THE DESIGN AND TESTING OF A NATIONAL ESTUARINE MONITORING PROGRAMME FOR SOUTH AFRICA

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for tomorrow

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SUMMARY

Adaptive water resource management requires sound scientific based decisions, emanating from robust scientific data. The Department of Environmental Affairs are mandated for collaborative management of the South African coast, including estuaries, through the Integrated Coastal Management Act (Act no 24 of 2008) (ICMA). The Department Water and Sanitation is mandated through the National Water Act (Act no 36 of 1998) (NWA) to design, test and implement monitoring programmes to provide water resource data. Extensive freshwater monitoring programmes exist in South Africa but there is no standard long-term monitoring programme for estuaries. This study designed and tested a National Estuarine Monitoring Programme (NESMP) that is anchored in the NWA and the ICMA. The design was based on a review of international estuary monitoring programmes, consultation with relevant role players and five decades experience in the design, testing and implementation of water resource monitoring programmes by DWS. The main objective of this thesis is 1) to design a national estuarine monitoring programme 2) test the design of the programme for practical implementation by reflecting on collected data from case studies, and 3) design a Decision Support System to translate complex monitoring data into management information. The main objective of the NESMP is 1) to collect long-term data to determine trends in the condition of estuaries in South Africa and 2) to provide management orientated information for effective estuary management. The National Estuary Monitoring programme consists of three tiers. Tier 1 focuses on basic data including system variables and nutrient data. Tier 2 collects data required for the determination of the Ecological Water Requirements (EWR) of estuaries in accordance with a standardised method used by DWS. A tailor made monitoring programme

addressing specific issues including pollution incidents and localised development pressure, making use of a combination of Tier 1 and Tier 2 components, forms Tier 3 of the NESMP. This study tested the Tier 1 components of the programme on 28 estuaries across the South African coast since 2012. However, due to space constraints, the data reflected on in this thesis, is only for case studies on the Berg and Breede estuaries between 2012 and 2016. The results indicate that the establishment and operation of the NESMP on South African estuaries making use of monthly surveys, and the deployment of permanent water quality loggers, in line with the proposed protocol, are possible. This does however require collaboration with other role players in order to share responsibility and associated resources. A tiered management structure ensures national, regional and local level implementation takes place seamlessly. A decision support system (DSS) was also designed as part of this thesis to assist with data interpretation and the creation of management orientated information. This DSS includes a measurement of the percentage exceedance of the Threshold of Potential Concern (TPC), which acts as an early warning system for water resource deterioration. This study showed that effective collaboration will ensure the sustainability of the NESMP. Implementation of the more complex and resource intensive Tier 2 and Tier 3 sampling will however need to be investigated to establish the overall success of the NESMP.

LIST OF ACRONYMS

DAFF: Department of Agriculture, Fisheries and Forestry

DEA: Department of Environmental Affairs

DPSIR: Driver, Pressure, State, Impact, Response

DSS: Decision Support System

DST: Department of Science and Technology

EFZ: Estuarine Functional Zone

EHI: Estuarine Health Index

EIA: Environmental Impact Assessment

EIS: Estuarine Importance Score

EMP: Estuarine Management Plan

EPA: Environmental Protection Agency

EU: European Union

EWR: Ecological Water Requirement

ICMA: Integrated Coastal Management Act

IFR: Instream Flow Requirement

KZN: KwaZulu-Natal

MCC: Municipal Coastal Committee

NEMP: National Estuarine Management Protocol

NESMP: National Estuarine Monitoring Programme

NFEPA: National Freshwater Ecosystem Priority Areas

NGO: Non-Government Organisations

NMMU: Nelson Mandela Metropolitan University

NWA: National Water Act

PCC: Provincial Coastal Committee

PEC: Present Ecological State

REC: Recommended Ecological Category

RHP: Rivers Health Programme

RQIS: Directorate Resource Quality Services

RQO: Resource Quality Objectives

SAEIS: South African Estuarine Information System

SAEON: South African Environmental Observatory Network

SAM: Strategic Adaptive Management

SANParks: South African National Parks

SoE: State of Environment

TPC: Threshold of Potential Concern

UKZN: University of KwaZulu-Natal

UNIZUL: University of Zululand

WFD: Water Framework Directive

WWF: World Wildlife Fund

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CHAPTER 1. GENERAL INTRODUCTION

Estuaries are highly complex ecosystems that provide critical support for coastal and marine biodiversity (Van Niekerk et al., 2015; Hallet et al., 2016a). Estuaries further provide important ecosystem services including, but not limited to, food security, flood attenuation, nutrient cycling and tourism opportunities (Heydorn et al., 1994; Millennium Ecosystem Assessment, 2005, Barbier et al., 2011). Globally estuaries are under pressure as a result of flow alteration water quality deterioration, overutilization of biotic resource and habitat destruction (Breen and McKenzie, 2001, Adams, 2014; DEA, 2014, Hallet et al., 2016a). The impact of global climate change on estuary functioning have also been summarised by Whitfield et al. (2016). The picture that emanates indicate a dire situation for estuaries and in a global context estuaries are seen as critically endangered (Jackson, 2008). The impact of man on the limited water resources of South Africa, especially estuaries, is well known and documented (Day, 1981; Heydorn et al., 1994; O'Keefe et al., 1994; Davies and Day, 1998; Whitfield, 1998; Whitfield and Elliot, 2002; Bate et al., 2004; Adams, 2012; Van Niekerk and Turpie, 2012; Van Niekerk et al., 2013; Veldkornet et al., 2015; DWS, 2016). Estuaries are one of South Africa's most productive ecosystems, which are not only important from a biodiversity point of view, but also in a socio-economic context (Cooper et al., 2003; Lambeth and Turpie, 2003; Turpie and Hoskings, 2005; Nel et al., 2011; Adams, 2012; Van Niekerk and Turpie, 2012). Economic opportunities associated with estuaries include the industrial and tourism sector as well as subsistence and commercial fisheries (Lamberth and Turpie, 2003; Lamberth et al., 2009; Van Niekerk and Turpie, 2012).

In order to ensure the sustainable utilisation of estuaries, effective management is required. Environmental management is a complex discipline (Fuggle and Rabie, 1994) as ecosystems are complex and subsequently react in a similarly complex and usually unpredictable manner. The diverse nature of South African estuaries further complicates management of these systems. The words of Winnie the Pooh: "*You never can tell with bees*" (Milne, 1926) being appropriate in the context of estuarine management. Incorporate human needs and aspirations into the equation, especially in a country where past disenfranchisement of the larger population resulted in extensive socio-political imbalance; and one deals with a quagmire of decisions where the environment tends to play second fiddle. Understanding the degree to which human activities affect estuarine ecosystems is critical to ensure the sustainable utilisation of these productive systems (DWAF, 2008a). Sustainable use of estuaries will ensure that the ecosystem services that estuaries provide are not compromised (Van Niekerk and Turpie, 2012; Adams et al., 2016). Deterioration of these ecosystem services in the end will be to the detriment of coastal populations and the country as a whole. This is especially true in the context of ever increasing environmental pressure, because of exponential human population growth and the current manifestation of climate change.

Estuaries have been the subject of basic research for decades (Whitfield and Baliwe, 2013). Academic institutions and conservation bodies, with the purpose of developing an understanding of the functioning and conservation of these systems, mostly drove this research. In recent years, this basic research developed into an understanding of the influence that anthropogenic activity has on the functioning of these systems. Therefore, we are able to start "*telling a bit more about bees*" and we are in the process of using basic research to pave the way for effective management of estuaries. Management however depends on information and information depends on data (DWAF, 2004a; DWAF, 2004b; DWAF, 2005). Therefore, the required good environmental management decisions depend on good science. Various streams of environmental data, specifically on estuaries, were generated over the past forty years.

The national, regional and local management responsibilities for the coastal zone, including estuaries, have not been clearly defined in the past, until the promulgation of the Integrated Coastal Management Act (Act no 24 of 2008) (ICMA). This act indicates that the overarching responsibility lies with the Department of Environmental Affairs (DEA). Estuarine management should however take place in collaboration with other interested parties. Therefore, collaborative management of estuaries is central to the ICMA (DEA, 2014). The Department of Water and Sanitation (DWS) is the custodian of all South Africa's water resources and therefore responsible for the sustainable management of this finite resource through the National Water Act (Act no 36 of 1998) (NWA). The NWA addresses sustainable management of South African water resources through different components including classification, setting management objectives and determining the human and environmental reserve of all water bodies, including estuaries (DWS, 2016). Various national water resource monitoring programmes are currently being implemented in South Africa by the DWS as part of this management mandate (DWAF, 2005; DWS, 2016). These monitoring programmes have historically focussed on the freshwater environment with very little focus on estuaries. There is no overarching estuarine monitoring programme in South Africa through which changes in a standard set of biotic and abiotic response and stressor indicators can be determined on a national scale. The objective of such a monitoring programme being primarily to track long-term changes in the ecosystem health and provide management orientated information. This should however be seen in the context of available resources to undertake this type of monitoring. Ecosystem health monitoring is expensive and requires specific skills. Such a monitoring programme therefore needs to make best use of available resources. There is a multitude of roleplayers involved with different aspects of estuarine management, from national oversight to localised water quality monitoring. This assists in following an integrative approach in the design and implementation of a national estuarine monitoring programme and support co-operative governance in line with ICMA. Cognizance should be taken of the fact that different institutions and role players have different objectives for monitoring of estuarine condition.

This thesis investigates the design and testing of a national estuarine monitoring programme to establish a long-term database and inform management decisions on South African estuaries. The programme and the implementation thereof should be based on Strategic Adaptive Management (SAM), as the National Estuarine Monitoring Programme (NESMP) may change in the future as more information and experience is gained with the implementation of the programme. This in itself results in the dynamic characteristics of such a monitoring programme. The time is ready for the implementation of a national estuarine monitoring programme due to the legislative mandate of DWS and DEA that requires management and monitoring of estuaries in a collaborative fashion. The available scientific studies and associated databases on the condition of estuaries in South Africa can be used as a departure point for a national monitoring programme. There are also various institutions involved in basic and applied research, monitoring and management of estuaries on whose expertise a national monitoring programme can be built. The experience gained in the design and implementation of national monitoring programme by DWS over the past three decades including the National Ecosystem Health Monitoring Programme (NAEHMP) is also available to facilitate the design of a national estuarine monitoring programme. Building on all of these factors, a cost effective programme can be designed, tested and implemented.

The objectives of the thesis therefore are:

1) To design a National Estuarine Monitoring Programme (NESMP) to determine long-term trends in the condition of South African estuaries;

2) To evaluate and test the implementation of the NESMP to collect data that is useful for estuarine management;

3) To design a Decision Support System (DSS) to facilitate data interpretation and management intervention;

4) To evaluate the use of the collected data from the monitoring programme with the designed DSS, to present management-orientated estuarine water resource information; and

5) To identify challenges with the design and implementation of a national estuarine monitoring programme.

Chapter 2 of this thesis provides an overview of estuaries and their management in South Africa. This includes the ecology, importance and current state of estuaries. The current management of estuaries in South Africa, within the framework of integrated water resource management is also outlined. This chapter further provides a critical overview of estuarine monitoring initiatives in the United States of America, the European Union and Australia. This section evaluates international practises by identifying strengths and weaknesses of each of the countries monitoring initiatives. This chapter therefore contextualises a potential monitoring programme for South Africa based on international practise and local conditions, thereby setting the scene for the design of a National Estuarine Monitoring Programme for South Africa.

Chapter 3 provides the basis of this thesis in the form of the NESMP protocol. This chapter alludes to the objectives of the NESMP, the methodology that was used for the programme design and presents the monitoring protocol. The NESMP protocol is presented in terms of methods to be used, spatial and temporal scales for national implementation, including prioritisation of estuaries, data archiving, data analysis and reporting. Finally, roles and responsibilities are identified and a management framework proposed. This chapter therefore addresses Objective 1, the design of the NESMP and has been published in a peer reviewed journal (Cilliers, GJ and JB Adams. 2016. Development and implementation of a monitoring programme for South African estuaries. *Water SA 42: 279-290*).

Chapter 4 evaluates the pilot testing of the NESMP between 2012 and 2016, based on the protocol that was identified and proposed in Chapter 3. Although the NESMP is currently being pilot tested on 28 estuaries across South Africa through collaboration between DWS and various roleplayers, time and space limitations allow for the examination of only two case studies in this thesis, namely the Berg and Breede estuaries. I lead this programme within the DWS thus providing the opportunity for this analysis. This chapter further makes recommendations for its full scale implementation on a national scale. It therefore addresses Objective 2 of the thesis, namely the testing of the National Estuarine Monitoring Programme.

Chapter 5 provides a Decision Support System for the NESMP. The objective of the DSS is to assist with making informed management decisions on estuaries, based on the data collected through the NESMP. The monitoring data collected and reflected on in Chapter 4 are analysed and used to illustrate the use of the data to inform management decisions through the use of the DSS. This chapter therefore addresses closing the data – information – management decision cycle through adaptive management and addresses Objective 3 and 4 of the thesis.

Chapter 6 provides conclusions and recommendations for the implementation of the National Estuarine Monitoring Programme based on the findings of the thesis. The success of the programme design and pilot testing are evaluated against the main objective of the thesis. The outcomes of the study are critically reviewed to identify potential complications with the long-term sustainability and implementation of the programme and requirements for future implementation of the programme and therefore address Objective 5.

Finally a detailed reference list and a series of annexures are provided. The annexures provide additional information in support of the design of the National Estuarine Monitoring Programme and the data collected between 2012 and 2016 on the Berg and Breede estuaries and used in Chapter 4.

CHAPTER 2. LITERATURE REVIEW

2.1. SOUTH AFRICAN ESTUARIES

Almost half of the world population lives in the coastal zone (Borja and Dauer, 2008). In South Africa the coastal zone acts as a major convergence point of people as a result of the available economic activities resulting in areas of high population density (Figure 1). The South African coastal zone contributes an estimated R57 billion (35% of the annual GDP) to the South African economy (DEA, 2014). Urban development along the coastal zone creates various environmental pressures, whilst catchment related activities including water pollution, water abstraction and agricultural activities further impact on estuaries. As such, estuaries are the final receiving environment for all catchment related perturbations, before discharge into the marine environment. During the past four decades, there has been substantial pressure on these productive ecosystems because of this anthropogenic activity.

Estuaries are defined by the National Water Act (Act no 36 of 1998) (NWA) as a partially or fully enclosed body of water – (a) which is open to the sea permanently or periodically; and (b) within which the seawater can be diluted, to an extent that is measurable, with freshwater drained from land. Estuaries that periodically close results in back flooding within the estuary and for this reason the estuary extends further and wider than during an open phase. This has management implications for estuaries. For this reason, the 5 m contour line (elevation above mean sea level) is used as the boundary of estuaries and is known as the estuary functional zone (EFZ) (Van Niekerk and Turpie, 2012). The EFZ is seen as the entire area associated with an estuary that ensures its functionality and therefore includes open water area, floodplains and salt marsh areas. Estuarine ecosystems function through a complex relationship between fresh and marine water. Various ecological drivers influence estuaries on a longitudinal and horizontal, spatial and temporal scale. These being, amongst others, salinity, temperature, turbidity, dissolved oxygen, river flow, tidal exchange, tidal range, sediment characteristics, littoral drift, geomorphology of the coastal belt and rainfall (Day, 1981; Whitfield and Elliot, 2002). Whitfield (2000) has done an extensive review of available information on South African estuaries.

Whitfield and Elliot (2002) indicated the difficulty in observing environmental and ecological change because of anthropogenic activity, primarily because of a high background variability that naturally occurs within estuaries. There is significant variability between and even within ecological drivers and processes that in turn drive the ecosystem response (generally changes in the biological composition) within estuaries. Ecosystem response indicators in estuaries include fish, macro-benthos, vegetation and birds (Whitfield and Elliot, 2002). In many instances, the distinction between drivers and response indicators in estuaries is not as clear as is the case in rivers. Ecosystem drivers in estuaries may also act as response indicators (i.e. mouth condition, hydrodynamics, sediment), which play a role in the estuarine habitat or template within which biological response indicators function. An example is mouth condition that acts as a driver by influencing the tidal exchange and therefore the fish or benthic community within the estuary, but also responds (thus being a response indicator) to river inflow, which dictates when and how the mouth opens to the sea (Figure 2). River flow and tidal exchange may in a similar manner act as drivers of water quality and sediment characteristics (response indicators), which are themselves drivers of the biotic response. Because approximately 80 % of South Africa's estuaries are temporarily open to the sea, mouth condition is a key aspect of estuarine ecology that can be used as an early warning system in determining estuary condition. It is therefore important to include both driver and response variables in estuary monitoring programmes.

Van Niekerk et al., (2013) did a comprehensive assessment of the health of South African estuaries and identified key anthropogenic pressures on estuaries as being freshwater inflow modification, water quality, artificial breaching of temporarily open / closed systems, habitat modification and exploitation of living resources. Freshwater inflow is critical for driving the natural variability of estuaries (Adams et al., 2016a) on which these systems resilience is based. Reduced freshwater inflow results in decreased flushing of estuaries and subsequent decreased breaching of the estuary mouth. Estuaries require a substantial higher base flow than rivers (Van Niekerk et al, 2015). Reduced freshwater flows do not alone alter estuarine functioning, but the timing and magnitude of floods also play a critical role in ensuring ecosystem resilience. This is specifically the case with temporarily open-closed systems. Reduced flows into estuaries because of upstream regulation by dams results in salinization of estuaries (Giliomee, 1994; Bate et al. 2002; Whitfield and Wood, 2003), which may render these areas less productive. A reduction in the freshwater flow into the marine environment has severe impacts on marine biodiversity and resources (Lamberth and Turpie, 2003). Ecological functions that change because of decreased freshwater flow to the marine environment include nursery function, environmental cues, productivity and food web processes (Van Niekerk and Turpie, 2012). Lamberth et al., (2009) indicated that decreased flow results in decreased nutrient input to the Thukela banks. This has resulted in impacts on the shoreline fisheries of the nutrient poor east coast of South Africa. Reduced flow also alters hydrodynamics and reduced sediment input into the marine environment, thereby having implications for beach and subtidal habitats (Van Niekerk and Turpie, 2012). According to these authors, the total freshwater flows to the marine environment have been reduced by approximately 40%. The biggest flow reductions have taken place in the largest rivers in South Africa including Orange, Breede, Thukela and Mzimvubu with subsequent changes in the marine environment. These functions are not only changed in the marine environment but also the estuarine environment.

Mouth manipulation results in a decreased use of estuaries as nursery areas by estuarine dependant species (e.g. fish). This flow reduction will be exacerbated because of climate change (Adams et al., 2016b). Indications are that the west will become drier because of decreased rainfall, while the east will become wetter as a result of increased rainfall. This potentially, will have substantial ecological consequences to estuarine systems. Whitfield et al. (2016) alluded to these potential changes and evaluated the potential role of climate change in the distribution changes of various organisms around the southern African coastline. The monitoring of some of these organisms to better understand the drivers and responses of climate change is highlighted as well as the importance of the combined impact of climate change and anthropogenic activities on the long and short term distribution of organisms.

