the study site) this is being given effect through operationalising the Reserve through the development of real-time WRM tools. Moreover, catchments are part of wider-systems each with their own institutional norms and realities which need to be considered. These systems may extend across international boundaries which also require attention.

Embedding WatRES within a complex, systemic and dynamic framing
The framework must be cognizant of the catchment as a complex (socio-ecological) system requiring a systemic and dynamic view.

> Firstly this recognises the role of ecosystem services in understanding catchments as complex socio-ecological systems. The elaboration of ES provides the basis for understanding the links between so-called 'ecological' on the one hand and 'social' systems on the other (the latter includes politics, power and governance). The derived ES benefits support human well-being in multiple ways. Understanding benefits must be explicated with stakeholders.
>
> Secondly, a systems view means recognising that ecosystems services are linked in a relational way that varies in space and time and that is not always predictable (due to the influences of varying drivers and feedbacks). Equally benefits of ES are likely to accrue to *different beneficiaries in both space and time* Thus changes in practice such as through a different management class of a river – or through non-compliance – are likely to change not just one but multiple ES or *bundles of ecosystem.* Moreover, ES can be produced in an area distinct from their consumption in the catchment and hence impacts of changes in practice can be felt downstream and differentially by different users. The international component of this must be considered so that it is sufficiently flexible and robust to support coherence at an international scale.

A process which is stakeholder-centered and attentive to learning for transformation
This complexity highlights the need for a stakeholder-centered process that clearly articulates the learning processes within a framework for participation. The involvement of stakeholders should be at the start of such work and support a process of collaborative social learning for collective action (see Deliverable 14).

A process which is iterative and which combines qualitative and quantitative approaches
The framework must allow for different 'ways of knowing' that might be partial, divergent and qualitative or quantitative in nature. The critical point is to support an iterative process that brings these epistemologies together and seeks the possibility of 'the sum is greater than the parts.

6.2. Reflections and discussion against the framework

The need to consider the wider management context was beneficial in a number of ways. On the one hand it compelled the team to think into both policy and practice in practical ways. For example, the setting of conditions for stakeholder engagement through national policies with seemingly simple requirements such as '*evaluating (classification) options with stakeholders'* imposes huge conceptual and logistical parameters for the way in which such processes need to be undertaken in reality. Many questions arise that have methodological implications: On what basis will stakeholders be able to provide meaningful inputs and engage in evaluations? Therefore what is it that stakeholders need to know to do so? How will this 'knowing' be brought to the process? And so on. Equally, seeking coherence with the evolving management tools such as the real-time WRM system being developed by the ICMA also meant ensuring methodological and technical coherence. For example, any quantitative modelling that might be required for the development of scenarios needs to be compatible with the afore-mentioned WRM system. On the other hand, being able to assure stakeholders that this work was being undertaken as part of a broader process (i.e. not just as a research project) provided the grounding for a tenable relationship between the researchers and stakeholders and between the managers and stakeholders.

Simplifying or demystifying certain terms is essential. For example, the term *ecosystem services* is not easily understandable except at a very general level, and helping stakeholders to understand important underlying concepts is critical to a coherent process (for example, differentiating a *final service* from the underlying (intermediate) *ecosystems services, processes and functions* helps to mitigate potential conceptual confusion that can confound participatory processes). Once again as we have eluded to elsewhere, there is a need to seek the *requisite simplicity* and no more or no less (Stirzaker et al. 2010). The development of a conceptual model by the core team did much to assist in this process. Further, starting with the concept of benefits – as something most people can relate to – as opposed to ecosystem services proved to be invaluable in starting the participatory engagement.

The view of catchments as **complex SES** underpins a number of theoretical and practical principles (see Sections 3 and 4) that guided the framework. Thus a question for the team was: *Did this process support the view of catchments as complex systems*? To remind ourselves, this requires a recognition of linkages between ES (land and water), feedbacks in the system, the role of multiple drivers and emergence. Importantly this underscores the dynamic nature of the production of ES and their consumption in space (e.g. in different IUAs) and time (seasonal variation, different management classes). The key tool for this was in the development of concept maps which allowed for the naming ES and benefits in a linked and relational way. The following comments are offered in this regard.

