Development of effective ways of extracting information from research to support decision making on social-ecological systems

Report to the
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by

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Executive Summary

Aquatic ecosystems in southern Africa form part of complex social-ecological systems within which the production of ecosystem services increasingly limits social and economic development. At a regional scale, there are no substitutes for these services, and thus resource users have to learn to live within the limits of the capacity of the ecosystems to provide services that accommodates both efficiency and equity. Users must further manage use in ways that will offer better prospects for sustaining a future flow of benefits.

The Millennium Ecosystem Assessment (MEA 2005) provides an internationally accepted definition for the benefits provided by ecosystems. The MEA also provides a sound and well established framework for the assessment of ecosystem services and the benefits to human well-being. The MA established the concept of ecosystem services as an essential model for linking the functioning of ecosystems to human welfare benefits.

WRC project K5/1644 developed a set of guidelines and a manual for the evaluation of trade-offs in aquatic ecosystem services that may result from different water management scenarios. These guidelines combine water management practices; the Millennium Ecosystems Assessment (MEA) framework of ecosystem services, and best practices in environmental and resource economics (ERE) valuation into a four-phased approach. This four-phased approach contains a series of analysis methods through which to analyse and evaluate chains of causality and the trade-offs that result from different water resource management scenarios. It thus connects the social and ecological sub-systems such that we can consider in a structured and repeatable way, how they might respond to interventions we may choose to make or to naturally occurring changes.

However, a key gap identified relates to both the methodology through which to analyse chains of causality and the burden of evidence required to specify and quantify chains of causality. However, the knowledge of and data for analysing chains of causality are often dispersed and poorly archived. Furthermore, limited guidance is available on how to make use of different types of available evidence.

The purpose of this study is thus to explore the field of 'evidence-based analysis of socio-ecological systems' (which we have abbreviated "E-BASES"), with the purpose of identifying potentially feasible methodologies for finding evidence, both ecological and social, in support of analysing chains of causality in complex, water resource dependent, socio-ecological systems.

The study investigates the applicability of ecological production functions to analyse chains of causality; investigates the applicability of the evidence-extraction methods of evidence-based medicine (EBM), and evidence-based conservation (EBC) to Southern African conditions; proposes alternative evidence-extraction methods; and demonstrates the application of a set of five evidence-extraction methods at the hand of selected case studies.

The MEA framework of ecosystem services defines four sets of ecosystem services: supporting, regulating, provisioning and cultural services. The supporting and regulating services are of an intermediate nature (i.e. it is mostly not directly used by resource users), but are fundamental in connecting the biophysical components of the water resource to human wellbeing. Well-developed environmental and resource economics (ERE) techniques exist through which to value provisioning and cultural ecosystem services. However, valuation techniques for regulating and supporting services are less well developed, and require development and improvement production function valuation methodology.

Leading international environmental economists have proposed ecosystem derived demand methods (or the production functions) as a means to regulating ecosystem service valuation (Jogo and Hassan 2010; Perrings 2006; Mäler 1991; Perrings 2006; Kinzig et al. 2007; Barbier 2000; Barbier 2003; Barbier et al. 2009). In its simplest form, such a production function would have, as dependent variable (or response variable) an ecosystem service, and as independent variables (or influencing factors/determining variables) one or more ecosystem component and/or process indicators. The theoretical foundations for the ecosystem production function approach were pioneered by Mäler (1991). The field of econometrics provides best practice in the development of production functions. However, only a small number of empirical production function studies exist in the literature. The reasons for this are twofold:

- We still have a poor understanding of the complex linkages that characterise socio-ecological systems (Barbier et al. 2009); and
- There is a dearth of suitable empirical data, and related evidence through which to quantify production functions.

It follows from the above that the formulation of production functions that adequately describe likely consequences of changes in multiple variables of complex systems, requires a combination of expert knowledge and empirical evidence.

The Centre for Evidence-Based Concervation (CEBC) in the United Kindom, has pioneered methodologies for evidence-based decision-making. These methdologies are based on successes in the field of evidence-based medicine. These methodologies extract evidence in a systematic and scientifically credible manner to test an assertion using systematic reviews. Systematic reviews have an established credibility based on a scientific approach to extracting evidence in a manner that is conscientious, judious and explicit.

There are valuable lessons to be learnt from evidence-based approaches in medicine and conservation for southern African applications. However, two key limitations exist with respect to the development of E-BASES methodology within complex socio-economic systems. These limitations result from two implicit assumptions made in both EBM and EBC. The first assumption is that the research question, which is formulated in step 1 of the systematic review, can be simplified to a two-variable cause and effect relationship. For instance, in the case of EBC an actual question in investigated by the CEBC was whether in-stream habitat improvement increased the abundance of a particular genus of fish. However, aquatic ecosystems management in South Africa, with respect to the RDM, requires analysis of complex socio-ecological systems with chains of causality containing multiple cause and effect relationships.

The above discussion also highlights the limits to statistical meta-analysis. Although past research in aquatic ecosystems in South Africa has accumulated a notable body of research publications, the research outputs are not necessarily suited to meta-analysis. It is important to note that this phenomenon is to be expected in any country, is a characteristic of research outputs in any research field and is the particular challenge addressed by both the EBM and EBC fields of practice.

The above limits are currently being addressed as numerous examples of mixed methods exist in EBM and are coming into EBC (personal communication – Prof Andrew Pullin).

In addition, in South Africa, these limitations are exacerbated by relatively low research intensity. Research funding availability and efforts in the field of aquatic ecology in particular are regarded as insufficient in South Africa, in spite of the excellent efforts of organizations such as the WRC (Harding 2010). This results in a relative dearth of research publications upon which meta-analysis may be performed. The second assumption is that a sufficiently large body of suitable research outputs exists upon which meta-analysis can be performed. The suitability of the research outputs is determined by the extent to which the research outputs have been based on empirical data. However, in a relatively small country such as South Africa, it is highly unlikely that a suitably large body of such outputs do exist.

Thus, in South Africa, we need to identify evidence extraction methods that would compliment meta-analyses within the systematic review process.

We thus propose the following working definition for E-BASES in the SA context:

E-BASES is:

a) the systematic review and synthesis of a large quantity of primary and secondary data, research and information, and;
b) the summary, appraisal and communication of its results and implications in order to support expert opinion with the best available evidence;
c) on the likely outcomes of cause and effect relationships in complex socio-ecological systems.

The proposed E-BASES methodology departs from evidence-based conservation methodology in two ways. Firstly, the systematic review question is formulated as a hypothesis of how a specific section of an SES works and the associated assumptions. The review question may therefore not explicitly identify a two-component relationship, but more likely a system of cause and effect relationships, involving multiple system components, which, together, comprise a chain of causality. Secondly, the evidence-extraction is expanded to explicitly include five evidence-extraction methods[1], which we have termed meta-analysis, scientific experimentation, database analysis, data mining and expert knowledge harvesting. This report defines these methods.

[1] The CEE guidelines allows for application of various evidence-extraction methods (personal communication – Prof Andrew Pullin). In this report, we explicitly identify five such methods that are of relevance to South African applications.

We further propose several guiding principles for E-BASES, and highlight that they are only a guide for extracting evidence and scientific inquiry:

PRINCIPLE 1. Pose significant questions that can be investigated empirically;
PRINCIPLE 2. Link research to relevant theory;
PRINCIPLE 3. Use methods that permit direct investigation of the question;
PRINCIPLE 4. Provide a coherent and explicit chain of reasoning;
PRINCIPLE 5. Disclose research to encourage professional scrutiny and critique.

A key finding of this report is that evidence relating to cause and effect relationships in complex systems, may in many instances be incidental to the study objectives of the reports or databases that provide the evidence. This is an important learning point for the WRC, as most WRC-funded research work likely deliver evidence of some kind, which may be of use in future studies. The most effective way of managing such evidence is for the WRC to remain aware of the emergence of such evidence and to preserve all data generated.

Aquatic research can benefit significantly from the large body of evidence currently available through the WRC Knowledge Hub and other initiatives such as the River Health Programme or various initiatives of the Department of Water Affairs. This body of evidence can primarily be accessed through evidence extraction methods such as experimentation and harvesting of expert knowledge. The WRC Knowledge Hub currently does not lend itself to meta-analyses, database analysis and data mining as much as it could. However, scope does exist for the WRC Knowledge Hub to become a more effective source of scientific evidence, especially through the evidence extraction methods of database analysis and data mining. This can be achieved through improved archiving of raw data.

Research reports generally present the results of the analysis of the data collected during a project. Current WRC policy is to have raw data from projects archived by the researchers on the understanding that if it is required in the future then people needing the raw data know who to contact to obtain this data. We recommend that the raw data behind projects are made more readily accessible to future researchers. There are several ways in which this may be done. The simplest would be to include a CD / DVD of the unmoderated data in the report. Another way would be to have it on a database curated by the WRC. The location of the data should be recorded as an agenda item during the final review committee meeting.

Following from the above, the key-wording search capability of the WRC Knowledge Hub search engine can be further expanded. This can be done through inclusion of selected keywords denoting reports for which certain information key to extraction for evidence-based analysis, such as a CD / DVD with the raw data, can be identified.

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Acronyms

CBA	Cost-benefit Analysis
CEBC	Centre for Evidence-based Conservation
CEE	Collaboration for Environmental Evidence
CMA	Catchment Management Agency
DWA	Department of Water Affairs
E-BASES	Evidence-based analysis of socio-ecological systems
EBC	Evidence-based Conservation
EBM	Evidence-based Medicine
GEF	Global Environmental Facility
IUA	Integrated Unit of Analysis
MC	Management Class
MDGs	Millennium Development Goals
MEA	Millennium Ecosystems Assessment
NLB	National Library of Medicine (US)
NPC	National Planning Commission
NWA	National Water Act
NWRS	National Water Resources Strategy
RDM	Resource Directed Measures
RQO	Resource Quality Objectives
SA	South Africa
SASQAF	South African Statistical Quality Assessment Framework
SES	Socio-ecological System
SM	Systematic Mapping
SR	Systematic Review
SRBRP	Shared River Basins Research Programme
SWR	Significant Water Resource
UN	United Nations
WBCSD	World Business Council for Sustainable Development
WMA	Water Management Area
WRC	Water Research Commission
WRCS	Water Resource Classification System
WUA	Water User Association

1. Introduction

1.1. The importance of social-ecological systems (SES)[2]

Aquatic ecosystems in southern Africa are complex social-ecological systems in which the supply of ecosystem services increasingly limits social and economic development.

At a regional scale, there are no substitutes for these services, and thus resource users have to learn to live within the limits of the capacity of the ecosystems to provide services that accommodates both efficiency and equity. Users must further manage use in ways that will offer better prospects for sustaining a future flow of benefits.

In response to this, the WRC has been directing research effort to a Shared River Basins Research Programme (SRBRP), with the purpose of integrating water resource science into the analyses of complex social-ecological systems.

The theoretical point of departure for the SRBRP is the way in which river systems in South Africa are defined: namely ‘the resource’. This definition acknowledges that river systems produce a variety of ecosystem services of potential benefit. These ecosystem services vary in space (for example along the length of a river) and in time, as run-off varies or as we choose to modify river flow. And as we use these (water for example) to produce other goods and services such as food or electricity, we diversify the benefits and beneficiaries in time and space.

SES comprises of several key components including the Resource (river systems in this case); Resource users (those who use ecosystem services); Public infrastructure (the interventions that are made to gain access to or regulate use of); and Public infrastructure providers.

Social and ecological systems and their components are dynamically linked; changes in one elicit changes in the other and the effects are transmitted through both systems, sometimes with quite unexpected and undesirable outcomes.

In the resulting complex system it is often difficult to identify and connect benefits and beneficiaries and to appreciate the consequences of decisions that are made around the allocation of access to ecosystem services. Every choice that is made alters the distribution of benefits and costs in both space and time. And, it affects the path to sustainable and equitable use, particularly because the resource is finite and in some rivers more water has been allocated than there is available.

[2] This section was adapted from unpublished material provided by Prof Charles Breen, in support of the Shared River Basins Research Programme of the WRC.

1.2. The legal framework for managing aquatic SES in South Africa

The National Planning Commission (NPC) of the South African government has prioritised the long term availability of water and the conservation of biodiversity (i.e. also aquatic biodiversity) as key thematic issues in the strategic plan for South Africa (Revised Green Paper: National Planning Commission, February 2010[3]). This is also consonant with Goals 1, 7.A and 7.B of the Millennium Development Goals (MDGs).

This implies a special focus, over the next decade, on the implementation of the National Water Act (NWA, No 36 of 1998). The National Water Resource Strategy (NWRS) is an instrument of policy following from the NWA which seeks management for sustainable use of South Africa's water resources. The NWRS talks about striking "a balance between the use of resources … and conservation of the resource to sustain its functions …", in other words, negotiating trade-offs around the conservation of water resources so that they continue to deliver ecosystem service benefits to a wide range of beneficiaries. These trade-offs are principally between water resource quality (as defined in the National Water Act (No 36 of 1998) as "*the quality of all the aspects of a water resource*" and the ecosystem services they deliver) on the one hand and the beneficial use of water on the other. The NWRS adopts Resource Directed Measures (RDM) to achieve this balance.

It is ultimately the responsibility of Catchment Management Agencies (CMAs) to determine, for each water management area, the amount of allocatable water as the balance between available water (reliable local yield) and the amount of water required for the Reserve.

While significant progress has been made in a number of aspects of implementation, the full RDM process has yet to be fully 'operationalised':

- The ecological Reserve has been determined for in excess of 900 sites (Grobler 2007); however, it has not been fully implemented anywhere in South Africa, mainly because it has not been aligned with user requirements in the catchments. The recent gazetting of the WRCS in September 2010 now means that the Reserve can be aligned with user requirements allowing for a comprehensive water resources strategy as envisioned by the NWA.
- Water Resource Classification is currently being piloted in several Water Management Areas (WMAs) across South Africa.

A key challenge in the operationalization process remains the analysis of trade-off decisions in water resource management scenarios.

The Water Research Commission (WRC) recently completed a three year study which proposed a framework through which to address these challenges (WRC Project K5/1644, Ginsburg et al. 2010).

[3] http://www.thepresidency.gov.za/docs/pcsa/planning/gp_nsp.pdf

1.3. Key findings of WRC Project K5/1644

WRC project K5/1644 developed a set of guidelines and a manual for the evaluation of trade-offs in aquatic ecosystem services that may result from different RDM scenarios.

These guidelines combine RDM and water resource classification methodologies; the Millennium Ecosystems Assessment (MEA) framework of ecosystem services, and best practices in environmental and resource economics (ERE) valuation into a four-phased approach.

A key concept emerging from the MEA framework is the concept of `chain of causality'. Chains of causality link water resources to the ecosystem services consumed by beneficiaries. The MEA framework of ecosystem services assists in consistently and transparently defining chains of causality.

The four-phased approach proposed in K5/1644 contains a series of analysis methods through which to analyse and evaluate such chains of causality and the trade-offs that result from different water resource management scenarios. This approach thus connects the social and ecological sub-systems such that we can consider in a structured and repeatable way, how they might respond to interventions we may choose to make or to naturally occurring changes. Importantly it requires that we make our assumptions explicit such that they can be tested and provide for a structured approach to learning.

K5/1644 concluded that the MEA framework is an extremely useful and robust framework and that a number of existing ERE valuation techniques and complimentary methods may be applied in the analyses of SES.

However, a key gap identified relates to both the methodology through which to analyse chains of causality and the burden of evidence required to specify and quantify chains of causality.

K5/1644 therefore further defines the concept of ecosystem production functions. These functions are akin to both economic and ecological production functions. They are extremely useful because they can be used to statistically and mathematically quantify chains of causality, which in turn allows analysts to quantify the effects of water resource management scenarios, at some level of confidence.

