WATER RESOURCE PROTECTION: RESEARCH REPORT
A REVIEW OF THE STATE-OF-THE-ART AND RESEARCH AND DEVELOPMENT NEEDS FOR SOUTH AFRICA

Report to the

Water Research Commission

by

K Riemann, DC McGibbon, K Gerstner, S Scheibert, M Hoosain, ER Hay

Umvoto Africa (Pty) Ltd

WRC Report No. 2532/1/17

ISBN 978-1-4312-0879-1

May 2017

Obtainable from

Water Research Commission

Private Bag X03

Gezina, 0031

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

DISCLAIMER

This report has been reviewed by the Water Research Commission (WRC) and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the WRC, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

EXECUTIVE SUMMARY

Water plays a significant role in the economies of the agricultural, business and industrial sectors. Expanding populations, economies and climate change have put pressure on the quality and availability of water resources in South Africa. Water resource protection therefore becomes increasingly important for sustainable water supply management.

Hence, a review of the state-of-the-art of water resource protection in South Africa has been undertaken. Gaps in scientific understanding and implementation regarding water resource protection have been identified through literature review and discussions with stakeholders and experts. Aiming to improve the water resource protection in South Africa, a research strategy has been developed to tackle the most relevant of the identified gaps.

Literature Review

The literature was reviewed with a system of pillars and layers in mind. The three pillars of the various disciplines and human activities significantly affecting water resource quality and quantity are: legislative framework; implementation and management; and scientific complex systems understanding. These pillars are based on the governance framework as defined by Riemann et al. (2016), comprising government, society and science. The pillars are broken into layers that focus on resource-directed measures (RDM) for water resource protection, water use authorisation/source-directed controls (SDC), and land use/land care and its impact on water resource protection, based on the mandate and chapters in the National Water Act (NWA), Act 36 of 1998.

Various issues regarding implementing the NWA have been identified; for example, the classification procedure identified in Chapter 3 of the NWA is not applicable to aquifers; furthermore, once a water resource has been classified, it cannot be reclassified. As a result, changes to water resources because of climate change or usage are not considered regarding classification. The concept of a Groundwater Reserve is not implementable.

The Water Research Commission (WRC) has set out a roadmap for research, development, and innovation (WRC, 2015). The two main focus areas are water supply and water demand. Sub-sections under water supply are improving governance, planning and management; improving performance and infrastructure; managing water as an economical and sustainable business; using more resources and utilising these resources to their full potential. Under water demand, the focus is on improving governance, planning and management; reducing losses of water; and improving pricing, monitoring and metering.

Gap Analysis

The identified gaps in knowledge and understanding of water resource protection processes and implementation of associated regulations for the different water resources can be grouped into several aspects that are common for all or most of the water resources:

- The standard methodology for determining RDM is not applicable to all water resources and is mostly carried out at a scale that is insufficient for effective water resource protection. The methodology must be updated to incorporate potential impacts of climate change, changing land use and changing demographics. The different elements of the RDM methodology need to be aligned.
- The behaviour of emergent contaminants in different water resources and their impact on water resources have not been determined yet. The research programme into emergent contaminants should be expanded in this regard.
- The role of different water resources and their sub-types in catchment functioning is crucial for the complex system understanding that is required for integrated catchment management to be implemented.
- There is an insufficient spatial and temporal distribution of monitoring networks for most water resources. There is no standard regarding *how*, *what* and *where* to monitor and the subsequent process of quality control, data analysis and decision-making.

The identified gaps in knowledge and understanding of water resource protection processes and implementation of associated regulations for the different activities and challenges, impacting on water resources, can be grouped into several aspects that are common for all or most of the activities:

- The responsibility for authorising activities impacting on water resources is often split between several departments; for example, mining activities are authorised by the Department of Mineral Resources and the Department of Water and Sanitation (DWS). In reality, there is no cooperative governance as required for integrated catchment management and water resource protection.
- There are no case studies regarding the success of rehabilitation and remediation actions with respect to complying to RDM limits.
- The diffuse discharge and uncontrolled discharge from a range of land use activities are not regulated and do not have limits or standards determined.
- There is an insufficient spatial and temporal distribution of monitoring networks for most water resources and relevant activities. Hence, compliance and enforcement are lacking. The crucial parameters for monitoring the impact of agricultural, industrial or urban activities need to be determined.

It is important to note that advances in knowledge and systems in one pillar or layer does not necessarily translate into advances in the other pillars or layers. Hence, emphasis should be placed on translating scientific understanding into regulations and implementation strategies. Similarly, advances in complex systems understanding and its meaning for integrated catchment management must feed into updates of the RDM methodology and permit limits on RDM and SDC.

Research Strategy

The objective and strategic intent of follow-up research studies is to build knowledge for:

Enabling water resource protection through integrated catchment management that supports adaptation to climate and socio-economic change.

The gaps identified and their causes were turned into research questions and prioritised according to the following criteria:

- Possible short-term gain by changing implementation (Pillar Society).
- Possible medium-term gain by reviewing and updating legislation/regulations (Pillar Legislation).
- Initiating a structured, longer-term programme to build knowledge (Pillar Science).

The following five research studies or programmes were prioritised:

- Auditing the current status of RDM and SDC implementation and enforcement.
- Establishing “model catchments” on a sub-catchment and catchment scale.
- Implementing awareness campaigns and training programmes for social behaviour changes.
- Rolling out a cooperative governance framework ensuring cooperative governance across all sectors and all tiers of government, and enabling enforcement of compliance with rules and permits.
- Reviewing and updating existing tools and best practice guidelines.

Recommendations

The currently initiated research studies for emerging contaminants and recommended catchment management need to be expanded into research programmes and linked to the research programmes listed below.

The following research studies or programmes should be initiated by the WRC or DWS within the next financial year:

- Doing a detailed audit of the current status of RDM and SDC implementation and enforcement with the aim of highlighting crucial shortcomings not identified yet.
- Initiating the improvement and further establishment of “model catchment” on a catchment scale to study and understand the complex relationships between different water resources and different land use activities.

- Developing and rolling out awareness campaigns and training programmes for social behaviour changes.
- Developing and rolling out a cooperative governance framework ensuring cooperative governance across all sectors and all tiers of government, and enabling enforcement.
- Reviewing and updating existing tools and best practice guidelines.

Further research studies and programmes should be initiated within the next five years. Each research programme should include an implementation or roll-out phase, which then needs to be evaluated regarding the effectiveness of changes towards improved water resource protection. To achieve this, an independent monitoring network and national monitoring programme has to be installed, monitored and evaluated by the DWS and or relevant catchment management agencies.

Table of Contents

1. Introduction 1

1.1 Study Outline 1
1.2 Definitions 1
1.2.1 Water resources 1
1.2.2 Water resource protection 2
1.2.3 Ecosystem health 2
1.2.4 Risks to water resources 2
1.2.5 Land use activities 3

2. Research Methodology 5

2.1 Defining the “Pillars” 5
2.1.1 Government/legislation 5
2.1.2 Society/implementation and management 5
2.1.3 Complex scientific systems understanding 6
2.2 Defining the “Layers” 6
2.2.1 Integrated catchment management (ICM) 6
2.2.2 RDM 6
2.2.3 Water use authorisation/SDC 6
2.2.4 Monitoring and enforcement 6
2.3 Literature Review 7
2.4 Stakeholder Engagement 7

3. Literature Review 8

3.1 Legislative 8
3.1.1 NWA 8
3.1.2 NEMA 9
3.1.3 Disaster Management Act 9
3.2 Implementation of Legislation 10
3.3 Scientific 10
3.3.1 National 10
3.3.2 International 12
3.4 Summary 12

4. Research Gap Analysis 13

4.1 Water Resource Specific 13
4.1.1 Perennial surface water 13
4.1.2 Non-perennial surface water 13
4.1.3 Wetlands 14
4.1.4 Estuaries 15
4.1.5 Groundwater 17
4.1.6 Near-shore marine environment 17
4.2 Activity/Challenge Specific 18
4.2.1 Urbanisation 19
4.2.2 Agriculture 19
4.2.3 Mining and industry 20
4.2.4 Climate change 21
4.3 ICM 22

4.4 Summary of Gap Analysis 23
4.4.1 Water resource specific 23
4.4.2 Activity/challenge specific 24
4.4.3 Linkage between pillars and layers 25

5. Research Strategy **26**

5.1 State-of-the-art Legislation 26
5.2 Aim and Objective 26
5.3 Cause-effect Analysis 26
5.3.1 RDM implementation 26
5.3.2 Monitoring and enforcement 27
5.3.3 ICM 28
5.4 Prioritisation 29

6. Recommendations **31**

7. Bibliography **32**

List of Tables

Table 1: Selected topics for online discussion forum 7
Table 2: Responsibilities of different government departments for various activities that could impact on the water resource integrity 10
Table 3: Research gaps for protection of perennial rivers and streams 13
Table 4: Research gaps for protection of non-perennial rivers and streams 14
Table 5: Research gaps for protection of wetlands 14
Table 6: Research gaps for protection of estuaries 16
Table 7: Research gaps for groundwater protection 17
Table 8: Research gaps for protection of near-shore marine environment 18
Table 9: Research gaps for protection of water resources regarding urbanisation 19
Table 10: Research gaps for protection of water resources regarding agricultural activities 19
Table 11: Research gaps for protection of water resources regarding mining and industrial activities 21
Table 12: Research gaps for protection of water resources due to climate change 21
Table 13: Research gaps for protection of water resources in the context of ICM and integrated water resources management 22
Table 14: Common research gaps for water resource protection across different water resources 24
Table 15: Research gaps for protection of water resources across different activities 24

List of Figures

Figure 1: Water cycle, indicating water resources and their interaction (Owens, 2006) 2
Figure 2: Example of land use activities that could negatively affect water resource integrity in a catchment landscape (Water Sanitation Program, 2016) 3
Figure 3: Urban impacts on water resources (Schreier, 2015) 4
Figure 4: Governance framework, using the Trialogue approach (Turton et al., 2006) 5
Figure 5: Review framework of pillars and layers related to water resource protection 6
Figure 6: Split of research funded by the WRC between KSAs and water resources 11
Figure 7: Split of research on water resource protection between pillars and layers; a) for the years 2011 to 2016, b) for the financial year 2014/2015 12
Figure 8: Examples of wetland types (Olis et al., 2013) 15
Figure 9: Variety of selected upstream impacts on estuaries (Teachoceanscience, 2016) 16
Figure 10: Possible impacts on near-shore marine environment (Heyvaert, 2013) 18
Figure 11: Agricultural management strategies to support water resource protection (Sharpley, 2016) 20
Figure 12: Climate change impacts and mitigation (Munang et al., 2013) 22
Figure 13: Variety of land use impacts on water resources (The University of British Columbia, 2016) 23
Figure 14: Cause-effect analysis for the lack of RDM implementation 27
Figure 15: Cause-effect analysis for the lack of enforcement 28
Figure 16: Cause-effect analysis for ICM 29

List of Abbreviations

RDM	Resource-directed Measures
SDC	Source-directed Controls
NWA	National Water Act
WRC	Water Research Commission
DWS	Department of Water and Sanitation
NEMA	National Environmental Management Act
ICM	Integrated Catchment Management
CME	Compliance, Monitoring and Enforcement
NWRS	National Water Resource Strategy
CMA	Catchment Management Agencies
SEMA	Specific Environmental Management Acts
ICMA	Integrated Coastal Management Act
KSA	Key Strategic Area
RQO	Resource Quality Objectives
RDP	Reconstruction and Development Programme
DWA	Department of Water Affairs

1. INTRODUCTION

Water plays a significant role in the economies of the agricultural, business and industrial sectors. Expanding populations, economies and climate change have put pressure on the quality and availability of water resources in South Africa, therefore, water resource protection becomes increasingly important for sustainable water supply management.

1.1 Study Outline

Umvoto Africa (Pty) Ltd was appointed by the Water Research Commission (WRC) in April 2016 to undertake a research study on *Water resource protection: A review of the state-of-the-art and research and development needs for South Africa*.

The aims of the project were:

- To review current legislation, regulations, implementation strategies and academic research with respect to water resource protection.
- To identify gaps in legislation, implementation and or knowledge for improved water resource protection.
- To develop a research strategy for future studies into the identified research gaps with emphasis on incipient threats to water resources (quality and quantity).

The project comprised three phases; namely, a literature review and initial gap analysis, a detailed gap analysis, and a research strategy.

Gaps in scientific understanding and implementation regarding water resource protection have been identified through a literature review and discussions with stakeholders and experts. Aiming to improve the water resource protection in South Africa, a research strategy has been developed to tackle the most relevant of the identified gaps.

Although the literature review (Deliverable 1) and the gap analysis (Deliverable 2) have been reported separately, this report summarises the findings from these two tasks and then presents the research strategy. The report comprises:

- Relevant definitions in Section 1.2.
- Outline of the research methodology for the literature review and gap analysis in Section 2.
- Findings from the literature review on legislative issues and scientific studies in Section 3.
- Summary of the research gap analysis in Section 4.
- Outline of the research strategy as final product of the study in Section 5.

1.2 Definitions

1.2.1 Water resources

The water resources focused on during the study include water courses as defined in the National Water Act (NWA), Act 36 of 1998 (see Figure 1), namely:

- Surface water (perennial and ephemeral).
- Wetlands.
- Estuaries.
- Aquifers.

Water resources also include the near-shore marine environment.[1] The off-shore marine environment[2] falls outside the scope of work of the study.