Pollution from catchment related activities including agriculture, industry and human settlements impact on biota of estuaries. Lemley et al. (2014) described the scale of nutrient loading from catchments into the estuaries of the Gouritz Water Management area and indicated the role that locally based wastewater treatment works play in nutrient loading of estuaries. This study highlighted the importance of water quality monitoring of freshwater entering estuarine systems in order to identify management interventions. Lemley et al. (2015) indicated that eutrophication in estuaries usually results when there is high nutrient loading and low flushing rates of estuarine systems. Habitat change, because of urban development including housing, road and transport infrastructure expansion next to estuaries, influences the estuarine ecosystem. Over exploitation of natural resources including invertebrates, fish and vegetation for recreational, subsistence and industrial use also play a major role in ecosystem degradation. Invasive alien species, mariculture and desalination plants are emerging pressures that could pose a significant risk to estuarine biodiversity (Van Niekerk and Turpie, 2012). These impacts on estuaries are cumulative pressures in need of management intervention.

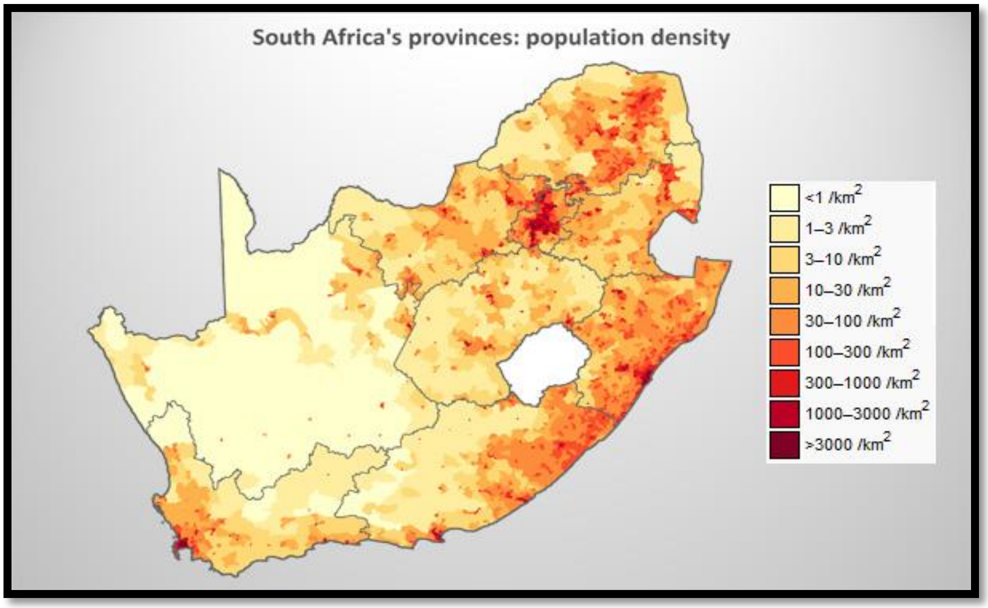


Figure 1 South African population density is highest in areas of economic growth, including the coastal zone (From:http://www.mediaclubsouthafrica.com/landstatic/163-provinces_new#population).

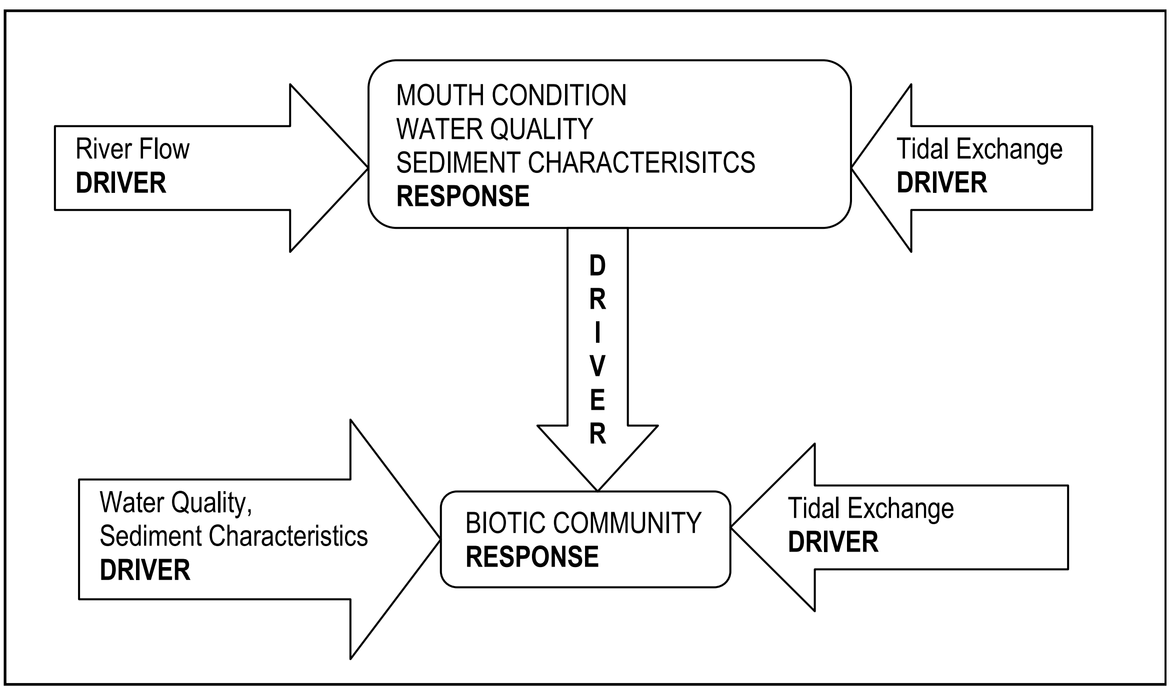


Figure 2 Interaction between drivers and responses in estuaries.

2.2. ESTUARY TYPES AND DISTRIBUTION

The National Biodiversity Assessment (NBA) classified 291 estuaries in South Africa into 46 estuarine ecosystem types (Nel et al., 2011). This is a refinement of the classification system developed by Whitfield (1992) which consisted of five types and is based on the key physical characteristics of estuaries (Table 1). The EFZ in South Africa covers 173 930 ha according to Van Niekerk and Turpie (2012). An assessment by Veldkornet et al. (2015) indicate the EFZ to be 186 887 ha and cover 304 estuaries / outlets. This indicates that the EFZ zone was underestimated by approximately 6.9% because of exclusion of some estuarine vegetation types. The latter work also included smaller, unnamed micro-estuaries or outlets. South Africa's estuaries are situated in three biogeographical regions (Figure 3) namely subtropical, warm temperate and cool temperate (Day, 1981; Whitfield, 1992; Whitfield, 1998, Whitfield and Balewa, 2013).

The subtropical region on the east coast of South Africa stretches from Kosi Bay on the border with Mozambique to the Mbashe Estuary on the southern border of the South African wild coast. These estuaries are generally small systems with limited catchment areas, although various ecologically important and large systems do occur. This includes the Kosi system, Lake St Lucia and the Thukela mouth. Important export harbours occur in this region and are associated with estuaries. This includes the Port of Richards Bay and Durban Bay. These ports are associated with industrial activities and associated urban sprawl. The tourism industry is also associated with various estuaries in the region, the most well-known being Lake St Lucia and Kosi Bay. The Wild Coast and its associated estuaries are also increasingly becoming tourism destinations. Mining activity associated with the mineral rich sands in the Zululand coastal plain takes place in the area and also puts pressure on the estuaries of the region. It is anticipated that mining activities will keep on playing an important socio-economic role and may expand to other areas within the region. According to Nel et al. (2011), 56 estuaries have National Freshwater Ecosystem Priority Area (NFEPA) status in this region. The National Freshwater Ecosystem Priority Areas (NFEPA) is a cross sectoral project that had as objective to align conservation and water sector policies and prioritise freshwater systems, including estuaries, for management intervention to ensure sustainable development of South Africa's water resources (Nel et al., 2011).

The warm temperate region stretches from the Mbashe Estuary, across the southern coast of South Africa to the Ratels Estuary (Figure 3). Various important and large systems occur in this area, including the Swartkops Estuary, the Knysna system and the Breede Estuary (one of the largest estuaries in South Africa). Activities associated with this regions estuaries include tourism (Knysna, Breede and Wilderness lakes), industrial (Swartkops and Buffalo estuaries), agricultural (Gamtoos, Kromme and Gourits estuaries) and harbour development (Buffalo and Coega estuaries). Urban sprawl is associated with most of the estuaries in this region that are not situated in protected areas. The urban sprawl is a result of tourism, industry and harbour developments. According to Nel et al. (2011), 52 estuaries have NFEPA status in this region.

The cold temperate region stretches from the Ratels Estuary to the Orange River mouth and has fewer estuaries in comparison the other two regions. This is as a result of the arid nature of the western part of South Africa. Due to the arid nature of this region, these estuaries play an important ecological and economic role and include the Olifants and Berg estuaries. Activities associated with this regions estuaries include tourism (Berg Estuary, Verlorenvlei), harbour development (Berg Estuary), agriculture and subsistence fisheries (Berg and Olifants estuaries). Mining of the mineral rich sands of the West Coast also occurs in the coastal zone, which have direct and indirect impact on these estuaries. It is foreseen that this impact will continue into the future as the need for raw material keeps on increasing on a global scale. According to Nel et al. (2012), 15 estuaries have NFEPA status in this region. The distribution of the estuary types according to Whitfield (1992) within the three biogeographical areas of the South African coast is reflected in Table 2.

Table 1 South African estuary types according to Whitfield (1992).

TYPE	CHARACTERISITCS
Temporarily open/closed estuaries	• Sand bars form in mouth of estuaries – a result of low river flows and longshore sand movement of the adjacent coast. • Flooding results in opening of the system / sediment removal. • Hypersaline conditions may develop during droughts. • Tidal and riverine inputs control water temperature when systems are open, but are independent during closed phases. • Marine, estuarine and freshwater biota occurs in these systems. • Approximately 75 % of South African estuaries in this category.
Estuarine Bay	• Water area covering more than 1200 ha which is permanently linked to sea with a very limited salinity gradient. • Hypersaline conditions are not common with water temperature being influenced by the sea. • Marine and estuarine biota dominate these systems, often with extensive wetlands and mangrove swamps.
Permanently open estuaries	• Vertical and horizontal salinity gradients dominate, which is a function of river flow, tidal range and mouth condition. The river-estuary interface in these estuaries is the productive zone where phytoplankton biomass is high, salinity is less than 10 and where filter feeding benthic invertebrates dominate (Bate et al., 2002). • Salt marshes and submerged macrophyte beds are common and the fauna is predominantly marine and estuarine. • Hypersaline conditions may occur in the upper reaches, especially during droughts. • Water temperature is dictated by the sea during normal flow conditions and by the river during flood conditions.
River mouths	• The riverine input dominates these systems resulting in olighaline conditions that are commonly found. • The mouth is generally permanently open and the tidal prism is small; the strong river outflow limits marine water inflow. • Water temperature is strongly influenced by the river inflow. • During flood events, the salinity level of the marine environment may be influenced over a large area adjacent to the river mouth.
Estuarine lakes	• Water area exceeds 1200 ha and are usually drowned river valleys filled in by reworked sediment and separated from the sea by vegetated dunes. • The dunes may result in the complete separation from the marine environment, resulting in a loss of estuarine function. These systems are then called coastal lakes. • These systems may be temporary or permanently linked to the sea and the associated salinity may be very variable as a result of freshwater input, evaporation and the marine connection. • Tidal prism is small, with marine and freshwater playing a small role in the temperature regime, which is mostly influenced by solar heating and radiation. Estuarine, marine and freshwater biota occur in these systems.

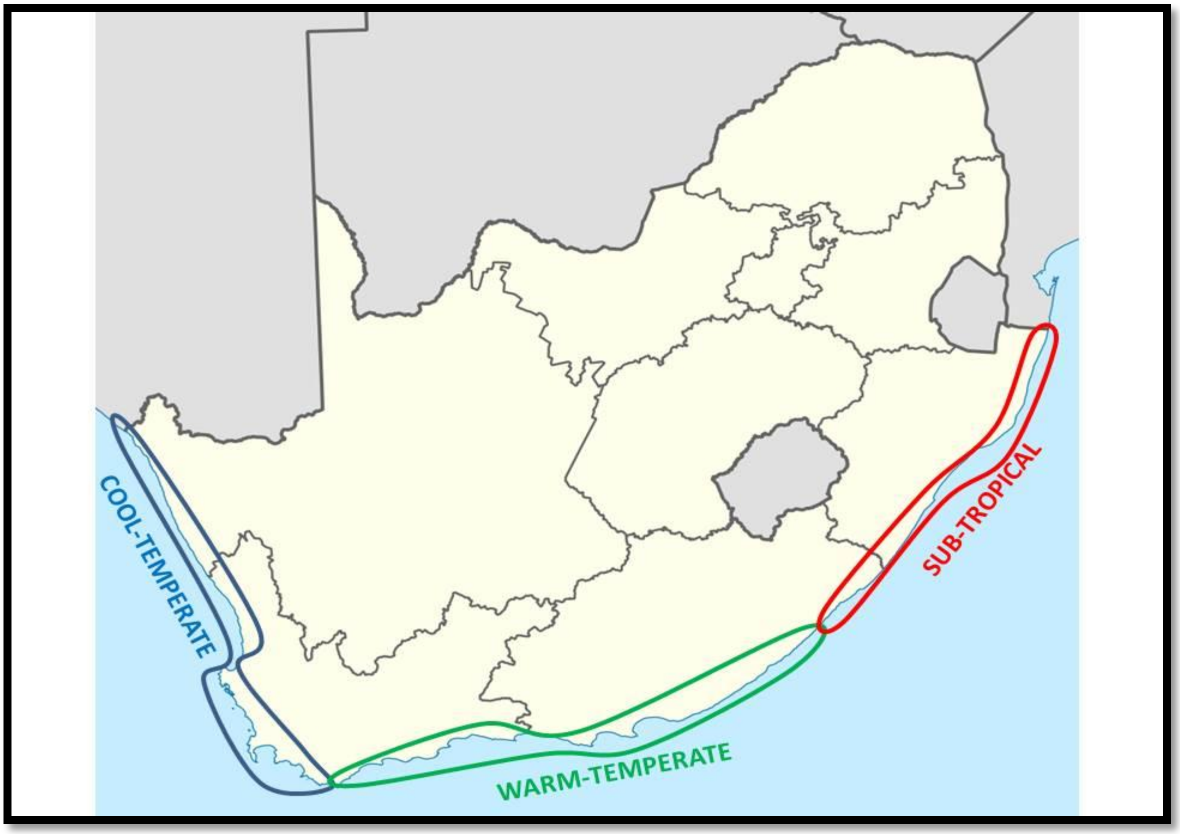


Figure 3 The three biogeographical regions of the South African coast (After Whitfield, 1998).

Table 2 Distribution of estuary types in the three biogeographical regions of the South African coast.

ESTUARY TYPE	BIOGEOGRAPHICAL REGION		
	SUBTROPICAL	WARM TEMPERATE	COOL TEMPERATE
Estuarine Bay	3	1	0
Permanently open estuary	16	29	2
Estuarine lake	4	4	0
Temporarily open closed estuary	94	86	5
Modified or canalised estuary	0	2	1
River mouth	4	6	2

The highest number of estuarine bays and temporarily open/closed estuaries occur in the subtropical region, while the highest number of permanently open and river mouths occurs in the warm temperate region. This is reflective of the role that rainfall plays in dictating the type and number of estuaries. This is further observable by the limited number of estuaries in the cool temperate region that are characterised by the winter rainfall of the Western Cape and the semi-arid nature of the west coast of South Africa. According to Van Niekerk and Turpie (2012), the functional zones for the subtropical, warm temperate and cold temperate regions are 102 746 ha (60% of total), 41 785 ha (24% of total) and 26 516 (16% of total), respectively. The largest EFZ area and percentage coverage also occur in the subtropical region, followed by the warm temperate region. The smallest EFZ and percentage cover occur in the cool temperate region. This is a further indication of the important role that rainfall and larger environmental characteristics play in the distribution of estuaries in South Africa.

Key findings of the National Biodiversity Assessment (Driver et al., 2011; Van Niekerk & Turpie, 2012) with reference to South African estuaries were that the Lake St Lucia system represents over 55 % of estuarine area in South Africa and is in a very poor condition. Forty three percent of estuary ecosystem types (20 of 46 types) are classified as threatened, representing 79 % of SA estuarine area. In addition 59 % (27 of 46 types) of South African estuarine ecosystem types are not protected, which makes up 83 % of South African estuarine area. According to Veldkornet et al. (2016) based on land cover classification, only 81 (28 % of total) estuaries were in a completely natural state without any infringement by anthropogenic activities, covering an area of 7 883 ha. Urban built up cover was associated with 275 estuaries covering an area of 6 630 ha and 168 estuaries covering 26 855 ha are infringed by cultivation.

2.3. ECOSYSTEM SERVICES

The term ecosystem services have been used since the 1970’s in publications by Westman (1977) and later by Costanza and Daly (1987). Costanza et al. (1997) indicated that ecosystem goods and services were the flow of material, energy and information from the natural and anthropogenic altered ecosystems to society. According to these authors the ecosystem goods and services are the benefits that human populations derive, directly or indirectly from ecosystem functions. The natural environment provides a range of ecosystems services to society. These services include provisioning services (such as food, water and other resources), regulating services (e.g. air and water purification), cultural services (e.g. aesthetic, spiritual, recreational, educational and cultural benefits), and life-support services (such as nutrient cycling and soil formation) (Breen and McKenzie, 2001; Reid et al., 2005; Van Niekerk and Turpie, 2012).

Estuaries are important nursery areas for juvenile estuarine and marine fish species (Day, 1981). Some species of fish enter estuarine nursery areas as juveniles and some as larvae (Beckley, 1985; Whitfield, 1998). This nursery function plays an important role in ensuring restocking of both estuaries and the marine environment. Strydom (2002) indicated that although different habitats in estuaries play an important role in the early development stages of estuary dependant fishes, the intricacies of estuary use or the factors driving the recruitment process into permanently open and intermittently open estuaries are not well understood and still open to debate. Lamberth and Turpie (2003) estimated that 50 % of 160 fish species occurring in estuaries are utilised in commercial, recreational or subsistence fisheries. Of these, approximately 60 % are entirely or partially dependant on estuaries. These authors indicated that annually approximately 2 480 tons of fish is taken directly from estuaries. This is substantially less than the fish taken from the inshore fisheries (28 000 tons) but, dependant on the bioregion and fishery sector, up to 83 % of the catch of inshore fisheries may comprise of estuarine associated fish (Lamberth and Turpie, 2003). Salt marsh plants can be used as alternative energy or food source due to their high oil and protein content. They can be potential sources of biofuel with a lower impact on the environment and food production than terrestrial sources of biofuel (Van Niekerk and Turpie, 2012).