Thus, the need for evidence about the linkages between water resources and ecosystem services now becomes a matter of finding evidence about production functions.

However, the knowledge of and data for analysing chains of causality are often dispersed and poorly archived. Furthermore, limited guidance is available on how to make use of different types of available evidence.

K5/1644 proposed the application of 'evidence-based analysis of socio-ecological systems' and recommended that further work in this field be conducted.

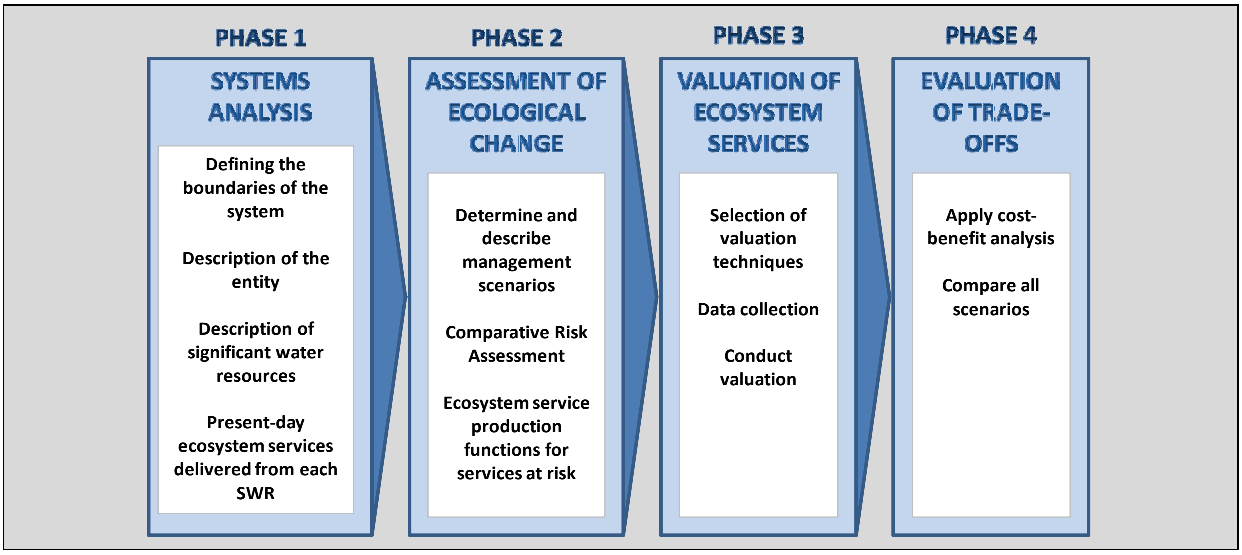

Figure 1. Simplified overview of the WRC aquatic ecosystem service evaluation framework

1.4. Purpose of this study

The current study explores the field of 'evidence-based analysis of socio-ecological systems' (E-BASES), with the purpose of identifying potentially feasible methodologies for finding evidence, both ecological and social, in support of analysing chains of causality in complex, water resource dependent, socio-ecological systems.

The study:

- Investigates the applicability of production functions to analyse chains of causality;
- Investigates the applicability of the evidence-extraction methods of evidence-based medicine (EBM), and evidence-based conservation (EBC) to Southern African conditions;
- Proposes alternative evidence-extraction methods; and
- Demonstrates the application of a set of five evidence-extraction methods at the hand of selected case studies.

1.5. Report structure

This report comprises four key sections. Section 2 introduces production functions and their importance in connecting ecological and social systems. Section 3 provides an overview of evidence-based analyses methods. Sections 4 and 5 defines 'evidence-based analysis of socio-ecological systems' (E-BASES) and proposes a set of evidence-extraction methods. The appendixes to this report demonstrate the application of these methods.

2. Production functions

2.1. Section overview

The MEA framework of ecosystem services defines four sets of ecosystem services: supporting, regulating, provisioning and cultural services. The supporting and regulating services are of an intermediate nature (i.e. it is mostly not directly used by resource users), but are fundamental in connecting the biophysical components of the water resource to human wellbeing.

Well-developed environmental and resource economics (ERE) techniques exist through which to value provisioning and cultural ecosystem services.

However, valuation techniques for regulating and supporting services are less well developed, and require development and improvement production function valuation methodology.

2.2. A brief overview of the development of ERE valuation techniques

The evolution of environmental goods and services (or ecosystem services) valuation techniques is characterised by an increasing demand for precise quantification of the values of these goods and services, and driven by various incidences of environmental pressure or disasters (Brown 2000).

Techniques such as cost-benefit analysis (CBA), the travel cost method (TCM), hedonic valuation method (HVM) developed between the 1920's and 1970's. The contingent valuation method (CVM) was intended to value public goods for which no behavioural activity could yield an economic value, direct or indirect and received prominence with the 1989 Exxon-Valdez oil spill. Other valuation techniques also emerged from the field of market research. All of the above techniques follow one of two methodologies: stated preference or revealed preference methodologies. In the stated preference methods, economists ask people to place a value on ecological resources. In the revealed preferences method (also called observed behaviour methods), economists study the actual choices of people to infer the value people place on ecological resources (Freeman 2003, Pearce et al. *2*002, Dasgupta 2010).

Both of these methodologies, however, have limitations. One of the limitations is that most valuation studies have focused on a single dimension of a problem only, and have thus failed to adequately address the complexity inherent in ecosystem processes and functionality (Perrings 2006). For many years, economists circumvented this problem by using the total economic value (TEV) framework. Whilst this framework provides an adequate categorisation of both market and non-market ecosystem services, it failed to address ecosystem complexity, particularly the dynamic aspects thereof.

Another limitation of several existing valuation methodologies has been that the people interviewed (stated preference method) or studied (revealed preference method) are often not aware of environmental risks (Perrings 2006, Dasgupta 2010). People often have little conception of the role of ecosystem assets in the generation of ecosystem services, or of the link between those services and the production of commodities (Winkler 2006a). This is because so many ecosystem services are intermediate inputs into the production of final goods and services and are not themselves traded in the market so are not visible (Perrings 2006). This holds true not only for the supporting and regulating services, but also for some provisioning and cultural services, such as fresh water, genetic resources or aesthetic services.

Perrings (2006) described and analysed these weaknesses based on meta-analysis of publications in the Journal of Ecological Economics. Perrings (2006) found that most studies had focused on a single dimension only, and ignored the multiple environmental goods and services effects of a shock introduced to a local system. Furthermore, most environmental economic studies had focused primarily on the direct use values of the environment, and put comparatively little effort into understanding the indirect linkages between ecological functioning, ecosystem services and the production and consumption of marketed goods and services. Ecosystems and the goods and services they provide are, for the largest part, intermediate inputs into goods and services that are produced or consumed by economic agents. As with other intermediate inputs, their value derives from the value of those goods and services (Perrings 2006). This was aggravated by a dependence on stated preference studies (such as CVM) of sample populations who have insufficient knowledge of the role of ecosystem stocks in the generation of environmental goods and services, or of the link between those goods and services and the production of commodities (Winkler 2006a as quoted in Perrings 2006).

Another set of concerns related to the way in which valuation studies addressed the problems of risk and uncertainty (Winkler 2006b as quoted in Perrings 2006). Since the value of ecosystem stocks is the discounted stream of net benefits they provide, it is sensitive to uncertainty about the environmental and market conditions under which they will be exploited. Most valuation studies simply sidestepped the problem, whilst others addressed it indirectly through the discount rate. Where uncertainty about the future consequences of the use of the environment includes the likelihood of severe and irreversible consequences, this is not satisfactory. Since social-ecological systems are complex, coupled and adaptive, the capacity to predict the future consequences of current actions are limited at best (Perrings 2006). Closely associated with this was the problem that little effort also went into understanding the value of the role of the environment in either mitigating or exacerbating the risks we face (Perrings 2006).

In response to these weaknesses, the Millennium Ecosystem Assessment (MEA 2005, MEA 2007) introduced a new approach (or framework) to the analysis of the interface of the ecology and the economy – through an ecosystem services framework.

2.3. Defining ecosystem services

Ecosystem services are broadly defined as “the benefits people obtain from ecosystems” (MEA 2005). The concept of ‘ecosystem services’ has been useful as it relates to the way many people think about their environments, in terms of the benefits they receive and the ways in which they can utilize natural resources (Fisher et al. 2008). Ecosystem services and their chains of causality connect ecological functioning, ecosystem processes, human use of ecosystem services with the production of marketed goods and services and this identifies ecological change as an economic problem (Perrings 2006).

Ecosystem services thus serve as a basis for the evaluation of the economic consequences of biodiversity loss (Costanza et al. 1997, de Groot et al. 2002, MA 2003, Pagiola et al. 2004, Balmford et al. 2008) and habitat alteration (CIC 2007, CIC 2009a,b).

The MEA definition of ecosystem services is purposefully broad as the benefits derived from ecosystems. Other authors have defined it as "the aspects of ecosystems utilised (actively or passively) to produce human well-being" (Fisher et al. 2008, Boyd and Banzhaf 2007).

The analyses of ecosystem services and their chains of causality require both the analyses of ecological phenomena and the level of utilization by society, either directly or indirectly.

2.4. Intermediate and final consumption ecosystem services

The notion of intermediate and final consumption ecosystem services is important.

For instance, nutrient cycling and water regulation and erosion regulation are examples of intermediate services which interact to deliver water flow, nutrients and a certain range of sediment loads to a downstream estuary which supports a large fishery and beautiful estuarine environment (food provision and recreation are the final services). In this example, the value of water regulation, nutrient cycling and erosion regulation are captured in the collective benefit yielded by recreation and subsistence fishing services. The fish as well as the safe and healthy shoreline and water body are the benefits that are the endpoints, or final consumption ecosystem services, that have a direct effect on human well-being.

One intermediate ecosystem service may also input into multiple benefits. For instance, water regulation is intermediate to flood protection and avoided damage or injury, water provision for multiple purposes, riparian subsistence agriculture, downstream aquatic ecosystems and recreation.

Final consumption ecosystem services are methodologically easier to value. Intermediate services are valued through final consumption services. But both the intermediate and final consumption services are important, and valuable. Intermediate ecosystem services are especially important with respect to their long-term sustainability and the resilience of ecosystems.

2.5. Classification of ecosystem services

The MEA[4] introduced a new approach to the analysis of the interface between ecosystems' function and human society published in various documents proposing a radically improved framework for analysis of ecosystem services (MEA 2005, 2007). The key benefit of the MEA framework is that it allows investigators to systematically unpack a development problem into its biodiversity components and the ecosystem services dependent on them.

[4] The MEA was a four-year international scientific assessment of the consequences of ecosystem change for human well-being (www.millenniumassessment.org)

The MEA[5] framework of ecosystem services provides a sound and internationally accepted definition of ecosystem services. The MA framework of ecosystem services defines four categories of ecosystem services:

- **Provisioning services** are often referred to as ecosystem 'goods', such as foods, fuels, fibers, biochemicals, medicine, and genetic material, that are in many cases directly consumed; subject to reasonably well-defined property rights (even in the case of genetic or biochemical material where patent rights protect novel products drawn from ecosystems); and are priced in the market.
- **Cultural services** are the less familiar services such as religious, spiritual, inspirational and aesthetic well-being derived from ecosystems, recreation, and traditional and scientific knowledge that are mainly passive or non-use values of ecological resources (non-consumptive uses); that have poorly-developed markets (with the exception of ecotourism); and poorly-defined property rights (most cultural services are regulated by traditional customs, rights and obligations); but are still used directly by people and are therefore open to valuation.
- **Regulating services** are services, such as water purification, air quality regulation, climate regulation, disease regulation, or natural hazard regulation, that affect the impact of shocks and stresses to socio-ecological systems and are: public goods (globally in the case of disease or climate regulation) meaning that they "offer non-exclusive and non-rival benefits to particular communities" (Perrings 2006); and are thus frequently undervalued in economic markets; many of these are indirectly used being intermediate in the provision of cultural or provisioning services.
- **Supporting services** are an additional set of ecosystem services referred to in the MA, such as nutrient and water cycling, soil formation and primary production, that capture the basic ecosystem functions and processes that underpin all other services and thus: are embedded in those other services (indirectly used); and are not evaluated separately (CIC 2007).

The regulating and supporting services are mostly of an intermediate nature and property rights for these services are poorly defined (our final deliverable will explore the issue of property rights in more detail. Provisioning and cultural services on the other hand are mostly of a final consumption nature, as demonstrated by Figure 2 below. (It is also important to note that provisioning and cultural services may in some cases be intermediately utilised.)

[5] The MA framework is widely accepted, contributed to by more than 1,360 international experts, and has broadly changed the way the interaction between social and ecological systems is thought about The key outputs of the MA have been published in five technical volumes and six synthesis reports. These contain a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems and the services they provide (such clean water, food, forest products, flood control, and natural resources) and the options to restore, conserve or enhance the sustainable use of ecosystems (MA 2007).

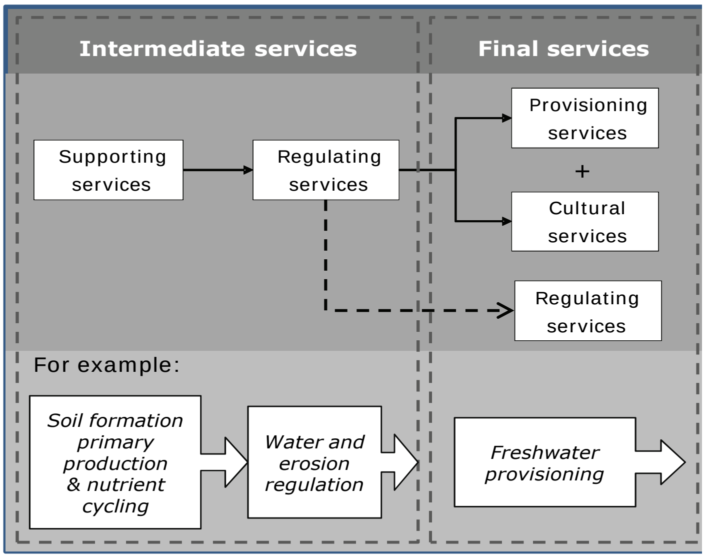

Figure 2. The distinction between intermediate services, final services and benefits (adapted from Fisher et al. 2008) illustrated by the stylised relationship between supporting, regulating, provisioning and cultural services as defined by the MEA.

2.6. The production function valuation approach

Ecosystem production functions apply knowledge of ecosystem functioning and processes to derive the value of supporting and regulating ecosystem services (Mäler 1991, Perrings 2006, Kinzig et al. 2007, Barbier 2000, Barbier 2003, Barbier et al. 2009). They do this through deriving the value of ecosystems and the services they provide as intermediate inputs into goods and services that are produced or consumed by economic agents.

In its simplest form, such a production function would have, as dependent variable (or response variable) an ecosystem service, and as independent variables (or influencing factors/determining variables) one or more ecosystem component and/or process indicators:

$$E_i(t) = f(S_{ij}(t); X_{ij}(t)) \qquad (1)$$

Where $E_i(t)$ is a vector of ecosystem services at time t
$S_{ij}(t)$ is a vector of the stock of ecosystem assets and other assets
$X(t)$ is a vector of ecosystem processes and other processes.

The theoretical foundations for the production function approach were pioneered by Mäler (1991). The field of econometrics provides best practice in the development of production functions. However, only a small number of empirical production function studies exist in the literature. The reasons for this are twofold:

- We still have a poor understanding of the complex linkages that characterise socio-ecological systems (Barbier et al. 2009); and
- There is a dearth of suitable empirical data, and related evidence through which to quantify production functions.

It follows from the above that the formulation of production functions that adequately describe likely consequences of changes in multiple variables of complex systems, requires a combination of expert knowledge and empirical evidence.