1 The area encompassing the transition from subtidal marine habitats to associated upland systems (Centre for Coastal Resources Management, 2016).
2 Area from and beyond subtidal marine habitats.

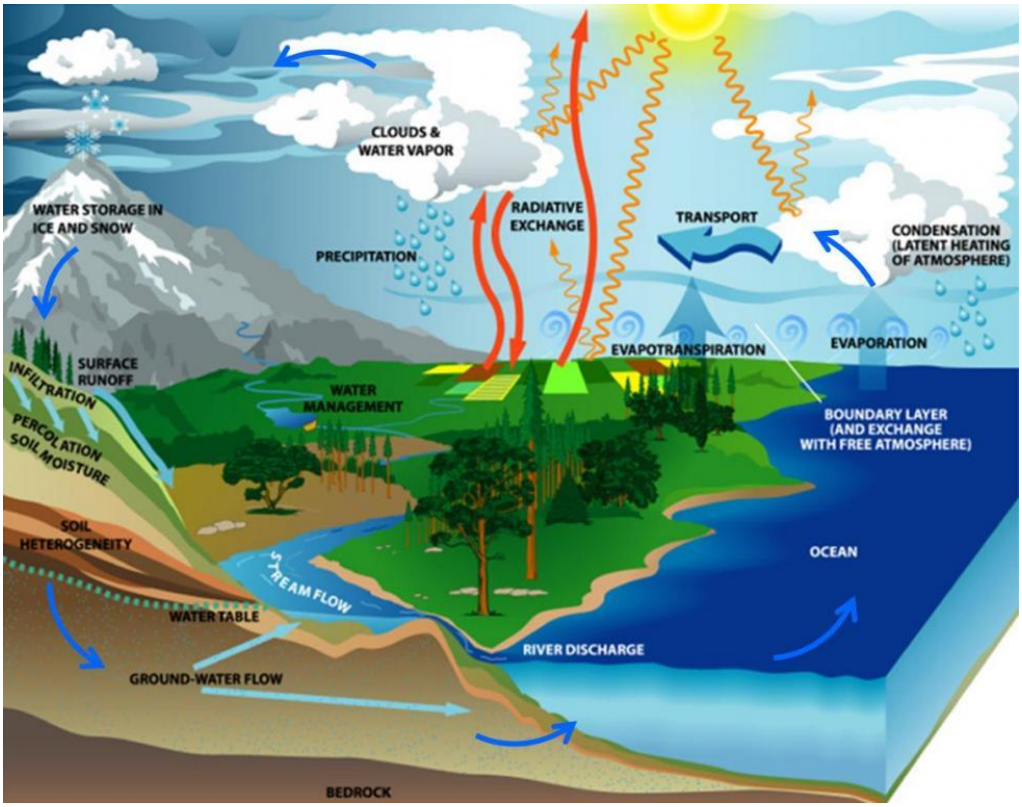


Figure 1: Water cycle, indicating water resources and their interaction (Owens, 2006)

1.2.2 Water resource protection

The NWA (Act 36 of 1998) defines water resource protection as being fundamentally related to the use, development, conservation, management, and control of water resources. The Act divides water resource protection into three sections of different activities and focus points to ensure the comprehensive protection of water resources in South Africa (see Section 3.1.1).

1.2.3 Ecosystem health

A healthy ecosystem is often defined as one not showing signs of illness such as pollution, algae or loss of species. (Rapport et al., 2001). Relevant aspects include flow requirements and water quality.

Flow requirements and future use

Flow requirement is the existing flow of a river to meet the current lawful uses of the water and the requirements of the existing ecosystem. The future use of a water resource needs to consider existing flow requirements as well as future conditions relating to recharge of the resource.

Water quality

Water quality is defined as the physical and biological characteristics of a particular water resource. This is in relation to its particular usage and ecological requirements.

1.2.4 Risks to water resources

The United Nations Office for Disaster Risk Reduction defines “risk” as being the combination of the probability of an event happening and the negative consequences thereof (UNISDR, 2009). Risks in the context of water resource protection include any event or activity that can threaten or have a negative impact on a water resource. Hence, water resource protection should comprise risk management measures to identify and mitigate against these risks. The main risks are summarised in the sub-sections that follow:

Pollution threats

Pollution threats include any form of pollution that decreases the present quality of a water resource thus making it unsuitable as a water resource for human usage and has a negative impact on the ecology of the water resource.

Encroachment

Infrastructure developments close to or encroaching on water courses could threaten the ecological requirements of the water resource and the availability and water quality of the water resources for human consumption.

Overallocation

It is important to allocate the correct quantity of water to the various stakeholders to ensure equity and sustainability in the usage of water resources. However, allocation needs to ensure that aspects of water resource replenishment and ecological requirements are met when making allocations. Overallocation of water resources can result in permanent damage to water resources and hinder meeting future allocation goals.

Climate change

It is also important to consider aspects of climate change and the likelihood of less water resources in the future when making water resource allocations.

1.2.5 Land use activities

A variety of land use activities affect water resources. These activities need to be considered for the protection of water resources (see Figure 2).

Figure 2: Example of land use activities that could negatively affect water resource integrity in a catchment landscape (Water Sanitation Program, 2016)

Based on the extent of possible impacts, involved pollutants and spatial scale of activities and impacts, these land use activities can be grouped into:

- Agriculture.
- Mining and industry.
- Urbanisation.

Agriculture

While agriculture is the biggest water user in South Africa, agricultural activities, such as irrigation and use of fertilisers and pesticides, are a constant threat to the functioning of water resources. This is exacerbated by the diffuse nature of impacts, which are often only detected far downgradient of the sources.

Mining and industry

Mining and large industry are big contributors to the economy. However, they are large water users and are among the biggest polluters of water resources, especially old closed mines where contaminated water decants into surface water ecosystems and further pollutes groundwater resources. Other impacts include mining in wetlands, sand mining in riverbeds, acid rain, emissions, brines and other effluents from industries.

Urbanisation

The growing urbanisation and concentration of possible pollution sources is an ongoing trend that could threaten water resources and human health (see Figure 3) if not managed properly.

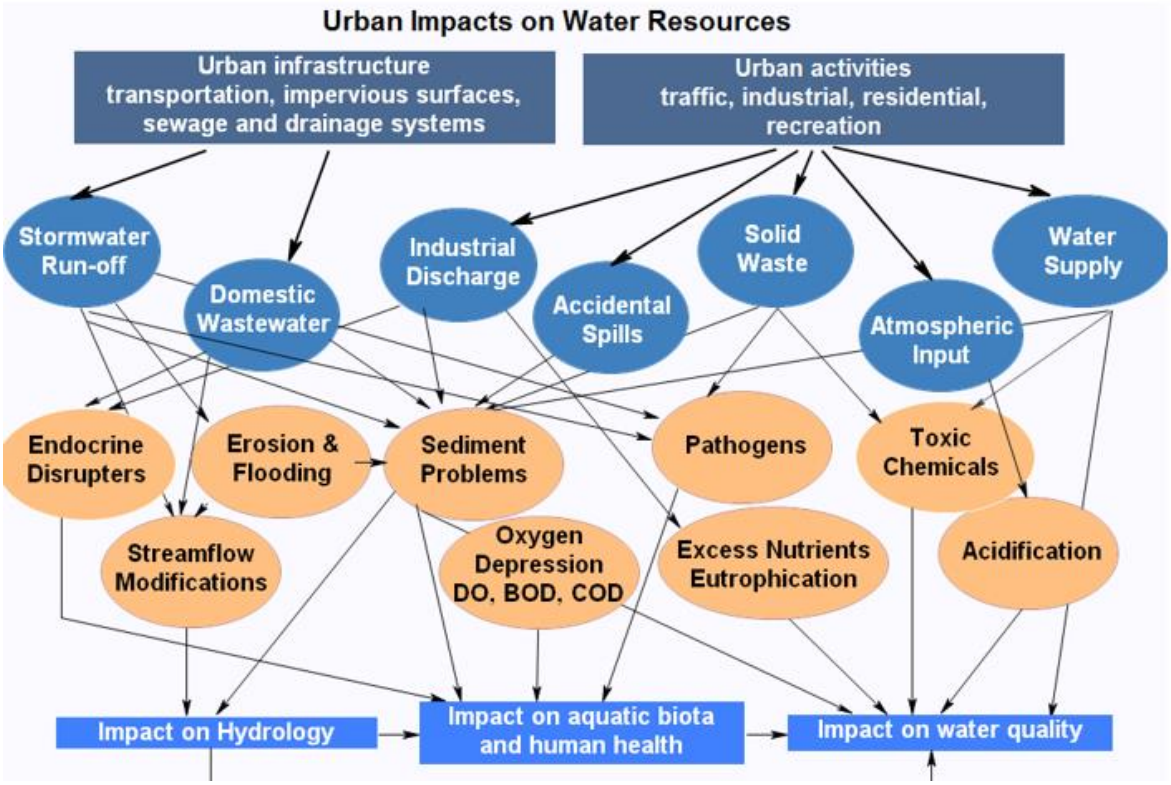


Figure 3: Urban impacts on water resources (Schreier, 2015)

Legend:
DO: Dissolved oxygen
BOD: Biological oxygen demand
COD: Chemical oxygen demand

2. RESEARCH METHODOLOGY

The study commenced with a literature review of current legislation, regulation and governance to identify gaps in water resource protection. In addition, recent reports on water resource protection were reviewed to provide a starting point for identifying gaps in legislation, regulation and governance.

The literature was reviewed with a system of pillars and layers in mind. The three pillars are:

- The legislative framework.
- The implementation of rules and societal interaction.
- The scientific understanding of complex natural systems.

These three pillars are broken into layers, which focus on resource-directed measures (RDM) for water resource protection, water use authorisation or source-directed controls (SDC), and land use/land care and its impact on water resource protection. A fourth overarching layer comprises monitoring and enforcement of activities.

2.1 Defining the "Pillars"

The pillars are based on the governance framework as defined by Riemann et al. (2016) using the Trialogue approach (Turton et al., 2006) comprising government, society and science (see Figure 4).

Figure 4: Governance framework, using the Trialogue approach (Turton et al., 2006)

2.1.1 Government/legislation

The legal framework pillar includes Chapters 2, 3, 4 and 14 of the NWA, Act 36 of 1998, the National Environmental Management Act (NEMA), Act 107 of 1998, associated regulations and relevant national strategies and plans.

2.1.2 Society/implementation and management

The implementation and management pillar focuses on the governance and management aspect of water resource protection, whilst also including societal aspects such as access to water and water allocations.

2.1.3 Complex scientific systems understanding

The scientific pillar focuses on developing scientific and academic knowledge into water resource protection. Identifying knowledge, data, and insight gaps in this pillar can assist with addressing gaps in legislation and management surrounding the implementation of sound water resource protection strategies.

2.2 Defining the "Layers"

The layers are defined by the legislative framework of the NWA and comprise:

- Chapter 2 – Water Management Strategies.
- Chapter 3 – Protection of Water Resources.
- Chapter 4 – Use of Water (Authorisation).
- Chapter 14 – Monitoring.

2.2.1 Integrated catchment management (ICM)

Catchment management and developments are aspects of land use and land care that influence water resource protection. These include areas of agriculture, mining, urban expansion/development, and protected areas.

2.2.2 RDM

Water resource protection is described in the NWA and implemented through RDM, comprising concepts of water resource classification, ecological reserve and resource quality objectives.

2.2.3 Water use authorisation/SDC

This layer focuses on permits, authorisations, and limits for water use, such as licensing of water use under section 21 and section 40 of the NWA, and water quality limits for discharge into the environment.

2.2.4 Monitoring and enforcement

It is crucial to monitor the water resource and possible impacts to understand the complex system and to translate this understanding into actions towards water resource protection. This must comprise both monitoring of regional and ambit conditions, and more local compliance monitoring, using a range of parameters and indicators. The monitoring results must feed into proper data analysis, resource management or operational decisions, and enforcement of regulations and standards. The combined framework is shown in Figure 5.

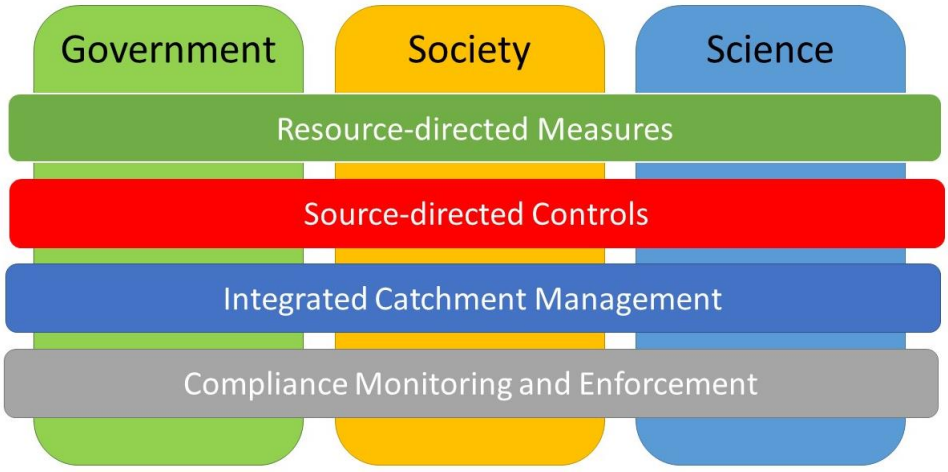


Figure 5: Review framework of pillars and layers related to water resource protection

2.3 Literature Review

A literature review was conducted on the various legislations in South Africa surrounding water resource protection, namely the NWA (Act 34 of 1998), the NEMA (Act 107 of 1998) and the various regulations and guidelines. A review was also conducted on the implementation of these legislations, which are shared between various institutions and involve ecological conservation, land use management, catchment management, urban growth management, water sensitive design, integrated development planning, as well as prompt remedial actions in cases of negative impacts.