Coastal wetlands and marine ecosystems are known for their ability to store carbon through biomass and sediment (McLeod et al. 2011, Duarte, 2009). Mangroves, marshes and submerged macrophytes remove carbon from the atmosphere and store this in the soil for millennia (Van Niekerk and Turpie, 2012). Estuarine ecosystems build up carbon pools, storing significant amounts of carbon in the sediment. When these systems are degraded through drainage or conversion to agriculture or mariculture, they emit large quantities of CO_2 to the atmosphere. Protecting estuarine ecosystems and the carbon they store can have significant benefit to coastal communities, with shoreline protection and increased fisheries productivity among the co-benefits provided by healthy estuaries. Through this, estuaries contribute to the resilience of coastal communities while sequestrating CO_2 (Van Niekerk and Turpie, 2012).

Estuaries provide a significant buffer against floods (Perkins et al. 2015). In South Africa, this takes place through a total open water area of 61 000 ha and floodplain area of approximately 171 000 ha of which 60 % is in the subtropical biogeographical region (Van Niekerk and Turpie, 2012,). Inappropriately development within the estuarine zone decreases the ability of estuarine ecosystems to provide this service to the surrounding landscape. Flow reduction results in a decrease in mouth breaching, thereby increasing the risk of flooding. Inappropriate timed mechanical breaching of estuaries results in a decrease in the flushing of sediment from the system. As a result, there is a long-term build-up of sediment that increases the risk of flooding during high rainfall events. Preventing inappropriate development within the estuarine zone and maintaining the required baseflows will ensure that this ecosystem service continues. The sand bar that develops at the mouth of temporarily open / closed systems, especially in the summer rainfall areas, protects the estuarine environment and associated properties against wave action, during severe sea-storms, which generally occur in the winter months (Van Niekerk and Turpie, 2012).

Estuaries are central hubs for business and associated community activities on the South African coast, as they provide for opportunities and benefits. Estuarine plants are used as building material and provide material for consumer and ecotourism related basketry (Van Niekerk and Turpie, 2012). Various studies in South Africa (Cooper et al., 2003; Lamberth and Turpie, 2003; Turpie and Hosking, 2005; Turpie and Clarke, 2007) indicate that estuaries contribute significantly to the local and national economy. Estuaries are seldom considered a local government asset, although their presence in a specific area, results in the generation of revenue through higher rates and taxes (Turpie and Hosking, 2005). This is associated with higher property values linked to waterfront property. In addition to this, estuaries also provide eco-tourism opportunities and sites for harbour development and associated industrial development. Coastal communities depend on estuaries as an important source of revenue (Van Niekerk and Turpie, 2012). The South African coast is exposed and offers few sheltered bathing areas because of this high energy coastline. Estuaries provide relative safe swimming areas as a result of their sheltered nature that are not influenced by near shore currents and high wave action (Van Niekerk and Turpie, 2012). This results in the increased recreational use and associated tourism development. Estuaries are valuable national assets providing essential ecosystem services that support ecosystem resilience and adaptation to climate change.

The use of estuaries should be balanced with the ability of estuaries to deliver services in order to ensure sustainable utilisation of these important ecosystems. Focussing on a wide range of complementary and sustainable uses, the greatest benefits can be generated for society at a minimal cost to society (Lambert and Turpie, 2003). In order to ensure the sustainable use of estuaries, it is important to have an indication of their current health status. Informed decision-making is therefore critical for their survival. This knowledge can only be acquired through systematic and consistent monitoring of the key health indicators of an estuary.

2.4. INTEGRATED WATER RESOURCE MANAGEMENT IN SOUTH AFRICA

South African water resources have increasingly become under pressure as a result of population growth and the post 1994 socio-economic landscape. This pressure is a result of consumptive and non-consumptive water use. More people require more water, which is a basic human right in terms of the South African constitution (DWS, 2016). This increased water requirement results in increased water harnessing for human use through damming and abstraction. At the same time there is increased pollution loading because of increased population growth. It has been stated that these pressures will become more evident on the water resources in South Africa during the next few decades (DWS, 2016). This may be as a result of changes in rainfall patterns due to climate change; increase in water demand due to higher temperatures and changes in the rate of biogeochemical and ecological processes that determine water quality. There will be an increase in unconventional oil and gas extraction in the form of hydraulic fracturing; population growth and urbanisation resulting in growth of inadequately serviced densely populated settlements; increased industrialisation and water demand due to the water-food-energy nexus (DWS, 2016).

Integrated Water Resource Management (IWRM) is the process which promotes the co-ordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Global Water Partnership, 2000). Integrated Water Resource Management is simultaneously a philosophy, a process, and an implementation strategy to achieve equitable access to, and sustainable use of water resources by all stakeholders at catchment, regional, national, and international levels. This should be achieved while maintaining the characteristics and integrity of water resources at the catchment scale within agreed limits. In the past water resource management has been typically fragmented in its approach. IWRM seeks to integrate the natural system, which is critically important with regards to resource availability and quality; and the human system which determines the resource use, production of waste and associated pollution of the resource. Through this integration, priorities for development should be set. Integration has to occur both within and between these categories. The cross-sectoral integration between water use sub-sectors, and the role that IWRM plays in their linkage is illustrated in Figure 4.

Integrated Water Resource Management is also required in terms of the National Water Act (Act 36 of 1998) (NWA) and is the cornerstone for current water resource management in South Africa. This concept is the foundation of the National Water Resources Strategy of South Africa (DWS 2016) and has recently been addressed through a DWS project on an integrated water quality management strategy to guide future water quality management in South Africa. The principles of this strategy encompass the improved alignment of policy and legislative framework, improved governance framework as well as efficient and affective water quality management practises and finally innovative financial mechanisms and improved knowledge and information management.

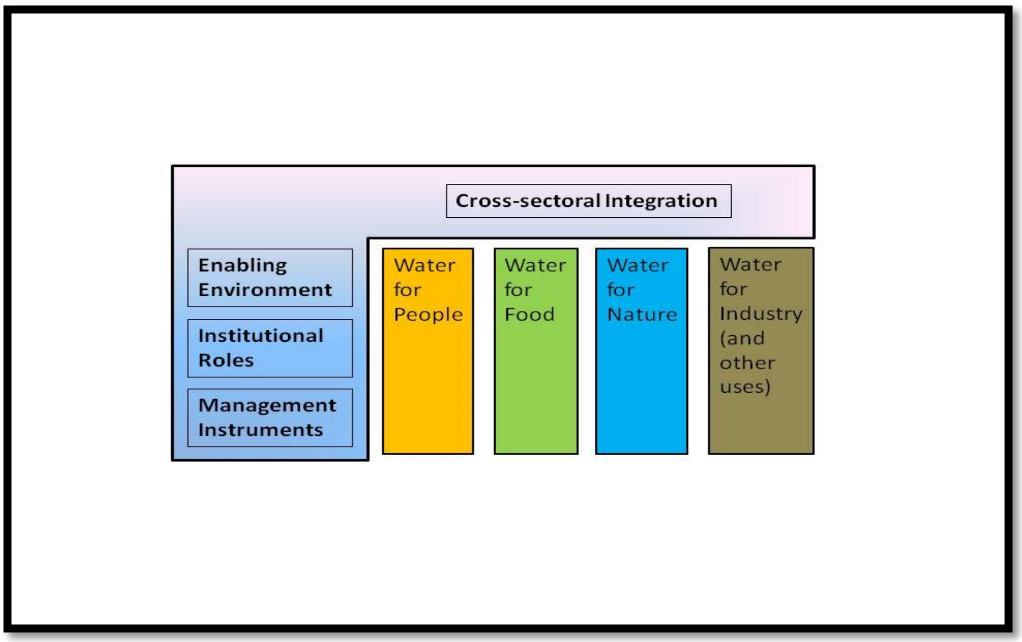


Figure 4 Cross sectoral integration between water and sub-sectors forms the basis for Integrated Water Resource Management (IWRM) (Adapted from Global Water Partnership)

The foundation of the Integrated Coastal Management Act (Act No 24 of 2008) (ICMA) is collaboration between all stakeholders and sectors involved with the co-operative management of estuaries. This is in line with Integrated Water Resource Management. There is currently an initiative to draft estuarine management plans, driven by Department of Environmental Affairs (DEA): Oceans and Coast (previously Marine and Coastal Management) amongst others (i.e. CAPE, through Cape Nature). Associated with this is the need for monitoring to provide data for management information and determine the success of these management plans. It is recognized that people at all levels in society in South Africa should participate in planning and decision making regarding the sustainable use of water resources. Through this, economic, social and environmental needs will be met.

2.5. ESTUARY MANAGEMENT IN SOUTH AFRICA

Sowman (1993) reviewed progress in South African coastal management in the early 1990's and indicated that progress in various fields has been made, but certain inadequacies still exist. These included absence of clear policies to guide management, lack of intergovernmental coordination and inadequacies in legislation and administrative processes. However, subsequent to this review, the ICMA and NWA came into effect. McGwynne and Adams (2004) indicated that an integrated management protocol should be followed that is iterative and adaptive, thereby providing managers and stakeholders with opportunities for learning through experience. Strategic Adaptive Management (SAM) is a management philosophy through which ecosystems are managed within the context of its dynamic characteristics. This type of management is founded on a philosophy that the actions and the objectives are subject to change as a result of the evidence provided through the management intervention and / or the societal changes that may be required (Scholes and Kruger, 2011). These dynamic characteristics are both internal and external features of ecosystems. Adaptive management states objectives provisionally, but also explicitly (Scholes and Kruger, 2011). Management actions that result from SAM are often seen as experiments from which learning can take place (Scholes and Kruger, 2011). The management interventions are undertaken on a specific scale and intensity to ensure that the outcomes are distinguishable against the natural variation within an ecosystem. The actions and the outcomes therefore need to be documented as part of the monitoring process.

Chapter 4 of the ICMA requires the establishment of estuarine management plans for all the estuaries in South Africa. This is to be facilitated through the DEA and the different provincial and municipal coastal committees. This recent development took a huge step towards filling a gap in the management of South African estuaries. Chapter 3 of the NWA requires DWA to set Resource Quality Objectives and to give effect to the ecological reserve. The Act recognises that water is a national asset. It establishes the concept of a reserve for basic human needs and the environment (the ecological reserve); a certain amount of water must be set aside for these components before licenses can be allocated for other water use. The ecological water requirements must first be determined so that the resource (the estuary) can be protected (Adams, 2014). This is currently the mandate of the Chief-Directorate Resource Directed Measures of DWA. This implies that the resource quality of all water resources (including estuaries) needs to be determined. The ecological reserves are set based on scientific information. The successful implementation of these ecological reserves and therefore the methods used, as well as compliance to these ecological reserves need to be audited, through a monitoring programme. Compliance monitoring has a different objective than a monitoring programme to determine the condition, or long-term trends in ecosystem health of estuaries on a national scale (DWAF, 2004b; Taljaard, 2003). There are however, commonalities that can provide the opportunity for an integrated approach to the design and implementation of a national estuarine monitoring programme. Chapter 14 of the NWA, mandates the Department of Water and Sanitation (DWS) to provide information on South Africa's water resources through the establishment of national monitoring systems and to coordinate water resource monitoring.

Various parties are mandated for the management of estuaries on a national, regional and local scale in South Africa through relevant legislation (Table 3). This includes the Department of Environmental Affairs (DEA), Department of Water and Sanitation (DWS), Department of Agriculture Forestry and Fisheries (DAFF), South African National Parks Board (SANPARKS), Regional Conservation Authorities (Ezemvelo/KZN Wildlife, CAPE Nature, etc.), catchment management agencies, local and district municipalities. The main national government departments responsible for co-operative governance of estuaries are DWS, DEA and DAFF. Not all institutions involved with estuarine research and monitoring are mandated through national legislation, although they play a key role in providing scientific data. This includes universities, parastatal research organisations and Non-Government Organisations (NGOs).

Table 3 Organisations playing a role in estuary management in South Africa, their mandates in terms of relevant legislation and identified roles in the National Estuarine Monitoring Programme.

ORGANISATION AND RELEVANT LEGISLATION	MANDATE	ROLE IN THE NESMP
Department of Water and Sanitation • National Water Act, 1998 (Act No. 36 of 1998)	• Management of all South Africa's inland water resources through the mandate of the NWA. • Protection of water resources through classification and EWR studies • Water Use Licensing • Setting charges for water use • Establishment of catchment management agencies • Establishment and management of monitoring programmes • Data storage and information generation on water quantity and quality	• National management programme • Financial support • Training • Logistical support • Database design and management • Information product generation • Reporting
DEAT : Marine & Coastal Management • Environment Conservation Act, 1989 (Act No. 73 of 1989) • National Environmental Management: Protected Areas Act, 2003 (ACT NO. 57 OF 2003) • National Environmental Management: Waste Act, 2008 (Act No. 59 Of 2008)	• Management and protection of coastal and estuarine resources; • Demarcating and adjusting the boundaries of the coastal zone; • Coordinate management of estuaries in accordance with an estuarine management protocol and provision for the drafting of estuarine management plans for individual estuaries; • Establishment of a statutory framework for institutional arrangement to ensure integrated and coordinated coastal management; • Set out management and planning procedures to ensure sustainable development within the coastal zone; and • Address marine and coastal pollution.	• Strategic management of programme • Data collection • Financial support • Logistical support
DEAT : REGIONAL OFFICES • Environment Conservation Act, 1989 (Act No. 73 of 1989) • National Environmental Management: Waste Act, 2008 (Act No. 59 Of 2008) • Environment Conservation Act, 1989 (Act No. 73 of 1989)	• Regional environmental management • Regional environmental monitoring • Management of the environmental authorisation process • Evaluation and approval of Environmental Impact Assessment • Environmental enforcement	• Data input (from EIA's, EMP's, EMPR's) • Development based audit information – from EIA'a , EMP's . • Data collection • Strategic management support • Programme coordination • Financial support • Logistical support • Human resource support
DAFF • Marine Living Resources Act, 1998 (Act No. 18 of 1998)	• Allocation and management of fishing rights, regulating recreational fishing, protecting and monitoring coastal and estuarine resources, conduct research on and advice on status of fish stocks and promoting mariculture	• Data collection • Logistical support • Strategic management support

ORGANISATION AND RELEVANT LEGISLATION	MANDATE	ROLE IN THE NESMP
Department of Science and Technology: South African Earth Observation Network (SAEON) • National Research Foundation Act, 1998 (Act No. 23 Of 1998)	• Establishment of long-term environmental monitoring baseline in support of research initiatives	• Database design and management • Data collection • Data archiving • Strategic management support • Financial support
Regional and local conservation bodies • National Environmental Management: Protected Areas Act, 2003 (Act No. 57 of 2003) • National Environmental Management: Biodiversity Act (Act No. 10 of 2004) • Environment Conservation Act, 1989 (Act No. 73 of 1989) • Marine Living Resources Act, 1998 (Act No. 18 of 1998)	• Establishment and management of local and regional protected area	• Local management of programme • Data collection • Logistical support
Local and regional municipalities • The Organised Local Government Act, 1997 (Act No. 52 of 1997) • The Municipal Systems Act, 2000 (Act No. 32 of 2000) • The Intergovernmental Relations Framework Act, 2005 (Act No. 13 of 2005)	• Coordinate the national and provincial organisations that represent different categories of municipalites • Facilitate local and regional municipal management • Promote intergovernmental relations • Social and economic upliftment of local communities • Provide for community participation; • Ensure local public administration and human resource development; • Empower the poor • Integrating activities of all spheres of government for social and economic upliftment of communities in harmony with their local natural environment.	• Local management of programme • Data collection • Human resource support • Logisticalsupport
Academic Institutes	• Undertake basic ecological research	• Data collection • Logistical support • Specialist support • Applied ecosystem research
Para-Statals		
Water Research Commission (WRC) National Water Research Act, 1971 (Act No. 34 of 1971)	• Coordinating research related to sustainable use of South African water resources	• Finanacial provision for applied research
Oceanographic Research Institute (ORI)	• Basic research, technological development and awareness-raising on the South African marine and	• Applied research

ORGANISATION AND RELEVANT LEGISLATION	MANDATE	ROLE IN THE NESMP
n/a	coastal environment	
Council for Scientific and Industrial Research (CSIR) • Scientific Research Council Act, 1988 (No. 46 Of 1988)	• Responsible for research and technological development on various fronts including the sustainable use of South African natural resources	• Applied research Specialist support Data provision Strategic management support
South Africa National Biodiversity Institute (SANBI) • National Environmental Management: Biodiversity Act (Act No 10 of 2004).	• Play a leading role in South Africa's national commitment to biodiversity management. In partnership with the Department of Environmental Affairs and the biodiversity sector, SANBI is tasked with leading the biodiversity research agenda.	• Strategic management support
South African National Parks (SANParks) • National Environmental Management: Protected Areas Act, 2003 (Act No 57 of 2003).	• In terms of this act, the primary mandate of SANParks is to oversee the conservation of South Africa's biodiversity, landscapes and associated heritage assets through a system of national parks.	• Specialist support • Data collection • Logistical support • Human resource support
NGO (WWF, Conservancies) n/a	• Support sustainable management of coastal resources	• Financial support • Research support • Data collection • Logistical support • Local Programme coordination

2.6. ESTUARY CLASSIFICATION, RESOURCE QUALITY OBJECTIVES AND RESERVE DETERMINATION

Chapter 3 of the NWA specifically address the protection of water resources through the creation of a classification system and setting of Resource Quality Objectives (RQO) (Chapter 3, Part 1 and 2), The Reserve (Chapter 3, Part 3), pollution prevention (Chapter 3, Part 4) and emergency incidents (Chapter 3, Part 4). The Reserve consists of (a) the basic human needs and (b) the ecological water requirements. The Reserve specifically addresses water requirements of aquatic ecosystems in the form of ecological water requirements (EWR). The basic human needs reserve provides for the essential needs of the individual for drinking, food preparation and personal hygiene. The ecological water requirements relate to the water required to protect the aquatic ecosystem and will vary depending on the class of the resource. Only after this is guaranteed, water use for other uses including agriculture and industry is allocated. This ensures a balanced approached to water use and water conservation. The classification system classifies water resources, based on their current condition and current pressures in order to set management targets. Linked to the classification system is the setting of RQO's to provide clear objectives to guide management of a specific water resource. These

RQO's are gazetted in the South African Government Gazette and therefore have legal standing. The RQO's explicitly state a Threshold of Potential Concern (TPC) for each constituent (water quality, biological components and habitat) that act as a trigger for management intervention. The use of TPC's are a recent development in South African water resource management. They are developed as part of the RQO studies and depend on expert opinion and therefore, are in most cases subjective. Once TPCs are reached management intervention is required to address and rectify environmental perturbations.