The figure below provides an example of this. It is a schematic summary of the relationship between drivers of change in a socio-ecological system, the ecological consequences thereof, and how that impacts on human well-being. It then logically ties these to valuation techniques that would be used. The diagram thus illustrates that one needs to understand the system, through expert knowledge, so we can begin to quantify how drivers of change will affect ecological systems and how that affects social and economic components.

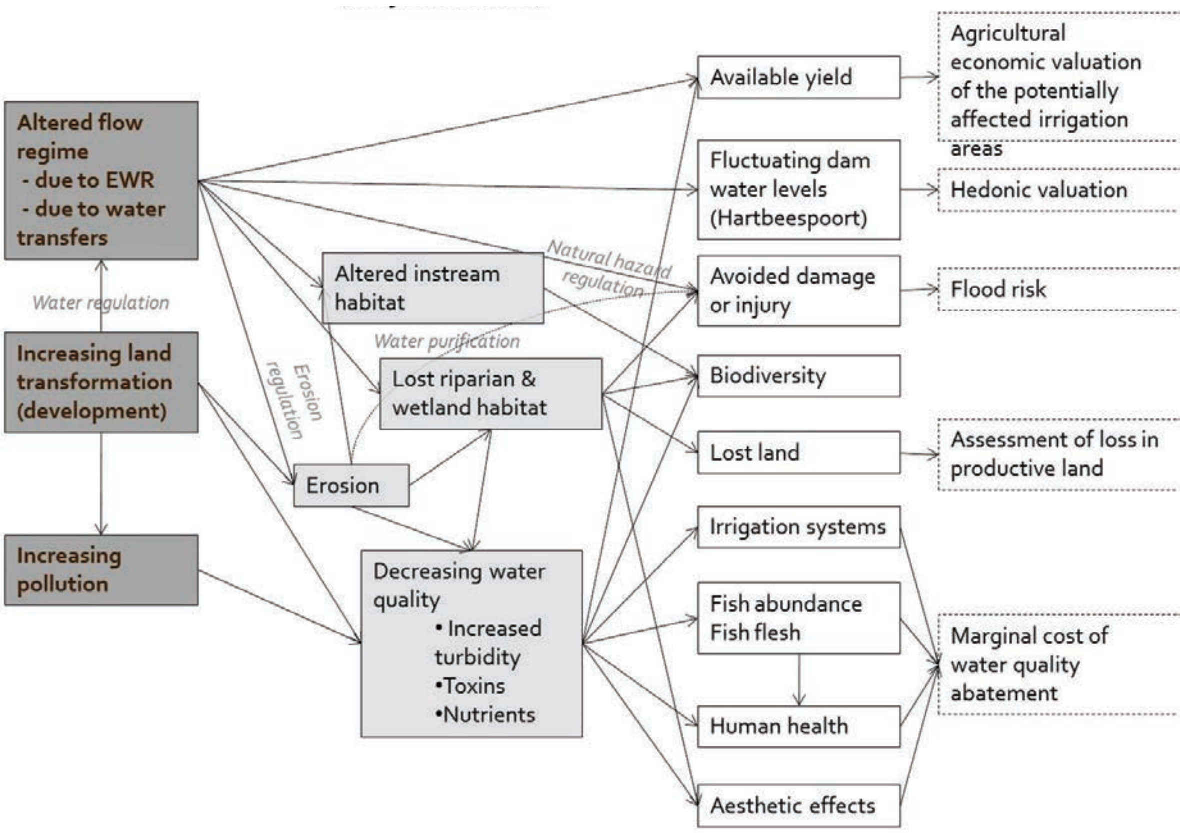

Figure 3. Schematic summary of the relationship between drivers of change, ecosystem services and valuation considerations

3. Evidence-based analyses practices

3.1. Section overview

In this section we provide a background to evidence-based medicine and evidence-based conservation and then summarise the main lessons from these evidence-based approaches. This section concludes with a proposed definition of evidence-based analysis of socio-ecological systems.

3.2. What is evidence?

Management of ecosystems, like medicine and law, require decisions to be made on best available evidence within a limited timeframe (Miller and Miller 2005).

"Evidence is information. It supports or undermines a proposition, whether a hypothesis in science, a diagnosis in medicine, or a fact or point in question in a legal investigation" (Miller and Miller 2005). Evidence is the consideration of both the data as well as how much and in what ways we can infer from that data, at some degree of confidence. Evidence is also often referred to as the currency by which one fulfils the burden of proof (Wikipedia).

In common law, evidence includes anything that can be used to determine or demonstrate the truth of an assertion. Evidence may include testimony, documentary evidence, physical evidence, digital evidence, scientific evidence, demonstrative evidence, eyewitness identification and genetic evidence.

Standards of proof are important. Well-defined evidentiary standards are applied in law, through which to judge a "standard of proof appropriate to the fact or point in question" (Miller and Miller 2005). The standard of proof is the level of proof required in a legal action to convince the court that a given proposition is true (i.e. to discharge the burden of proof). The standard of proof required depends on the circumstances of the proposition. These range from the lowest, the Precautionary Principle, to 'more likely than not' (the balance of probability) or 'clear and convincing' being a standard used in civil cases, to criminal standards of 'beyond a reasonable doubt' (Table 1).

Table 1. Legal and scientific standards of proof (taken from Miller and Miller 2005).

Kind	Level of Evidence	Standard
Regulatory, Legal		Precautionary Principle
Legal — Civil	*	More likely than not
Legal — Civil	**	Clear and convincing
Legal — Criminal	***	Beyond a reasonable doubt
Scientific	****	Irrefutable

Thus, the proof of an assertion, within the context of the degree of certainty required, depends on both the quantity and quality of evidence. Sufficiency of evidence in the case of a decision that needs to be made is thus dependent on the degree of certitude required.

In the case of WRM this, like in environmental health impact assessments, depend on the magnitude and likelihood of consequences to human well-being.

The Precautionary Principle is an interesting standard of proof with relevance here. It is derived from the 1990 Bergen Declaration, which states, “Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation" (Miller and Miller 2005). The precautionary principle is broadly analogous to 'probable cause'. It therefore requires a low standard of proof.

Evidence-based medicine and evidence-based conservation are two fields of practise which have developed techniques through which to extract scientific evidence, to support improved decision-making. We examine these in the proceeding sections.

3.3. Evidence-based medicine (EBM)

3.3.1. *History*

The development of the practise evidence-based medicine (EBM) has been driven by the need of medical practitioners to cope with information overload, by cost-control, and by a public who are impatient for the best in diagnostics and treatment (McQueen 2001).

Although the idea of testing the efficacy of medical interventions has existed for centuries, it was Professor Archie Cochrane's work on testing the efficacy of medical interventions in the 1960's and 70's that increased the acceptance of concepts behind evidence-based practice of medicine (Wikipedia 30th July 210). Explicit methodologies to determine 'best evidence' were largely created by a research group led by David Sackett MD. He founded Canada's Department of Clinical Epidemiology & Biostatistics. From 1967 to 1994, he developed an applied clinician-science field and created and disseminated evidence-based medicine (EBM) internationally.

Prior to EBM, doctors had based treatments on their own experience and that of their colleagues or on reference to some literature, without keeping up to date on new developments. Part of the problem was that the sheer numbers of relevant publications in any branch of medicine had reached levels where it had become effectively impossible for a practitioner to keep up to date. EBM was developed to solve these problems.

A key question in EBM was how the individual practitioner would be able to differentiate between good and poor evidence. EBM proposed a clearly defined code of practice to ensure that its implementation of EBM would be effective and consistent.

Best practices are now defined by the United Nations (UN) and the international community at large (UNESCO, undated).

EBM is thus defined as ‘*the conscientious, explicit and judicious use of current best evidence in making decisions about the care of individual patients*.’ (Sackett et al. 1996, WHO, undated).

The Free Dictionary (undated) defines these three key adjectives in the above definition as follows:

Conscientious: Guided by, or in accordance, with the dictates of conscience; thorough and assiduous;
Explicit: Fully and clearly expressed; leaving nothing implied;
Judicious: Having or exhibiting sound judgment; prudent.

In pursuit of conscientious, explicit and judicious use of current best evidence EBM practitioners have developed two methodologies which contribute to the assembly of best evidence:

- systematic review and
- meta-analysis.

3.3.2. *Systematic review defined*

In EBM, a systematic review involves the application of scientific strategies, to the assembly, critical appraisal, and synthesis of all relevant studies that address a specific clinical question (Cook et al. 1997).

A systematic review is a pre-cursor to meta-analysis. It provides an exhaustive summary of literature relevant to a particular research question. A systematic review will first analyse relevant databases, citation indexes and individual journals. Thereafter, the titles and the abstracts of applicable articles are identified and assessed against pre-determined criteria for eligibility and relevance. A systematic review thus uses an objective and transparent approach for research synthesis, with the aim of minimizing bias. (Ader et al. 2008). Systematic reviews are often accompanied by statistical techniques (meta-analysis) to combine results of the eligible studies.

The Cochrane Handbook for EBM (http://www.cochrane-handbook.org/) thus defines a systematic review as follows:

- "a clearly stated set of objectives with pre-defined eligibility criteria for studies;
- an explicit, reproducible methodology;
- a systematic search that attempts to identify all studies that would meet the eligibility criteria;
- an assessment of the validity of the findings of the included studies, for example through the assessment of risk of bias; and
- a systematic presentation, and synthesis, of the characteristics and findings of the included studies."

3.3.3. *Meta-analysis defined*

A meta-analysis is a mathematical synthesis of the results of two or more primary studies that addressed the same hypothesis in the same way Greenhalgh (1997).

Meta-analysis is applied within the systematic review.

A good meta-analysis presents an easy to understand summary of the studies as well as tabulating relevant information such as sample size and baseline condition of patients. By pooling results from trials conducted using the same methodologies it is possible to effectively increase the sample size.

Antman et al. (1992) give an example of a series of randomised controlled trials which individually did not show any significant difference between the treatment and the control because the sample size of each was small. The pooled results of the meta-analysis, however, did show that the treatment was significantly different from the control.

3.4. Evidence-based conservation (EBC)

3.4.1. *History*

EBC is the systematic review and synthesis of a large quantity of research and information and the summary, appraisal and communication of its results and implications in order to provide the best available evidence on the likely outcomes of conservation management actions (adapted from www.cebc.bangor.ac.uk).

The EBC discipline developed over the past decade due to the rapidly increasing global conservation area, and the management challenge that most conservation management decisions are experienced-based and make insufficient use of available scientific evidence (Pullin and Knight 2001). Pullin et al. (2004) conducted a survey of conservation management plans of major conservation organizations within the UK. Most of the planners had access to either a library or the internet but, as shown in Table 2, over 70% of the proposed actions in the management plans were based on accounts of traditional management. Pullin and Knight compared this situation to the case of medicine in the latter part of the 20th Century. Evidence-based medicine (EBM) had provided the practice of medicine with an effectiveness revolution. It achieved this through improving the criteria upon which treatment strategies were based, and it progressed from reliance mostly on personal experience to reliance on a balance of personal and scientific evidence.

Pullin and Knight (2003) and Sutherland (2003) both drew on the practice of EBM, and proposed a multi-step framework for evidence based conservation (Table 2).

The Centre for Evidence-Based Conservation (CEBC) and the Collaboration for Environmental Evidence (CEE) emerged from the work of Pullin, Knight and Sutherland, and endeavours to develop the field of evidence use in environmental management.

The Centre for Evidence-Based Conservation[6] (CEBC) (http://www.cebc.bangor.ac.uk/), established in 2003. This Centre site provides comprehensive information on the field of Evidence-Based Conservation (EBC).

The Collaboration for Environmental Evidence (CEE) is a partnership between scientists and managers working towards a sustainable global environment and the conservation of biodiversity (http://www.environmentalevidence.org/index.htm). The CEBC is a CEE partner, and the key authors referenced above all form part of the CEE.

[6] Director: Prof Andrew Pullin

Table 2. The process suggested by Sutherland (2003) (left hand column) and Pullin and Knight (2003) (centre column) and evidence-based management (right hand column) for making evidence-based decisions

Step number	Process proposed by Sutherland (2003)	Process proposed by Pullin and Knight (2003)
1	Convert information into answerable questions	Ask an answerable question
2	Efficiently track down the best evidence with which to answer the question, and Critically appraise evidence both for its validity and usefulness	Appraise the evidence provided for them
3	Apply results of this appraisal	Modify action in response to the evidence
4	Evaluate performance	Monitor and evaluate the new action
5		Actively disseminate knowledge and share learning

3.4.2. *Systematic mapping defined*

As in EBM, systematic review and meta-analysis from key methodological components of EBC. In addition, a method termed systematic mapping has been developed.

Systematic mapping is a precursor to systematic review in a response to the need to examine the availability, quality and diversity of a body of literature evidence, before proceeding with a full systematic review (Clapton et al. 2009). This method provides a rich-description, or map, of the research literature relevant to a particular topic in a manner that was rigorous, objective and transparent. A systematic mapping methodology was originally developed by the EPPI-Centre (Evidence for Policy and Practice Information and Co-ordinating Centre; Gough et al. 2003) to develop a comprehensive database of literature on a particular topic. The EPPI-Centre methodology has since been adapted by the *Social Care Institute for Excellence* (SCIE) (Clapton et al. 2009).

The aims of systematic mapping are to identify the bulk of the readily available resources towards answering a specific question; systematically and transparently “describe the existing literature, and gaps in the literature, in a broad topic area”; provide direct links to the evidence base for those wishing to locate relevant research; and analyse the literature quality and content to a level appropriate to the individual project (Clapton et al. 2009).

Systematic mapping therefore results in an overview that is still relevant to policy-makers, practitioners and researches. It is also a stepping stone to identifying “narrower policy and practice-relevant research and review questions” which can be addressed in a full SR if needed and appropriate (Clapton et al. 2009).

3.4.3. *Benefits of systematic reviews*

Ultimately, evidence-based conservation seek to extract evidence in a systematic and scientifically credible manner to test an assertion (review question) using systematic reviews. Systematic reviews “have become an important tool for facilitating evidence-informed policy and practice as they bring together, and combine, the findings from multiple studies” (Oliver et al. 2005). They have an established credibility based on a scientific approach to extracting evidence in a manner that is conscientious, judious and explicit.

The key principles of systematic review are that they:

- Involve “a range of users to drive review topics and questions to better realise the potential for research to inform policy and practice” (Harden 2006);
- Identify “clear research questions and appropriate study designs for each synthesis” (Oliver et al. 2005);
- “Minimise the chances of drawing wrong or misleading conclusions as a result of biases” (Gough 2007), which may be present in primary studies (e.g. methodological quality of studies included in review, validity of findings);
- Synthesize evidence to be clear about what is known from research and how it is known (Gough 2007), this includes judging the quality and relevance assessment of that evidence (Gough 2007) and “choosing quality assessment and synthesis methods according to types of studies and findings to be synthesized” (Oliver et al. 2005);
- Clearly and explicitly record are therefore open to scrutiny (Harden 2006).

3.4.4. *Limitations of systematic review methods*

Oliver et al. (2005) discusses the “critiques about the usefulness of systematic reviews of the effects of interventions for helping policymakers, practitioners or other groups to make decisions”. They list the following factors which can limit the utility of systematic reviews (taken from Oliver et al. 2005):

- a lack of rigorous studies, particularly in relation to the evaluation of multifaceted and multilevel social interventions; and
- estimates of the benefit or harm from interventions stripped of context (e.g. details of appropriateness, feasibility and implementation issues) (e.g. Greenhalgh et al. 2003; McDonald 1997; Macintyre 2001; Oliver 2001; White 2001).

These limitations become especially evident in the analyses of complex socio-ecological systems in Southern African conditions.