Recent studies on water resource protection were reviewed, which specifically focused on governance (control) and management of water resources but not on legislative gaps nor systems understanding gaps, especially emerging threats to sources of water (quality and quantity). The latter would promote proactive protection, informed development and conservation of our water resources.

Based on the literature review, an initial gap analysis was carried out. Various gaps were identified in the review of legislation surrounding water resource protection. These included that the classification procedure does not include aquifers, and does not make provision for climate change. The concept of the "Groundwater Reserve" is also not implementable as the socio-economic impact of this is often not considered and the volume to be reserved cannot be measured. Licensing is also a very drawn-out procedure, which makes access to water resources often very difficult for those who urgently need it. It was also noted that the general authorisation procedure needed to be reviewed, and that there was a lack of experience within the government surrounding water resource protection. There was also a great deal of institutional complexity within the realm of water resource protection. The results of the literature review are summarised in Section 3.

2.4 Stakeholder Engagement

The initially identified research gaps were further discussed with various stakeholders who are experts working in the field of water resource protection or who have in-depth knowledge and understanding of the subject. The engagement was facilitated through an online discussion forum and direct invitations to selected stakeholders to participate. The process was divided into the different layers (RDM, SDC and ICM) and categories related to the different water resources and various threats. Topics and leading questions were provided per layer and category. Stakeholders were invited per category (see Table 1).

Table 1: Selected topics for online discussion forum

Category	Topic/Key Questions
RDM	
Groundwater	• Legislative framework inadequate for groundwater protection
Estuaries/Wetlands	• Scale issue of RDM for wetlands
Rivers	• RDM for ephemeral rivers and water courses
SDC	
Agriculture	• Responsibility for legislating and enforcing agricultural activities and agricultural water use; cooperative governance • Water quality of return flow – best practice, monitoring, enforcement
Urbanisation	• Multiple sources of pollutants, multiple responsibilities – cooperative governance • Contaminants of emerging concern
Mining	• Responsibility for legislating and enforcing mining activities and water use – cooperative governance • Legacy of old mines • Best practice guidelines – do they help to protect water resources?
ICM	
Catchment Management	• Multiple role players – cooperative governance • Understanding interactions between water resources and activities, evaluating impacts, trade-offs

3. LITERATURE REVIEW

3.1 Legislative

3.1.1 NWA

The NWA (Act No. 36 of 1998) is the overarching legislation governing South Africa's water resources. The NWA promotes the development, protection and equitable use of water resources for present and future generations. The Minister of the Department of Water and Sanitation (DWS) is entrusted with the duty of overseeing and managing the implementation of the NWA requirements. The NWA recognises that South Africa is a water-scarce country. The average rainfall is only about 60% of the world average which is distributed unevenly across the country due to factors such as climate, rainfall intensity and soil factors (CSIR, 2010).

Chapter 1 of the NWA sets out guiding principles for all water users. These guiding principles give effect to the purpose of the NWA whilst promoting social and economic development and ensuring sustainable use of water resources. Chapter 2 of the NWA provides for the establishment of a National Water Resource Strategy (NWRS) that will outline the specific objectives, procedures, plans and institutional arrangements relating to the management and control of water resources in various regions of South Africa. The required contents of the NWRS are specified as well as the need for demarcating water management areas. Chapter 2 of the NWA also provides for the establishment of catchment management agencies (CMAs).

Chapter 3 of the NWA provides for the protection of water resources through the conservation, use, development and control of water resources. It also sets out the measures to be taken to prevent the pollution of water resources and to remedy the effects of pollution of water resources. Part 1 of Chapter 3 provides that the Minister may issue a classification system to classify the country's water resources for effective management. The classification system may also list certain water uses for instream and/or land-based activities to protect water resources from degradation. Chapter 3 of the NWA also provides consideration for the "Reserve", which is the quantity and quality of water required to satisfy basic human needs and protect aquatic ecosystems. Under the context of the "Reserve" and section 18 of the NWA, all water resources must be classified. This is the responsibility of the Minister, Director General, and all organs of state.

Section 19 of the NWA addresses the prevention of pollution and remedial interventions for water resources. It provides that any person who owns land on which pollution occurs or undertakes an activity that results in pollution is responsible for remedying the pollution and preventing it from recurring. Such person must take all measures necessary to do so. If the person does not take the necessary steps as set out by the CMA, the CMA may undertake the necessary steps to control the pollution and recover full costs from the responsible person. This is also specified in similar fashion in section 30 of the NEMA (Act 107 of 1998).

Section 20 of the NWA provides for emergency incidents resulting in pollution of a water resource. It defines an emergency incident as being an incident or accident where a substance may, or is likely to result in pollution of a water resource. The responsible person must report the incident to the department (the NWA does not stipulate national or provincial department), the police services or fire department, or the relevant CMA. A verbal directive may be issued to the responsible person, and must be followed up in writing by the department within seven days or it will be deemed to be withdrawn.

Chapter 4 of the NWA focuses on the use and authorisation of water. Water use is defined as the:

- Taking and storing of water.
- Undertaking of any activities that reduce stream flow.
- Discharging and disposing of waste.
- Engaging in controlled activities (activities which impact detrimentally on a water resource).
- Altering a water source.
- Removing groundwater for certain purposes.
- Using water for recreational purposes.

The Minister may limit water allocations and differentiate between water resources when making regulations. Activities reducing stream flow must be declared as such by the Minister and must include land use practices. Controlled activities are listed by section 37 of the Act. The Act allows for the Minister to declare other activities as controlled activities if the need arises. Water use must be licensed, unless specified under schedule 1, is an existing lawful use, is permissible under general authorisation, or if a responsible authority waives the need for a licence. The granting of a licence has conditions attached to it, as well as effective periods. The granting of a licence does not guarantee the availability or quality of the water which it covers. Existing lawful uses of water repealed by the Act may continue, provided that they are not limited, prohibited, or terminated by the Act. A licence for such usage is not required until a person or responsible authority requires a person claiming lawful use to apply for a licence. General authorisations do not require a licence, but may be restricted to a particular water resource, category of persons, defined geographical area, or period of time.

An application for a water use licence must be done through a responsible authority where a licence is required to use water. However, part 8 of Chapter 4 of the NWA lays out the procedure for a responsible authority to undertake compulsory licensing for any aspect of water use in respect of one or more water resources in a specific geographical area. In this case, a general invitation must be sent out to all users of water within the area to apply for a water use licence. Licences must be reviewed within the time frame stipulated on the licence. Contraventions for disobeying licence conditions are laid out in part 10 of Chapter 4 of the Act.

3.1.2 NEMA

The NEMA (Act No. 107 of 1998) is South Africa's primary environmental framework legislation. According to NEMA, the environment includes water, land, all micro-organisms, plants, and animals associated with land and water. The Constitution empowers the Department of Environmental Affairs and the Minister of Environmental Affairs to carry out the functions required by the NEMA.

The NEMA principles in Chapter 1 of the Act specify guidelines that stem from the Constitution and apply to all people and organs of state. The NEMA principles promote equitable use of natural resources, sustainability, and a balanced social, economic and environmental development. The NEMA provides for the administration and enforcement of the Act where necessary. It aims to ensure the proper management of land, agricultural and water resources, especially where new developments are concerned. These functions are delegated to the respective provincial ministers. Existing developments must also adhere to the provisions as set out in the NEMA, as each person has a duty of care towards the environment.

There are five specific environmental management acts (SEMAs) that fall under the auspices of the NEMA. The SEMAs were promulgated so that each address a specific aspect of the environment, namely, air quality, coastal areas, biodiversity, protected areas and waste. Most of the SEMAs have an interest in the protection of water resources, such as the Biodiversity Act (Act No. 10 of 2004), the Protected Areas Act (Act No. 57 of 2003), the Integrated Coastal Management Act (ICMA) (Act No. 24 of 2008), the Air Quality Act (Act No. 39 of 2004) and the Waste Act (Act No. 59 of 2008).

All SEMAs, except for the Air Quality Act, have a significant interest in the protection of water resources. The Biodiversity Act of 2004 supports the conservation of plant and animal biodiversity, as well as the soil and water resources upon which they depend. The Protected Areas Act of 2003 also promotes the conservation of biodiversity, soil and water. The ICMA of 2008 promotes the conservation of estuaries, the coastal landscape, coastal waters, and all ecosystems that rely on them to function optimally. The ICMA also supports the use of natural resources within coastal areas that are sustainable and economically justifiable. The Waste Act of 2008 serves to regulate waste and disposal thereof. It also promotes the reuse of waste and the prevention of pollution, environmental degradation and land contamination.

3.1.3 Disaster Management Act

The Disaster Management Act (Act 57 of 2002) is usually neglected in discussions around water resource protection, but plays a crucial role regarding the coordination of activities in case of failure of the above systems and regulations. The Act provides "for an integrated and co-ordinated disaster management policy that focuses on preventing or reducing the risk of disasters, mitigating the severity of disasters, emergency preparedness, rapid and effective response to disasters and post-disaster recovery". It contains rules for intergovernmental, national, provincial and municipal level institutions

and actions. Hence, some of the responsibilities are delegated to the third tier of government, while national oversight is maintained.

3.2 Implementation of Legislation

Implementation of the legislation is done via several government departments (see Table 2). The DWS and various CMAs deal with aspects of catchment vision, regulation, classification and Reserve defining, licensing, compliance monitoring, and resource monitoring. The Department of Environmental Affairs deals with environmental authorisations and pollution incidents, whilst various environmental programmes such as Working for Water, Working for Wetlands, and Working on Fire are involved in various aspects of water resource management.

Implementation of the legislation was reviewed through the scope of where it falls short and where issues with the legislation arise. Various issues of implementation arise in Chapter 3 and Chapter 4 of the NWA. For example, the classification procedure identified in Chapter 3 of the NWA does not apply to aquifers. Furthermore, once a water resource has been classified, it cannot be reclassified. As a result, the classification does not consider changes to water resources because of climate change or usage. Chapter 3 defines the concept of a "Groundwater Reserve", but it was found not to be implementable as the volume to be reserved is not measurable, the volume allocated is of no guarantee for non-impact, and the definition of aquifer stress is not a suitable guidance. Ultimately, the Groundwater Reserve does not support groundwater management and groundwater protection.

Chapter 4 of the NWA, which focuses on the use of water and water authorisation, also has several implementation issues. The licensing process is long and onerous, and the general authorisation process needs revision. There is also a lack of clarity surrounding the verification and validation of existing lawful users. Water use is still linked to property and property size, and licensing is per single user and not per resource. Thus, the accumulative impact on the water resource is often not known.

Table 2: Responsibilities of different government departments for various activities that could impact on the water resource integrity

Activity/Threat	DWS/CMA	Department of Environmental Affairs	Department of Agriculture, Forestry and Fisheries	Department of Mineral Resources
Abstraction	x			
Dam, weir, etc.	x	x		
Waste water	x			
Agriculture		x	(x)	
Mining	(x)	(x)		x
Industry	(x)	x		
Solid waste		x		
Soil contamination	(x)	x	(x)	
Urbanisation	(x)	x		
Catchment management	x			
Land use		x	(x)	(x)
Climate change	(x)	x	(x)	

3.3 Scientific

3.3.1 National

Several articles were selected for a review of national scientific information surrounding water resource protection. Articles from the WRC such as project reports, articles on the state of water in South Africa, conference papers, and scientific journals were analysed. The literature was selected to encompass the pillars and layers previously defined, to analyse where the literature was lacking regarding resource protection, and to show gaps between the literature and the legislation.

The research funded by the WRC in the 2014/2015 financial year (WRC, 2016) focused on water services issues (40%) and water resource related research (29%). Only 16% of the research was in the Key Strategic Area (KSA) 2: Ecosystems, while 13% focused on water in agriculture (see Figure 6). Water resource related research between 2011 and 2016 focused on perennial rivers (38%) and groundwater (29%), while wetlands were covered in 16% and estuaries in 13% of studies. Only 4% of studies were undertaken for non-perennial water courses.