The licensing process acts as the trigger for the determination of the Reserve. The required process resulted in the creation of various classification and ecological water requirement tools by DWS and other related entities to ensure sustainable use of South African water resources (DWAF, 2008). Various methods were developed for the determination of ecological water requirements of estuaries (Adams, 2012; Adams, 2013; Adams et al., 2016b). Adams (2012) stated that these methods are data intensive and advocate that long-term monitoring is essential to understand estuarine ecosystems and the role freshwater inflow alteration plays in the sustainability of these systems. Monitoring data is therefore critical to set EWR's for estuaries (Pierson, 2002; DWA, 2008a; Adams, 2012; Adams et al., 2016a; Adams et al., 2016b). Finally, it is stated that the implementation of water requirements for estuaries are dependent on the presence of strong governance structures, stakeholder participation, monitoring (Adams, 2012; Adams, 2014). The generic methodology used to determine the EWR of estuaries are reflected in Figure 5.

Central to the data requirements for the EWR of estuaries is the Estuarine Health Index (EHI) as developed by Turpie et al. (2012b). This consists of a weighted habitat and biotic health score that is combined to give the EHI score (Table 4). The weighted score for each component is calculated using the following equation:

$$\text{SCORE (out of 100) x WEIGHT/100}$$

The Habitat Health Score is calculated by summing each of the weighted scores of each components for habitat health and the biological health scores by summing all the weighted scores for the components for the biotic health score. The overall Estuary Health Score is determined by calculating the average of the Habitat Health Score and the Biotic Health Score.

The Estuary Importance Rating (EIR) is based on a weighted score for estuary size, zonal rarity type, habitat diversity, biodiversity importance and functional importance (Table 5). This is calculated in a similar manner as the EHI and also requires knowledge of the system, based on long-term data. Where long term data are not available, once off surveys and expert opinion are used for the data intensive components in Step 2 and 3 of the EWR method (Figure 5).

The EHI and EIR for the Berg Estuary are reflected in Tables 4 and 5. This translated into a Present Ecological Status (PES) of 64, placing the Berg Estuary into a Category C, which is a moderately modified estuary. The Resource Quality Objectives (DWA, 2012) took various flow scenarios into consideration as well as the current and future development pressures. The study also investigated the feasibility of various environmental interventions, including increased flows, better agricultural practices and decreased pressure on biological resources. With all of these factors in mind, the outcome of the RQO study was that the estuary should be managed as a Category C estuary, instead of striving to achieve Category B. Linked to this RQO were a series of TPC's (DWA, 2012) to ensure that the RQO's are achieved. TPC's have successfully been used in river management in South Africa, specifically in the Kruger National Park (Mchloughlin et al., 2011), where it evolved from terrestrial application. These TPC's are explicit statements on specific estuary components, for example as used in the Berg EWR study (DWAF, 2007):

"*Estuary (low flows < 1* m^3s^{-1}*, summer): DIN >300 µg/l; DRP >100 µg/l in Zones A and B DIN >80 µg/l; DRP >30 µg/l in Zones C and D*" and "*Estuary (high flows > 5* m^3s^{-1}*, winter): DIN >800 µg/l; DRP >60 µg/l in Zones A-D*"

As part of the EWR study a specific monitoring programme is also drafted to ensure that the implementation of the reserve is monitored. The main components of this monitoring programme is 1) collection of additional 'baseline' data where needed and 2) long term monitoring to evaluate the implementation of the reserve (DWAF, 2008a; DWAF, 2008b). The priority indicators required for the long term monitoring programme include hydrodynamics, sediment dynamics, water quality, microalgae, macrophytes, invertebrates, fish and birds (Appendix A). These monitoring programmes are however labour intensive, expensive and the practical implementation is hampered by logistical and budget constraints.

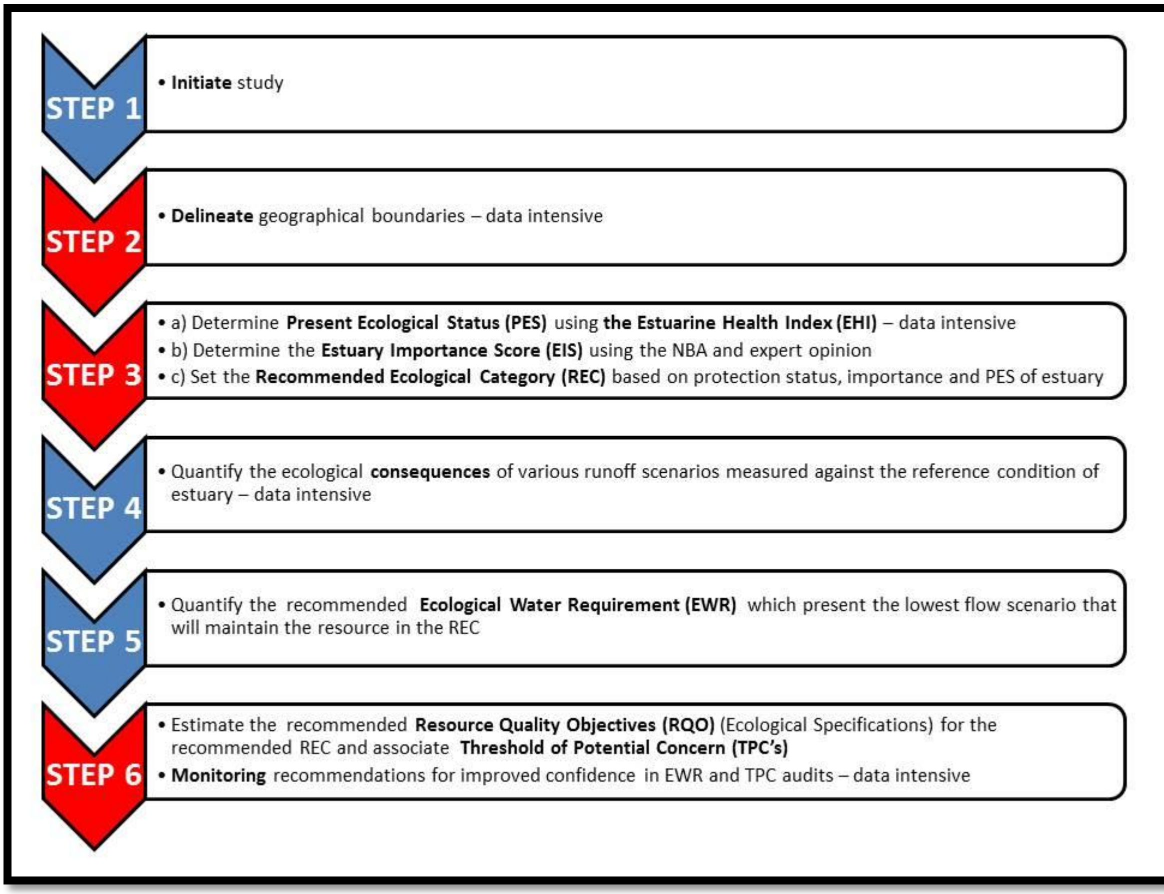


Figure 5 Generic method used to determine the Ecological Water Requirement (EWR) of estuaries (After DWAF, 2008a and Turpie et al., 2012a).

Table 4 The Estuarine Health Index that was calculated for the Berg Estuary (DWA, 2012) that forms the basis of the Ecological Water Requirment study (after Turpie et al., 2012b).

VARIABLE	SCORE	WEIGHT	WEIGHTED SCORE
Hydrology	72	25	18
Hydrodynamics and mouth condition	90	25	23
Water quality	40	25	10
Physical habitat alteration	59	25	15
Habitat Health Score			**65**
Microalgae	75	20	15
Macrophytes	54	20	11
Invertebrates	50	20	10
Fish	56	20	11
Birds	78	20	16
Biotic Health Score			**63**
ESTUARY HEALTH SCORE (Mean of Habitat and biotic health)			**64**

Table 5 Estuary Importance Rating for the Berg Estuary (DWA, 2012) that forms part of the EWR study (after Turpie et al., 2012b).

CRITERION	SCORE	WEIGHT	WEIGHTED SCORE
Estuary Size	100	15	15
Zonal Rarity Rating	90	10	9
Habitat Diversity	100	25	25
Biodiversity Importance	98	25	25
Functional Importance	100	25	25
Weighted Estuary Importance Score			**99**

Four levels of assessment of EWRs exists (DWAF, 2008a). The desktop assessment makes use of available data in a desktop approach and has a low level of confidence. This assessment is usually used for water resource strategy planning (Van Niekerk et al, 2015). The rapid determination makes use of existing data and is a more detailed assessment than the desktop and may include limited field work. This level of assessment is used for individual licensing of small impacts in unstressed catchments of low importance and sensitivity. Intermediate determination is also based on existing data but is a more detailed assessment and will entail additional fieldwork ensuring a more comprehensive study. This assessment is used for individual licensing in relatively unstressed catchments. A comprehensive determination entails a detailed study of a catchment. This level of assessment also makes use of existing data and extensive field work by a group of specialists. This level of assessment is used for all compulsory licensing of large impacts in any catchment and / or small to large impacts in very important and / or sensitive catchments. The criteria used for assessing the appropriate level of determination include the degree to which a catchment is already utilised, the sensitivity and importance of the catchment and the potential impacts of the proposed water use (DWAF, 2007).

Currently EWR studies have been conducted on 40 % of South Africa's estuaries (Adams et al., 2016) of which the majority (69 %) have been completed as low confidence desktop or rapid assessments. The EWRs of half of South Africa's permanently open systems have been determined. Adams et al., (2016b) indicated that each estuary is unique in terms of its EWR. Water release from dams cannot mimic the entire natural flow regime, and floods are critical to reset estuarine systems. These authors also indicated that increased flows as a result of wastewater input and agricultural return flows result in more frequent mouth breaching of estuaries, resulting in unstable conditions in open / closed systems. The associated deterioration of water quality in South Africa is a concern and an integrated catchment to sea management approach is needed to ensure connectivity. This will require co-operative governance to address non-flow related impacts and improve estuarine health. The role of groundwater in estuaries is unknown and the off-shore marine environment also has a EWR, which is currently not part of the legal framework. Finally Adams et al. (2016b) indicated that long-term field data is required for high confidence EWR's and that monitoring must take place in a strategic adaptive management cycle.

It is clear that substantial progress has been made in term of estuary management over the past fifteen years as a result of various legislative requirements included in the NWA. This includes the requirements for EWR and classification studies of South African water resources, which includes estuaries. These studies are however dependant on robust long term datasets. In the South African context data have been generated on estuaries over the past 50 plus years, but this was as a result of disjointed, focused research studies, with very little room for comparison on a national, long term scale. International monitoring programmes have been able to collect relevant long term dataset to inform environmental management decisions, as a result of matured environmental awareness and associated financial commitment. The South African context does however not lend itself to the collection of long term data in a similar manner as is the case in the USA, Europe and Australia due to major financial and capacity constraints. The South African situation is complicated by the socio-political change since 1994, resulting in a reprioritisation of government funding for much needed socio-economic empowerment of previous disenfranchised communities. In order to address the lack in long term data and limited resources to address this, it is critical to evaluate international estuarine monitoring practises in terms of it practicality in a South African context.

2.7 TECHNOLOGICAL ADVANCES IN ESTUARINE MONITORING

Internationally, technological advances over the past three decades have facilitated more efficient monitoring of estuaries. Chapman and Wang (2001) reviewed chemical, toxicological and community level assessments of estuaries and acknowledged the complexity of estuaries, thereby directly implicating the complexity of estuarine monitoring. These authors identified the need to tailor assessment techniques specifically for estuaries. Sindermann (1988) and Morrison (1986) made the same conclusion in the review of the biological indicators for estuarine and coastal pollution. Scott et al. (2006) evaluated the use of events-based sampling from passive samplers fitted to ferries in the USA and concluded that intensive nutrient sampling do have merit in understanding system responses better to pollution incidents, in comparison to systematic, but once off sampling. Danovaro et al. (2016) reviewed innovative marine monitoring approaches. This included molecular approaches with the use of microarray, real time quantitative PCR and metagenetic tools; remote sensing and acoustic methods; and in situ monitoring instruments. Although this reviews focus was on the marine environment these new technologies do show potential use within estuaries for routine monitoring. This would include the use of meta-barcoding to detect indicator species (sensitive or pollution tolerant species and invasive species) and changes in community structure. This can be used for microbes, meiofauna and macrofauna (Danovaro et al., 2016). This method is becoming more cost effective but has some technical problems resulting in over or under estimation of biodiversity as a result of variability in primers, Polymerase Chain Reactions conditions, sequencing technology and bioinformatics. These shortcomings should however be resolved as this technique is used and developed further in future. Real time polymerase chain reaction (qPCR) can quantify unicellular organisms and are also used for detection of microbial organisms. These methods are already being developed to detect E coli and faecal enterococci as an indicator of sewerage pollution (Agudelo et al., 2010); detection of viruses in freshwater in the Tyume river, Eastern Cape, South Africa (Sibanda and Okoh, 2013); and large scale studies on the microbial quality of the ground and surface water resources of the North West Province, South Africa (WRC, 2013). Microarrays being deployed in situ are being used to detect toxic algal species in the EU through their MIDTAL project (Danovaro et al., 2016).

In situ “smart bouys” can be fitted with chemical sensors and cameras to provide real time data. These buoys can be moored or roving. DWS is currently involved with a project to investigate the use of these real time stationary buoys in the Knysna Estuary, forming part of a larger monitoring programme. Biosensors and acoustic monitoring also show great promise for use in estuarine monitoring and is currently used in South Africa in the Breede River to detect shark, cob and grunter movement by DAFF and by SAEON across the South African coastline to detect fish migration, water quality changes and tidal variation. Cowley et al. (2008) also made use of acoustic telemetry to determine the movement patterns of juvenile dusky kob *Argyrosomus japonicas* in estuaries while Bennett et al. (2015) monitored the movement of juvenile Steenbras *Lithognathus lithognatus* with the same method. Becker et al., (2016) monitored the movement of fish into and out of estuaries, making use of a dual frequency acoustic camera on the Bhirha Estuary on the Warm Temperate east coast of South Africa. Artificial structures to monitor hard bottomed benthic invertebrates and high resolution sampling for zooplankton biodiversity studies also show promise for use in estuaries. Artificial mussels are already being tested in South Africa to determine metal contamination in harbours (Degger et al., 2011). Remote sensing can specifically detect eutrophication in dams (WRC, 2015; Xiang et al., 2015) and rivers and can also be used in estuarine assessments. The importance of abiotic indicators to detect eutrophication levels was highlighted by Lemley et al., (2015). Currently the DWS are involved with remote sensing studies on various dams in South Africa, for potential future use in routine monitoring.

2.8 INTERNATIONAL ESTUARY MONITORING

This review gives a synopsis of international trends and best practice in estuarine monitoring, thus setting the scene for the design and implementation of a South African National Estuarine Monitoring Programme (NESMP). In no way is this review intended to evaluate all estuarine monitoring programmes across the globe, but rather to discuss specific monitoring initiatives and create an information base from which to evaluate international trends and best practise and compare against the current practises in South Africa.

Borja et al. (2008) did an overview of integrated tools and methods in assessing the ecological integrity in estuarine and coastal systems, focussing on the United States of America, Australia, Asia and South Africa. Hallett et al., (2016a; 2016b; 2016c) did a more recent review of monitoring initiatives in Australia, United States of America, the European Union and South Africa. Estuarine management and associated monitoring worldwide is underpinned by the DPSIR (Drivers-Pressures-State-Change-Impact-Response) approach (Hallet et al. 2016c), *Drivers* are basic human needs that result in activities, which create *pressures* on the environmental *state* change. State *change* results in *impacts* on human welfare, which in turn require responses (Hallet et al., 2016c).

Water resource management depends on robust scientific data that is interpreted to provide management orientated information. Without the necessary data human induced perturbations cannot be identified and management intervention actioned. Limited work has been undertaken to coordinate and establish monitoring programmes for estuaries. This was noted in an international context by Pearce and Depres-Patanjoa (1987), but substantial progress has been made over the past 20 years in the USA and Australia. The transformation of scientific research information into environmental management strategies was identified as an issue needing to be resolved within the European Union (EU). The transfer of information between intrinsically different fields is complicated but essential. Elliot et al. (1999) discussed the implementation of certain statutes, the role of scientists and the nature of the data required, using examples from the UK, the Netherlands and Portugal. These authors found that the science should focus on monitoring and assessment in a well-structured and quality control manner. The European Framework Directive, the USA National Coastal Assessment (NCA) and National Estuaries Programme (NEP) are examples of how monitoring and assessment was translated into a practical, albeit complex structured process in a quality controlled environment. The need for structure and quality controlled in monitoring initiatives has also been identified in the South African context (DWAF, 2004a; DWAF 2004b; DWAF, 2004c; DWS, 2016).

2.8.1. United States Of America: National Coastal Assessment (NCA) And National Estuaries Programme (NEP).

The Clean Water Act requires that the United States Environmental Protection Agency (USEPA) periodically reports on the condition of the USA national estuarine waters through the National Coastal Assessment (NCA) initiative. This is also a requirement of Chapter 14 of the the NWA for the South African condition. The coast is divided into five coastal regions namely Northeast Coast, Southeast coast, Gulf Coast, West Coast, and Puerto Rico (U.S. EPA, 1997). The National Estuary Programme (NEP) developed subsequently from the NCA. The NCA surveys reported on estuarine condition on a state, regional and national level, while the NEP focussed on specific estuaries (Kennish, 2001a; Kennish 2001b; Kennish, 2004) and therefore reported on geographical areas smaller than a state (Table 6). Water quality modelling also play an important role in contributing information to these regional and local assessments and associated decision making as was the case in the Neuse River estuary in The United States of America (Wool, 2003). The application of citizen science also was evaluated in support of larger formalised state driven monitoring programmes. The MySound initiative on Long Island is one example of this (Tedesco et al., 2003). Citizen science is also an emerging discipline in the South African context that shows promise to support existing monitoring initiatives. The NCA surveys were not designed to provide the temporal or spatial variability of various indicators within an estuary and therefore did not provide estuarine specific locations of poor, fair or good conditions. The NCA sampling was developed to be randomized on a spatial scale, while the NEP targeted areas of specific concern / interest (U.S. EPA, 1997). The NCA therefore provides a strategic overview of the larger area and was not intended to answer estuary specific management questions. As such the NCA provide limited guidance for site specific management intervention. The development and the context of the NEP to the NCA are indicated in Figure 6. The NCA data provide a snapshot overview of estuaries in general on a national scale, whilst the NEP data provided longer term, more intensive data on changes of the biotic and abiotic components of the 28 prioritised estuaries. The National Estuary Programme Coastal Condition Report reports on the 28 prioritised estuaries identified as part of the EPA's national coastal assessment (NCA) and data collected by individual NEP's in partnership with state environmental agencies, universities, or volunteer monitoring groups. 1239 NCA sites were sampled in the NEP estuarine areas since 2001. Five ecological indices have been developed for these assessments; a water quality index, sediment quality index, benthic index, coastal habitat index and a fish tissue contamination index. A similar estuarine health index was developed for use in South Africa by Turpie et. al. (2012). In addition the National Oceanic and Atmospheric Administration (NOAA) also applied research through their National Estuarine Eutrophication Assessment on the levels of eutrophication in estuaries of the United States. The results from these surveys are periodically compiled and published as the National Coastal Condition Reports The reports provide coastal monitoring data, coastal ocean condition data, offshore fisheries data and advisory data. Five Coastal Condition Reports have been published since 2001, the most recent being in 2012 (EPA, 2001; EPA, 2004, EPA, 2008, EPA 2012).