Both EBM and EBC use explicit systematic reviews. Traditionally, it focuses on a hierarchy of evidence that places quantitative, scientific research at the top of the hierarchy. But the need for evidence-based approaches to extracting evidence from the social sciences has led to the development of frameworks and guidelines on systematic review of qualitative studies and their synthesis with quantitative studies.

In areas where data are scarce and research funds limited, such scientific evidence is often limited. But there is still a pressing need for informed decisions (i.e. no time to wait for answers even if funds were available). There is thus a need to extract evidence from multiple diffuse sources in a manner that is explicit, judicious and conscientious and to a standard that is defensible in court.

So facing the need to make informed decisions that are based on judiously and conscientiously considered evidence (best available evidence), we have to ask, is there a way of making use of a wider range of evidence?

4. Evidence-based analysis of socio-ecological systems (E-BASES) defined

4.1. Section overview

In this section we explore a range of topics that are of importance to the field of evidence-based analysis of socio-ecological systems. We combine these with our preceding discussions of SES, production functions and evidence-based practices, and conclude with a definition of evidence-based analysis of socio-ecological systems.

In addition, this section concludes that the systematic review process (as applied in EBM and EBC) is an appropriate method for evaluating evidence, but that additional analysis methods (in addition to meta-analysis) are required to extract useful evidence from available bodies of evidence relevant to Southern Africa.

4.2. Why E-BASES is important: SES and adaptive management

In management of socio-ecological systems, management interventions are often based on incomplete knowledge or understanding of ecosystem functioning, or of the social subsystems and interactions; have unforeseen feedbacks over the long term; are insufficient for coping with continuous change and future shocks; and are unable to account for all social, economic and ecological influences at multiple scales (MA 2003, Pollard et al. 2008).

As a result, an approach termed strategic adaptive management has been adopted by numerous management agencies. Adaptive management is process based on the philosophy of 'learning by doing'.

Strategic adaptive management is a framework that acknowledges the nature of complex systems and management by experiment (Biggs and Rogers 2003, Pollard and du Toit 2007). It can be applied in different situations and is independent of scale. We can use it to test assumptions that may be defined at any scale.

Evidence-based analysis is useful in the adaptive management context as it can take understanding and data input from the site-based studies into a generalized framework.

4.3. Limitations to evidence-based approaches to ecology in the Southern African context

There are valuable lessons to be learnt from evidence-based approaches in medicine and conservation. These lessons relate to the systematic and explicit approaches that have been developed for extracting evidence from published literature.

However, two key limitations exist with respect to the development of E-BASES methodology within complex socio-economic systems in Southern Africa. These limitations result from two implicit assumptions made in both EBM and EBC.

The first assumption is that the research question, which is formulated in step 1 of the systematic review, can be simplified to a two-variable cause and effect relationship. For instance, in the case of EBC an actual question in investigated by the CEBC was whether in-stream habitat improvement increased the abundance of a particular genus of fish. However, aquatic ecosystems management in Southern Africa, with respect to the RDM, requires analysis of complex socio-ecological systems with chains of causality containing multiple cause and effect relationships.

The above discussion also highlights the limits to statistical meta-analysis. Although past research in aquatic ecosystems in Southern Africa has accumulated a notable body of research publications, the research outputs are not necessarily suited to meta-analysis. It is important to note that this phenomenon is to be expected in any country, is a characteristic of research outputs in any research field and is the particular challenge addressed by both the EBM and EBC fields of practice.

The above limits are currently being addressed as numerous examples of mixed methods exist in EBM and are coming into EBC (Prof Andrew Pullin, personal communication).

In addition, in Southern Africa, these limitations are exacerbated by relatively low research intensity. Research funding availability and efforts in the field of aquatic ecology in particular are regarded as insufficient in Southern Africa, in spite of the excellent efforts of organizations such as the WRC (Harding 2010). This results in a relative dearth of research publications upon which meta-analysis may be performed. The second assumption is that a sufficiently large body of suitable research outputs exists upon which meta-analysis can be performed. The suitability of the research outputs is determined by the extent to which the research outputs have been based on empirical data. However, in a relatively small country such as Southern Africa, it is highly unlikely that a suitably large body of such outputs do exist.

Thus, in Southern Africa, we need to identify evidence extraction methods that would compliment meta-analyses within the systematic review process.

4.4. Summary

The complex socio-ecological systemic nature that characterises aquatic ecosystems creates uncertainty in water resources management decisions. The level of uncertainty needs to be reduced to acceptable levels where decisions can be made confidently.

The MEA provides a comprehensive and robust analytical framework through which to link water resources and the beneficiaries of ecosystem services. In this framework, water resources and ecosystem services connect through chains of causality. Production functions quantify chains of causality, and associated levels of uncertainty. Production functions thus derived provide us with hypotheses of how complex systems work, defining chains of causality and describing the delivery of ecosystem services to beneficiaries.

Evidence-based analyses practices enable us to evaluate existing evidence of production functions in a conscientious and judicious manner, but are limited by the existing body of evidence itself and the complexity of the type of problem under investigation.

The systematic review process (as applied in EBM and EBC) frames the evaluation of evidence, however, we require more explicit analysis methods, in addition to meta-analyses, to extract useful evidence from available bodies of evidence.

4.5. A working definition of E-BASES in the Southern African context

We thus propose the following working definition for E-BASES in the SA context:

E-BASES is:

d) the systematic review and synthesis of a large quantity of primary and secondary data, research and information, and;
e) the summary, appraisal and communication of its results and implications in order to support expert opinion with the best available evidence;
f) on the likely outcomes of cause and effect relationships in complex socio-ecological systems.

In the section below, we explore a methodology for E-BASES in Southern African applications.

5. A methodology for E-BASES

5.1. Overview

5.1.1. *Evidence-based conservation methodology as a foundation for E-BASES methodology*

The methodology of evidence-based conservation, as developed by the CEBC, is highly appropriate and forms a sound foundation for developing a methodology for E-BASES. Therefore we propose that the methodology follows that of the systematic review (SR) as described in CEBC (2010) (Figure 4).

The methodology of evidence-based conservation, and indeed for all other evidence-based reviews, is well defined and has an established credibility. All reviews follow the standard steps of a systematic review:

1. It determines the need for evidence and defines a review question;
2. The review is planned and a review protocol is developed;
3. The review involves:
    a. Searching for studies across a range of bibliographic sources
    b. Applying inclusion and exclusion criteria
    c. Assessing methodological quality
    d. Extracting data, and
    e. Synthesizing findings;
4. Evidence is interpreted and conclusions reported on; and
5. Outcomes are disseminated and archived.

5.1.2. *Departure from evidence-based conservation methodology*

The proposed E-BASES methodology departs from evidence-based conservation methodology in two ways.

Firstly, in step 1, the review question is formulated as a hypothesis of how a specific section of an SES works and the associated assumptions. The review question may therefore not explicitly identify a two-component relationship, but more likely a system of cause and effect relationships, involving multiple system components, which, together, comprise a chain of causality.

Secondly, the evidence-extraction is expanded to explicitly include five evidence-extraction methods[7], which we have termed meta-analysis, scientific experimentation, database analysis, data mining and expert knowledge harvesting. These methods inform the way in which steps 2 and 3 of the evidence-based conservation methodology may be conducted.

Table 3 elaborates on the detailed differences between the methodology for EBC and the adapted methodology for E-BASES.

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[7] The CEE guidelines allows for application of various evidence-extraction methods (personal communication – Prof Andrew Pullin). In this report, we explicitly identify five such methods that are of relevance to South African applications.

We demonstrate the adapted methodology in the sections below.

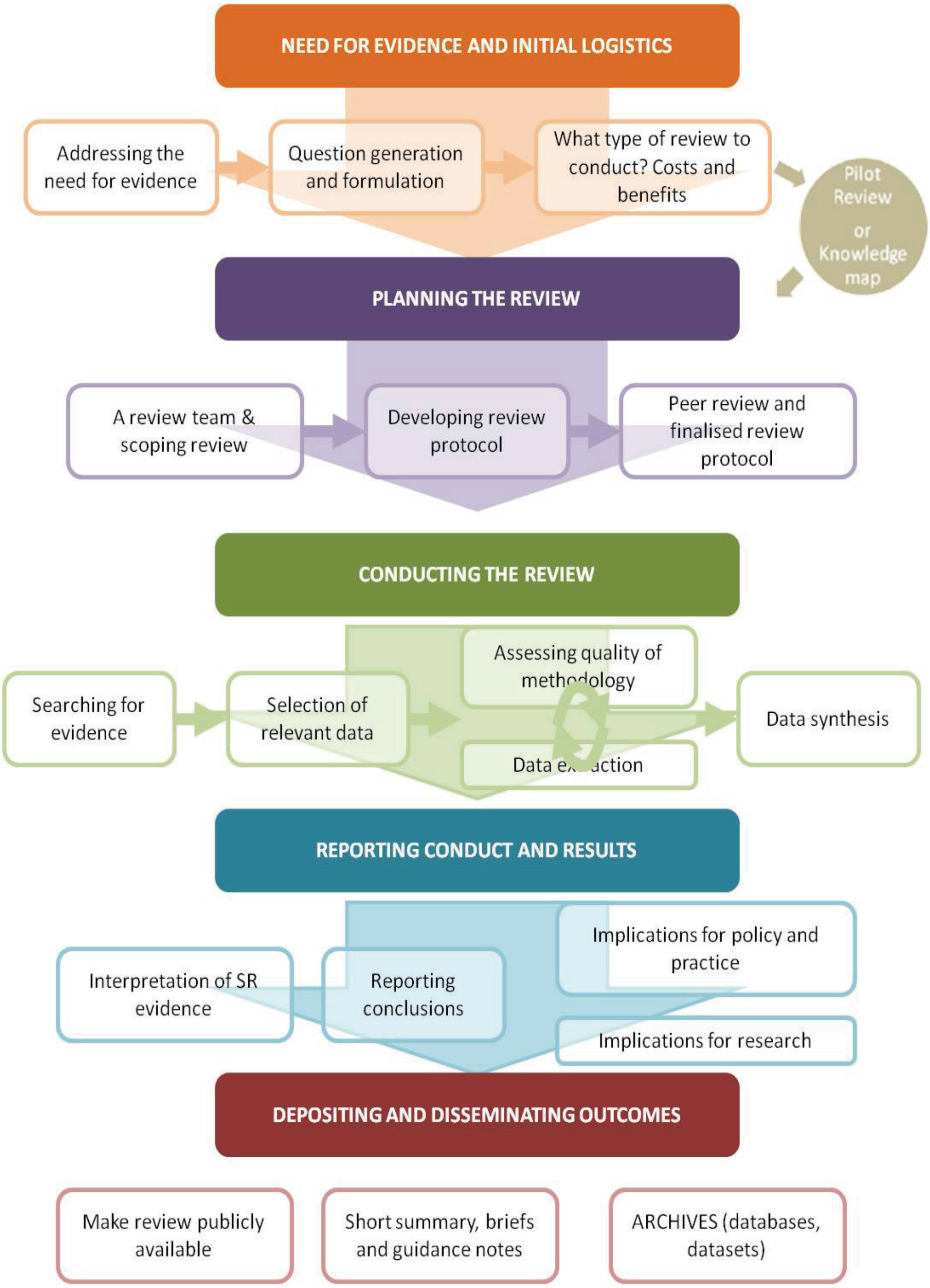

Figure 4. The steps followed in the Systematic Review process (taken from CEBC 2010)

Table 3. Summary of steps of the CEBC (2010) framework for systematic review and key differences of the adapted framework for systematic review in African socio-ecological systems (SES).

CEBC Steps	Methodology for EBC	Adapted methodology for E-BASES
Need for evidence and initial logistics		
Addressing the need for evidence	The need for evidence relating to concerns or problems	Unchanged
Question generation and formulation	Formulation of review question and its key elements (PICO/PECO)	Question formulation based on a systems analysis of priority ES.
Why conduct a review? Costs and benefits	Deciding whether to conduct a SR	Unchanged
Planning the review		
A review team and scoping review	Decide on review team and undertake review scoping	Unchanged
Developing review protocol	Develop review protocol	Broader search strategy and range of synthesis as required by the synthesis techniques described in this study
Peer review and finalised review protocol	Undertaken by the review team and/or larger user groups or experts	Unchanged
Conducting the review		
Searching for evidence	Use search strategy, including inclusion and exclusion criteria, to search for studies.	Unchanged
Selection of relevant data	Use screening and coding to select relevant studies	Search for and extract a wider range of evidence using a range of synthesis techniques as described in this report
Data extraction	Extract evidence from studies scientific studies for meta-analysis (approaching authors where necessary)	
Assessing quality of methodology	Assess quality of methodology of studies	Quality assurance of review process (SASQAF); Quality assessment of studies and use of Weight of Evidence frameworks
Data synthesis	Use of quantitative or narrative (qualitative) synthesis approaches	Unchanged
Reporting conduct and results		
Interpretation of SR evidence	Interpret evidence and biases using available guidelines	Unchanged
Reporting conclusions	High standards of reporting achieved through explicit review process	Unchanged
Implications for policy and practice and research	Interpretation of best available evidence that enables decision-makers and research managers to integrate evidence into their context	Unchanged
Depositing and disseminating outcomes		
Make review publicly available	Central location for reviews to be accessible	WRC Knowledge Hub
Short summary, briefs and guidance notes	Key messages for policy and practice implications and how review outcomes can be used	Unchanged
ARCHIVES (databases, datasets)	Important that data used/generated are accessible and comprehensive	Unchanged

5.1.3. *Guiding principles for evidence-based analysis of social-ecological systems (E-BASES)*

We've used the phrase "guiding principles" deliberately to highlight that they are only a guide for extracting evidence and scientific inquiry. This list of guiding principles was developed through wide reading of evidence-based approaches, scientific method, and through the practical application of the adapted methodologies for extracting evidence (see case studies; Halper 2008; Shavelson and Towne 2002, Cochrane Collaboration YEAR, Oancea and Pring 2008).

We believe these principles can be applied across scientific disciplines and are applicable to each of the ways of extracting evidence proposed in the adapted methodologies described in this project. There is however no need for a single study to fulfil all the principles, just that thought should be given to the principles in the application of evidence-based analysis of socio-ecological systems. They should be viewed as norms of conduct that should be followed by anyone involved in evidence-based analysis of socio-ecological systems.

Below we present several interrelated, but not necessarily ordered principles for extracting evidence and inquiry thereof. "The principles emphasize objectivity, rigorous thinking, open-mindedness, and honest and thorough reporting" (Shavelson and Towne 2002).

PRINCIPLE 1. Pose significant questions that can be investigated empirically

Posing a relevant and significant question is a typically undervalued part of scientific inquiry and fundamental to extracting evidence. There are two components to this principle:

a) **Significance of the question:** This is "established with reference to prior research and relevant theory, as well as to its relationship with important claims pertaining to policy or practice" (Shavelson & Towne 2002). It is related to one of the 10 key principles of an evidence-based approach (see appendix), "***Striving for relevance**, by promoting the assessment of interventions using outcomes that matter to people making choices in... [the management of socio-ecological systems]"*
b) **Empirically based:** Questions should be posed in a way that allows for empirical investigation.

PRINCIPLE 2. Link research to relevant theory

Scientific theory is essentially conceptual models of how we think components in a socio-ecological system are connected. Scientific inquiry is "fundamentally concerned with developing and testing theories, hypotheses, models, conjectures, or conceptual frameworks that can explain aspects of the physical and social world" (Shavelson & Towne 2002). Before extracting evidence to address a particular question, it is important that your thinking is grounded in the relevant literature and understanding so that you can apply **logic of thinking** and methodology (see Principle 4 & 5). The framework and methodology for systematic review provides a constructive method for looking back.

PRINCIPLE 3. Use methods that permit direct investigation of the question

This principle has several sub-components that relate to the collection, measurement and analysis of data.