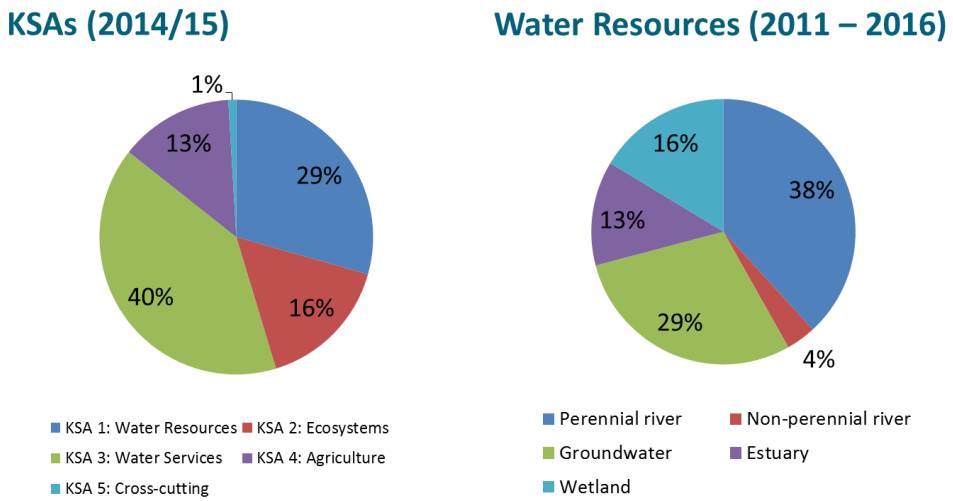
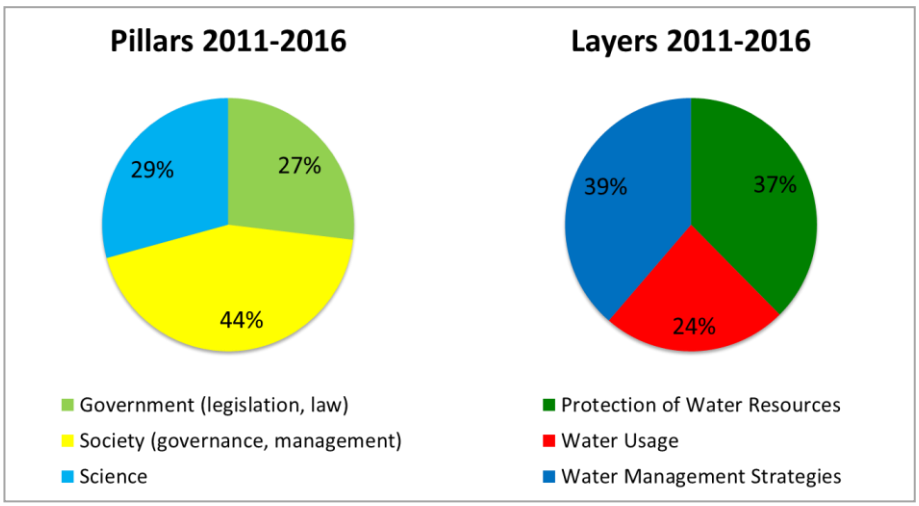


Figure 6: Split of research funded by the WRC between KSAs and water resources

Literature reviewed from 2011 to 2016 showed that 44% of research focused on implementation and management, and the societal aspects of water resource management. Of literature, 29% focused on scientific systems and understanding of water resource protection, whilst only 27% focused on legislation and law, and the implementation of governance in water resource protection. In relation to the layers defined in Section 2.2, 37% of the literature reviewed focused on RDM and the protection of water resources. There was a 39% focus on land use/land care and water management strategies, whilst 24% focused on water use authorisations/SDC (see Figure 7a).

Interestingly, there was a shift in thinking regarding the literature reviewed over the period of 2014/2015 (see Figure 7b). Regarding the pillars, scientific systems and understanding of water was at 41% of all literature for that period. Regarding the layers, protection of water resources and RDM was at 47% of all literature reviewed for the period. This shows that academic thinking is shifting towards bridging the scientific understanding of water resource protection with legislation and resource protection strategies.

a)



b)

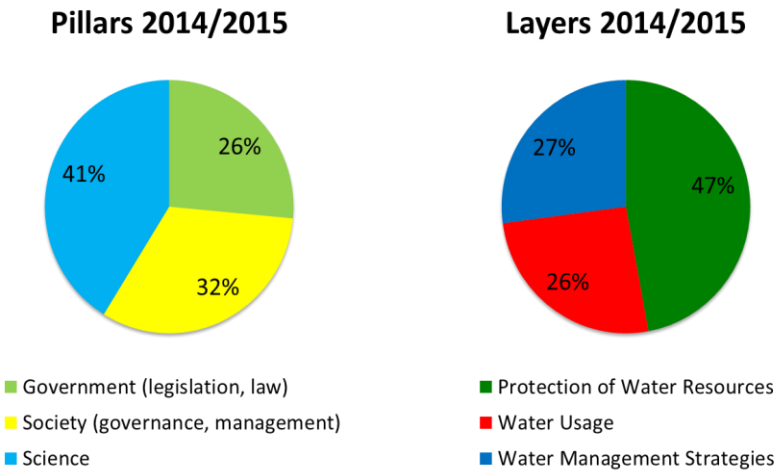


Figure 7: Split of research on water resource protection between pillars and layers; a) for the years 2011 to 2016, b) for the financial year 2014/2015

The WRC has set out a roadmap for water resource protection research, development and innovation (WRC, 2015). The two main focus areas are water supply and water demand. Sub-sections under water supply are improving governance, planning and management; improving performance and infrastructure; managing water as an economical and sustainable business; using more resources; and utilising these resources to their full potential. Under water demand, the focus is on improving governance, planning and management; reducing losses of water; and improving pricing, monitoring and metering.

3.3.2 International

International and national literature were compared. On the positive side, South Africa is noted to have a very high quality of water supply and resource management legislation, but with severe delays in implementation. There is a wide array of in-depth scientific knowledge, yet little uptake of this into resource management. South Africa also has a well-thought out division of water management areas, and a good planning horizon of 25 years. However, the classification of water resources is not sufficient to take aspects of climate change and changing water resources into account, and the economic value of water is not considered.

3.4 Summary

Based on the literature review, it can be concluded that the legislation with respect to water resource protection is state-of-the-art and one of the best in the world. However, there is still space for improvement – the different acts can be aligned better to facilitate cooperative governance and improve implementation. Regulations and guidelines are plentiful covering most of the relevant activities and various water resources. Similarly to the legislation, these regulations should be aligned to cover all water resources effectively and to cater for all critical activities that could impact negatively on water resources.

The literature review also indicated the vast amount of scientific knowledge and research underway. The gaps and suggested further research are detailed in Section 4 and Section 5.

4. RESEARCH GAP ANALYSIS

Since there was only very limited feedback from the stakeholders via the online discussion forum, further literature review has been undertaken to prepare a research gap analysis. The review and gap analysis was structured according to the different water resources, possible threats and applying the research methodology, as detailed in Section 2.

4.1 Water Resource Specific

Although water resource specific gaps in knowledge and implementation of water resource protection mainly apply to the layer of RDM, as defined in Section 2.2, research gaps were also identified for the other layers, where relevant to specific types of water resource.

4.1.1 Perennial surface water

Perennial rivers are probably the best understood and studied water resources with respect to water resource protection. The rules and processes for determining the Reserve, undertaking the classification and providing resource quality objectives (RQOs) have been developed for perennial rivers, and subsequently applied to other water resources.

The main gap identified relates to the implementation of these rules and the outcome of the processes. Adjustments to the rules and processes are also suggested to cater for the changing environment.

A summary of the identified gaps is provided in Table 3.

Table 3: Research gaps for protection of perennial rivers and streams

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM	Classification does not cater for changes due to climate change, land use practices etc.	Alignment of Reserve, classification and RQO processes required	Drought resilience of aquatic biota uncertain
SDC		Implementation of the Reserve still lacking	Impact of emergent contaminants on surface water environment
ICM		RDM processes are often applied in isolation without considering other water resources	Role of perennial rivers in catchment functioning
Compliance, Monitoring and Enforcement (CME)		Insufficient spatial and temporal distribution of monitoring network	

4.1.2 Non-perennial surface water

While perennial systems are well-understood, until recently, non-perennial rivers and water courses have been neglected in research. The standard methods for RDM are not applicable to non-perennial systems and there is no guidance yet. This is partly due to a lack of scientific research into the role of non-perennial systems and their interaction with other ecosystems and water resources.

A summary of the identified gaps is provided in Table 4.

Table 4: Research gaps for protection of non-perennial rivers and streams

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM	No guidance for RDM for non-perennial streams		Interaction between non-perennial streams and ecosystems not fully understood
SDC			Impact of land activities on non-perennial systems and water courses
ICM		Non-perennial systems often not considered in CMS and NWRS	Role of water courses in catchment functioning
CME		Insufficient spatial and temporal distribution of monitoring network	How and what to monitor?

4.1.3 Wetlands

Due to the variety of wetland types (for example perennial, non-perennial, groundwater-dependent, geomorphological; see Figure 8), their various positions within catchments and their relatively small size, the implementation of any scientific understanding or existing rules becomes difficult and cumbersome. The standard RDM methodology is also not applicable to wetlands.

A summary of the identified gaps is provided in Table 5.

Table 5: Research gaps for protection of wetlands

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM	Standard methodology not applicable to wetlands	Scale of standard investigation insufficient for protection	Determination of water source for wetlands on local and catchment scale
SDC			Buffer and treatment capacity of wetland types currently unknown
ICM		Identification of wetland location and wetland types in catchments across South Africa	Role of wetlands in catchment functioning
CME		Insufficient spatial and temporal distribution of monitoring network	What parameters need to be monitored for wetland protection?

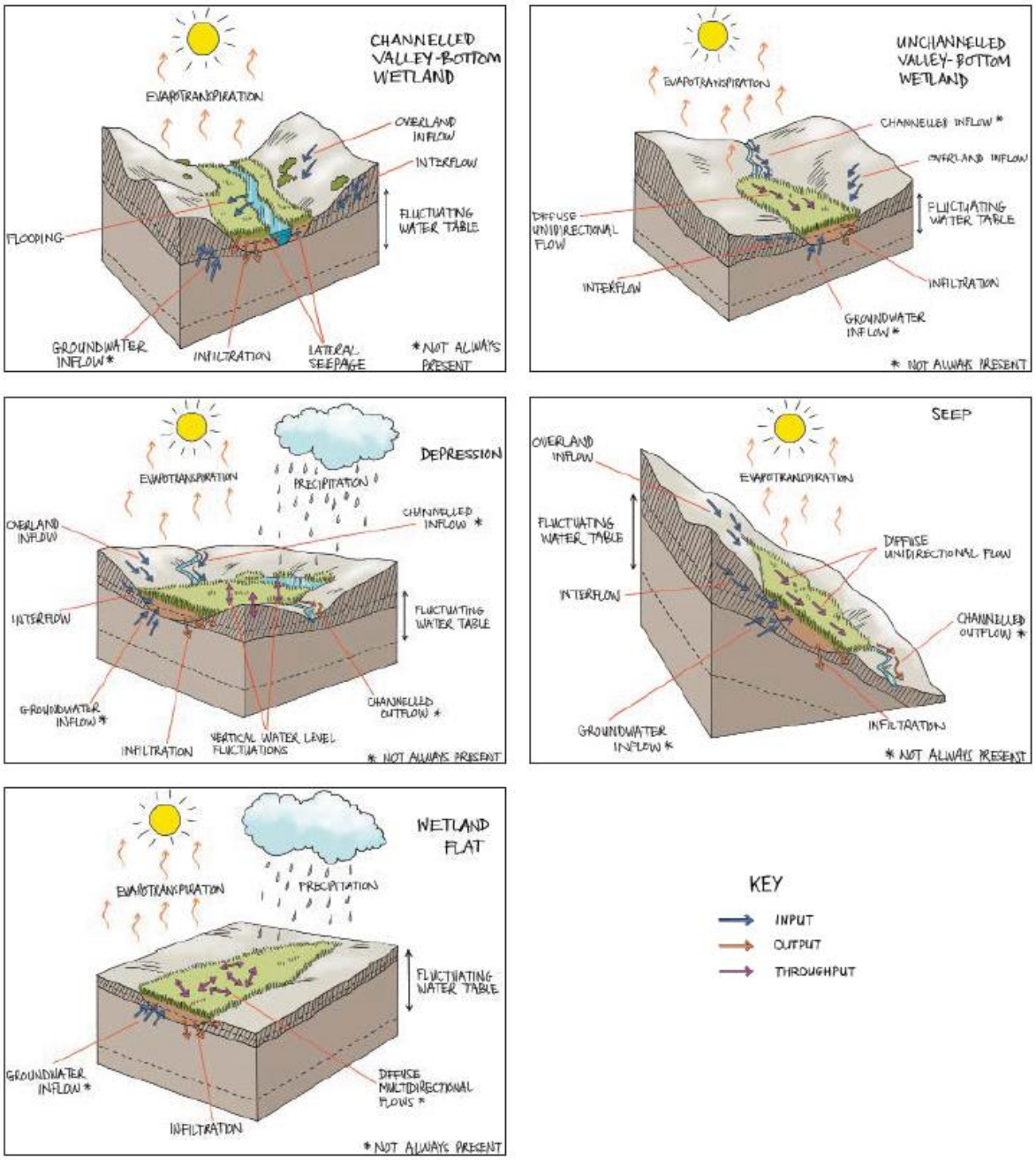


Figure 8: Examples of wetland types (Olis et al., 2013)

4.1.4 Estuaries

Estuaries are situated at the lowest point of catchments and are thus the receiving environment of all activities upstream (see Figure 9). This puts pressure on understanding and properly modelling these

interactions, and further research might be required for these aspects. A summary of the identified gaps is provided in Table 6.