Table 6 Comparison of the U.S.A National Coastal Assessment and the National Estuary programme.

	National Coastal Assessment (NCA)	**National Estuary Programme (NEP)**
Operational level	Strategic State – e.g. Florida Regional – e.g. Gulf of Mexico National – e.g. entire USA	Local. Geographical areas smaller than a state e.g. – Barnegat Bay National Estuary Programme
Number of estuaries	All on state, regional and national level	28 prioritised estuaries in 18 states and Puerto Rico
Output	National Coastal Condition Report (NCCR)	National Estuary Programme Coastal Condition Report (NEP CCR)

2.8.2. Europe: The Water Framework Directive (WFD)

The United Nations Economic Commission for Europe (UNECE) and the United Nations Environmental Programme (UNEP) advocated a co-ordinated regional approach for resolving water related problems of transboundary water, which include estuaries. This is similar to the South African situation where transboundary collaboration is advocated through the NWA. The ORASECOM initiative for collaborative management and monitoring of the Orange River basin between South Africa, Lesotho, Botswana and Namibia is an example of this. Countrywide collaborative management of the South African coastal zone is also supported through the ICMA. An inventory of transboundary estuaries in the UNECE region was compiled with an overview of the monitoring practices in these estuaries (Nöjd, 2003). This overview found that monitoring of these estuaries was based on national water laws, the EU Directives and to some extent on various international agreements.

The European Water Framework Directive (WFD) (European Communities, 2000) was established as a framework for the protection and enhancement of all European water resources, including estuarine and coastal waters (Impress, 2002; Borja, *et al*., 2005) as part of larger river basins. This is also the foundation of South African legislation in the form of the NWA and ICMA. In the WFD, this is to take place through specific measures for the progressive reduction of discharges, emissions and elimination of priority substances (European Communities, 2000). Achievement of at least good ecological quality status for all water bodies, based on biological, hydromorpological and physico-chemical quality elements by 2015 was originally the overall objective of the WFD. The WFD specified that member states should actively encourage the involvement of interested parties in the implementation of the directive and development of river basin management plans (RBMP). A similar situation exists in South Africa through the establishment of Catchment Management Agencies (CMA), where all relevant parties have a role to play in the management of water resources on a catchment base, as per the NWA. In addition collaboration is also advocated for the management of the South African coastal zone through the ICMA. The management plans in the WFD, need to be reviewed and amended if required every six years. Integration is the pivotal point to the implementation of the WFD (European Communities, 2003a). Accordingly, water resources need to be managed based on biological and ecological elements, with the ecosystem forming the centre of management decisions (Borja, et.al., 2005). Birk et al., (2012) evaluated 297 assessment methods using aquatic organism groups in 28 countries in the EU as part of the WFD. These authors found 28% of the methods were based on macroscopic plants, 26% on benthic invertebrates, 21% on phytoplankton, 15% on fish and 10% on phytobenthos. Only 19% of these methods were for transitional waters (estuaries and coastal waters). These authors advocated better reflection of the necessary sampling effort and precision, full validations of pressure-impact relationships and an implementation of more ecological components into classification. The NWA also advocates the use of this integrated approach in South Africa through the Classification process. The WFD should be applied to all European water resources as a whole and management should be based on the entire river basin, including the coastal zone. Several working groups were created to deal with technical issues of which the COAST working group dealt specifically with transitional (estuarine) and coastal waters (Borja et.al., 2005). Transitional water can extend as a plume into the coastal water as a result of high freshwater flow into an estuary from the associated river. Transitional water is usually characterized by morphological and chemical features in relation to the size and nature of the inflowing water (European Communities, 2003b).

The COAST working group was established to produce a practical Guidance Document for implementation of the WFD in transitional and coastal waters in 2001. The COAST document was not prescriptive and it was indicated that the document needed to be adapted for local circumstances. It also indicated that further development work was required for the classification scheme for coastal and transitional waters. In accordance with the WFD each of the member states is responsible for certain actions including monitoring and reporting (European Communities, 2003a).

The WFD therefore endorses the concept that classification, monitoring and management are interlinked and support each other. Article 5 of the directive required that all the river basins need to be characterized and the human impacts reviewed in accordance to Annex II (European Communities, 2000). Classification of water resources is also the basis for the NWA and associated water resource management in South Africa. The relationship between Article 5 requirements (waterbody characterization and risk assessment) and Article 8 (monitoring requirements) are illustrated in Figure 7.

Estuaries generally form part of a larger monitoring programme that may also include fresh or coastal water or a programme that covers all surface water. Monitoring was defined in the WFD as the gathering of data and information on the status of water and does not include the direct measurement of emissions and discharges to water. The WFD provided guidance regarding the spatial scale of monitoring sites relevant to bodies at risk from significant point sources, diffuse sources and hydromorphological pressures. The WFD did not dictate temporal and spatial scales of monitoring, but advised that each member state had to determine these scales based on state specific conditions. The WFD indicated further that the number of sites needs to be sufficient to access the magnitude and impact of the pressures and be scientifically and technically justifiable (European Communities, 2003a).

The key principle of the WFD is that the use of abiotic indicators in support of estimating the condition of a biological element, should complement the use of biotic indicators, but it should not replace it (Borja et al.,2005). In these instances the monitoring programmes needed to be designed in such a manner that the temporal scale of the biotic and abiotic assessments was not the same. Assessments of these two elements however needed to coincide when they were undertaken together. Without comprehensive knowledge of all the pressures on a water body and their combined biological effects, direct measures of the condition of the biological quality elements using abiotic indicators will always require validation of any biological impacts suggested by abiotic indicators. This however did not preclude only the use of abiotic indicators and would depend on specific conditions in the water body being investigated. Indicators should be chosen for which reference conditions can be determined and for which monitoring errors are small and well known (Borja et al., 2005). The WFD indicated that the biological quality elements had to be at an appropriate taxonomic level to achieve adequate confidence and precision during classification of the quality elements.

Hering et al., (2010) evaluated the successes and problems encountered during the implementation of the WFD between 2000 and 2010. They concluded that the development of the assessment methods were a transparent process, which resulted in standardised and improved tools for assessing water bodies in the EU. The process did however take longer and were more complex than anticipated. They also indicated that huge amounts of data are generated which resulted in major data management and distribution challenges. Finally they concluded that the timescale of achieving good ecological status by 2015, was over ambitious.

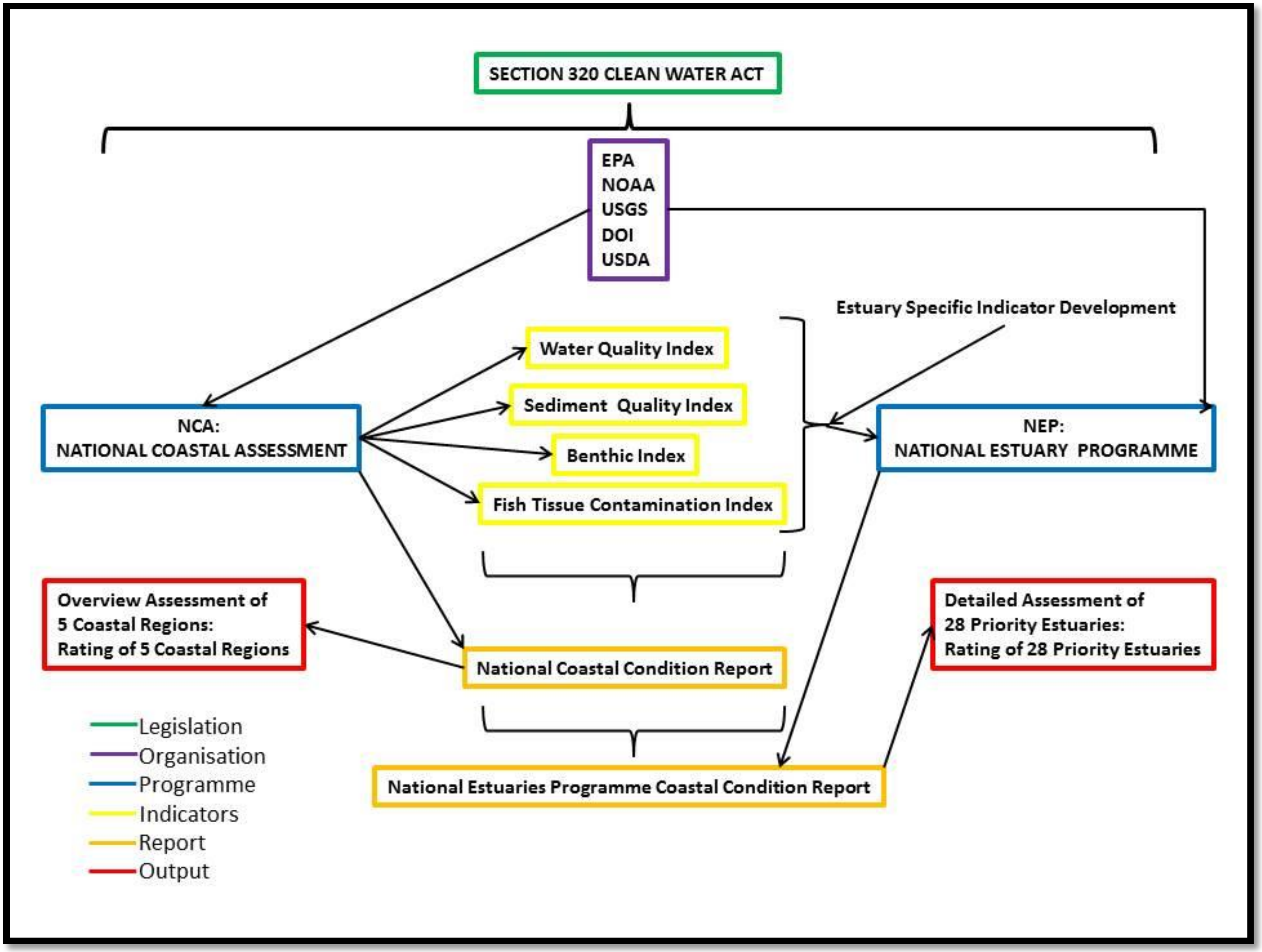


Figure 6 The development of the National Coastal Assessment (NEC) and National Estuary Programme (NEP) in the U.S.A.

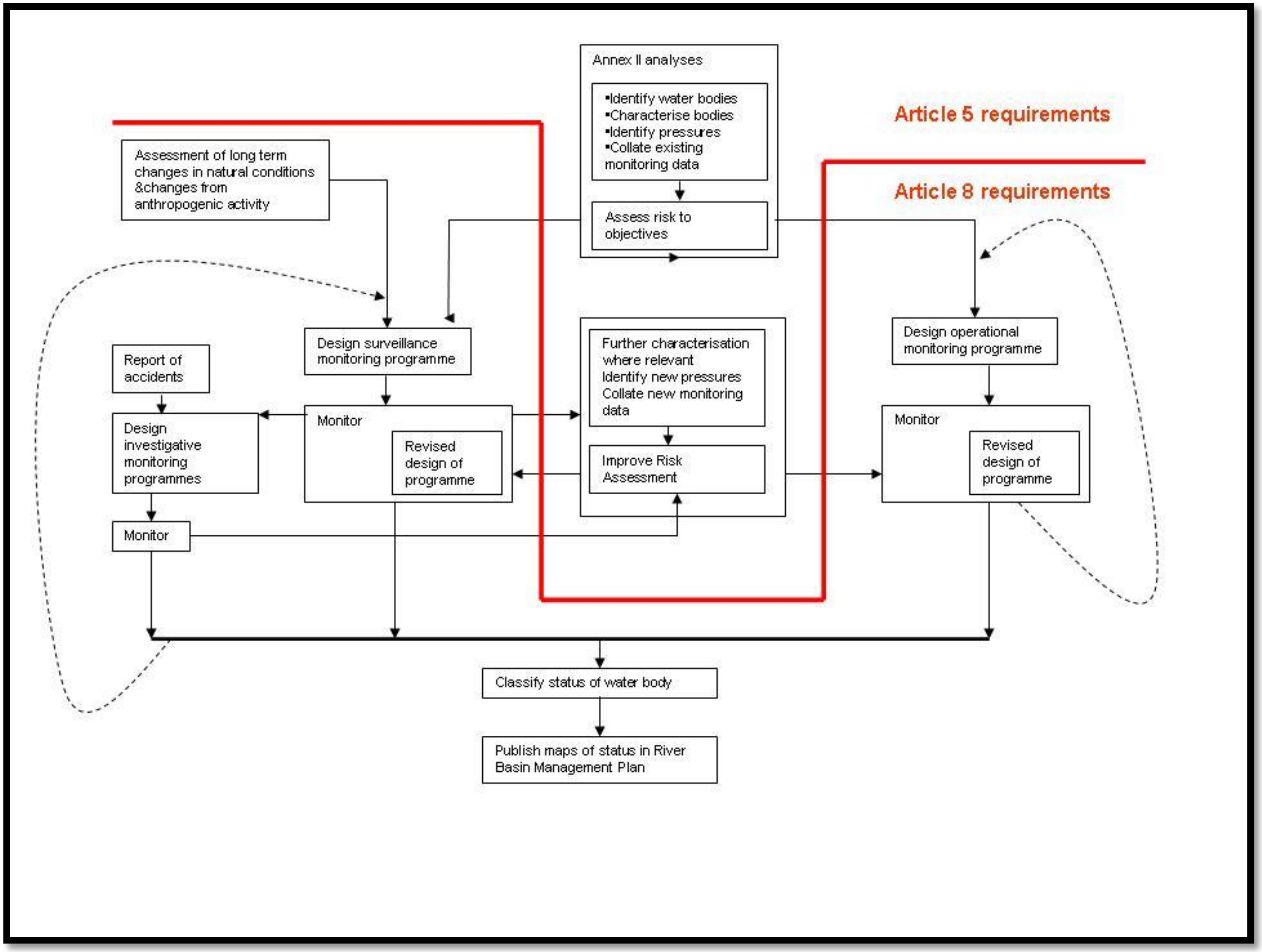


Figure 7 The relationship between Article 5 and Article 8 of the European Water Framework Directive for the design of surface monitoring programmes (From: European Communities, 2003a).

2.8.3. Australia: Various Initiatives

The development of integrated national monitoring initiatives in Australia has been erratic (Hallet et al., 2016a). The management of estuaries in Australia is governed by various acts and policies, but there is no overarching national legislation (Borja et al. 2008; Hallett et al., 2016b). In the South African situation, there is overarching legislation in the form of the NWA and ICMA that mandate specific national departments to manage water resources on a national scale. This allows for better coordination and implementation of water resource management. The Australian National Water Quality Management Strategy (NWQMS) addresses sustainable use of Australian water resources through protection and water quality enhancement (Hallet, et al. 2016a). The NWQMS consists of a series of guidelines and policies, which have limited legal standing, and therefore enforceability. Central to this is the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, ARMCANZ, 2000a) and the Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC, ARMCANZ, 2000b). The NWQMS has as an objective the creation of consistent and systematic monitoring practices, across Australia. The NWQMS also explicitly focuses on the maintenance of ecological integrity as a critical aspect for protection of aquatic ecosystems. The NWQMS, although of sound intent, has limited success as it is not legally binding (Hallet et al. 2016a). In addition, it is biased towards well mixed freshwater dominated systems and therefore has limited application in small stratified and periodically open estuaries (Hallet et al., 2016a; 2016c), typical of the southern coast of Australia. It also does not address systems that are data poor. Although the use of biological indicators is encouraged, the guidelines (ANZECC, ARMCANZ, 2000a) mostly focus on water quality.

State of the Environment (SoE) reporting in Australia is legislated under the Environmental Protection and Biodiversity Conservation Act of 1999. This Act however does not set clear guidelines for the reporting process or content (Hallet et al., 2016a). This results in broad based inventory-focussed reporting with limited management focus (Borja et al., 2012). This deficiency in the SoE reporting has been highlighted and there has been an initiative to develop a national set of estuarine and marine indicators (Ward et al., 1998). Assessments based on these indicators have however not been implemented consistently to determine estuarine condition (Hallet et al., 2016a; 2016b). In addition each state and territory is responsible for their own SoE reporting, making use of available regional data. This has resulted in each state developing indicators based on the available data in the state, which results in difficulty in evaluating estuarine condition on a national scale. Crawford et al. (2002) discussed the importance of having a standard set of indicators and monitoring methods in Tasmania. The importance of regular review and updating of indicators are necessary to ensure new and improved methods for monitoring (Crawford, 2006).

The National Land and Water Resources Audit (NLWRA) provided an assessment of Australian land, water and biological resources between 1997 and 2002 (Hallet et al., 2016a). Its aim was to inter alia, develop a consistent national mechanism for collation of information on natural resource condition in support of SoE reports and assessment reporting for government. This assessment provided a national overview of the condition of Australian estuaries into four classes namely near-pristine, largely unmodified, modified and extensively modified (Hallet et al., 2016) based on subjective assessments of changes in the estuary and their catchments. This included estuary use, estuarine ecology, estuarine pests, catchment cover, catchment hydrology and land use. The modified estuaries were then evaluated in more detail with qualitative indices to determine the relative extent of changes from the pre-European settlement conditions. These indices included Ecosystem Integrity, Water and Sediment Quality, Fish Health, Habitat condition. This assessment was not dependant on detailed quantitative data but on qualitative evaluation and expert opinion. In addition the evaluation against pre-European settlement conditions, which is unobtainable in the current day conditions of increased human induced development pressure, is of little use as reference point for management (Kopf, et al., 2015). The scale of the NLWRA assessment was also poorly suited for addressing estuary management objectives at local and regional levels (Moss, 2006). The NLWRA recommended that the institutional and lead agency roles need to be clarified on a state and national level. In addition, the need for monitoring and assessment of estuaries and the development of indicators and minimum datasets were also addressed (Hallet et al., 2016c). The NLWRA resulted in the development of a National Estuaries Network for estuary managers as well as an online national estuaries database. Both these initiatives reside currently under "OzCoasts" (http://www.ozcoasts.gov.au/about/about.jsp).

Other initiatives were also developed to coordinate Australian monitoring initiatives under a single framework. This includes the National Natural Resource Management Monitoring and Evaluation Framework, The Natural Framework for Natural Resource Management – Standards and Targets and an Integrated Estuary Assessment Framework (IEAF). These initiatives aimed to link estuary condition to relevant stressors and pressures, thereby identifying the best indicators for informing management decisions (Hallet et al., 2016a). Recently a National Estuarine Environmental Condition Assessment Framework (NEECAF) was also proposed to coordinate reporting across Australia on a regional, state and national level. The NEECAF is based on similar principles of the US EPA where priority estuaries are identified and in a tiered approach, certain estuaries are more intensively monitored resulting in fewer estuaries with more detailed assessments. According to Hallet et al. (2016a), none of the proposed frameworks have been implemented to date.