1. **Think first** – Before you decide on the statistical techniques you're going to use, consider carefully the question you are asking. Methods for data collection and analysis should be linked to question you're asking so as develop "a logical chain of reasoning based on the

interplay among investigative techniques, data, and hypotheses to reach justifiable conclusions." (Shavelson & Towne 2002).

2. **Question everything** – Especially with regards to other people's data or analyses. Did the analysis make sense? How did they get their results? Measures of data quality are useful here (e.g. does the study have a SASQAF stamp, has it been peer reviewed?). Your gut feeling based on your experience is important here.
3. **Get as close to the primary data source as possible** – when extracting data from other sources, it can be beneficial to understanding data limitations and assumptions to get as close to the primary data source as possible.
4. **Look before you leap** – Take a good look at the data you have. Do the data seem reasonable, accurate and complete? Just because the data are available, does not necessarily mean that the data are useful to the analysis or question.
5. **Select the method and implement competently** – Then select the method you believe will best fit the question posed. The truth is that some methods are better suited to address certain questions, but the choice of method can vary across disciplines, be dependent on the assumptions you are willing to accept in interpreting results, and can be limited by the data, software availability, or time. So reasons for methods chosen should just be stated explicitly. Apply best data management and statistical practices relevant to the analysis question, data and sampling design:
6. **Identify potential methodological limitations** – such as missing data, errors or assumptions in the data, potential researcher bias, unmeasured variables. Keep track of records that might be duplicates, obsoletes or inactive, considered incorrect/inconsistent (e.g. related to typing or data entry errors) or incomplete.

PRINCIPLE 4. Provide a coherent and explicit chain of reasoning

Coincidence or correlation does not necessarily mean causation. You need to conscientiously consider the socio-ecological system, the question posed, the evidence, assumptions and uncertainties, to provide a coherent and explicit chain of reasoning. "The extent to which the inferences that are made in the course of scientific work are warranted depends on rigorous reasoning that systematically and logically links empirical observations with the underlying theory and the degree to which both the theory and the observations are linked to the question or problem that lies at the root of the investigation" (Shavelson & Towne 2002). This requires "the development of a logical "chain of reasoning" (Lesh, Lovitts, and Kelly 2000) that moves from evidence to theory and back again" (Shavelson & Towne 2002). This chain of reasoning must be:

a) **Coherent** – demonstrate an "understanding of the subtleties of the question being asked and the procedures used to answer them" (Shavelson & Towne 2002)
b) **explicit and replicable** – make clear statements about assumptions underlying inferences and acknowledge potential biases, how evidence was judged, and how links between evidence and theory were made
c) **persuasive** – explain how alternative explanations (counterhypotheses) were addressed
d) **open about uncertainty or errors** – "Evidence is almost always incomplete, inconclusive, and amenable to multiple explanations" (Towne et al. 2001). Therefore scientists nearly always have to reason in the presence of uncertainty. However, it is still critical to estimate or measure the magnitude of this uncertainty, in qualitative or quantitative terms (Shavelson & Towne 2002)

e) **Minimise bias** – through a variety of approaches such as scientific rigour, ensuring broad participation, and avoiding conflicts of interest

PRINCIPLE 5. Disclose research to encourage professional scrutiny and critique

Professional scrutiny and criticism is an essential characteristic of scientific inquiry. The degree to which your work can be reviewed depends on true, complete, and accessible records of data, methodology (see principle 3), and inferential reasoning (see Principle 4). This relates to good data management and archiving as well as to making this accessible.

"This careful accounting not only makes transparent the reasoning that led to conclusions—promoting its credibility—but it also allows the community of scientists and analysts to comprehend, to replicate, and otherwise to inform theory, research, and practice in that area" (Shavelson & Towne 2002).

This principle is directly linked to one of the ten principles of systematic review: *Ensuring quality, by being open and responsive to criticism, applying advances in methodology, and developing systems for quality improvement.*

5.2. Formulation of hypotheses

5.2.1. *Addressing the need for evidence*

The need for evidence relating to concerns or problems that generate questions relevant in policy or practice come up in many ways (CEBC 2010). They should arise from the identification of issues or concerns related to the effectiveness of interventions, or impacts of humans on the environment that are considered a priority in terms of relevance to policy or practice in a particular system. "Identifying and agreeing on priority issues and the need for evidence is often an iterative process involving dialogue among different individuals and organisations" (CEBC 2010).

The CEBC (2010) doesn't say much more on the matter if identifying and agreeing on priority issues. However, in order to identify priorities issues, the system of interest needs to be defined and characterised in order to bind the analysis, identify key system drivers and make explicit the assumptions that lie beneath questions we might have. This is particularly important in complex, adaptive SES's (see Box) where multiple stressors interact with multiple ecosystem assets in ways that can be unpredictable to affect multiple ecosystem service benefits. Posing the right question is therefore important if the systematic review is to have relevance to policy or practice and time and resources are not to be wasted. It requires (a) consideration of the system of analysis and (b) the people to be involved in the systematic review.

The process of defining and characterising the system of analysis in aquatic ecosystems is described in the first phase of Ginsburg et al. (2010).

Box 1. Complex systems

Taken from Pollard and du Toit (2007):

Complex systems have multiple drivers which operate at different scales. Socio-ecological systems are heterogeneous, dynamic and in a state of flux. This brings about different effects both on an annual and cumulative basis. Some of the system drivers may relate to other 'sub-systems' such as a political or global drivers. Components of systems are interdependent and interacting and feedback loops are an important consideration. For example, a reinforcing loop – where an effect increases – can be seen when wetland health improves, resulting in an increase in the water table which, in turn causes a further improvement in wetland health. Counterbalancing loops may also exist, where effects are ameliorated. Multiple drivers and feedback loops often mean we can't predict exact outcomes; moreover they can lead to unexpected outcomes. Hence outcomes are usually not entirely predictable. Complex systems also display lags and thus it can take time to see benefits.

However, complex systems are not necessarily complicated. In fact they often only have a basic set of drivers and responses such as fire and rainfall. The essence of these systems is that their inherent variation is what determines the system function.

CEBC (2010) defines three definable, but not mutually exclusive, groups of people that should be involved in conducting a systematic review from an early stage:

- User group
- Review team
- Stakeholder group

Funders can be defined as a fourth group but should be declared with other conflicts of interest that may arise (CEBC 2010).

5.2.2. *Question generation and formulation*

The point of departure for any scientific evidence-based methodology is the definition of scientific method. Thus, the application of scientific evidence-based methodology in complex socio-ecological systems in water resource management begins with the formulation of the hypothesis, the research question and the assumptions that underlie these. And the formulation of a robust and elegant hypothesis is a requirement for a successful systematic review (CEBC 2010).

Defining the right question for review requires being explicit about its scope, implicit assumptions and conceptual framework, which is why a description of the SES is so important in the first step. All this will inform the methods to be used in the review and help develop the review protocol in Step 2 (Gough 2007).

There is no set formal process for question generation but CEBC (2010) provide some guidance on turning a concern or issue into a reviewable question:

1. The question must be answerable in scientific terms (Jackson 1980; Cooper 1984; Hedges 1994)
2. It should be generated by, or at least in collaboration with, relevant decision-makers (or organisations) for whom the question is real, and with the help of scientists, preferably experienced in SRs

3. It may also be important for the question to be seen as neutral (unbiased) to stakeholder groups to minimise conflicts
4. Definitions of the structural elements of the question are critical to the subsequent process because they generate the terms used in the literature search and determine relevance criteria.

The topic/question is often a permutation of *'does* ***stressor/intervention/exposure X*** *applied to* ***habitats/populations of subjects Y*** *produce* **ecosystem service outcome *Z*** and is described in terms of four elements referred to as PICO or PECO (Population, Intervention/Exposure, Comparator, and Outcome). The definition of these terms is provided in Table 4 below and CEBC (2010) provides several examples of these elements.

Table 4. Elements of a reviewable question: normally a permutation of 'does intervention/exposure I/E applied to populations of subjects P produce outcome O (extracted from CEBC 2010).

QUESTION ELEMENT	DESCRIPTION
Subject Population	Unit of study (e.g. ecosystem, species, important to the delivery of an ecosystem service) that should be defined in terms of the subject(s) to which the intervention will be applied
Intervention/exposure	Proposed management regime, policy, action or the environmental variable to which the subject population are exposed (e.g. a change in an aquatic ecosystem driver such as hydrology or water quality).
Comparator	Either a control with no intervention/exposure or an alternative intervention
Outcome (ecosystem service outcome)	All relevant objectives of the proposed intervention that can be reliably measured. Outcome of concern that might result from exposure to an environmental variable.

Complex systems can be quite simple if we chose to bind them in such a way (i.e. there are often only a few key drivers). This is why the question needs to be carefully formulated in order to target the outcomes in question/of concern. Because of the complex nature of SES's, the next sub-section offers some detail on the importance of and guidance on developing a sound hypothesis of the production of an ecosystem service.

Framing review questions that support the role of IWRM

Integrated Water Resources Management (IWRM) operates at the intersection of the natural system that delivers ecosystem services, the technical system that enables us to benefit from ecosystem services and the social system that is concerned with regulating who may access ecosystem services and under what conditions (Brugnach et al. 2008).

Each of these subsystems is complex and understanding is fraught with uncertainty to the extent that it is necessary to accept that prediction is a largely unattainable goal (Brugnach et al. 2008).

This understanding exposes the central role of IWRM in:

- Shaping how stakeholders communicate with each other to develop shared understanding that embodies uncertainty and the influence this has on the reliability of predictions;

- Influencing the way stakeholders relate to the resource, particularly how they acknowledge multiple uses, users and uncertainty;
- Enabling stakeholders to explore options and reframe ‘problems’, providing direction for solution-oriented research.

The usefulness of evidence-based approaches to learning for IWRM (as in other contexts) is critically dependent on understanding the context, framing the problem and thereafter posing the most appropriate question(s). Thus, by giving careful attention to interpreting the context it is possible to frame specific questions and interpret the answers more holistically.

IWRM is practiced in a context of complexity and uncertainty. Acknowledging this encourages us to ask questions about the evidence that has been amassed that supports the role of IWRM as set out above. A framework for the evaluation of aquatic ecosystem services for Resource Directed Measures, developed for the WRC (Project 1644; Ginsburg et al. 2010), provides some guidance on problem or question formulation.

The framework sets out a 4-phase method for the evaluation of aquatic ecosystem services. Fundamental to this method is an expert driven procedure (experts in this context include ‘managers’ as per the guidelines above) which identifies ecosystem services (the “population”); within the context of a complex social-ecological system. One or more management scenarios define the “intervention/exposure” (or ecosystem effect). The method further specifies the formulation of production functions for ecosystem services, which define the cause and effect relationships between the affected ecosystem service and the variables which affect them. Thus the “comparator” and the “outcome” are inherently defined through the appropriate production functions.

In WRC Project 1644, a case study in the Sand River demonstrates five causal chains for five sets of ecosystem services affected by the development of a new dam (Table 5). Ecosystem services ultimately link the complex system to the human well-being derived from the system. This is achieved through the development of a sound conceptual understanding of the biophysical attributes, ecological processes, system feedback controls as well as the inputs and outputs to and from the social and ecological system (Landis and Wiegers 1996; Pollard and du Toit 2007, WRC K5/1644).

A conceptual diagram of how ecosystem services are delivered by aquatic ecosystem is presented in Figure 5 below (also from WRC Project K5/1644). The diagram assists in defining the likely effects of one or more “interventions/exposures” on a specific ecosystem service in complex systems. An important characteristic of the diagram is the five EcoClassification methodologies (flow, quality, geomorphology, fauna and vegetation) at the centre of the diagram. The delivery of aquatic ecosystem services depends fundamentally on the state of these components.

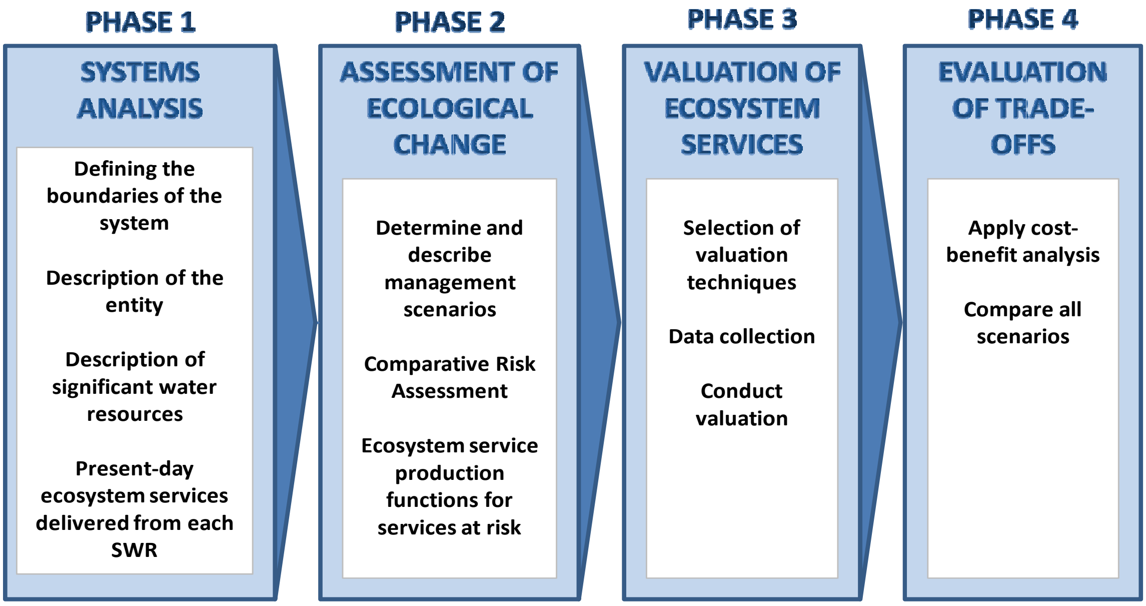

Figure 5. Simplified overview of the WRC aquatic ecosystem service evaluation framework

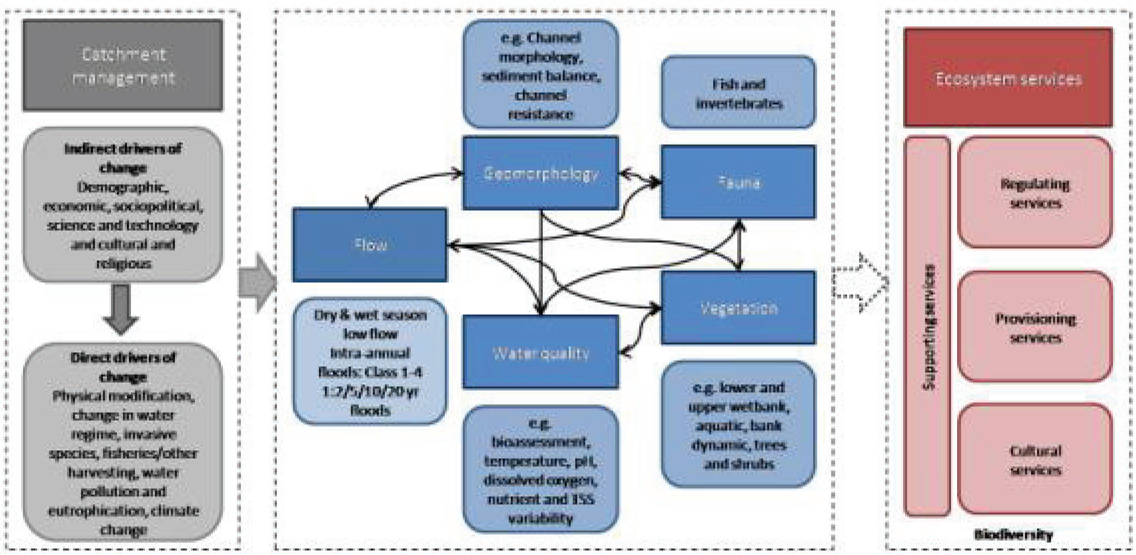

Figure 6. Schematic of the causal relationships that require modelling in the production function.