Table 6: Research gaps for protection of estuaries

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM		Link between river water balance and estuary hydrodynamic model	Impact of different water sources on estuary ecosystem functioning
SDC			Impact of land use and direct discharge on estuary ecosystem functioning
ICM			Role of estuaries in catchment functioning
CME		Insufficient spatial and temporal distribution of monitoring network	

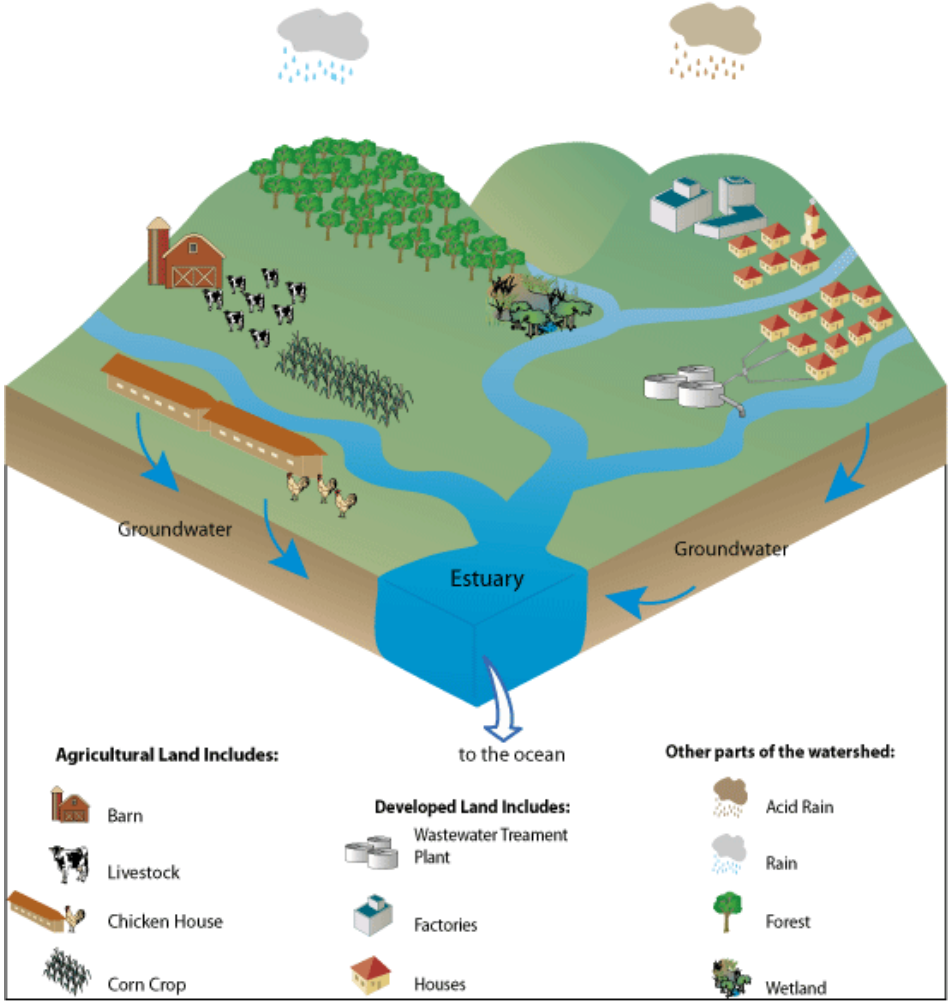


Figure 9: Variety of selected upstream impacts on estuaries (Teachoceanscience, 2016)

4.1.5 Groundwater

Aquifers play an important role in providing water resources in South Africa as well as providing socio-economic benefits within the scope of South Africa's Reconstruction and Development Programme (RDP). The concept of the "Groundwater Reserve" is enshrined in the NWA, which stipulates that a classification of all significant water resources must be undertaken and that the Reserve requirements be determined and gazetted. However, the classification procedure as it currently stands under the NWA (Act 36 of 1998) does not make provision for aquifers.

The concept of the "Groundwater Reserve" does not exist as a separate component within the bounds of the NWA (Act 36 of 1998). Rather, it adopts from the methodology developed for surface water resources. Hence, the implementation of this methodology often results in undesirable outcomes and is one of the inhibiting factors for sustainable groundwater development. The concept of the "Groundwater Reserve" is misleading and not implementable as the relevant spatial and temporal scale of investigation, the integration with the surface water Reserve and the buffer capacity of aquifers against droughts are not taken into account.

A summary of the identified gaps is provided in Table 7.

Table 7: Research gaps for groundwater protection

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM	Standard methodology not applicable to groundwater	Scale of investigation often incorrect and insufficient for protection	Buffer capacity of different aquifers to external impacts
SDC		Calculation of discharge limits for diffuse/indirect input of biological and chemical constituents	Behaviour of emergent contaminants in aquifers
ICM			Integral part of aquifers in maintaining ecosystem functioning not fully understood or overemphasised
CME		Insufficient spatial and temporal distribution of monitoring network	Inadequate time series data of quality and quantity to develop scientific understanding

4.1.6 Near-shore marine environment

The near-shore marine environment is impacted by direct discharge of effluent, pollution of surface and groundwater on-shore and other land-based activities (see Figure 10). However, the marine environment is usually not considered as receiving environment, as it is not governed under the NWA, but only under NEMA (see Section 3.1.2).

A summary of the identified gaps is provided in Table 8.

Table 8: Research gaps for protection of near-shore marine environment

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM	Marine environment is governed by NEMA and not linked to freshwater resource protection via NWA	NEMA only considers impact from on-shore land use and direct discharge	Impact of polluted groundwater or surface water discharging onto near-shore waters
SDC	Marine environment is governed by NEMA and not linked to freshwater resource protection via NWA	Limits for discharge loads not determined	
ICM			Role and functioning of near-shore marine environment as receiving body
CME		Insufficient spatial and temporal distribution of monitoring network	How to monitor impact of land-based activities on marine environment?

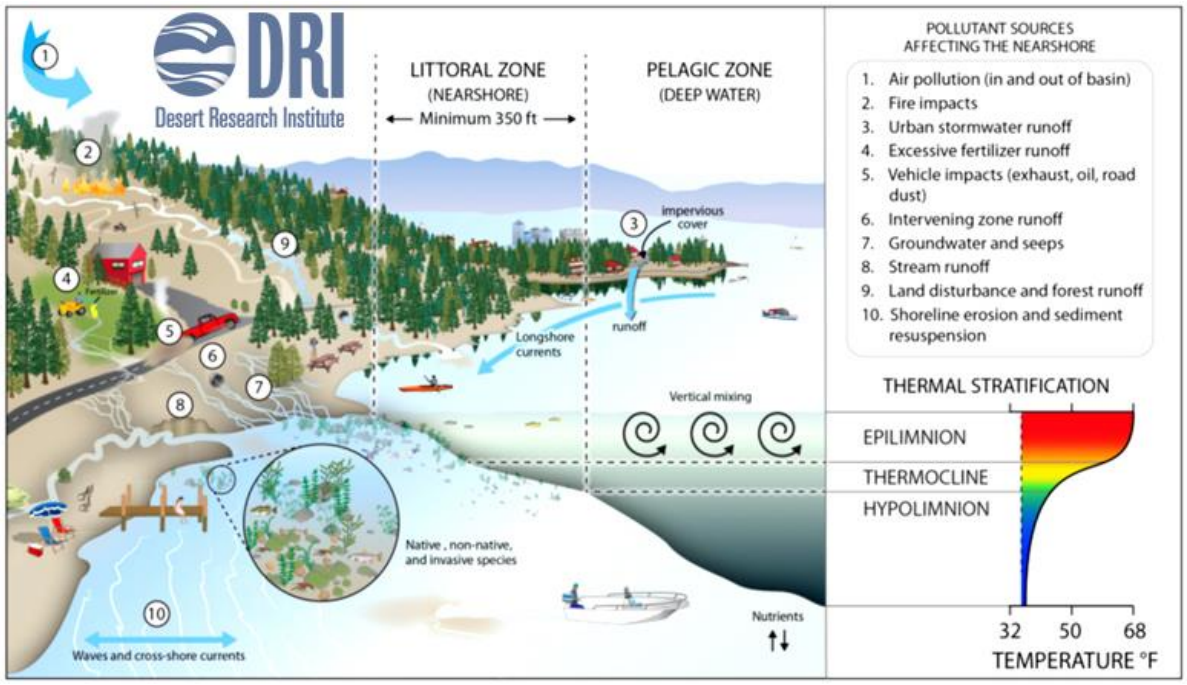


Figure 10: Possible impacts on near-shore marine environment (Heyvaert, 2013)

4.2 Activity/Challenge Specific

Activity-specific water resource protection focuses on the layer of SDC, as defined in Section 2.2. However, aspects of other layers were considered in the gap analysis provided below. The activities and challenges considered in the analysis are based on the risk assessment in Section 1.2.4 and comprise urbanisation, agriculture, mining and industry, and climate change.

4.2.1 Urbanisation

The varying sources of pollution in an urban environment, from storm-water run-off to effluent from waste water treatment works, industrial pollution *inter alia*, impact on water resources. At the same time, the natural buffer capacity of streams, wetlands and aquifers is compromised through developments, road networks and hard surface decreasing infiltration and increasing storm water run-off. The cumulative impact of these varying activities is not fully understood. In addition, urban planning usually does consider the impact on water resources.

A summary of the identified gaps is provided in Table 9.

Table 9: Research gaps for protection of water resources regarding urbanisation

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM		Water resource management in urban environment	
SDC	Responsibility for authorisation of activities impacting on water resources split between several departments	Permits and limits for storm water run-off	Impact of leaking sewage and supply pipelines on surface and groundwater
ICM	Cooperative governance	Environmental compliance and enforcement	
CME		Insufficient spatial and temporal distribution of monitoring network	What and how to monitor urban water resources, impacts and causes?

4.2.2 Agriculture

While agriculture is the biggest water user in South Africa, agricultural activities, such as irrigation and use of fertilisers and pesticides, are a constant threat to the functioning of water resources. This is exacerbated by the diffuse nature of impacts, which are often only detected far downgradient of the sources. Proper management measures can prevent or mitigate against these treats (see Figure 11).

The responsibility for the authorisation of the activities is split between the Department of Agriculture, the Department of Environmental Affairs and the DWS.

A summary of the identified gaps is provided in Table 10.

Table 10: Research gaps for protection of water resources regarding agricultural activities

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM		Success of rehabilitation and remediation of pollution	Possibilities for soil and water remediation
SDC	Responsibility for authorisation of activities impacting on water resources split between several departments	Management of water use (i.e. abstraction and irrigation); regarding impact on other users and ecosystems	Impact of irrigation return flow on water resources, dependent on soil type and water resource
ICM	Cooperative governance	Environmental compliance and enforcement	Ecologically sustainable agricultural practices
CME		Insufficient spatial and temporal distribution of monitoring network	What parameters are crucial for monitoring the impact of agricultural activities?

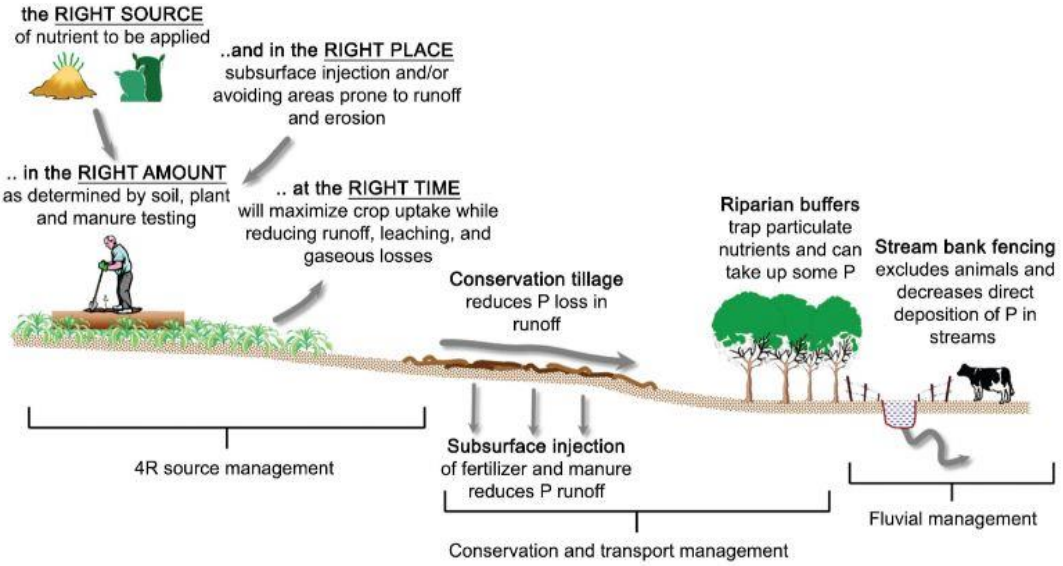


Figure 11: Agricultural management strategies to support water resource protection (Sharpley, 2016)

Legend:
P: Phosphate, indicator for nutrients

4.2.3 Mining and industry

Mining and large industry are big contributors to the economy and are large water users. However, they are among the biggest polluters of water resources, especially the old closed mines where contaminated water decants into surface water ecosystems and further pollutes groundwater resources.

Due to the large number of authorities involved in mining permits, water use aspects, and environmental compliance, there is confusion over the responsible parties for monitoring of impacts. Cooperative governance as laid out by NEMA seems not be fully implemented, leaving gaps in enforcement of mining activities regarding water resource protection.

The incomplete closure of old mines, some just left as is, has left a lasting environmental impact on groundwater and surface water in the vicinity of these mines. The responsibility for the rehabilitation and closure of these old mines is not clear, as the previous owners are not available anymore.

The Best Practice Guidelines for Water Resource Protection in the South African Mining Industry play an important role in guiding mines to prevent pollution, minimise impacts, and ensuring the polluter pays principle is carried out. How effective have these guidelines been, and how can they be improved to ensure mining practices are less harmful to water resources?

A summary of the identified gaps is provided in Table 11.