2.9. EVALUATION OF INTERNATIONAL ESTUARY MONITORING INITIATIVES

Different levels of monitoring and assessment of estuaries exist in the USA, Australia and European Union (Table 7). The levels of assessment differ from strategic national perspectives to detailed estuary specific assessments. There are also differences in the legal standing of these monitoring initiatives, with some being legislated on a national level and therefore enforceable as is the case with the Clean Water Act in the USA, and WFD in the EU (Hallet et al., 2016a) while others only have state wide legislation and are only guiding principles as is the case in Australia. It is therefore not enforceable on a national level. The absence of legal enforceability results in limited success in coordinating and implementation of these monitoring initiatives in Australia. This review accentuates the opinion that integrated formalised monitoring programmes are central to effective estuarine management. In all three countries, estuarine monitoring initiatives investigated, are based on the premise that monitoring, assessment and management intervention are interlinked and cannot be viewed as separate entities. Collaboration between different stakeholders (government, NGOs, tertiary and research institutes and the public) are also crucial for effective monitoring, assessment and management of estuaries. The use of biological health indicators is central to all the programmes and is supported by abiotic indicators and population data, as is the case in the USA. The monitoring programmes investigated generally had similar groups of indices (biological, hydromorphological, pollutants and water quality) as reflected in Appendix B.

Different temporal and spatial resolutions may result in different conclusions, and should therefore be one of the aspects to consider when analysing data from any monitoring programme. Although there is a need for consistency and repeatability in terms of the monitoring protocols, tailored monitoring to address specific situations is advocated in all initiatives. Quality standards for data collection, data analysis and data reporting are central to all initiatives in order to ensure that management decisions are based on data with appropriate scientific rigour. Different indices are being used for different monitoring initiatives in each country and associated regions and states. This results in inconsistencies, which result in difficulty in comparing data across regions and states in each country. The conversion of different indices into a single weighted index for each member country, as is the case in the European Union, ensures that data from different monitoring initiatives in different countries can continue and be used. The practical conversion of these different indices into a single index value does however have implications for the time and cost required, as well as the relevance and quality of management decisions that result from interpretation of this index. There needs to be a clear indication of the objectives of the monitoring programme, whether localised or strategic on a national level. National oversight is needed but it should still be of local relevance. This will also support better use of available human and financial resources, which is highly relevant to the South African context, and therefore critical to consider in and South African monitoring programme.

Table 7 Overview of the monitoring initiatives in the United States, Europe and Australia.

	UNITED STATES	EUROPE	AUSTRALIA
OPERATIONAL CONTEXT			
Guiding principles	Two levels of monitoring namely: • Long-term strategic conditional monitoring, and • Estuary specific detailed monitoring	Common Implementation Strategy is bases of EU WFD. Monitoring initiative consists of: • Surveillance monitoring – overall assessment of water resource status; • Operational monitoring – evaluate the status of water resources that are under pressure and determine the level of change; • Investigative monitoring – determine status for water resources where gaps exist or where specific incidents require and investigation.	Monitoring based on state and regional specific requirements.
Legislative framework	The Clean Water Act	• Member States national laws, • International agreements, • The EU Water Framework Directive	• Australian National Water Quality Management Strategy (NWQMS), • Australian and New Zealand Guidelines for Fresh and Marine Water Quality and Australian Guidelines for Water Quality Monitoring and Reporting (ANZECC and ARMCANZ). • No overarching national legislation.
Monitoring Objective	To report on 1) a national scale on the coast through the National Coastal Assessment (NCA) and 2) on an estuary specific scale through the	Reporting on the condition of water resource, including estuaries, of the EU member states using existing monitoring data from each state.	Report based on various State and federal legislation and guidelines relating to specific estuary components of

	UNITED STATES	EUROPE	AUSTRALIA
	National Estuary Programme (NEP) on 28 predetermined priority estuaries.		estuaries.
Spatial scale of initiatives	• NCA: National and state • NEP: estuary specific	Strategic based on EU member countries	State and region
Collaboration	National Oceanic and Atmospheric Administration (NOAA), USGS, universities, state entities, volunteer civil groups.	EU member states and all interested parties within states.	Volunteers, other government departments, research institutes
MONITORING INDICATORS			
Biotic	• Benthic index • Fish tissue contamination index	Based on guidelines set by the WFD. Biotic indicators with high confidence levels where possible. Indicators should be chosen for which reference conditions can be determined and for which monitoring errors are small and well known. This includes biological, hydromorpological and physico-chemical quality elements.	State specific indicators, depending on relevant pressures, but encourage the use of biological indicators.
Abiotic	• Water quality index, • Sediment quality index, • Coastal habitat index	Based on guidelines by the WFD. Should be used in support of Biotic indicators but may be used on their own.	• ANZECC and ARMCANZ use mostly water quality parameters. • National Land and Water Resources Audit (NLWRA) indices included Ecosystem Integrity, Water and Sediment Quality, Fish Health, Habitat condition.
Population information	Yes	No	No
Spatial scale	• NCA: State, regional and national	Sites representative of specific water bodies in	Depend on states monitoring

	UNITED STATES	EUROPE	AUSTRALIA
of assessment	level in terms • NEP: 28 preselected estuaries in terms of the NEP	each member state. Each member state have to determine these scales based on state specific conditions	objectives.
Temporal scale of assessment	Depend on monitoring objective and vary from state to state	Each member state have to determine these scales based on state specific conditions	Depend on states monitoring objectives
REPORTING CONTEXT			
Integrated reporting (i.e. monitoring, assessment and intervention)	Yes • NCA: National Coastal Condition Reports (NCCR) • NEP: National Estuary Programme Coastal Condition Report (NEP CCR) report on the twenty eight prioritised estuaries	Yes, with biological and ecological elements with the ecosystem forming the centre of management decisions.	No. • State of Environment reporting by each state, based on individual indicators. Mostly inventory based with limited management orientation. • National Land and Water Resources Audit (NLWRA) provided a strategic assessment of Australian land, water and biological resources.
Reporting Baseline	Make provision for current perturbations and not only pristine conditions.	Make provision for the range of natural variability and variability arising from anthropogenic activities	Pre-European settlement conditions for the NLWRA

2.10. MONITORING OF SOUTH AFRICA'S ESTUARIES

Sustainable management of South Africa's estuaries is only possible if reliable and quantitative data are available. Collection, analysis and interpretation of relevant data are however time consuming, expensive and require robust scientific methods. Generic design principles have been developed by DWS (DWAF, 2004b) for water resource quality monitoring in South Africa. These guidelines have however mostly been influenced by the need and past experiences in the freshwater environment. The knowledge base on estuary functioning is still limited, although it is globally an active field of scientific investigation. Due to the limited knowledge of these complex ecosystems, further monitoring for management purposes will depend heavily on future basic research on estuarine functioning. Future monitoring programmes need to be designed within the framework of the deficiency in knowledge and therefore provision needs to be made for incorporation of new knowledge and methods. Therefore, a monitoring programme needs to be scientifically robust enough to adapt as new knowledge is gained. McGwynne and Adams (2004) indicated that monitoring of key elements can outline long-term trends (> 5 years) and identify possible cause – effect relationships, which once being identified, can be managed and / or remediated. These authors also advocated SAM is the foundation for estuarine management in South Africa.

Estuarine monitoring has been limited to those undertaken by local municipalities for human health purposes or by conservation bodies for conservation purposes. Clear distinctions exist between monitoring and surveys. According to Taljaard et al. (2003), monitoring refers to ongoing data collection of indicator parameters in order to determine long-term change and trends. Long-term monitoring can be done for various reasons including compliance monitoring and water resource planning. Surveys normally refer to short-term, once off intensive investigations on a wide range of parameters to better understand the processes that drive estuarine ecology. Regional surveys and assessments of South African estuaries were undertaken by various authors (Begg, 1978; Heydorn and Tinley, 1980; Heydorn, 1986; Colloty et.al, 2001) over the past 40 years. Tertiary educational and research institutions as part of specific research programmes mostly undertook these surveys. Long-term monitoring programmes have resulted from some of these initial research programmes e.g. St Lucia system (various institutions including Ezemvelo / KZN Wildlife, SAEON, NMMU, UKZN, UNIZUL), Nhlabane Estuary (Richards Bay Minerals through UNIZUL, UKZN), Mhlatuze Estuary (WRC through UNIZUL), Durban Bay (UKZN, ORI, CSIR), Swartkops Estuary (SAEON, NMMU), Knysna Estuary (SANParks, NMMU) and Groot Brak Estuary (NMMU, PetroSA through CSIR). These monitoring programmes were largely driven and financed by industry and to an extent by government departments. These assessments were of great value to basic estuarine research and management but were undertaken by different institutions with different objectives and did not form part of a single nationwide programme driven by authorities. This has resulted in many instances, in the incomparability of data.

Turpie et al (2002) state that several indices have been developed to determine the “health” of South African estuaries although very few country wide assessments have been completed to determine the conservation priority status of estuaries. These point to the absence of a national monitoring programme as highlighted during two national estuaries workshops in Port Elizabeth (Boyd et al., 2000; DWAF, 2008b). George Begg undertook a nationwide photographic survey of the South African coastline in the 1980s and 1990s. These surveys were part of a spatial planning initiative, and were limited to observation of changes in the mouth conditions of estuaries thereby implicating geomorphology and vegetation associated with estuaries. The coastal sensitivity atlas was produced for oil spill contingency planning on the South African coast by Department of Transport (Jackson and Lipschitz, 1984). This atlas did address estuaries in a superficial manner. These two initiatives, amongst others, were the closest to national estuarine monitoring. Ramm (1988) developed an index to determine estuarine health, making use of a Community Degradation Index that compared observed fish species richness with that expected in pristine conditions. Cooper et al (1994) later used this index as a departure point for development of a Biological Health Index. Quinn et al. (1999) developed an index for management of estuaries for juvenile fish recruitment from the marine environment. More recently, an estuarine health index was developed by Turpie and MacKay (1999) and refined (Turpie et al, 2012b). This index was tested around the country on a number of estuaries. This estuarine health index combined the Biological Health Index of Cooper et al.(1994), the Water Quality Index of House (1989) and a newly developed Aesthetic Quality Index. There was no national monitoring programme to determine the state of South Africa’s estuaries. The State of Estuaries report (Harrison et al., 2000) summarised the findings of studies conducted between 1992 and 1999 on a limited number of estuaries, which were based on an Estuarine Health Index of Cooper et al. (1993). This report indicated the need for long-term biotic and abiotic data-sets to establish the range of natural variation between and within different estuaries on a spatial and temporal scale. This would provide a clearer understanding of ecosystem function, which is critical in addressing sustainable development and associated management issues. Turpie (2002) found that the practical implications of determining the extent of deviation of an estuary from the pristine state are immense as is the case for determining the conservation priority of estuaries, using their current state. Determination of the reference state of rivers has developed substantially over the past decade as part of the River Health Programme (RHP). This has provided important lessons that will assist with focusing the effort to estuaries. The most recent national assessment of estuaries formed part of the National Freshwater Ecosystem Priority Areas (NFEPA) (Nel et al., 2011), which provide a national overview of priority aquatic ecosystems. This assessment pooled existing knowledge that emanated from historical data, collected by different organisations with different objectives. The National Biodiversity Assessment (Van Niekerk and Turpie, 2012) was completed parallel to NFEPA and was largely based on the same information. The National Biodiversity Assessment had a component that specifically addressed estuaries (Van Niekerk and Turpie, 2012) and is currently being updated. The NBA specifically address two strategic indicators namely the ecosystem threat status and ecosystem protection level (Van Niekerk and Turpie, 2012). These indicators require data to set the status on a scientific defensible manner and to evaluate the trajectory of change of these indicators. Van Niekerk et al. (2015) compiled a provisional desktop eco-classification assessment of the cool and warm temperate estuaries of South Africa and found that 20% are in a Class A condition, 43% in Class B, 27% in Class C or D and 10% in Category E and F. These authors highlighted the importance of continual monitoring and management intervention to ensure these estuaries do not deteriorate further. From the above discussion it is clear that there have not been a single coordinated effort to collect long term data on South African estuaries to track long term changes in estuarine health and inform management decisions.

2.10.1 Design Of Water Resource Monitoring Programmes By DWS

The DWS have a standard framework, based on international best practise, for the process to be followed for the design of all new water resource monitoring programmes (DWAF, 2004b). This framework only guides the process to be followed and does not address the technical components of a monitoring programme. The technical components of the monitoring programme are guided by the objectives of the programme. Due to the thesis being supported and funded by DWS and forming part of the DWS mandate, this design framework was used for the National Estuarine Monitoring Programme (NESMP). This design process entails an 1) Initiation Phase, 2) Design Phase, 3) Pilot Testing Phase and 4) Implementation Phase.

Phase 1 - Initiation Phase (Situation and needs analysis)

This phase entails a 1) detailed literature review as per Chapter 1 and 2 of this thesis and 2) stakeholder consultation as reflected in Chapter 3 of this thesis. The literature review investigates international and national trends in monitoring of the specific water resource, thereby setting the scene for the design of a specific monitoring programme. Part of the literature review includes a feasibility study of the proposed monitoring programme. Internal and external stakeholder consultation to determine the needs for and requirements of a monitoring programme are also undertaken. Internal consultation within DWS take place as this is where the need for the monitoring programme originates. DWS also provided the funding for the design and implementation of the monitoring programme. Consultation with external parties also needs to take place as they may have a vested interest in the monitoring programme or have expertise that is needed for the design and implementation of a monitoring programme.

Phase 2 - Design phase

In this phase a concept monitoring programme is designed, which is the central objective of this thesis and reflected in Chapter 3 of this thesis. The design is based on the design framework document resulting from the initiation phase (Phase 1). The programme design needs to cover 1) data acquisition (what where, how often and how to analyse samples), 2) data management and storage and 3) information generation and dissemination. The concept design of the monitoring programme needs to take the spatial heterogeneity of South Africa into account. This may require a division of the monitoring programme into sub-programmes for each distinct geographical area or water management area. This phase also addressed the development of indices to indicate ecosystem health in line with the current eco-classification system being used for water resource management in South Africa. A co-operative approach needs to be followed, which includes all relevant parties (DWS, DEAT, Local and regional conservation bodies, NGOs and para-statals). Awareness raising and capacity building need to form part of the programme design in order to ensure buy-in and empowerment of all the parties involved. This will ensure that the workload is spread, resulting in efficient use of resources. The deliverables for this phase are a Terms of Reference, Implementation Manual and Record of Decision documents guiding the pilot testing of a national monitoring programme.

Phase 3 - Pilot testing phase

The pilot testing phase follows on from the design phase and is addressed in Chapter 4 of this thesis. The DWS design protocol (DWAF, 2004b) proposes that the pilot testing phase takes place over a three year period to ensure that a sufficiently sized dataset is collected to evaluate the success of the monitoring programme. Certain variables need to be monitored monthly (e.g. water quality, contaminants), while other aspects may only require quarterly or half yearly monitoring (e.g. benthic invertebrates, botanical components, fish). These details however only crystallize during the design phase. The pilot testing need to be undertaken on selected sites across South Africa, to incorporate regional variation. Adaptive management should provide for changes to be made to the monitoring programme, should it become necessary for the effective implementation thereof. The deliverable of the pilot testing phase is a report evaluating the pilot testing phase and final recommendations for the full scale implementation of the monitoring programme. This thesis was used as the main source of information for the drafting of the pilot testing report.

Phase 4 - Implementation Phase

The full scale implementation occurs after pilot testing and refinement of the proposed methodology. Implementation of the full scale monitoring programme will depend on the recommendation from the pilot testing phase. The implementation phase is informed by the design and pilot testing phase, which is the focus of this thesis. It is not reflected in this thesis as it falls outside the scope of the thesis.

2.11 CONCLUSIONS

Estuaries are highly productive and complex ecosystems that provide important ecosystem services. South African estuaries are exposed to various local estuary specific and catchment scale impacts. The most important being flow reduction, water pollution, mouth manipulation and development within the EFZ. The management of estuaries in South Africa is addressed by various pieces of legislation, the most important and relevant being the Integrated Coastal Management Act (Act No 24 of 2008), mandating the Department of Environmental Affairs and the National Water Act (Act No 36 of 1998), mandating the Department of Water and Sanitation. There are also regional and local municipalities that have to enforce local by-laws and regulations, as well as local, regional and national conservation bodies, each having their own mandates guiding their interests in estuaries. Management of estuaries depends on informed decision making based on scientific robust information. This management orientated information depends on long-term consistent data collected through monitoring initiatives. These two pieces of legislation pave the way for the design of a national estuarine monitoring programme to address the need for scientific based management information.

A comparison of estuarine monitoring in the USA, Europe and Australia indicates that different levels of monitoring with different objectives, levels of resolution and implementation are taking place. Estuarine monitoring has its own set of challenges, especially in view of various governing bodies that have different levels of involvement in estuarine management in these countries. Common departure points in all of these monitoring initiatives are the need for collaboration and alignment within countries of all the existing initiatives, classification of estuaries based on current conditions and pressures, ecosystem focus monitoring and the need for management orientated information based on scientific robust monitoring.

Estuaries, due to their unique characteristics, being influenced by freshwater inflow and marine tidal exchange, pose unique challenges for the design of a monitoring programme. The influence of the cold Benquela and the warm Mozambique current on biotic composition and abiotic characteristics, complicate the design of a single national estuarine monitoring programme for South Africa. It is therefore important to design a programme that can be adapted and used in these different geographical units. Defined endpoints are crucial for water resource management as they indicate points, which once being reached, should red flag potential unsustainable conditions. This will then require corrective environmental measures such as rehabilitation or remediation. The TPCs when defined in the RQO studies, or calculated when data become available, act as this endpoint in the South African context.

There is currently a lack in capacity and funds for water resource monitoring in South Africa. Central to the success of any monitoring programme is the consistency in methodology and compliance to quality standards. This is especially relevant across the different tiers of water resource governance. New technologies need to be developed and used to make estuarine monitoring cost effective. Capacity building including the creation of an enabling environment with appropriate policy and legal frameworks, institutional development, including community participation, awareness raising, human resource development and strengthening of managerial systems have been identified as crucial aspects to be addressed in the international context. Globally and locally, there are many government departments, parastatals and private organisations that have a vested interest in estuary management and monitoring. Capacity building should not only ensure that the quality expectations are met, but also foster collaboration between the different institutions involved in estuarine management and monitoring. This implicates inter alia the establishment of an efficient governance structure to oversee the management of a national water resource monitoring programme.

CHAPTER 3. DESIGN OF A NATIONAL ESTUARY MONITORING PROGRAMME (NESMP) FOR SOUTH AFRICA

3.1 INTRODUCTION

Chapter 4 of the Integrated Coastal Management Act (Act No.24 of 2008) makes provision for the drafting of estuary specific management plans. The National Estuarine Management Protocol (NEMP) was gazetted in May 2013 (Government Gazette No 341 of 2013). This protocol specifically addresses integrated cross-sectoral planning and management of South African estuaries by setting strategic objectives which, inter alia encompass sustainable use, maintenance of ecological integrity, protection and co-operative governance. The NEMP also addresses the institutional structures and arrangements necessary for co-operative coastal governance. Five to ten years ago, the Western Cape Province made progress in drafting estuarine management plans, through the C.A.P.E. Estuaries Programme, thereby giving effect to the ICM Act. Subsequently, various estuarine management plans have been drafted and implemented in the rest of South Africa, building on the experience gained through this pioneering work.