Table 5. Causal chains for 5 sets of ecosystem services affected by the development of a new dam: Source Case study in WRC Project K5/1644.

Causal chain	Provisioning and cultural services	Underlying regulatory services
1	Fresh water provisioning	Water regulation, Water purification, Erosion regulation
2	Fibre, Food and Biochemical and pharmaceutical products provisioning	Water regulation Erosion regulation
3	Grazing	Water regulation and habitat provisioning (after Balmford et al. 2008)
4	Inspiration, Recreation and Eco-tourism	Water regulation, Water purification, Erosion regulation, Seed dispersal
5	Human health effects	Disease regulation

Box 2. Two key variables in aquatic ecosystems: flow and quality

Water flow and quality are first order production function variables, and are fundamental to aquatic ecosystems service production. What is important about these is they are first order variables over which society can exert some control in its efforts to manage for uncertainty and exposure to desirable/undesirable outcomes of intervention. We thus hypothesize that water flow and quality are first order production variables that provide the greatest scope for affecting the delivery of ecosystem services for human benefit[8]. The case study results presented in Table 5 supports this, as every key independent variable in the production functions is an indicator of response to variation in flow and/or water quality.

Water flow is generally well modelled in South Africa. A recent study by the Department of Water Affairs has revealed that hydrological modelling in South Africa is well established, and a large community of practice exists in the country.

The same study however, also revealed that our social-ecological systems knowledge understanding of the implications of water quality is generally poor and requires much improvement and thus integrated modelling is poor.

5.3. Planning the review

5.3.1. *A review team and review scoping*

The establishment of a multidisciplinary, independent review team is important to a successful SR. This includes not only the project team involved in the SR, but also any specialist groups who might be involved. It is necessary to get the mix of stakeholders correct so that there is a broader understanding of implications along linear systems (of rivers) as well as across water basins.

At this stage a consultation plan, describing how stakeholders or specialist experts will be engaged, is decided upon. Consultation with stakeholders is not essential, but it is recommended by Clapton et al. (2009) when their acceptance of the results of a SR is important.

Before commencing a SR, a period of 'scoping' of the SR topic should be conducted to guide the development of a review protocol in the next step. The review scoping is used as part of the planning process and serves to develop and test a search strategy, and appraise the volume of available literature and data quality (CEBC 2010). This is developed in consultation with experts and information specialists.

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[8] "The reason we can distinguish aquatic ecosystems is because of the generally persistent influence of water. So, the presence of water has a profound effect on the nature and extent of ecosystem services"

In rivers this influence is by definition a consequence of both the presence of and the flow of water. Because of human dependence on water and the uncertainty that characterizes flow in many parts of the world we choose to store water thereby influencing its presence.....flow is a strong determinant of when and where water is present and so flow has profound consequences for the production of ecosystem services. How we choose to use ecosystem services (both terrestrial and aquatic) influences water quality and this influences production of aquatic ecosystem services. Because flow and quantity are related, quality may also vary with flow. As we use more water there is less flow/presence in rivers. As we use more water we add more substances to it so that less water in rivers carries more and more substances with significant consequences for production of ecosystem services.

So we have two controls: Increase the presence of water to raise ecosystem service production; and reduce the adverse influence water quality on ecosystem service production. Because these are related we generally balance them." – Working hypothesis by C Breen (2010) – to be explored in more detail in next Deliverable.

5.3.2. *Developing a review protocol*

A review protocol is designed for a specific question and describes what the SR aims to achieve, including the primary review question/objective, and details of the search strategy, search criteria, study quality assessment guidelines, and a strategy for data extraction and synthesis. The intention of a review protocol is that the "methodology be established and made available for scrutiny and comment at an early stage... to make the review process as rigorous, transparent, and well-defined as possible" (CEBC 2010).

The review protocol for SR will clearly state the questions and data requirements so that they can be easily understood and communicated to relevant experts who might be engaged with and to the people responsible for the search for evidence (in this case it is the students). The review protocol will include:

- Background[9]
- Review question/objectives
- Search strategy
- Inclusion/exclusion criteria
- Study quality assurance and assessment
- Data extraction strategy
- Data synthesis strategy

Guidance on developing a review protocol is available from the Collaboration for Environmental Evidence website, (www.environmentalevidence.org/Authors.htm), and examples of review protocols are available in the Environmental Evidence Library (www.environmentalevidence.org/Library.htm).

5.3.3. *Peer review and finalized review protocol*

Peer review of the review protocol is undertaken by the review team and perhaps the user group and stakeholder group defined in Step 1.

"It may become necessary during the course of a review to make changes to the protocol. These changes should be clearly documented within the final review so that transparency and repeatability can be maintained" (CEBC 2010).

5.4. Conducting the review of evidence

This step follows the review protocol defined in Step 2. It is in this step that the greatest adaptations to the CEBC (2010) framework for systematic review are made.

Fundamental to the review evidence is the methods that may be used to extract evidence. The selection of most appropriate methods is, to a large extent, determined in the planning phase.

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[9] This section includes a background to the topic/question including policy, practice and legislative context as well as any background research. The intention is to define the scope of the SR and not to provide a comprehensive overview of the field. Major debates in the field and any uncertainties should be identified briefly (Clapton et al. (2009). Relevant stakeholders (beneficiaries of benefits at risk) and/or experts on the topic/question can be mentioned.

We propose that five methods of evidence-extraction exist:

1. Scientific experimentation
2. Meta-analysis
3. Database analysis
4. Data mining, and
5. Knowledge harvesting.

Scientific experimentation may either collect new primary data through an appropriate sampling method (if budget allows), or directly apply the outputs of an appropriate scientific experiment conducted elsewhere. Please refer to Appendix 1 for more information and case studies.

Meta-analysis of selected completed scientific studies follows the well-documented methodology of the CEBC. In this method, the results or data from a sufficient number of experimental studies, which have generated a mean and a variance, are pooled and analyses statistically. Please refer to Appendix 2 for more information and case studies.

Database analyses involve the analysis of data from existing databases as a source of evidence. The abundance of electronic databases is increasing rapidly, and vast data on land use, water quality, habitat quality (e.g. River Health Programme), water flow and the like become increasingly available. The availability of such databases, combined with rapidly increasing computing power, enable simultaneous analyses of GIS data, water data and economic data, in ways that have not been possible before. Please refer to Appendix 3 for more information and case studies.

Data mining closely relates to database analysis. In this case however, the data is embedded in existing reports. Often, this kind of data is accidental to the hypothesis analysed in the particular review. Examples relevant to aquatic ecosystems include for instance, the scattered data collected by the River Health Programme, the background data to more than 900 EcoClassification projects, the vast amounts of data collected in the Estuaries of Natal and by SANBI in their 2000 assessment of the state of SA's estuaries, or the Global Environmental Facility's set of biodiversity investment reports. Please refer to Appendix 4 for more information and case studies.

Expert knowledge harvesting is much more than expert[10] opinion. Harvesting expert knowledge requires structured methodologies through which implicit, intuitive knowledge of experts is transferred into explicit knowledge. Ginsburg et al. (2010) explain how comparative risk assessment (also see Appendix 5) can be used as a tool to identify, elicit, capture and organize knowledge around the effect of sources of stress on ecosystem service benefits in particular socio-ecological systems. CRA ensures that all available evidence is drawn together with tacit knowledge and relevant opinion. The Reserve determination process, specifically the environmental flow requirement meetings, is another example of harvesting expert knowledge. For example, in 1996 Judge Francois Junod attended a seminal meeting of an instream flow requirements (IFR; now more

[10] An expert is someone "who by virtue of education, training, skill, or experience, is believed to have expertise and specialised knowledge in a particular subject beyond that of the average person, sufficient that others may officially and legally rely upon the witness's specialized (scientific, technical or other) opinion about an evidence or fact issue within the scope of his expertise, referred to as the expert opinion, as an assistance to the fact-finder" (Wikipedia 2011).

widely referred to environmental water requirements) to give opinion of whether the process being used would stand in court. It was his opinion that the days of expert input and deliberation of the IFR would be seen as best available evidence and it would stand up in a court of law. Please refer to Appendix 5 for more information and case studies.

5.4.1. *Searching for evidence*

The determination of the search strategy, including the inclusion and exclusion criteria, and the process of searching online databases and catalogues, organisations and professional networks, and the world-wide web is described in detail in CEBC (2010).

However, because of the expanded set of methods used for evidence extraction, we propose the use of a broader set of inclusion and exclusion criteria[11] than those demonstrated in most current international case studies. These provide the definition of the evidence to be considered in addressing the question being asked. A broader set of inclusion and exclusion criteria will avoid the exclusion of “studies with non-ideal designs for addressing the review question but these excluded studies might still contain useful information" (Gough 2007).

5.4.2. *Selection of relevant data*

This step aims to efficiently select relevant studies from those returned from the search. Inclusion criteria stated *a priori* in the review protocol are used to remove spurious data through two iterative filters such as:

- A first reading of article titles, and if they pass this stage;
- A reading of the abstracts, and if they pass this stage;
- An assessment of the full text.

The process for doing this is described in CEBC (2010). Gough (2007) describes how some inclusion or exclusion criteria might emerge through this assessment based on their “contribution to answering the review question (just as relevance of different types of data might only emerge during the process of some qualitative process studies)" (Gough 2007).

With the inclusion of a wider range of evidence, mapping is a useful tool that can provide a map of available evidence as (1) an important review product in its own right describing the research field and available evidence (e.g. systematic mapping; Clapton et al. 2009) or as (2) a means of guiding the systematic review further (Gough 2007). 'Keywording' (or coding) is a process used to describe and categorise studies included in a review, and to ensure relevance and map search results after screening (Clapton et al. 2009). It is worthwhile as it provides a systematic way of describing and considering what the evidence covers (i.e. the state of the evidence) and it can include a rapid assessment of a paper’s quality as evidence (Clapton et al. 2009). It is useful in:

- **Deciding what sort of systematic review to do:** Keywording (or coding) enables the studies to be described in a manner that will facilitate discussion early on and can help to identify pools of research which might be used to devise questions that the review can address

[11] Personal communication – Prof Andrew Pullin: “This is always an option in CEE reviews. The decision is made by the review team.”

(Clapton et al. 2009, CEBC 2010). This is helpful in the first Phase of extracting evidence (e.g. in a pilot review or knowledge mapping[12] stage) to decide what sort of systematic review can be done.

- **Finding relevant evidence:** Keywording is also important to extracting relevant papers. Keywords are the inclusion and exclusion criteria used in the process of searching for evidence and arise from the research question. They are defined early on in the development of a review protocol as they guide the search strings that are used in searching for evidence and will screen literature that is returned from searches to ensure the relevance of the literature to the research question.

Therefore, regardless of what type of systematic review to be used, a generic keywording of all references and/or data should be undertaken to characterize the evidence available. The keywords to be used should be specified in the review protocol. The SCIE systematic mapping guidance document provides a generic keywording tool and guidance on developing ones specific to review questions (Clapton et al. 2009).

It is possible to at first include a wider group of designs and then to use mapping as an opportunity of examining the whole field of research and subsequently identify pools of research that may be used to narrow down a review question (Gough 2007, CEBC 2010). But Gough (2007) suggests it is not necessarily required to narrow the review. "An alternative strategy is to include a wide group of designs all the way through to the synthesis but to use methods of quality and relevance to deal with this heterogeneity" (Gough 2007). This is a preferred strategy in E-BASES, where the emphasis placed in the selection of relevant data, is less on the research design of the search results and more on the relevance to the review question.

5.4.3. *Data extraction*

Here, best practices for each of the methods of evidence-extraction have to be applied.

Although the scientific foundations for such best practices are well established, much scope exists to develop guidelines in support of best practices. It is not the intention of this report to provide guidelines for such best practices; however, we do demonstrate how the methods work, at the hand of selected case studies.

5.4.4. *Data synthesis*

This stage involves the aggregation, integration and interpretation of all evidence being considered to answer the review question (Gough 2007). There are several approaches to the systematic synthesis of different types of evidence. Different methods for synthesizing research have "different implications for quality and relevance criteria" (Gough 2007).

Meta-analysis is the 'gold standard' of scientific evidence, but as Gough (2007) points out, meta-analysis refers to the synthesis of data although it is most regularly assumed to refer to the statistical

[12] It is not always necessary to do a pilot review or knowledge map to decide what sort of review will be possible –this can be surmised by experts if time and resources are limited.

meta-analysis of quantitative data. In fact that is only one type of meta-analysis. CEBC (2010) describe two forms of synthesis, quantitative (most commonly in the form of a statistical meta-analysis of quantitative data) and narrative (or qualitative) synthesis.

Statistical meta-analysis is now commonly used in ecological studies and thus is only briefly described in CEBC (2010). There are different forms of narrative synthesis “which may aim to synthesize facts or conceptual understandings (as in meta ethnography) or both empirical and conceptual as in some mixed methods reviews (Harden and Thomas 2005)” (Gough 2007). Popay et al. (2006) provide a useful guide in conducting narrative synthesis. “A narrative synthesis is often viewed as inferior to a quantitative synthesis and this may be true in terms of application of analytical rigour and statistical power but narrative synthesis has advantages when dealing with broader questions and disparate outcomes” and “some form of narrative synthesis can be valuable in any SR, simply to present the context and overview of the evidence” (CEBC 2010).

Finally, there are established methodologies for synthesizing different types of studies. A SR may contain more than one of these approaches (e.g. Oliver et al. 2005, Davies and Pullin 2006, Bowler et al. 2010):

- Quantitative experimental studies can also be combined with qualitative or non-experimental research using qualitative analysis methods (Oliver et al. (2005) or Bayesian methods (Roberts et al. 2002).
- Expert opinion can be synthesized with quantitative or qualitative studies, e.g. using Bayesian methods (REF)

If a wider range of research designs are included for consideration, such as what we propose, “then there are issues about the relative extent that the designs of each of these studies are of sufficient fitness for purpose to be included in the synthesis in a full or weighted form” (Gough 2007).

5.4.5. *Quality assessment*

“Knowledge use and production is complex and so also are attempts to judge its quality” (Gough 2007). The formal process of systematic review requires judgements of the quality and relevance of the evidence considered (CEBC 2010). This “requires a number of subjective decisions about the relative importance of different sources of bias and data quality elements specific to environmental data, particularly the appropriateness of variable temporal and spatial scales. It is therefore vital that the assessment process be standardized and as transparent and repeatable as possible” (CEBC 2010).

The assessment of quality and relevance happens in different ways throughout the review process[13] (Gough 2007). It refers not only to the quality of the methodology of studies selected, but also to the quality of other judgements in the review process such as inclusion criteria and search strategies or the type of review (quantitative and/or qualitative synthesis) and to the review process as a whole (Gough 2007, Clapton et al. 2009).

Clapton et al. (2009) use the term *quality assurance* to refer to the quality (rigour and transparency) of the entire review process, not to the quality of the individual literature records retrieved. Quality assurance is key to transparency, quality and utility of a SR. To maintain transparency and consistency it is recommended that "logs of decisions – around topic definition, search strategies, inclusion criteria, etc. – are taken throughout the process, as this will be indispensable when reviewing rationale and writing up methodology" (Clapton et al. 2009). The project team should discuss results of the quality assurance throughout.

In the South African context, the standard for quality assessment is set by the South African Statistical Quality Assessment Framework (SASQAF) developed by Statistics South Africa (Stats SA) (Stats SA 2008). This offers one of several tools available (in addition the broad guidelines developed by the CEBC (2010)) to critically analyse data quality. Methodological steps of assessing the quality of qualitative or non-experimental research have been described in Harden et al. (2001, 2004) and are summarized in Harden (2006).