Table 11: Research gaps for protection of water resources regarding mining and industrial activities

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM		Success of rehabilitation and remediation of mines and pollution	Methodologies and technologies for mine rehabilitation, remediation (acid mine drainage)
SDC	Responsibility for authorisation of activities impacting on water resources split between several departments; Legacy of old, abandoned mines	Best practice guidelines – do they help to protect the water resources?	Calculation of reasonable limits for long-term impacts and diffuse discharge
ICM	Cooperative governance	Environmental compliance and enforcement	
CME		Insufficient spatial and temporal distribution of monitoring network	

4.2.4 Climate change

Climate change is inevitable, but currently not considered in water resource protection. The water resource classification process and Reserve determination does not cater for climate change. Climate change impacts on water flow needs to be modelled and to be incorporated into yield and planning models. However, the lack of climate monitoring (rainfall gauges) to record trends of climate change makes the implementation of these recommendations difficult. Proper water resource management is crucial for climate change adaptation and mitigation (see Figure 12).

A summary of the identified gaps is provided in Table 12.

Table 12: Research gaps for protection of water resources due to climate change

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM	Classification outcome to cater for climate change scenarios	Climate change scenarios to be included in models for RDM process	Impact of climate change on ecosystems, water flow and biota
SDC			Impact of climate change on buffer capacities and chemical/biological processes in receiving environment
ICM	Cooperative governance	Development and implementation of climate change adaptation strategies on catchment scale	Impact of climate change on food production and resultant impacts on land use
CME		Insufficient spatial and temporal distribution of rainfall and climate monitoring network	Ongoing update of climate change models and downscaling to sub-catchment level

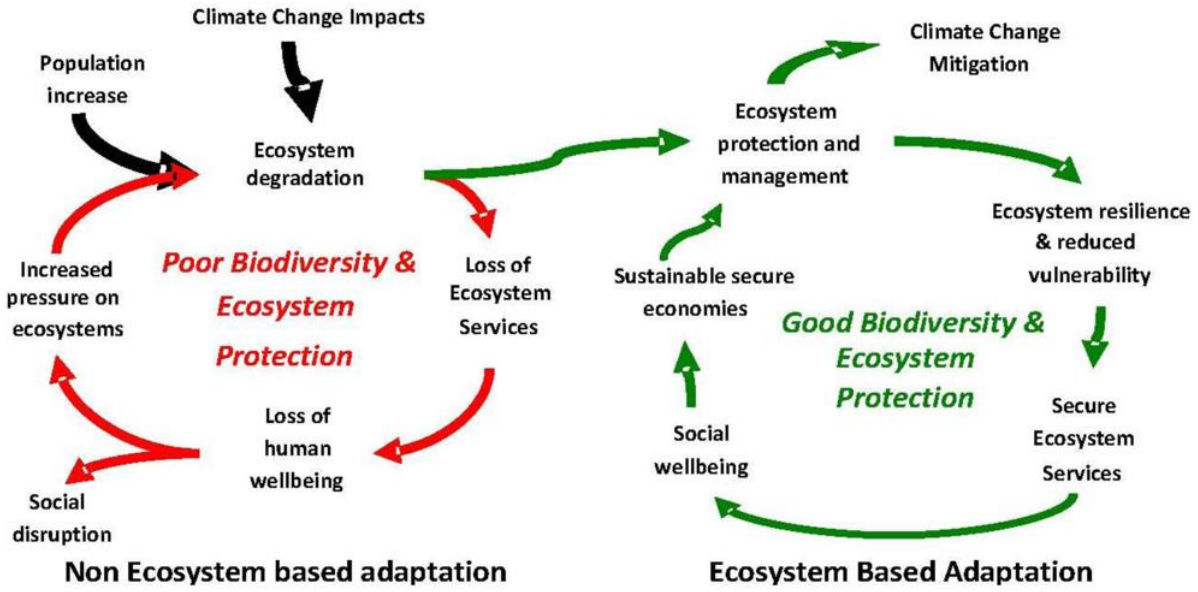


Figure 12: Climate change impacts and mitigation (Munang et al., 2013)

4.3 ICM

ICM can provide a solution to the current state of water resource protection. However, this must be based on a scientific understanding of the complex natural system. In addition to the knowledge and implementation gaps identified under Section 4.1 (water resource specific) and Section 4.2 (activity specific), the following gaps further exacerbate the lack of implementation (see Table 13).

Table 13: Research gaps for protection of water resources in the context of ICM and integrated water resources management

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM	Integration of all processes	CMAs are not set up yet	
SDC		CMAs are not set up yet	Lack of understanding of different land use effects on water resources
ICM	Cooperative governance	CMAs are not set up yet	Lack of understanding of different land use effects on water resources
CME		Insufficient spatial and temporal distribution of integrated monitoring network	

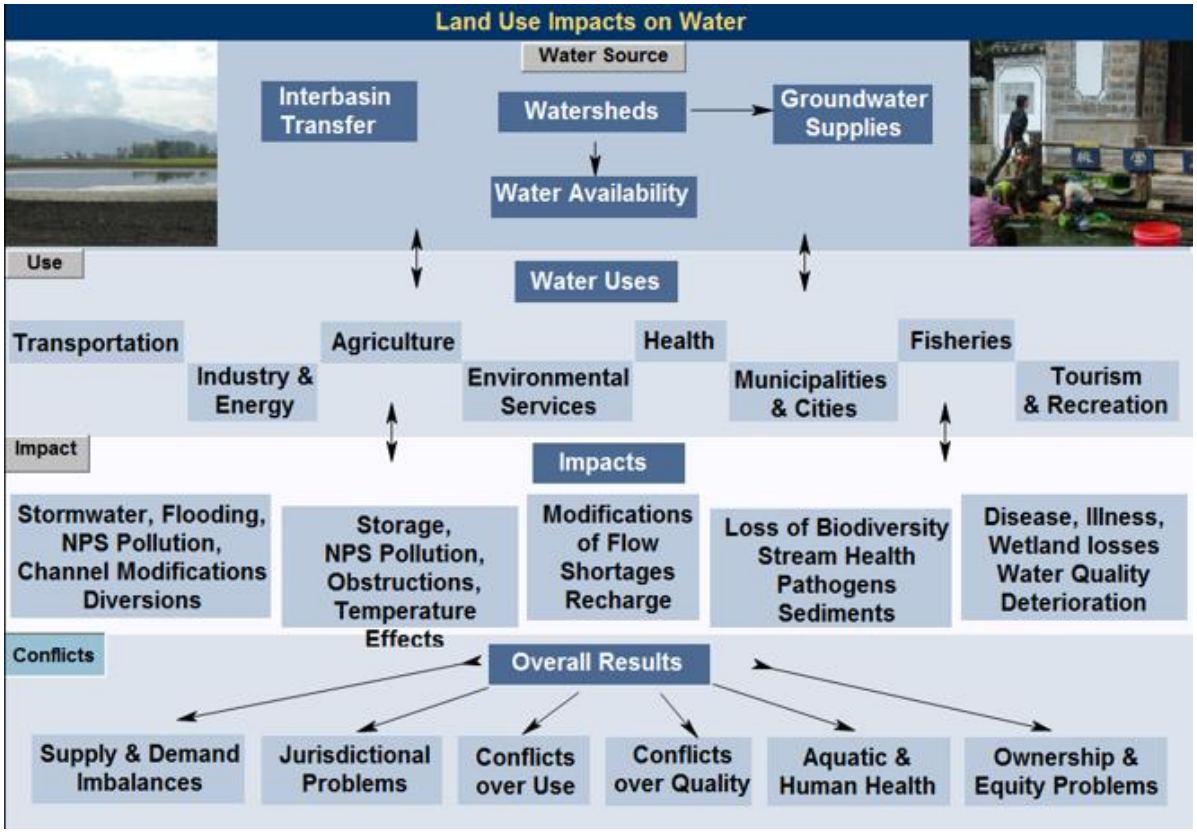


Figure 13: Variety of land use impacts on water resources (The University of British Columbia, 2016)

Legend:
NPS: Non-point source

4.4 Summary of Gap Analysis

Several common and cross-cutting themes were identified in both the water resource specific and activity-specific gap analysis.

4.4.1 Water resource specific

Some of the identified gaps in knowledge and understanding of water resource protection processes and implementation of associated regulations for the different water resources (see Section 4.1) can be grouped into several aspects that are common for all or most water resources (see Table 14):

- The RDM methodology is not applicable to all water resources and mostly carried out at a scale that is insufficient for water resource protection. The methodology requires update to incorporate aspects of climate change, changing land use and changing demographics. The methodologies for the groundwater, wetlands and estuaries need to be updated and aligned to the overall methodology.
- The behaviour of emergent contaminants in different water resources and their impact on water resources have not been determined yet. The recently initiated research programme into emergent contaminants should be expanded in this regard.
- The role of different water resources and their sub-types in catchment functioning is crucial for the complex system understanding that is required for ICM to be implemented.
- There is an insufficient spatial and temporal distribution of monitoring networks for most water resources. There is no standard regarding how, what and where to monitor and the subsequent process of quality control, data analysis and decision-making.

Table 14: Common research gaps for water resource protection across different water resources

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM	Classification does not cater for changes due to climate change, land use practices etc.	Alignment of Reserve, classification and RQO processes required	
	RDM methodology not applicable to all water resources	Scale of investigation often incorrect and insufficient for protection	
SDC		Implementation of the Reserve still lacking	Behaviour and impact of emergent contaminants on water resources
ICM			Role of different water resources in catchment functioning
CME		Insufficient spatial and temporal distribution of monitoring network	How and what to monitor?

4.4.2 Activity/challenge specific

Some of the identified gaps in knowledge and understanding of water resource protection processes and implementation of associated regulations for the different activities and challenges (see Section 4.2) can be grouped into several aspects that are common across most of activities (see Table 15):

- The responsibility for authorisation of activities impacting on water resources is often split between several departments; for example, mining activities authorised by the Department of Mineral Resources and the DWS. Cooperative governance, as required for ICM and water resource protection, is not a reality.
- There are no case studies regarding the success of rehabilitation and remediation actions with respect to compliance to RDM limits.
- The diffuse discharge and uncontrolled discharge from a range of land use activities are not regulated and do not have limits or standards determined.
- There is an insufficient spatial and temporal distribution of monitoring networks for most water resources and relevant activities. Hence, compliance and enforcement is lacking. The crucial parameters for monitoring the impact of agricultural, industrial or urban activities need to be determined.

Table 15: Research gaps for protection of water resources across different activities

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
RDM		Success of rehabilitation and remediation	
SDC	Responsibility for authorisation of activities impacting on water resources split between several departments	Permit limits for diffuse or uncontrolled discharge	
ICM	Cooperative governance		

Pillar / Layer	Rules and Legislation	Society/Implementation	Scientific Understanding
CME		Environmental compliance and enforcement Insufficient spatial and temporal distribution of monitoring network	What parameters are crucial for monitoring the impact of agricultural, industrial and urban activities?

4.4.3 Linkage between pillars and layers

It is important to note that advances in knowledge and systems in one pillar or layer does not necessarily translate into advances in the other pillars or layers. Hence, emphasis should be placed on translating scientific understanding into regulations and implementation strategies. Similarly, advances in complex systems understanding and its meaning for ICM must feed into updates of the RDM methodology and permit limits on RDM and SDC.

5. RESEARCH STRATEGY

For the development of the research strategy, potential research studies addressing the identified gaps in knowledge and implementation need to be identified and prioritised. This is based on a further cause-effect analysis of the gaps, identified in Section 4, and development of a clear overarching objective.

5.1 State-of-the-art Legislation

The legislation in South Africa regarding water resource protection is state-of-the-art and one of the best in the world. However, there is still space for improvement in that the different acts need to be aligned better to facilitate cooperative governance and improve the implementation of the legislation. Regulations and guidelines are plentiful covering most of the relevant activities and various water resources. Similarly to the legislation, these regulations should be aligned to cover all water resources effectively and to cater for all critical activities that could impact negatively on water resources. Implementation of these regulations and guidelines could also be simplified.

There is already a vast amount of scientific knowledge and research underway with respect to the impact of various activities on water resources and mitigation measures towards water resource protection. However, these are mostly limited to specific water resources and/or specific impacts or activities. Research into an integrated view of catchments comprising all water resources, land use activities, the social context of the residents, and external factors such as climate change and socio-economic drivers have just started.

5.2 Aim and Objective

The objective and strategic intent of follow-up research studies is to build knowledge for:

Enabling water resource protection through ICM that supports adaptation to climate and socio-economic change.

5.3 Cause-effect Analysis

Cause-effect analyses have been carried out for the following common research and implementation gaps, as identified in Section 4.3 and Section 4.4:

- RDM implementation.
- Monitoring and enforcement.
- ICM.

5.3.1 RDM implementation

The effect of “lack of RDM implementation” is caused by a variety of factors, which cover all three pillars. The four main factors are:

- Insufficient or conflicting rules and standards.
- Lack of cooperative governance and decision-making.
- Gaps in scientific understanding and knowledge.
- Lack of consideration of context and scale.

These have sub-factors (see Figure 14) that have to be considered and addressed to solve the lack of implementation. The factors and sub-factors are also interlinked and partly codependent; for example:

- Considering and addressing the *context/scale* of natural process and data is a prerequisite for enhancing the *science/understanding* of the different water resources and their interactions.
- Improving scientific knowledge and understanding should result in better regulations and guidelines and improved decision-making.
- The cooperation of different institutions is hampered by disjointed and varying legislation.