The associated standards for estuarine management, as defined through the NEMP, states that management actions should be based on sound scientific evidence. A monitoring programme therefore forms an integral part of estuarine management plans as the data and resulting information will be used to facilitate informed management decisions. The potential implementers for this long-term monitoring programme should be identified through the guidance of this specific section of the NEMP and working relationships established at an early phase of testing and implementation of the NESMP. The parties involved will differ from estuary to estuary and may consist of NGOs (e.g. Wildlife Associations, Conservation Trusts, Rate Payers Association), conservation bodies (e.g. SANPARKS, Ezemvelo / KZN Wildlife, CapeNature, Eastern Cape Parks & Tourism Agency), and government institutions (e.g. SAEON, DWS, DAFF, DEA, local and / or district municipality).

The Department of Water and Sanitation (DWS, previously Department of Water Affairs) is responsible for the regulation of South Africa's water resources, which include estuaries as part of the "source to sea" concept. This concept indicates that a river stretches from the headwaters to where it spills into the ocean, and that different functionalities and characteristics of rivers and estuaries are interlinked to each other. Department of Water and Sanitation in accordance with the NWA are mandated to, amongst others, attend to development of water management strategies, protection of water resources, undertake monitoring, do assessments of and ensure information dissemination on the quantity and quality of water resources in South Africa.

The DWS have been responsible for monitoring of water resources over the past seven decades and have created a substantial knowledge base about the design and implementation of national water resource monitoring programmes. The Department currently has eleven national water resource monitoring programmes (DWAF, 2004a, DWAF, 2005; DWS, 2016) which are dependent on robust scientific data and aim to produce information that is used for water resource management. Most programmes are associated with the freshwater environment, with limited overlap with the estuarine environment. These programmes provide appropriate data and information necessary to assess, amongst others, the quantity, quality, use and rehabilitation of water resources, the compliance with water resource objectives, the health of aquatic ecosystems, and the atmospheric conditions that may influence water resources.

The National Aquatic Ecosystem Health Monitoring Programme and specifically, the River Ecostatus Monitoring Programme (REMP) component there-of, are more recent examples of successful programmes undertaken by the Directorate: Resource Quality Information Services (RQIS) of DWS. In addition, RQIS is also responsible for the testing and implementation of various additional monitoring programmes that overlap with the estuarine monitoring programme.

The national water resource monitoring programmes have historically focused on the freshwater environment with very little focus on estuaries. There is no overarching estuarine monitoring programme in South Africa through which changes in a standard set of biotic and abiotic response and stressor indicators can be determined on a national scale. The objective of such a monitoring programme being primarily to track long-term changes in the ecosystem health and provide management orientated information. The objective of this chapter is to provide the protocol for a National Estuarine Monitoring Programme (NESMP) for South Africa, which ensures that the mandate of DWS as custodian of South Africa's water resources as entrenched in the NWA are achieved; and is in support of integrated co-operative coastal governance as per the ICMA. The research question that this chapter addressed was "Can a single monitoring programme be designed that will facilitate the collection of biotic and abiotic data in a consistent manner to evaluate national long-term trends in estuary health in South Africa; and provide data which informs management decisions?" The need for a national estuarine monitoring programme has been established in the preceding chapter. This chapter will discuss 1) the method used to design the NESMP, 2) define the objectives of a national estuarine monitoring programme, 3) prioritise estuaries for testing and implementation of the NESMP, and 4) discuss the NESMP protocol which includes constituents to be sampled, sampling methods, spatial and temporal scales of sampling, data management, roles, responsibilities and management structures.

3.2 METHODS

3.2.1 Design Process

The process followed during the design of the National Estuary Monitoring Programme was based on the framework prescribed by DWS (DWAF, 2004b; DWAF, 2004c) and Bartram and Ballance (1996). The process consists of six steps as indicated in Figure 8 and is expanded on specifically for the NESMP in Figure 9.

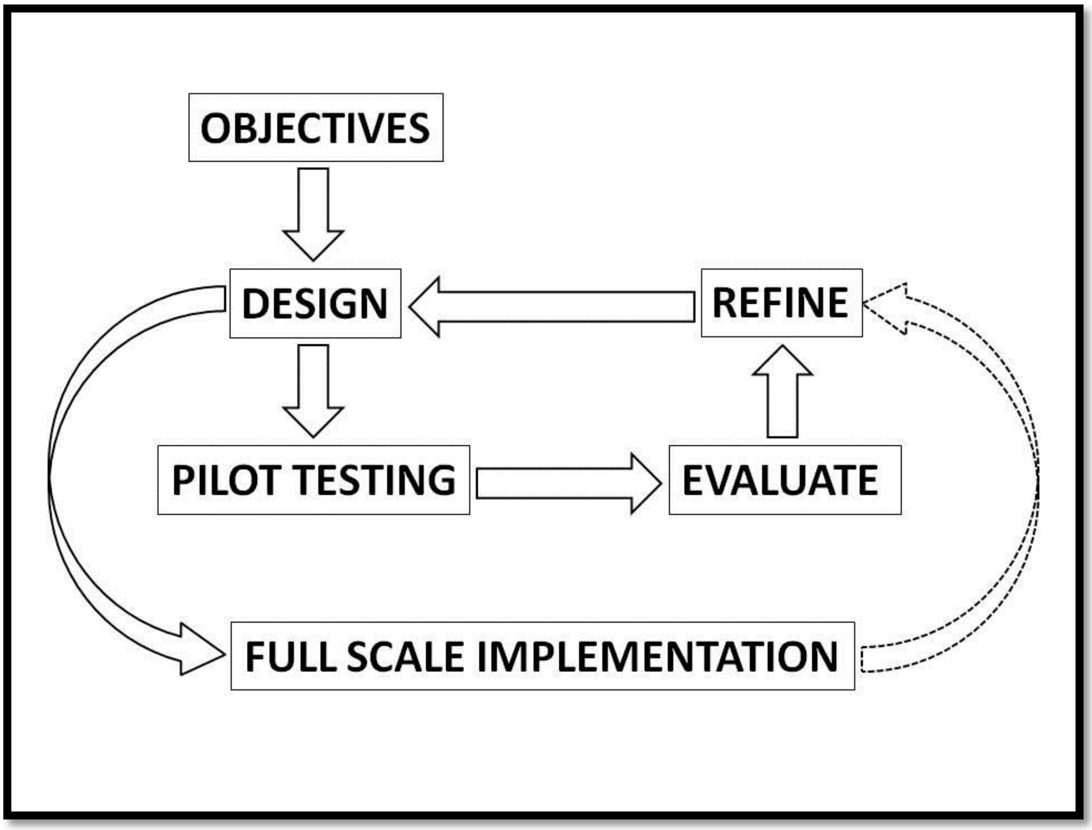


Figure 8 The process followed by the Department of Water and Sanitation during the design, testing and full scale implementation of national water resource monitoring programmes.

A needs assessment for the NESMP was a precursor to its design. The needs assessment identified objectives (Section 3.3.1: Objectives of the National Estuarine Monitoring Programme), target users, criteria for choosing variables, and the general design considerations. A pilot testing phase followed the design phase between 2012 and 2016. During the pilot testing the design was revisited and refined where needed, to incorporate changes that were identified. Full scale implementation will follow the pilot testing phase. Provision is made for adaptive management during the full scale implementation, to accommodate changes in roles and responsibilities, priorities and financial support for the programme.

The design process was based on three components (Figure 9). These components, although being independent entities, were linked through feedback paths to revisit existing views and refine these as design understanding was gained, opinions were formed and the design parameters established. The three components were a literature review of international monitoring practice pertaining to the estuarine environment in Europe, Australia and United States of America. This was followed by a critical evaluation of existing national monitoring programmes implemented by DWS within the context of the NWA (Act No 36 of 1998), the Strategic Framework for National Water Resource Quality Monitoring (DWAF, 2004b), National Water Resource Strategy (DWAF, 2004a) and the 5 Year Water Resource Quality Monitoring Plan of DWS (DWAF, 2004c). This two components culminated in Chapter 1 and 2 of this thesis. Finally, I convened a workshop as part of this study (DWAF 2008b), where South African estuarine ecologists and managers discussed and agreed on the requirements for a national programme. The objective of the workshop was to determine a) what constituents need to be monitored (Section 3.3.2: Design of the National Estuarine Monitoring Programme), b) how these constituents should be monitored (Section 3.3.3: Sampling Methods), c) where these constituents should be monitored (Section 3.3.4: Estuary Site Selection), d) when these constituents should be monitored (Section 3.3.3: Design of the National Estuarine Monitoring Programme); and e) by whom should these constituents be monitored (Section 3.3.5: Roles and Responsibilities)? The outcome of this workshop was used to guide the design of the NESMP and is summarised in DWAF (2008b).

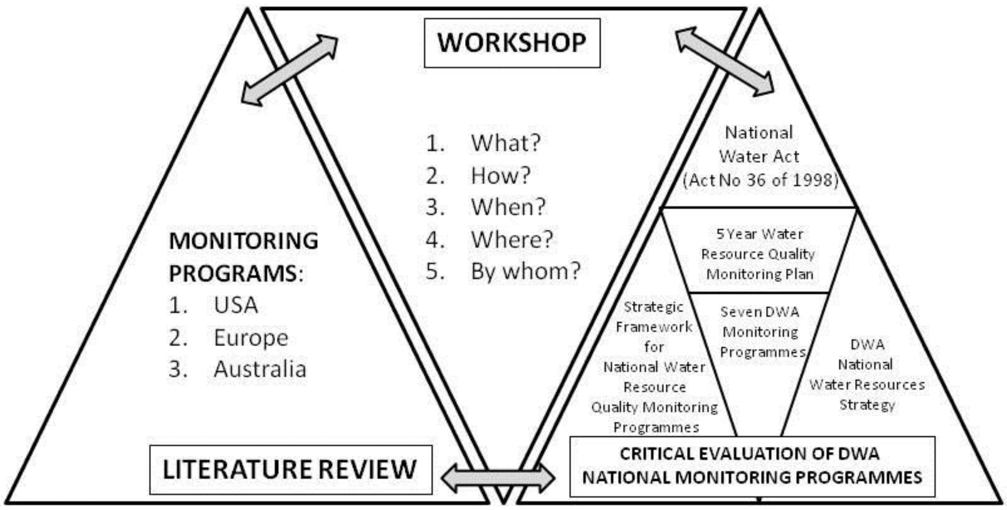


Figure 9 The design process for the National Estuarine Monitoring Programme consisted of three separate but interlinking components.

3.2.2 Estuary Prioritisation

Selecting estuaries for monitoring should be as objective as possible, to ensure that systems that need monitoring, based on the DWS management mandate, are prioritised on a national level. The primary objective of the NESMP, being the collection of long-term data to inform future management decisions, should always be the focus of such a prioritisation effort. Six criteria (Table 8) were identified as part of this study, to determine priority estuaries through a ranking system that is based on the application of an objective numerical equation. The overall priority (P) for the estuary is calculated using the following formula:

$$P= A(K+D+E+F) \qquad \textbf{(1)} \quad \text{where}$$

$$K = (B+2C/3) \qquad \textbf{(2)}$$

Practicality (A) is the main driver for the programme, and thus plays a key role as a common multiplier of the sum of all the components (ecological, socio-economic and level of available data) of the equation. This value is multiplied with functions of the ecological components

(*K*) and added to the socio-economic importance (*D*), which is added as a separate value to the ecological components (*K*) as it is seen as an independent factor, based on social and associated development pressure. Through this a balance of priority is achieved between the ecological components and socio-economic importance, thus addressing sustainability in a broad context.

In terms of the calculation of the ecological component (*K*), ecological importance (*C*) is seen as having twice the weight of current state (*B*) and therefore multiplied by 2. In order to average the ecological importance (*C*) and the current state (*B*) contribution, the value is divided by 3. Future impacts (*E*) are added to this value as it is linked to and influences both the current state (*B*) and ecological importance (*C*). The level of available data (*F*) is also contextualised within the programme with its addition to the equation.

Those with the highest calculated *P* value (the maximum value being 42) are the "high priority" estuaries and should be considered first for monitoring. This was applied on an estuarine specific basis, and not on a water management area or catchment scale as the criteria used already integrates catchment scale / water management area information on an estuarine specific level. Direct consultation with estuarine experts and water resource managers will solicit estuary specific knowledge ensuring a balanced view based on objective criteria and subjective system specific knowledge. For this approach, it is adequate for the programme manager of the NESMP to meet with relevant estuarine specialists, conservation bodies and representatives of DWS regional office or catchment management agencies to determine their subjective opinion on the list of priority estuaries based on the objective approach (Figure 10) as defined with the use of equation 1. It should however be kept in mind that there is still subjectivity involved with the rating scores as defined in Table 8, as this is strongly based on expert opinions as defined in the literature cited. Using this local knowledge a refined list of estuaries should be identified that are likely to be most appropriate for monitoring based on the objective prioritisation criteria. The participants that attended the Estuaries Monitoring Workshop in Port Elizabeth in 2008 undertook a similar exercise during this workshop (DWAF, 2008b). The outcome of this prioritisation exercise is reflected in Table 10 and guided the refinement of the list. Participants were asked to indicate the 10 priority estuaries per biogeographical region where monitoring should be initiated during the testing phase of the NESMP, based on their expert opinion. The estuaries were selected to cover a broad spectrum of estuarine types with different characteristics and management issues.

The prioritisation process therefore consisted of two steps with feedback loops to ensure the highest level of trustworthiness is ensured when choosing estuaries to monitor (Figure 10). The subjective approach is in support of the objective approach.

The financial and human resources available for monitoring, already reflected in practicality (A) of the prioritization calculation will also guide which estuaries are selected for monitoring. Estuaries where there is a lack of available resources will receive lowest priority. Monitoring on these estuaries could take place in the future, as estuary specific situations (impacts, knowledge, available resources) may change, paving the way for future monitoring. The programme manager and relevant stakeholders should reach consensus on the relative rankings. The priority list should be reviewed every five years to incorporate new knowledge / information on the selection criteria that may have developed since the initial prioritisation list was compiled.

Table 8 Criteria and rating used to prioritise estuaries for monitoring.

CRITERIA	RATING
Practicality (*A*) The monitoring program is volunteer based and therefore depends on the availability of human resources on a specific estuary to undertake the sampling.	1 – Impractical 2 – Possible 3 - Highly practical
Current state (*B*) The estuary may be important to monitor because of its pristine state (current and / or historic ecological state) based on the ranking of Turpie et al. (2002) and Turpie, Wilson and Van Niekerk (2012).	1 - Highly degraded 2 - Fair / good 3 – Pristine
Ecological importance (*C*). The ecological importance of an estuary is based on a local, regional or national level. Based on the ranking of the National Freshwater Ecosystem Prioritisation Atlas (NFEPA) by Nel et al. (2011) and Turpie, Wilson and Van Niekerk (2012).	1 – Low 2 – Medium 3 – High
Socio-economic importance (*D*). This entails the importance of estuaries to provide economic opportunity in the form of industry and associated harbour development (D1), tourism (D2) and subsistence fisheries (D3) on a national scale and is based on Turpie et al. (2002). The socio-economic importance is evaluated for each of these categories and averaged to provide the final rating used in the equation.	1 – Low 2 – Meduim 3 – High
Future impacts (*E*). Future environmental impacts are where development pressure is likely to increase in the future on a specific estuary through urban development, tourism, industry and subsistence fisheries and based on professional opinion and Turpie et al. (2002).	1 – Low 2 – Medium 3 – High
Level of available data (*F*). Estuaries where a low level of data is available merit the establishment of a monitoring programme to address this inadequacy. In certain instances an estuary may have a high level of data available, but due to current and future pressures (pollution, pending EWRs, development pressure) and/or its national importance (St. Lucia for example), there is merit in building on this existing data. In these instances separate motivation for prioritising a specific estuary should be provided, although it may have a lower calculated prioritisation as a result of the existence of historical data. The rating system used for level of available data is based on Whitfield and Baliwe (2013).	3 – Low 2 – Moderate 1 - Excellent.

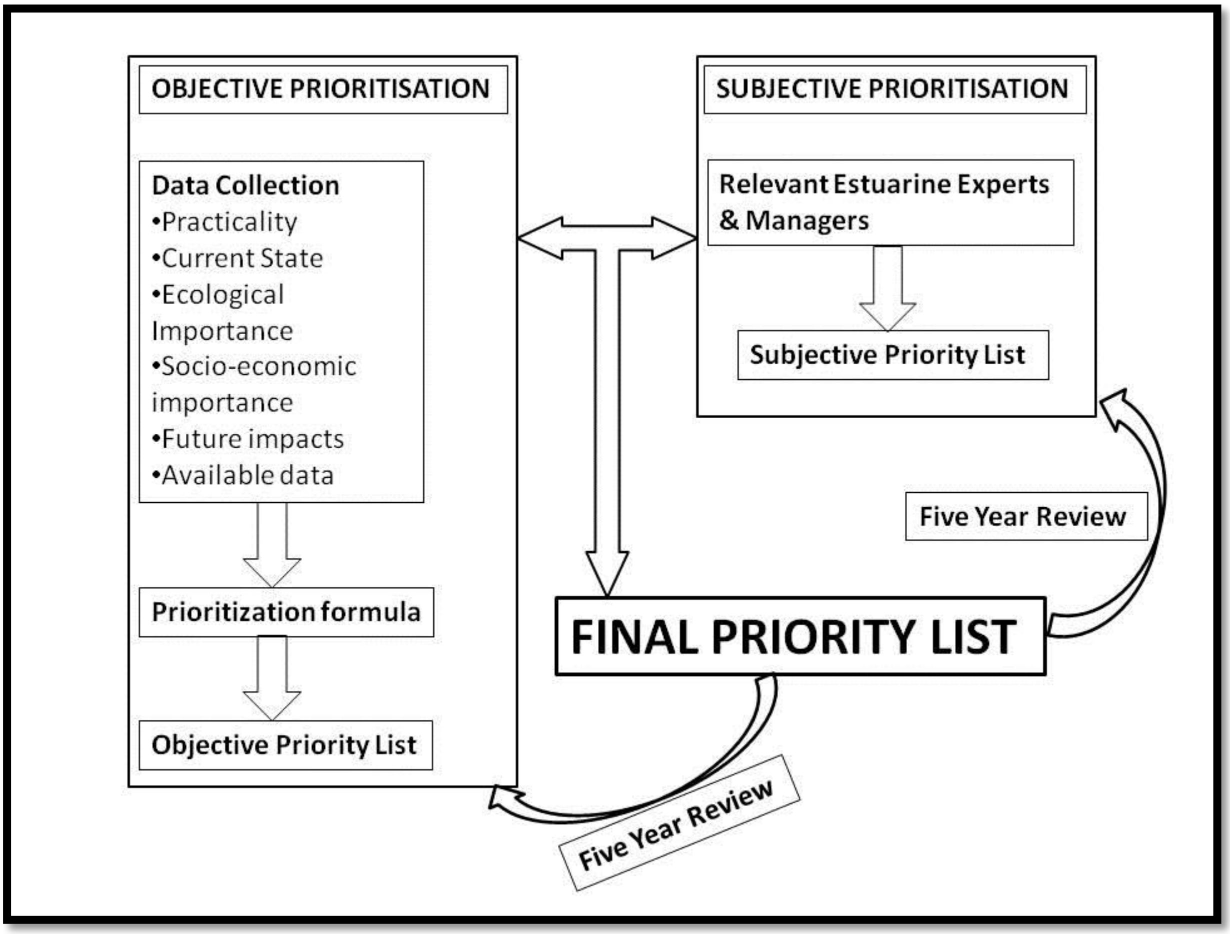


Figure 10 Two-step objective and subjective process followed to determine the priority estuaries for monitoring.