Box 3. South African Statistical Quality Assessment Framework (SASQAF)

The main purpose of SASQAF is to provide flexible structure for the assessment of statistical products. According to the SASQAF, data quality is defined in terms of the eight dimensions of quality, namely, relevance, accuracy, timeliness, accessibility, interpretability, coherence, methodological soundness and integrity. Adherence to these quality requirements determines the level of these national statistics (Stats SA 2008). These levels are:

- Level Four: Quality Statistics. These are statistics that adhere to all the quality requirements set out by SASQAF. They are designated as quality statistics and deductions can be made from them.
- Level Three: Acceptable Statistics. These are statistics that meet most of the quality requirements set out by SASQAF. They are designated as acceptable and despite their limitations, deductions can be made from them.
- Level Two: Questionable Statistics. These statistics meet few of the quality requirements as stipulated by SASQAF. They are designated as questionable as only very limited deductions can be made from them.
- Level One: Poor Statistics: These are statistics that meet almost none of the quality requirements set out by SASQAF. They are designated as poor as no deductions can be made from them.

Using this framework, researchers will be able to assess the quality of data in a practical way.

[13] "The subjective decisions may be a focus of criticism; thus, we advocate consultation with the scientific community and relevant stakeholders before moving on to data extraction" (CEBC 2010). However, sometimes it is only after data extraction that there is "data extraction that there is sufficient information available to make the assessment" (Gough 2007). "In other cases, the quality and relevance assessment can only occur later in the process because they occur at the same time as synthesis", such as in a sensitivity analysis or in "some of the more interpretative types of synthesis (for example in Realist Synthesis, Pawson 2006)" (Gough 2007).

Weight-of-evidence frameworks might be useful here where we are essentially using different types of evidence with varying quality as circumstantial evidence towards corroborating a particular review question (hypothesis).

Judgements of the quality of evidence can be according to “generic judgments of evidence quality according to generally accepted criteria (within that approach to evidence)”, or “review specific evaluations based on the fitness for purpose of the review” (Gough 2007). A study could be perfectly executed in terms of quantitative experimental design for instance, but it is have only partial relevance to the review question. Or in another case, a study may not be very well executed (show certain types of bias) but it does help to answer the review question. Distinguishing between these two avoids confusion not always evident in other schemas (Gough 2007).

Gough (2007) provides a Weight of Evidence[14] framework that “allows the reviewer to make explicit decisions on these two separate dimensions of quality of execution and appropriateness of design to answer the review question”. Weighting allows reviewers to “employ a broader question and thus broader inclusion criteria in the knowledge that weighted judgements can be applied to the broader range of evidence identified... the purpose is to make the judgements more transparent so that they can be considered and debated by all" (Gough 2007).

CEBC (2010) also suggest a “pragmatic grouping of studies into high, medium and low quality based on simple but discriminatory checklists of “desirable” study features may be necessary if sample sizes are small and do not allow investigation of all the study features individually”.

5.5. Reporting conduct and results

As described in CEBC (2010), transparency and open access are key in an evidence-based framework. High standards of reporting are achieved through explicit capturing of the review process and peer review and expert scrutiny of reports. The same requirements are applied to a broader range of evidence. Examples of the wider acceptance of for instance local expert and generalist knowledge in scientific research are provided in Chalmers and Fabricius (2007) and Nel et al. (2004).

5.5.1. *Interpretation of SR evidence*

The guidelines given in CEBC (2010) on the interpretation of SR evidence and the biases that can occur in the SR process, which may affect the conclusions drawn from the SR are applicable to the wider range of evidence incorporated.

In systematic reviews of a wider range of evidence for ecosystem service production functions we realise that there is complexity. We therefore are looking rather for improved understanding of how the system works by being transparent, integrating different types of evidence (such as expert opinion) and encapsulating best available evidence. This is likely to be particularly important when

[14] “Weight of evidence is a concept used in several fields (including law and statistics) referring to the preponderance of evidence to inform decision making” (Gough 2007).

traversing disciplines (ecological and social) and because much sociological research gathers and presents data differently from the approach in ecology.

There are several types of bias that might impact on review results – reviewed by Borenstein et al. (2009). These should be discussed in relation to the confidence that this might place on how this might affect decision-making.

5.5.2. *Reporting conclusions*

"SRs are conducted to assess available evidence of effectiveness or of impact. In doing so, SRs assess the strength of a causal inference (Hill 1971). Aspects of effectiveness that may be reported in the conclusion section include:

1. The quality of the included studies
2. The size and significance of the observed effects
3. The consistency of the effects across studies or sites and the extent to which this can be explained by other variables (effect modifiers)
4. The clarity of the relationship between the intensity of the intervention and the outcome
5. The existence of any indirect evidence that supports or refutes the inference
6. The lack of other plausible competing explanations of the observed effects (bias or confounding)

There are a range of approaches to grading the strength of evidence presented in health-related reviews but there is no universal approach (Higgins & Green 2009). We suggest that authors of ecological reviews explicitly state weaknesses associated with each of the aspects above, but the overall impact they make on conclusions can only be considered subjectively" (CEBC 2010).

5.5.3. *Implications for policy, practice and research*

"They key objective of SR is to inform decision-makers of the implications of the best available evidence relating to a question of concern, and enable them to integrate this evidence with their own (and others') personal experience of the context, in order to make a decision on the best course of action." (CEBC 2010). In the context of SES's this will inevitably require data and information gathered about the social subsystem and its linkages to the ecological subsystem.

Reporting conclusions with implications for policy and practice as well as implications for research is therefore important.

5.6. Depositing and disseminating outcomes

5.6.1. *Make review publicly available*

CEEBC has a website and database on reviews but in Southern Africa, the WRC Knowledge Hub is an accessible 'location' and resource that could be developed to host a database of systematic reviews.

5.6.2. *Short summary, briefs and guidance notes*

CEBC requires that reviews be summarized in a few pages with key messages for policy and practice implications. Also with guidance on how the review outcomes can be used and interpreted. These briefs and guidance notes would provide WRC research managers with recommendations on how to capture evidence, identified research gaps.

5.6.3. *Archives*

CEBC stresses the importance of accessible and comprehensive archives that facilitate learning over time, accessibility to data, etc.

However it is important to note that data accessibility from researchers in the ecological field is often a contentious issue but it is important to develop the culture and expectation of data accessibility, particularly when the research was publicly funded.

5.7. Summary of resources

A summary of the resources available to the reviewer at each step is provided in Box 4.

Box 4. Summary of resources

Guidelines for systematic review in general

- The Collaboration for Environmental Evidence http://www.environmentalevidence.org/Authors.htm

Need for evidence and initial logistics

Determining which type of review to conduct:

- References on the approaches to reviewing including determining user involvement, different types of review and methodological and other challenges in systematic reviews in social sciences are available on the EPPI-Centre website (EPPI-Centre 2007).

Planning the review

Review team and scoping:

- References on review team and advisory groups, and setting the scope for systematic reviews in social sciences are available on the EPPI-Centre website (EPPI-Centre 2007).

Developing a review protocol:

- Guidance on developing a review protocol is available from the Collaboration for Environmental Evidence website, (www.environmentalevidence.org/Authors.htm), and examples of review protocols are available in the Environmental Evidence Library (www.environmentalevidence.org/Library.htm).
- References on methods for a review, administrative systems and assuring quality in systematic reviews in social sciences are available on the EPPI-Centre website (EPPI-Centre 2007).

Project management:

- EPPI-Centre (2011) offers a web-based tool called EPPI-Reviewer, which enables researchers to manage the whole lifecycle of a review in a single location.

Conducting the review

Gathering and describing research:

- References on searching for studies, screening and describing studies, and mapping and refining scope in systematic reviews in social sciences are available on the EPPI-Centre website (EPPI-Centre 2007).
- EPPI-Centre (2011) also offers a ***Data Management Tool*** for downloading, storing and managing information on studies used in reviews.

Keywording/data extraction:

- Guidelines and tools for outlining the types of information needed to synthesise primary research effectively in social sciences as well as a ***Keywording Sheet*** are available on the EPPI-Centre website (EPPI-Centre 2011).

Appraising and synthesising data:

- CEE has several methods groups including statistical methods, narrative synthesis, search techniques, and systematic mapping – http://www.environmentalevidence.org/Mgroups.html
- Assessing quality – South African Statistical Quality Assessment Framework (SASQAF) developed by Statistics South Africa (Stats SA) (Stats SA 2008)
- References on quality and relevance appraisal, synthesising study findings, conclusions and recommendations, and developing the final report of systematic reviews in social sciences are available on the EPPI-Centre website (EPPI-Centre 2007).
- EPPI-Centre (2011) offers an online tool called ***CCEMG*** – ***EPPI-Centre Cost Converter***, which assists with currency conversion.

Reporting conduct and results

Making use of the review:

- References on communication, interpretation and application, and updating systematic reviews in social sciences are available on the EPPI-Centre website (EPPI-Centre 2007).

Depositing and disseminating outcomes

Databases:

- CEE has an Environmental Library at http://www.environmentalevidence.org/Reviews.htm
- EPPI-Centre (2011) supports an Evidence Library and a number of databases that contain primary research studies and evidence reviews on social sciences.

6. Recommendations

The proposed SRBRP can benefit significantly from the large body of evidence currently available through the WRC Knowledge Hub. This body of evidence can primarily be accessed through evidence extraction methods such as experimentation and harvesting of expert knowledge. The WRC Knowledge Hub currently does not lend itself to meta-analyses, database analysis and data mining as much as it could. However, scope does exist for the WRC Knowledge Hub to become a more effective source of scientific evidence, especially through the evidence extraction methods of database analysis and data mining. This can be achieved through improved archiving of raw data.

Research reports generally present the results of the analysis of the data collected during a project. Current WRC policy is to have raw data from projects archived by the researchers on the understanding that if it is required in the future then people needing the raw data know who to contact to obtain this data. We recommend that the raw data behind projects are made more readily accessible to future researchers. There are several ways in which this may be done. The simplest would be to include a CD / DVD of the unmoderated data in the report. Another way would be to have it on a database curated by the WRC. The location of the data should be recorded as an agenda item during the final review committee meeting.

Following from the above, the key-wording search capability of the WRC Knowledge Hub search engine can be further expanded. This can be done through inclusion of selected keywords denoting reports for which certain information key to extraction for evidence-based analysis, such as a CD / DVD with the raw data, can be identified.

A key finding of this report is that evidence relating to cause and effect relationships in complex systems, may in many instances be incidental to the study objectives of the reports or databases that provide the evidence. This is demonstrated for instance through a case study which extracts project information from Global Environmental Facility (GEF) reports and finds statistical relations between occurrence of red data species and the level of project investment. This is an important learning point for the WRC, as most WRC-funded research work likely deliver evidence of some kind, which may be of use in future studies. The most effective way of managing such evidence is for the WRC to remain aware of the emergence of such evidence and to preserve all data generated.

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8. Appendix 1: Case studies demonstrating evidence extraction methods

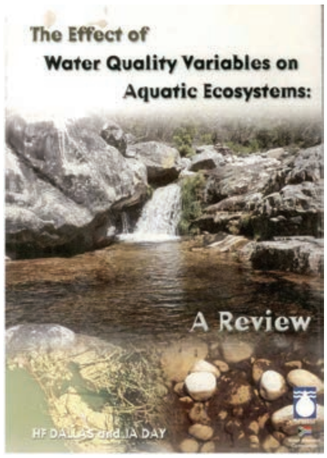
Case 1: Experimentation – A seminal piece of work – single study/review

A seminal piece of work representing the consolidation of research and expertise, done by highly regarded and experienced researchers can be used on its own as evidence, very much in the same way as an expert witness is brought in to give expert testimonial in a court case.

The expertise of the researcher or expert in question on its own gives credence to their findings, constitutes best available evidence in the absence of other studies or when there are limited time and resources for further investigation.

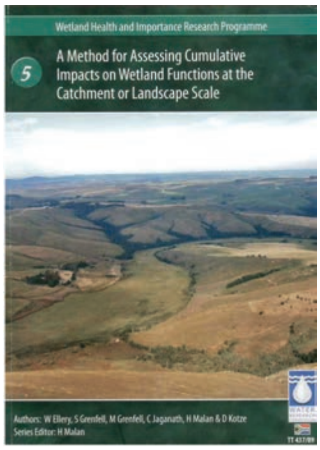
The WRC reports by Dallas and Day (2004) and Malan and Day (2002) on water quality variables and their effect on aquatic ecosystems are examples. Comparing this study against the five guiding principles distilled in section 5, one can conclude that the studies are:

1. Highly relevant and significant questions relevant to reserve determination studies are posed, and that can be empirically tested; and
2. Links research to relevant theory through extensive literature review and development of numerical models.



Another example is the Ellery et al. 2011 report as part of the WHIRP series. It represents the only of its kind linking wetland function change to change in ecosystem service delivery. Comparing it against the five guiding principles, one can conclude that the work:

1. Poses very significant questions that can be empirically tested if the data are available;
2. However, it is less comprehensive in linking the research to relevant theory. It is poorly referenced so one cannot explore the relationships analysed.
3. Not all data are disclosed and without proper referencing or discussion of how they developed some of their production functions, and limited disclosure about assumptions, it is hard to apply the findings in other studies.



Case 2: Meta-analysis

This appendix takes an example from the CEE library of a meta-analysis on *The importance of nature for health: is there a specific benefit of contact with green space?* By Bowler et al. (2010).

“There is increasing interest in the potential role of the natural environment in human health and well-being. Natural environments could impact on health through a number of pathways, either acting directly on health and therefore having a specific benefit, or acting indirectly, for instance, by promoting health-enhancing behaviour such as participation in physical activity. Despite the discussion on this topic, the evidence for there being a specific and direct benefit from contact with the natural environment has not been systematically reviewed.

There is some evidence that activity in a natural environment compared to a different environment can have a positive impact on mental well-being. However, this is primarily drawn from short-term tests on self-reported feelings such as ‘anger/aggression’, ‘sadness/depression’ and 'fatigue/tiredness’. The validity of these psychological scores as measures of mental well-being is not clear. There is little evidence of an impact on physiological outcomes but this is limited by the low number of studies available which measured similar outcomes. There was insufficient data to allow comparison of differences types of exposure to nature. Clearly, a ‘natural environment’ has many components. It is likely that further investigation on this topic and the design of more appropriate studies would be aided by refining the hypotheses on how specifically nature might impact on health and which specific attributes are the most important.

Thus the assessment concludes that the evidence is suggestive that nature may be used within the context of public health promotion interventions but we require a more comprehensive evidence-base in order to make appropriate and effective use of natural resources.

This example illustrates how every principle and aspect thereof is met by this study:

1. It is relevant and can be empirically tested;
2. It is well grounded in relevant theory;
3. It meets principle 3 in full, explicit about assumptions;
4. There is a clear line of reasoning; and
5. It meets principle 5, as it is explicit, available online.