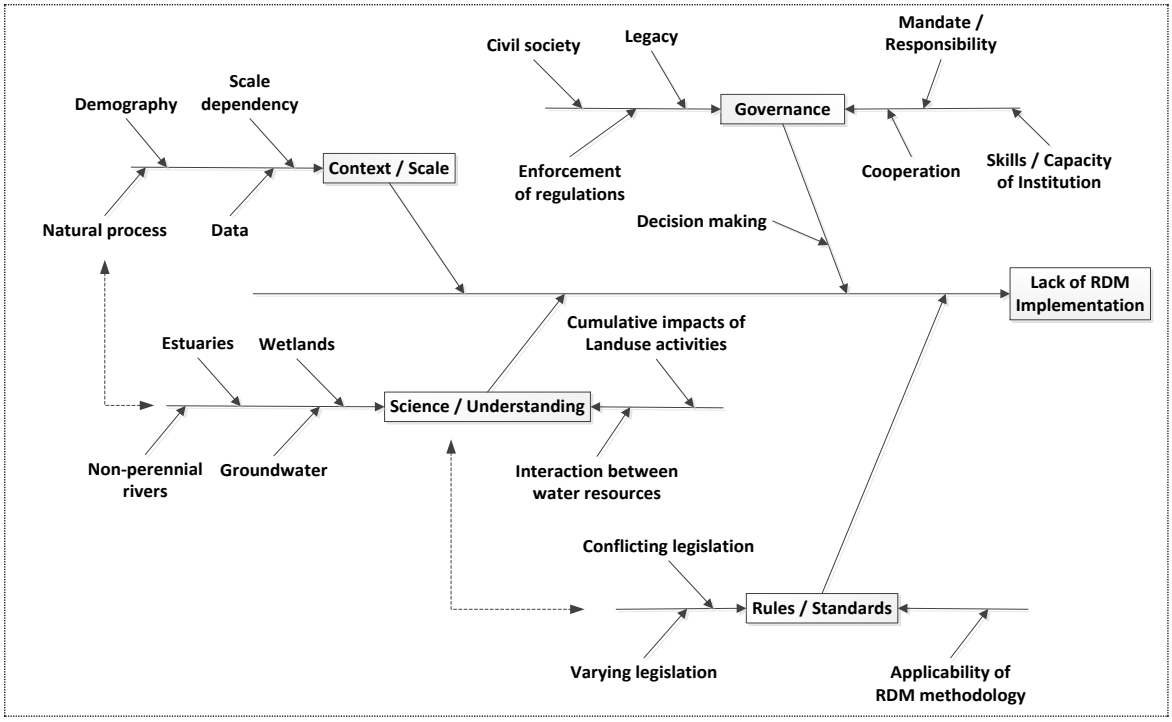


Figure 14: Cause-effect analysis for the lack of RDM implementation

Examples of research studies and programmes that address either single sub-factors with specific topics and/or a group of sub-factors/factors in a more integrated way are:

- Doing a detailed audit of the current status of RDM and SDC implementation and enforcement with the aim of highlighting crucial shortcomings not identified yet.
- Reviewing NWA and Regulations with the aim of aligning the different processes and integrate the different water resources into one coherent methodology (part of this is currently underway).
- Initiating the improvement and further establishment of "model catchments" to study and understand the complex relationships between different water resources and relevant flow and transport processes.
- Rolling out of the water resource governance framework developed by the WRC (Riemann et al., 2016) across all tiers of government.
- Determine impact of climate change scenarios on ecosystems, water flow and biota to enable integration of climate change scenarios in RDM process.
- Assessing the impact of polluted groundwater or surface water discharging onto near-shore waters under different hydrogeological and hydrological conditions.

5.3.2 Monitoring and enforcement

The effect of "lack of enforcement" is caused by a variety of factors, which cover all three pillars. The four main factors are

- Insufficient spatial and temporal distribution of monitoring networks and activities.
- Lack of data management.
- Lack of cooperative governance and decision-making.
- Gaps in scientific understanding and knowledge of required parameters.

These have sub-factors (see Figure 15) that need to be considered and addressed for solving the lack of implementation. The factors and sub-factors are also interlinked and partly codependent; for example:

- An optimised monitoring network and monitoring programme depends on the scientific understanding and assessment of the risks and pathways.

- Enforcement of rules and regulations and decision-making by the relevant authorities in this regard is dependent on sufficient and accurate monitoring data about the conditions of water resources in relation to RDM and or SDC indicators and limits.

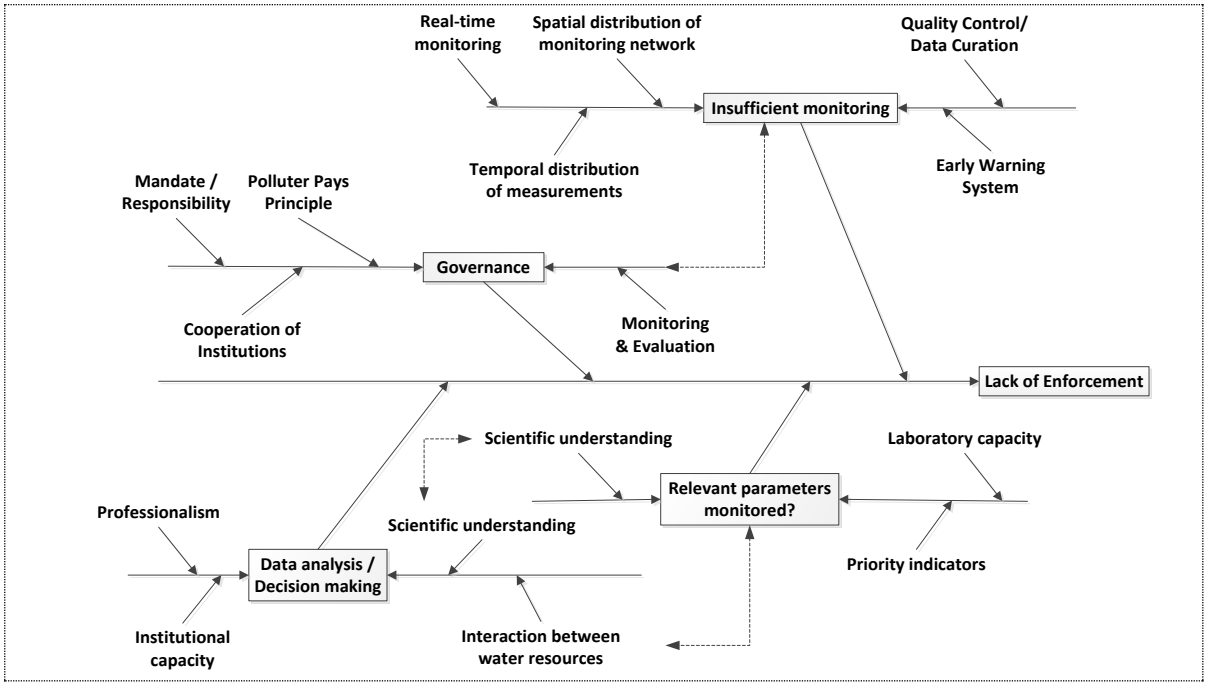


Figure 15: Cause-effect analysis for the lack of enforcement

Examples of research studies and programmes that address either single sub-factors with specific topics and/or a group of sub-factors/factors in a more integrated way are:

- Providing guidelines for establishing monitoring networks to support agricultural best practice and water resource protection.
- Providing guidelines for establishing scale- and context-dependent early warning systems for water resource quality and availability.
- Reviewing mandates and responsibilities of departments and other organs of state, with the aim of enhancing cooperative governance and decision-making.
- Establishing a centre for water resource related data curation and analysis.
- Strengthening the effectiveness of the Blue and Green Scorpions.

5.3.3 ICM

The concept of ICM requires a variety of factors covering all three pillars. The four main factors are:

- Identifying risks and impacts within the catchment and external factors.
- Establishing functioning cooperative governance on all tiers of government and civil society.
- Gaining a scientific understanding and knowledge of the catchment functioning.
- Considering context and scale, and sufficient monitoring.

These have sub-factors (see Figure 16) that need to be considered and addressed for solving the lack of implementation. The factors and sub-factors are also interlinked and partly codependent; for example:

- Considering and addressing the *context/scale* of natural process and data is a prerequisite for enhancing the *science/understanding* of the different water resources and their interactions, both of which are required for successful *cooperative governance.*
- Making decisions and enforcing rules and regulations require sufficient data of the correct context and scale, as well as a detailed risk identification and assessment.

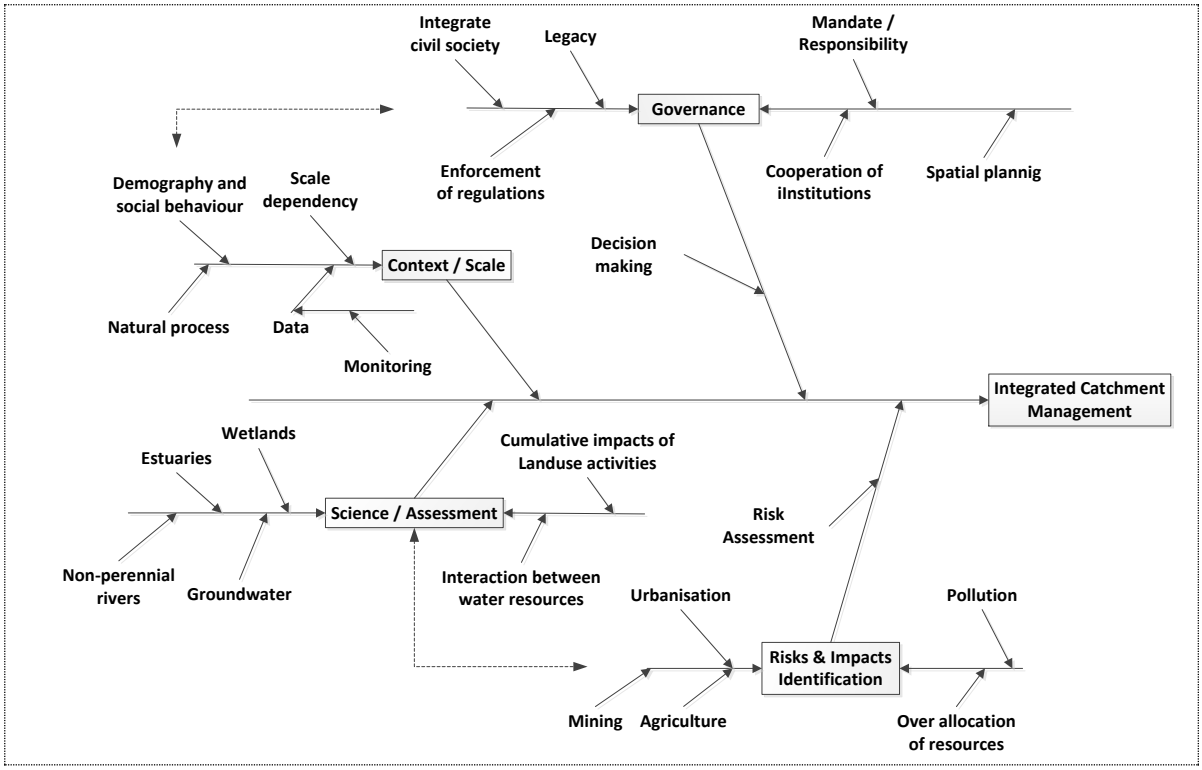


Figure 16: Cause-effect analysis for ICM

Examples of research studies and programmes that address either single sub-factors with specific topics and/or a group of sub-factors/factors in a more integrated way are:

- Reviewing general and special limits for waste water discharge.
- Providing a guideline for use of artificial wetlands for treatment and flood regulation.
- Determining catchment functioning for different types of water resource under varying stresses in an integrated manner across pilot catchments.
- Establishing model catchments on a catchment or sub-catchment scale to study and understand the complex relationships between different water resources and different land use activities.
- Providing a guideline for upscaling of technology advances and knowledge gained in model catchments.
- Developing and rolling out awareness campaigns and training programmes for social behaviour changes.

5.4 Prioritisation

The gaps identified from Section 4.1 to Section 4.3 and summarised in Section 4.4, and their causes as identified in Section 5.3, were turned into research questions and prioritised according to the following criteria:

- Possible short-term gain by changing implementation (Pillar Society).
- Possible medium-term gain by reviewing and updating legislation/regulations (Pillar Legislation).
- Initiating a structured, longer-term programme to build knowledge (Pillar Science).

The following five focus areas were prioritised:

- Auditing the current status of RDM and SDC implementation and enforcement.
- Establishing “model catchments” on a sub-catchment and catchment scale.
- Implementing awareness campaigns and training programmes for social behaviour changes.

- Rolling out a cooperative governance framework ensuring cooperative governance across all sectors and all tiers of government, and enforcing compliance.
- Reviewing and updating existing tools and best practice guidelines.

6. RECOMMENDATIONS

The currently initiated research studies regarding emerging contaminants and catchment management need to be expanded into research programmes and linked to the research programmes listed below.

The following focus areas should be initiated by the WRC or DWS within the next financial year:

- Doing a detailed audit of the current status of RDM and SDC implementation and enforcement with the aim of highlighting crucial shortcomings that have not been identified yet.
- Initiating the improvement and further establishment of “model catchment” on a catchment scale to study and understand the complex relationships between different water resources and different land use activities.
- Developing and rolling out awareness campaigns and training programmes for social behaviour changes.
- Developing and rolling out a cooperative governance framework ensuring cooperative governance across all sectors and all tiers of government, and enabling enforcement.
- Reviewing and updating existing tools and best practice guidelines.