- Although the system boundary is artificial selecting appropriate scales of analysis is important so that studies and processes can be bounded as internal, external, or ignored (see below).
- Any understanding of water-related ecosystem services must involve an understanding of the wider SES system. In particular WatRES are inherently influenced by landcover and land use, as well as other drivers which may be internal or external to the 'system'.
- In terms of developing a systemic view, participants were able to
  - develop a more systemic perspective of ESs using concept maps through noting the *links between ecosystem services, between terrestrial and terrestrial-aquatic ESs, and the links to drivers and benefits in their concept maps.* This also addressed the need to understand relationships between variables;
  - think about upstream-downstream linkages where the supply of ES may be disconnected from their consumption and hence beneficiation. The use of the visualization exercise – following from a process of first working with bundles of ES – was successful at supporting participants to think about spatial characteristics and discontinuities between the production and consumption of ES; and
  - start to understand drivers in the system and their linkages and impacts in space and time by including them in the concept maps.
- Changes in a management class or any other management action (e.g. water allocation plans) of a river are likely to change not just one but multiple ES- or bundles of ES, and participants did work with *bundles of ecosystem.* Nonetheless the constraints of time and complexity did mean selecting priority ES. Whilst this is perfectly reasonable it did mean that some interesting 'outliers' which can be just as important in complex systems, may be ignored. A process where all named ES are considered is thus highly recommended.
- The benefits of ES are likely to accrue to *different beneficiaries in both space and time*. Thus another important consideration for modelling is to be able to consider the provision of ES to different sectors in different parts of the catchment (Spatially explicit in terms of supply and provision). Although this process was started it was not well developed again due to time constraints.

- Further time and tools are needed to support peoples' ability internalize the dynamic nature of the systems under consideration e.g. a driver may change in strength and this resonates throughout the system. Indeed dynamic modelling with a user-friendly visual interface may offer exactly such support.

All of these points highlight the importance of time in the learning process. Whilst the process was designed to take account of stakeholder fatigue and the limits on peoples' time and was largely successful at achieving a balance, there were certain constraints. For example, compressing the specialist process into a day had many of the aforementioned limitations. Rather an iterative process of people working together and 'working away' would be far more beneficial and contribute to a more robust learning process. This is essential in complex matters such as evaluating potential management classes for a river. A useful outcome of the process was the recognition by stakeholders that not everyone needs to be involved in every step. Towards the end of the final workshop, participants noted that they had sufficient understanding to endorse further work by a smaller task team. This suggests that if people arrive at an informed position through a process they trust that allows them to dialogue, then certain tasks can be taken up by others. Moreover, not everyone needs to understand details but they must understand and endorse key principles and the process.

Such discussions raised concerns about the level of eco-literacy on ecosystem services needed by the catchment residents in order to be able to engage in the process. To address this issue, AWARD has purposefully not used the language of *ecosystem services* during the first stages of working with residents. Instead, they started by getting the residents to think about the benefits derived from a healthy river focusing on the resident's understanding of benefits to support an initial conceptualisation of WatRES.

Another question that arose was whether a systemic model of ecosystem services can be (a) developed and (b) used as the basis for participants to understand WatRES? Indeed, the challenge for this project – and the first attempt to do so within the broader 'discipline' of ES – is the attempt to produce a systemic conceptualisation of ES. Much of this has been addressed above but a further point worth noting is that the process helped participants understand the need for collaboration. As their evaluations indicated, they began to appreciate that understanding the benefits associated with river flows (such as the Reserve) is a complex task; they also began to appreciate linkages in the system so that for example, a water quality issue in one area impacts on others elsewhere. Most importantly people began to understand that they are being asked to think and act transformatively and that despite the complexity, there is a way to work through this that allows them to be invoked meaningfully. In this respect we stress that the starting point for understanding WatRES must be with stakeholders and their conceptualisation of the benefits and risks: only then should quantitative models be developed and used- specifically for the purposes of exploring future scenarios and not as an end in themselves. Equally stakeholders must be supported to understand that the dynamic and uncertain nature of complex systems such as catchments requires both adaptive planning and management.

Finally and returning to our initial assertion that in contrast to conventional financial approaches to valuing ecosystems through specialist assessments, it is suggested that this approach allows people to value ecosystems services as an *emergent* outcome of a process of learning and collaboration (informed by, but not restricted to, best available science). This work has also explored how ecosystems services institutions can be designed in context-specific ways that build local ownership and provide contributions to livelihoods in the context of catchments and IWRM.

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