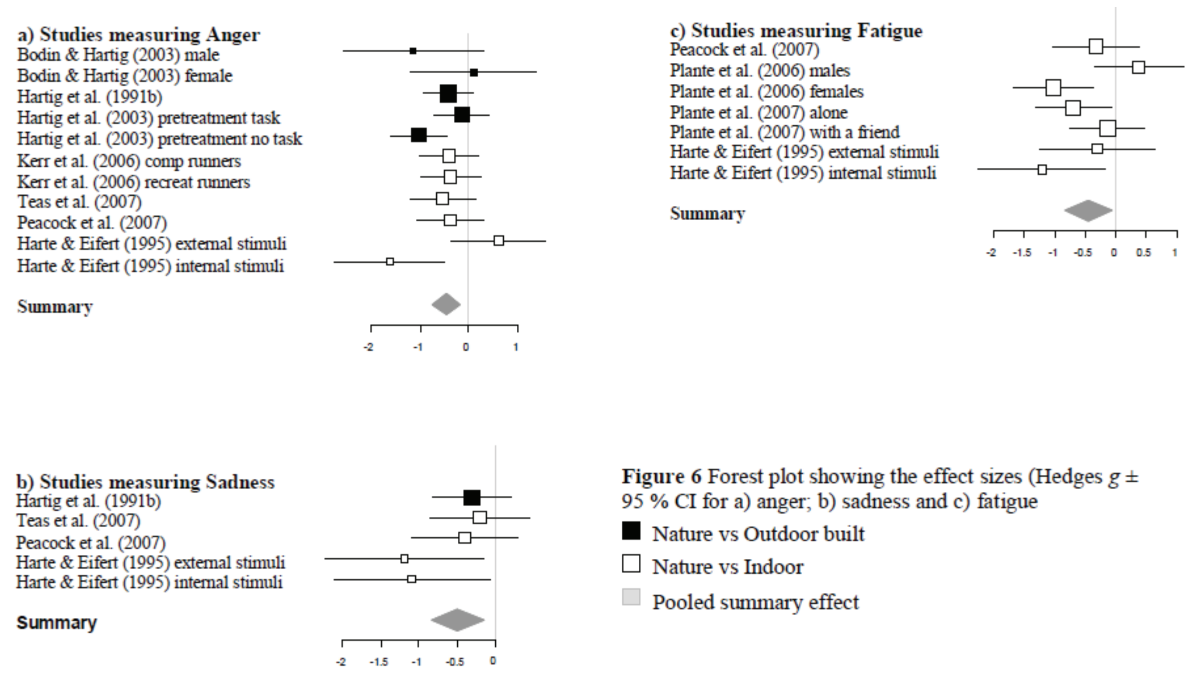


Figure 7. Forest plot showing the effect sizes (taken from Bowler et al. 2010)

Case 3: Database extraction

A key finding of this report is that evidence relating to cause and effect relationships in complex systems may in many instances be incidental to the study objectives of the database(s) that provide the evidence.

An example of database extraction is demonstrated by Crafford (2011). In this study, the effect of nutrient levels on marine productivity is investigated as part of a system of production functions off the KwaZulu-Natal coast. In the absence of direct measures of marine productivity (S_t) a time series of fish egg abundance collected by Dr Allan Connell over the period 1987-present, was used. The data consisted of two decades of records, in 215 separate species data sheets, of eggs and early larvae of fishes spawning pelagic eggs on the inshore shelf, within 5km of the coast, along a short section of the KwaZulu-Natal coastline, about 50km south of Durban. Annual spawning period, and egg abundance trends were provided, as well as egg and larval descriptions. The primary collection purpose was of taxonomical nature and the study resulted from concern regarding the effects of effluent discharges into the marine environment, on the early life stages of marine fishes with pelagic eggs. (Source: www.fisheggsandlarvae.com)

The number of eggs and larvae collected in each sample was extracted from the database and used as a measure of biomass abundance (S_t). Nutrient contribution into the system studied here originates mainly from terrestrial sources. It is deposited into the system during rainfall events when runoff from land washes nutrients into the estuarine and marine components of the system under study. Thus Mean Annual Runoff (MAR) was used a measure of nutrient contribution. The MAR record of the Mkomazi River, provided from a database of the Department of Water Affairs provided an adequate set of data for the purposes of this study.

Egg and larvae production is expected to be influenced by MAR in the current year, as nutrient inflow promotes spawning. However, a lagged MAR effect is also expected as fish population size is affected by historical spawning patterns.

The resulting equation is:
$S_t = c_0 + c_1 MAR_t + c_2 MAR_{t-2}$

The modelling results are presented in Table 6 below, and are promising. The results show that nutrient input into the system in the current period, combined with nutrient input into the system in period t-2 explains 77% of the variation in S_t (fish egg and larvae abundance). The lagged effect was consistent with the life cycle characteristics of fish, which reaches spawning maturity after 12-24 months.

When combining these results with the conclusions of other production functions (not reported on here) it provided scientific evidence that fishing effort and catch in period t were dependent upon fishing effort and catch in period t-1 as well as the fish egg and larvae abundance in period t-2 as well as the MAR in t-2 and t-4. This knowledge can greatly assist policymakers in the issuance if fishing permits.

Table 6. Multivariate analysis of data extracted from two different data-bases which provided a key production function in a marine resources study (source: Crafford 2011).

Dependent Variable: EGGS				
Method: Least Squares				
Date: 05/31/10 Time: 21:52				
Sample (adjusted): 4 24				
Included observations: 21 after adjustments				
	Coefficient	Std. Error	t-Statistic	Prob.
MAR_t	0.27982	0.03815	7.33458	0
MAR_{t-2}	0.09215	0.0314	2.93458	0.0085
R-squared	0.7772	Mean dependent var		513.819
Adjusted R-squared	*0.76548*	*S.D. dependent var*		*302.903*
S.E. of regression	146.689	Akaike info criterion		12.9049
Sum squared resid	408837	Schwarz criterion		13.0044
Log likelihood	-133.5	Hannan-Quinn criter.		12.9265
Durbin-Watson stat	2.17507			

Case 4: Data mining

A key finding of this report is that evidence relating to cause and effect relationships in complex systems may in many instances be incidental to the study objectives of the reports that provide the evidence. This method is different from the database extraction method in that the data source is a report rather than a database.

An example of database extraction was proposed to the project team by Prof Charles Perrings of the Arizona State University (personal communication).

The value of some ecosystem assets is difficult to estimate because they are currently under-appreciated and exhibit low revealed preference values. Future knowledge and awareness of the system might reveal higher values. The value of this ecosystem could best be estimated through estimating the cost of establishing a protected area around the special features identified to protect them from local activities. For instance, if the North West Government or SANParks were to put this into the form of a proposal to the Global Environmental Facility (GEF) for funding for the establishment of the protected area and result in the establishment of a reserve with local management rules, this would internalize the local externalities of use. In principle, the resultant valuation would reflect the quasi-option value of the genetic resources protected.

We thus selected 25 biodiversity investment projects of the GEF in Africa. We data-mined the GEF database of conservation planning documents to generate data for use in statistical analyses. The mined data included project information relating to project costs, country, date of start and end and co-financing. We used different measures of biodiversity, such as number of species, endemics, threatened species as dependent variables.

We then performed multivariate analysis on the data:

1. The key question was whether we could estimate a demand function for "biodiversity"
2. We used Total GEF project cost as a dependent variable.
3. We tested various indicators of "biodiversity" and found that the total number of red data species provided the most significant correlation coefficients.
4. We also included the area affected (in hectares) as an independent variable.
5. Finally, we included the value of the GEF Grant as an independent variable.

The data was sparse, and only 6 of the 25 project reports delivered the required data. However, the technique definitely holds promise: the R^2 = 86% was encouraging, and another A key result was that the total number of red data species was significant at a 97% confidence limit. The size of the protected area (Area2) was not significant, which proves that the quality of the ecological system is more important than its size. By holding grant size and area constant, we constructed a demand curve for biodiversity in Africa.

Table 7. Multivariate analysis of data mined from the GEF database on biodiversity protection projects in Africa.

Dependent Variable: **Project investment cost**				
Method: Least Squares				
Date: 04/12/11 Time: 11:33				
Sample (adjusted): 1 20				
Included observations: 6 after adjustments				
	Coefficient	Std. Error	t-Statistic	Prob.
Number of Red data species	0.32965	0.083214	3.961463	0.0287
Size of GEF Grant	1.021261	0.058104	17.57657	0.0004
Size of protected area	-0.01768	0.079015	-0.22374	0.8373
R-squared	0.921968	Mean dependent var		17.21069
Adjusted R-squared	0.869947	S.D. dependent var		0.896362
S.E. of regression	0.323253	Akaike info criterion		0.886093
Sum squared resid	0.313478	Schwarz criterion		0.781972
Log likelihood	3.42E-01	Hannan-Quinn criter.		0.469291
Durbin-Watson stat	0.674958			
Prob(F-statistic)	0.054692			

Case 5: Expert knowledge harvesting

Expert testimonial is often relied upon in court because science in socio-ecological systems (i.e. the real world) needs translation and interpretation. Expert knowledge harvesting is different from expert testimonial as it uses a consensus-based framework or method for harvesting the collective knowledge of a group of experts. We demonstrate two cases below:

EcoClassification

The EcoClassification process towards reserve determination is an example of how expert knowledge is combined with collected data and past research or experience in indices for different aspects of aquatic ecosystems. This method is relatively well-known and also widely applied in ecological reserve determination studies in South Africa.

The Reserve determination process, specifically the environmental flow requirement meetings, is an example of harvesting expert knowledge. For example, in 1996 Judge Francois Junod attended a seminal meeting of an instream flow requirements (IFR; now more widely referred to environmental water requirements) to give opinion of whether the process being used would stand in court. It was his opinion that the days of expert input and deliberation of the IFR would be seen as best available evidence and it would stand up in a court of law.

Comparative Risk Assessment

A second example is expert workshops using comparative risk assessment (CRA). CRA provides a structured way for experts to describe how a change might impact on an ecosystem service in question. It is explicit about assumptions and certainty, can quantify, and help focus other extraction of evidence.

Comparative risk assessment (CRA) is both an analytical process and a methodology for prioritizing complex problems. A recent authoritative publication on this concept is titled Comparative Risk Assessment: Concepts, Problems and Applications (Schütz et al. 2006). The discussion below was adapted from this publication.

Comparative risk assessment is a multi-attribute evaluation procedure which allows for a theoretically sound and structured progression by way of manageable individual steps. For each step (such as structuring the problem, structuring and weighting the attributes, sensitivity analysis) a range of practically tested techniques exist. The strength of the CRA is that it facilitates an explicit examination of assumptions and values and thus aids in a transparent comparative risk evaluation. This approach is therefore eminently suitable for those comparative risk assessment processes in which a variety of evaluators, both experts and other stakeholders take part.

Risk assessment begins with the identification of hazards. Three problem areas are of significance here. Firstly, the degree of evidence required to substantiate a causal link between the causes and effects in question, secondly, the classification of an effect as adverse or undesirable, and thirdly, possible exposure effects. The evaluation of evidence is a substantial problem. Dose-response type assessments are generally applied. In the light of the importance of hazards, exposure assessments are also of considerable significance. Thus the risk characterization brings together the results of the identification of hazards, dose-response assessments, and exposure assessments.

This examination of the data is also a factual prerequisite for comparative analyses. Risk evaluation constitutes the link between the predominantly scientific / technical risk assessment and a socio-politically oriented valuation of risks. A consensus on what are tolerable risks, reached through societal debate, can be the basis for an evaluation of quantifiable risks. Many risks may be unquantifiable, and thus criteria for differentiating (on the basis of scientific expertise) between averting a substantiated danger and precautionary measures often need to be developed.

However, standards of quality for the scientific understanding of risk have yet to be developed.

A benefit of a CRA lies in the comparison of a new development fields (and by inference also complex systems), in the comparison of public risk perceptions for different cases, and in the comparison of cost and benefit effects. Risk assessment is focused on the evaluation of evidence. "This is however where scientific controversy is often found and a comparison of different evidence evaluations, for instance with the use of tried and tested guidelines and categories of evidence, could contribute considerably to the solution of the problem" (Robu 2007). Risk evaluation is generally characterised by four components: (a) the evaluation of intensity, (b) the evaluation of exposure, (c) the evaluation of the vulnerability of beneficiary populations, and (d) the comparative evaluation of the various risks.

Comparative risk assessment, as a combination of scientifically based risk assessments and value judgments, requires the cooperation of experts and societal stakeholders. A challenge to a successful CRA is that experts and general public (civil society) frequently have very different understanding and interpretation of risk. A substantial problem, from the point of view of experts is that the final results of analyses are separated from their principal constraints, methodological uncertainties, and scope, of which the public remains unaware.

Generally, the technical conception of experts is from the public's point of view, extremely narrow and encompasses only a fraction of the aspects and values that the general public – broadly represented by societal stakeholders – consider important to an appraisal of risk. Even the consideration of frequency and loss equivalent, which is derived from the insurance industry, is disputed. Both factors are related by lay people (i.e. those who are not risk experts) individually; in particular, the upper limit of potential damages is seen as an independent issue and is increasingly demanded. In addition, the concept of risk underlying risk assessments usually encompasses only a few of the dimensions of loss, often only loss of life and harm of health, and, in rare cases, loss of prosperity.

CRA thus provides an objective process for prioritizing risks, and therefore the nature and extent of ecosystem effects resulting from development, captured in a risk description for each asset.

The table below provides an example of the output of a CRA where the effects of management scenarios (Sc2b, Sc3 and Sc4) in a river system were rated by various domain experts. The risks were evaluated for aquatic ecosystem services, at three river sites (EWR1, EWR2 and EWR3). The risk categories were rated as very high (VH), high (H), medium (M) and low (L), using the risk rating profile described in Figure 8 below.

Table 8. Typical output of a CRA workshop. This risk table is accompanied by a thoroughly documented set of assumptions and casual effect explanations.

	EWR1			EWR2			EWR3		
Ecosystem services	Sc2b	Sc3	Sc4	Sc2b	Sc3	Sc4	Sc2b	Sc3	Sc4
Water provisioning	L	L	L	L	L	L	L	L	L
Water purification	L	M	H	L	M	H	L	L	L
Subsistence agriculture, medicinal plants	L	L	L	L	L	L	L	L	L
Food (commercial agriculture)	L	L	L	L	L	L	L	L	L
Fibre	L	L	L	L	L	L			
Woodfuel	L	L	L	L	L	L	L	L	L
Fish	L	L	L	L	L	L	L	L	L
Water regulation	L	M	H	L	M	H	L	L	M
Aesthetic value	L	M	M	L	L	L	L	L	M
Recreation	L	L	M	L	L	L	L	L	M
Cultural value	L	L	L	L	L	L	L	L	L
Genetic resources	L	L	L	L	L	L	L	L	L
Erosion regulation	L	M	M	L	M	H	L	L	VH
Natural hazard regulation	L	L	M	L	M	H	L	L	H
Human health	L	M	M	L	L	L	L	M	M

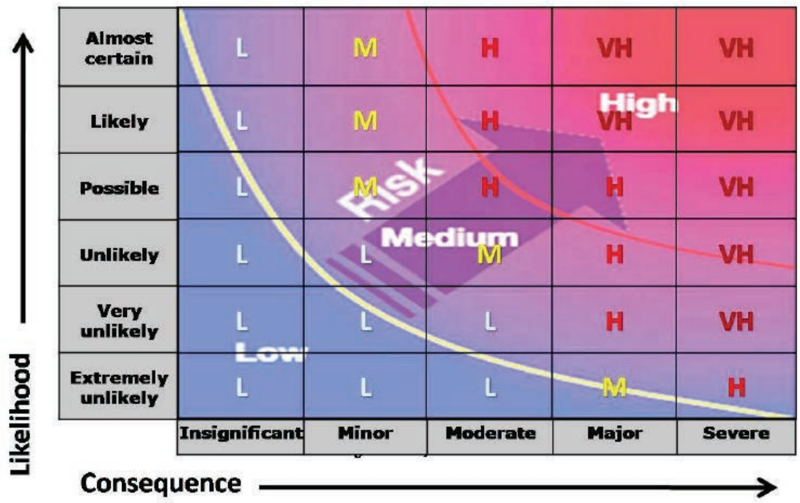


Figure 8. Levels of risk, assessed as the product of likelihood and consequence in the event of an environmental effect on an ecosystem asset (Adapted from Australian/New Zealand Standard on Risk Management (2004)).