Further research studies and programmes, as identified in Section 4 and Section 5, should be initiated within the next five years. Each research programme should include an implementation or roll-out phase, which then needs to be evaluated for the effectiveness of changes towards improved water resource protection. To achieve this, an independent monitoring network and national monitoring programme is required, to be installed, monitored and evaluated by the DWS and or relevant CMA.

7. BIBLIOGRAPHY

Boyd, L, Malete, O, Strydom, M and Hart, B, 2015. Integrated Water Quality Management: A Mind-Set Change Using an Integrated Water Quality Management Model (IWQM) to Support the Implementation of National Water Act Water Use Authorisations.

Braune, E, Adams, S and Fourie, F, 2014. 20 Years of Groundwater – Research, Development and Implementation in South Africa (1994-2014). *WRC Report No. SP 78/14*.

Centre for Coastal Resources Management, 2016. Supporting Integrated and Adaptive Management of Coastal Zone Resources. Online [Available]: http://www.ccrm.vims.edu/ (Accessed: 4 November 2016).

Chapman, AA, Venter, EA and Pearson, H, 2011. Aquatic Toxicity Testing in South Africa: Status of Aquatic Toxicity testing in South Africa. *WRC Report No. 1853/1/11*.

Conrad, J, Matoti, A and Jones, S, 1999. Aquifer Classification Map of South Africa.

Council for Scientific and Industrial Research (CSIR), 2010. A CSIR Perspective on Water in South Africa – 2010. *CSIR Report No. CSIR/NRE/PW/IR/2011/0012/A*.

Cox, D, Oosthuizen, S and Dickens, C, 2015. Moving from Integrated Water to Integrated Natural Resources Management (INRM): A Proposed Framework for INRM at the District Scale in South Africa. *WRC Report No. K 8/1035*.

Dabrowski JM, 2015. Investigation of the Contamination of Water Resources by Agricultural Chemicals and the Impact on Environmental Health Volume 1: Risk Assessment of Agricultural Chemicals to Human and Animal Health. *WRC Report No. 1956/1/15*.

De Clerq, W, Jovanovic, N, Bugan, R, Mashimbye, D, du Toit, T, van Niekerk, A, Ellis, F, Wasserfall, N, Botha, P, Steudels, T, Helmschrot, J and Flugel, W, 2013. Management of Human-induced Salinisation in the Berg River Catchment and Development of Criteria for Regulating Agricultural Land Use in terms of Salt Generating Capacity. *WRC Report No. 1849/1/13*.

Dennis, I, Witthüsser, K, Vivier, K, Dennis, R and Mavurayi, A, 2012. Groundwater Resource Directed Measures (2012 Edition). *WRC Report TT 506/12*.

Department of Water Affairs and Forestry (DWAF), 2008. A Guideline for the Assessment, Planning and Management of Groundwater Resources in South Africa (1st ed.). Department of Water Affairs and Forestry, Pretoria, South Africa.

Department of Water Affairs (DWA), 2010. Regulations for the Establishment of a Water Resource Classification System. Regulation 810, Published in Government Gazette No. 33541, 17 September 2010.

Department of Water Affairs (DWA), 2013a. A Framework for the Amendment of Groundwater Classification Guidelines (2007). Department of Water Affairs, South Africa. Directorate: Water Resource Classification; June 2013.

Department of Water Affairs (DWA), 2013b. Determination of Resource Quality Objectives for the Olifants Doorn Water Management Area – Report No. 3 – RQO Determination Report. Umvoto Africa (Pty) Ltd in association with Southern Water Ecological Research and Consulting cc (Authors: K Riemann. A Joubert, C Brown) on behalf of the Directorate: RDM Compliance.

Department of Water Affairs (DWA), 2013c. National Water Resource Strategy: Water for an Equitable and Sustainable Future. June 2013.

Department of Water Affairs (DWA), 2014. New Vision for Catchment Management Forums, Vision 2014–2024. Department of Water Affairs, Pretoria.

Gleick, PH, 2010. The Critical Role of Water Efficiency and Conservation in Solving California's Water Problems. US House of Representatives Testimony, 25 January 2010.

Government of South Africa. 1996. Constitution of the Republic of South Africa (Constitution), No. 108 of 1996.

Government of South Africa, 1998a. National Water Act, Act No. 36 of 1998.

Government of South Africa, 1998b. National Environmental Management Act, Act No. 107 of 1998.

Government of South Africa, 2002. Disaster Management Act, Act No. 57 of 2002.

Government of South Africa, 2003. Protected Areas Act, Act No. 57 of 2003.

Government of South Africa, 2004a. Biodiversity Act, Act No. 10 of 2004.

Government of South Africa, 2004b. Air Quality Act, Act No. 39 of 2004.

Government of South Africa, 2008a. Integrated Coastal Management Act, Act No. 24 of 2008.

Government of South Africa, 2008b. Waste Act, Act No. 59 of 2008.

Gowlland-Gualtieri, A, 2007. South Africa's Water Law and Policy Framework: Implications for the Right to Water. International Environmental Law Research Centre, Switzerland.

Griffin, NJ, Palmer, CG and Scherman, P-A, 2014. Critical Analysis of Environmental Water Quality in South Africa: Historic and Current Trends. *WRC Report No. 2814/1/14*.

Herselman, JE, Papenfus, M, Styen CE, De Jager, PC and Tesfamariam, EH, 2013. Evaluation of Partitioning Coefficients for South African Soils to Inform the National Framework for the Management of Contaminated Land with Emphasis on the Protection of Water Resources. *WRC Report No. 2102/1/13*.

Heyvaert, A, 2013. Lake Tahoe Nearshore Evaluation and Monitoring Framework. Desert Research Institute. Online [Available]: https://www.dri.edu/images/stories/centers/cwes/Lake_Tahoe_ Nearshore_Evaluation_and_Monitoring_Framework.pdf. (Accessed: 4 November 2016).

King, JM and Pienaar, HH, 2011. Sustainable Use of South Africa's Inland Waters: A Situation Assessment of RDM 12 Years After the 1998 National Water Act. Water Research Commission.

Kotze, P, 2015. Monitoring the Ecological Success of Wetland Rehabilitation. The Water Wheel March/April 2015. Water Research Commission.

Macfarlane, DM, Bredin, IP, Adams, JB, Zungu, MM, Gates, BC and Dickens, CWS, 2014. Preliminary Guideline for the Determination of Buffer Zones for Rivers, Wetlands, and Estuaries. Institute of Natural Resources.

McLoughlin, C, MacKenzie, J, Rountree, M and Grant, R, 2011. Implementation of Strategic Adaptive Management for Freshwater Protection under the South African National Water Policy. *WRC Report No. 1797/1/11*.

Middleton, J, Goldblatt, M, Jakoet, J and Palmer, I, 2011. PDG Occasional Paper No. 1: Environmental Management and Local Government. Online: [Available] http://pdg.co.za/wp-content/uploads/2012/04/Environmental-management-and-local-government.pdf.

Munang, R; Thiaw, I; Alverson, K; Mumba, M; Liu, J and Rivington, M, 2013. Climate Change and Ecosystem-based Adaption: A New Pragmatic Approach to Buffering Climate Change Impacts. Online [Available]: http://www.sciencedirect.com/science/article/pii/S1877343512001881 (Accessed: 4 November 2016).

National Planning Commission South Africa, 2012. National Development Plan 2030. South African Government Information.

Nel, J, Nel, M, Dustay, S, Siwawa, S and Mbali, S, 2014. Towards a Guideline for the Delineation of Groundwater Protection Zones in Complex Aquifer Settings. *WRC Report No. 2288/1/14*.

Olis, D, Snaddon, K, Job, N and Mbona, N, 2013. Classification System for Wetlands and Other Aquatic Ecosystems in South Africa, User Manual: Inland Systems. SANBI Biodiversity Series 22, South African National Biodiversity Institute, Pretoria.

Owens, M, 2006. The Water Cycle. Online [Available]: http://www.sswm.info/category/concept/water-cycle (Accessed: 4 November 2016).

Park, C and Allaby, M, 2013a. Minimum Acceptable Flow. In A Dictionary of Environment and Conservation: Oxford University Press. Online [Available]: http://www.oxfordreference.cm/view/ 10.1093/acref/9780199641666.001.0001/acref-9780199641666-e-5040 (Accessed: 11 July 2016).

Park, C, and Allaby, M, 2013b. Water Quality. In A Dictionary of Environment and Conservation: Oxford University Press. Online [Available]: http://www.oxfordreference.com/view/10.1093/acref/9780199641666.001.0001/acref-9780199641666-e-8819 (Accessed: 11 July 2016).

Parsons, R, 1995. A South African Aquifer System Management Classification. *WRC Report KV 77/95*.

Pearson, H, Shaddock, BF, Mulder, PFS and Cloete, YC, 2015. Development of Research Support to Enable the Issuing of Aquatic Toxicity-Based Water Use Licenses: Guideline Document. *WRC Report No. KV 347/15*.

Pejan, R, Du Toit, D and Thompson, H, 2011. Norms for Policy Implementation Lags in the South African Water Sector. *WRC Report No. KV 286/11*.

Phillips, T and Madlokazi, N, 2011. An Impact Assessment of the Research Funded by WRC on Wetland Management in South Africa. *WRC Report No.: KV 253/11*.

Pollard, S, Mallory, SJL, Riddell, E and Sawunyama, T, 2012. Towards Improving the Assessment and Implementation of the Reserve. *WRC Report No. KV 282/11*.

Rapport, DF, Fyfe, WS, Costanza, R, Spiegel, J, Yassie, A, Bohm, GM, Patil, GP, Lannigan, R, Anjema, CM, Whiteford, WG and Horwitz, P, 2001. Ecosystem Health: Definitions, Assessment and Case Studies. *Our Fragile World: Challenges and Opportunities for Sustainable Development. EOLSS, Oxford*, 21–42.

Riemann, K, Chimboza, N and Fubesi, M, 2012. A Proposed Groundwater Management Framework for Municipalities in South Africa. Water SA Vol. 38 No. 3 International Conference on Groundwater Special Edition 2012.

Riemann, K, Rust, J, Hoosain, M and Jack, S, 2016. Water Governance Framework and Action Plan for Conjunctive Use, Water Governance of Groundwater and Surface Water Resources in South Africa Deliverable 6. Report to the Water Research Commission South Africa, Pretoria.

Rivers-Moore, NA, Hughes, DA and Mantel, S, 2008. Links between Water Temperatures, Ecological Responses and Flow Rates: A Framework for Establishing Water Temperature Guidelines, for the Ecological Reserve. *WRC Report No. KV 214/08*.

Sami, A, Meliko, M, Mojapelo, P, Mashau, F, Nefefe, T and Ntekele, P, 2012. Parasites and Related Interactions in Water Resources and Rural Communities. *WRC Report No. 1910/1/11*.

Schreier, H, 2015. Land Use Impacts on Water. Online [Available]: http://ubclfs-wmc.landfood.ubc.ca/webapp/WID/course/land-use-impacts-on-water-3/urban-impacts-13/ (Accessed: 4 November 2016) .

Seago, CJ, 2016. A Comparison of the South African Approach to Water Resource Management and Planning with Four International Countries. *WRC Report No. KV 341/15.*

Seaman, MT, Watson, M, Avenant, MF, Joubert, AR, King, JM, Barker, CH, Esterhuyse, S, Graham, D, Le Roux PA, Prucha, B, Redelinghuys, N, Rossouw, L, Rowentree, K, Sokolic, F, Van Rensburg, L, van der Waal, B, van Tol, J, Vos, AT and Kemp, ME, 2013. Testing a Methodology for Environmental Water Requirements in Non-perennial Rivers: The Mokolo River Case Study. *WRC Report No. TT 579/13*.

Sharpley, A, 2016. Review: Managing Agricultural Phosphorus to Minimize Water Quality Impacts, Scientia Agricola. Online [Available]: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-90162016000100001 (Accessed: 4 November 2016).

Southern African Development Community, 2005. Regional Water Policy. Online [Available]: www.sadc.int/files/1913/5292/8376/Regional_Water_Policy.pdf.

South African Government News Agency, 2013. The National Development Plan Unpacked. Online [Available]: http://www.sanews.gov.za/south-africa/national-development-plan-unpacked.

Teachoceanscience, 2016. How Does the Land Affect the Sea? Online [Available]: http://www.teachoceanscience.net/teaching_resources/education_modules/from_land_to_the_sea/learn/ (Accessed: 4 November 2016) .

The University of British Columbia (UBC), 2016. Land Use Impacts on Water. Online [Available]: http://ubclfs-wmc.landfood.ubc.ca/webapp/WID/course/land-use-impacts-on-water-3/introduction-11/ (Accessed: 4 November 2016).

Turton, A, Godfrey, L, Julien, F, Hattingh, H, 2006. Unpacking Groundwater Governance through the Lens of a Trialogue: *CSIR Report No. CSIR/NRE/WRE/EXP/2005/0002/A*.

UNISDR, 2009, Terminology on Disaster Risk Reduction. Online [Available]: http://www.unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf (Accessed: 4 November 2016).

Water Research Commission (WRC), 2015. Research, Development and Innovation Roadmap, Policy Brief.

Water Research Commission (WRC), 2016. Annual Report 2014/2015, WRC *Report No. RP 155/2015*, ISBN No. 978-0-621-43642-6.

Wegelin, WA and Jacobs, HE, 2012. The Development of a Municipal Water Conservation and Demand Management Strategy and Business Plan as Required by the Water Services Act, South Africa. *Department of Civil Engineering, Stellenbosch University*.