3.3 RESULTS AND DISCUSSION

3.3.1 Objectives of the National Estuarine Monitoring Programme

The objectives of a monitoring programme define the reasons for its existence (DWAF, 2005) and provide the primary statement by which the success of the monitoring programme will ultimately be assessed. Based on the three design components (Figure 9) the objectives of the NESMP were to measure, assess and report on a regular basis on the status and trends of the nature and extent of the condition of South African estuaries. This would be done in a manner that will support strategic management decisions to ensure sustainable use of estuaries and ensure ecosystem integrity, being mindful of financial and capacity constraints, while also being be scientifically sound.

The overall objective will result in an estuarine monitoring programme that will collect relevant, consistent and reproducible long-term data to facilitate information generation and dissemination for the future integrated national, regional and local management of South African estuaries (Figure 11). It will also investigate the use and development of the Estuary

Health Index. Eventually the NESMP will compare the health of South African estuaries on a temporal and spatial scale.

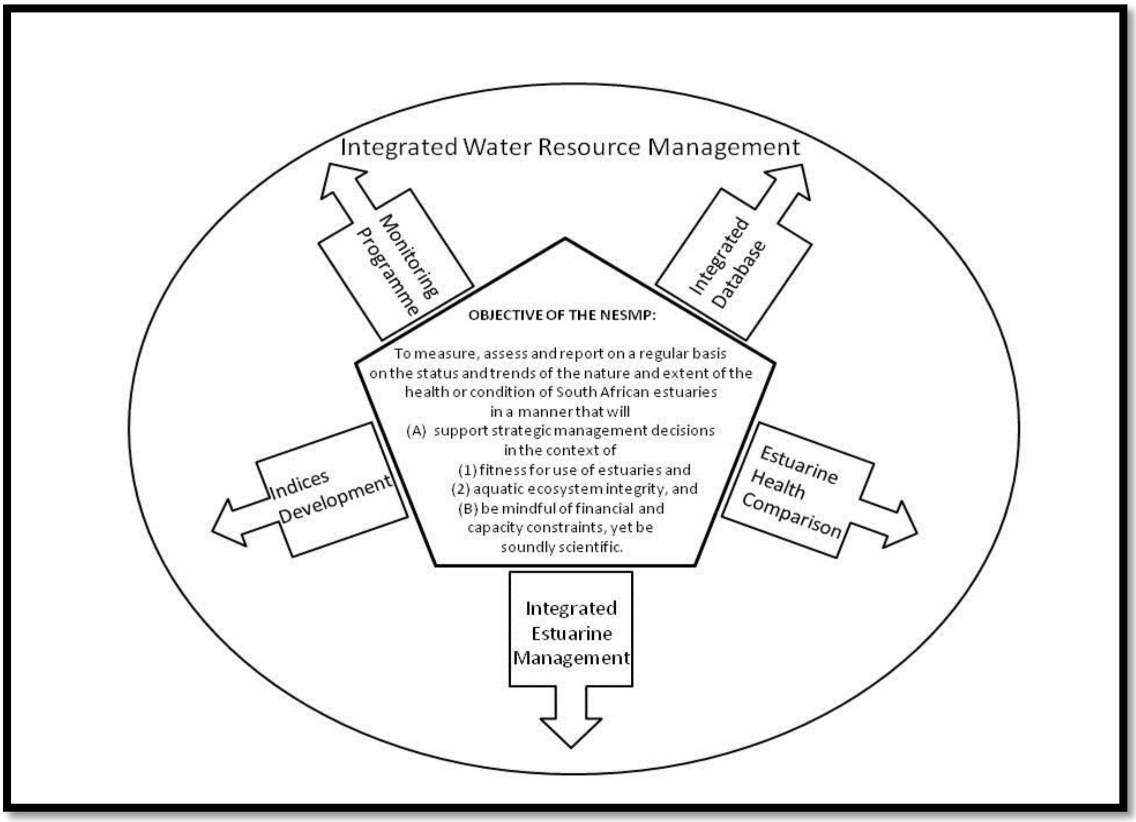


Figure 11 The objective of the NESMP will result in key outcomes that addresses aspects of Integrated Water Resource Management.

3.3.2 Design of the National Estuarine Monitoring Programme

A three tiered approach forms the basis for this programme (Figure 12). This ensures that the monitoring programme can be implemented in a financial limited and human resource poor environment as experienced in the South African context. The main departure point for this programme, based on the literature review and the subsequent workshop held in 2008 (DWAF, 2008b), was practical implementation. From the workshop outcomes it was clear that a national monitoring programme is needed to be implemented as soon as possible, as past efforts did not move beyond the identification for the need of a programme. Therefore the programme was designed in such a manner that the aims and objectives of the monitoring programme are achieved through implementation. There is a need that the programme is robust enough to adapt to changing financial and human resources situations, thereby ensuring its long term sustainability. Designing a comprehensive monitoring programme, that addresses all the data requirements too rigorously, will result in a financial and human resource hungry programme with limited practical implementation capabilities.

Therefore the design philosophy was centred on starting small and expanding the programme based on small successes.

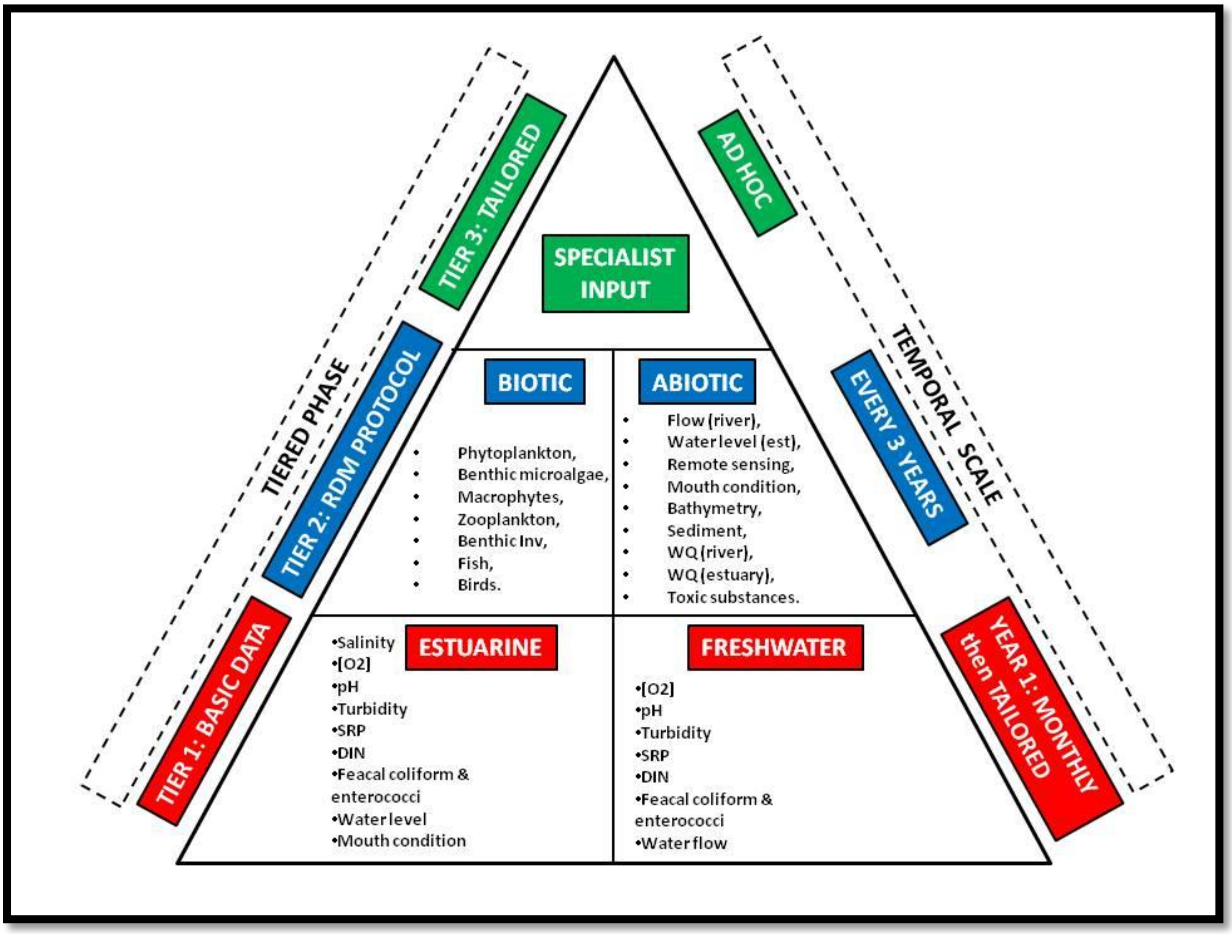


Figure 12 The National Estuarine Monitoring Programme for South Africa.

Tier 1 entails the collection of basic environmental data to develop a long-term database of the most important drivers within estuaries. Data on these drivers are needed to understand the functioning of a system and to determine the level of environmental perturbations as a result of human induced activities and /or natural phenomena. The basic data are divided into an estuarine and a freshwater component. For the freshwater component, measurements are made at a point above the head of the estuary that represents a site above the furthest point of saline intrusion, while the estuarine component is collected along the length of the estuary up to the mouth of the estuary. The rationale for the selection of the estuarine components of Tier 1 is based on Taljaard et al. (2003). The estuarine component entails the measurement of water quality variables within the estuary and includes fixed point photography of the mouth and/or mouth state records. The freshwater aspect of the programme is indicative of exogenous compounds and therefore the phyisco-chemical condition of the water entering from the catchment. The rationale of the selection of the freshwater components are also based on Taljaard et al. (2003) and includes measurement of freshwater inflow if an operational flow gauging weir is available.

Tier 2 makes use of the methods employed for determining estuarine freshwater requirements (Taljaard et al., 2003; DWA, 2008a) and is divided into abiotic and biotic components. Only selected aspects of the RDM process will form part of this tier in view of its financial and practical implications. The protocol includes variables, which provide an indication of the health of the system. The RDM protocol (DWA, 2008a) standardises the methods to be used for assessing estuarine freshwater requirements on a national scale. The Tier 1 assessment should be done concurrently when the Tier 2 assessments are undertaken. Through the use of the estuarine freshwater requirements protocol, the NESMP will not only give an indication of the health of the system, but also provide important background information for future ecological water requirement studies, setting of resource quality objectives and associated reserve auditing. These aspects are legal requirements of the National Water Act (Act No 36 of 1998). The abiotic components of Tier 2 are mostly drivers of the system and the same as the abiotic components of the Tier 1 assessment, while the biotic components, summarised in Table 9 are response indicators.

Tier 3 will be tailored monitoring to address specific management issues that may occur from time to time in a specific estuary. This may include, amongst others, pollution incidents, fish kills and specific developments that may influence the health of an estuary. This tailored assessment will be done as a focused short term study in consultation with relevant estuary specialists. These experts will advise on which biotic and abiotic components should be included in the Tier 3 protocol to be used. These components will however need to be selected from the Tier 1 and /or Tier 2 protocol to ensure method consistency across the different tiers of the monitoring programmes, thereby ensuring usability of the data in the NESMP, even though the focus of the Tier 3 assessment may be over a short temporal scale. In the instance where no historic data is available, the Tier 3 study may act/contribute to a future baseline study. The study does not need to be limited to the Tier 3 protocol, but may, depending on the specific situation, include constituents that do not form part of the NESMP.

Table 9 Rationale for the selection of specific biotic components of Tier 2 of the NESMP (Taljaard et al., 2003).

COMPONENT	RATIONALE FOR CHOICE
Phytoplankton	Phytoplankton biomass is an indicator of nutrient loading and is done concurrently with nutrient analysis to provide a nutrient “balance”. Changes in the phytoplankton assemblage are also an indication of changes in the water quality and quantity. They also act as important primary producers within permanently open systems.
Benthic microalgae	Changes in the microalgae composition are an indication of changes in the nutrient levels in an estuary and therefore water quality. Microalgae are important primary producers in shallower, non-turbid systems.
Macrophytes	Estuarine macrophytes form the habitat for many estuarine species including birds, fish and invertebrates. The condition of the macrophyte habitat are therefore a direct indication of the health of an estuary.
Zooplankton	Zooplankton is an important aspect of the estuarine food web as they act as a food source to fish, birds and invertebrates.
Benthic Invertebrates	Benthic invertebrates are also important components of the estuarine food web as they serve as a food source for other invertebrates, birds and fish.
Fish	Fish are important in the water based estuarine food web. They reflect what is happening with the biotic and abiotic component of the estuarine ecosystem.
Birds	Birds are part of the top of the estuarine food web, and therefore also reflect the condition of the estuarine ecosystem.

3.3.3 Sampling Methods

Method consistency when sampling is critical to the success of any monitoring programme. This ensures quality of the data and the credibility of the information generated and associated comparability of results. In order to ensure consistency the methods stipulated for (DWAF, 2008a) should be used for the NESMP (Appendix A). This will also ensure that the data from the NESMP can be used and compared in future EWR assessments, ecological reserve audits and setting of resource quality objectives.

3.3.4 *Estuary Site Selection*

In order to increase the cost-effectiveness of the NESMP, high priority estuaries were identified where monitoring could begin. Only 12 (40 %) of the estuaries that fell within the top 30 estuaries (Table 10) according to the prioritisation or objective model were also selected during the 2008 workshop (DWAF, 2008b) in a subjective manner. This low number of subjective selected estuaries in the objective list, which is driven by the practicality to undertake the monitoring, indicates that the subjective approach does not take into consideration the practicality and human resources required to undertake the monitoring. Monitoring commenced on 7 of the 12 (58 %) subjectively chosen estuaries during the first three years (2012 to 2014) of the programme, although monitoring commenced on only 16 (53 %) of the top 30 estuaries according to the priority model. The subjective approach therefore assists to prioritise the monitoring effort to systems where it is most needed according to the objective prioritization model. The subjective approach acts as a refinement step to the objective approach, focusing the required monitoring to estuaries where monitoring is most needed based on professional opinion.

All 28 of the estuaries selected for the pilot testing between 2012 and 2015 have NFEPA priority rating and are of national importance. Human resources were available at all these estuaries to undertake the sampling. Based on Turpie et al. (2002), Nel et al. (2011), Van Niekerk and Turpie (2012), and Turpie et al., (2012), 38% of these estuaries are in a relative pristine state, while 52% and 10% are utilized and highly utilized respectively. Twenty nine percent of the estuaries are formally protected, 19% have active conservation forums and 36% have estuarine management plans in place. Only 16% of the estuaries do not have some sort of protection status or management intervention in place. Historic monitoring and / or research did take place on 52% of these estuaries before 2012. Monitoring and / or research, independent of this national monitoring programme, are currently (2012 to 2015) taking place on 45% of these estuaries, while only 3% of these estuaries did not have any form of monitoring and / or research.

In smaller systems (up to 30 km in length), at least four sites per estuary for Tier 1 and 2 sampling should be selected. These can be sites that have been used for previous research and/or monitoring programmes in order to ensure comparability and consistency with historical data. The sites should be representative of the upper, middle and lower estuary and a site immediately upstream of the furthest point of tidal exchange, therefore at the point indicative of freshwater entering the estuary. In the case of larger estuaries (>30 km) a rough estimate for setting the distance between stations is to divide the length of the estuary by 10 (i.e. if an estuary is 30 km long, the distance between each site should be 3 km). This should only be used as a guideline and would depend on the estuary specific conditions and specialist opinion for a particular estuary. The sites selected for Tier 3 assessments will depend on the spatial orientation of the specific issue being investigated. It is advised that the sites should be representative of the above stream and below stream environment of the area of study, in order to identify the impacts associated with the aspect being investigated. Where possible, these sites should also be representative of sites that have previously been monitored. The temporal scales for sampling vary between the different tiers and vary from monthly sampling for Tier 1 to three to five years for Tier 2. Tier 3 will depend on site specific conditions (Table 11).

3.3.5 Roles and Responsibilities

Collaboration is the foundation of the NESMP and ensures sharing of responsibilities for the programme, thereby making best use of available financial and human resources. Central to the successful implementation of the NESMP is programme management, funding and implementation (Figure 13). The responsibility for these three main activities rest with different and in most instances, overlapping organizations.

Table 12 indicates the main participants in the estuaries monitoring programme for the initial 28 estuaries, as well as the roles and responsibilities. The provision of capital equipment including boats, in situ multiprobes and sampling material is largely the responsibility of DWS, although it is shared in certain instances, where capital equipment is already available with the entities which are responsible for monitoring. Sampling is done by ground personnel of conservation bodies (e.g. Ezemvelo / KZN Wildlife, SANPARKS, CapeNature), volunteers from the different conservation forums (including Zinkwazi / Blythdale Conservancy, Lower Breede River Conservation Trust), local and district municipalities (including West Coast and Eden) and government departments (e.g. DST through SAEON, DAFF, DEA). In most instances the entities that are responsible for the sampling are also responsible for the operational costs (fuel, travel, subsistence). Water quality analysis, including nutrient analysis, is the responsibility of DWS, while microbial analysis is in most instances part of the mandate of the local authorities. Raw data are stored in the DWS national database, through the Water Management System (WMS) and HYDSTRA platforms in Pretoria. These data, as well as information products will also be accessible via the South African Estuary Information System (SAEIS) housed at the SAEON Elwandle Node. Annual reporting will be the responsibility of DWS, although other authorities including conservation bodies, government departments and municipalities may also do ad hoc and / or estuary specific reporting based on the mutually collected data.

Table 10 Prioritisation of estuaries for monitoring based on the objective numerical model and the subjective outcomes of the monitoring workshop. Estuaries where the programme is currently operational with year of commencement is indicated. Estuaries where monitoring commenced but which is outside the top 30 priorities, are also included.

PRIORITY ACCORDING TO THE NUMERICAL MODEL	ESTUARY	FINAL SCORE	SUBJECTIVE PRIORITISATION DURING 2008 WORKSHOP	MONITORING COMMENCED OR PLANNED				
				2012	2013	2014	2015	2016
1	Swartkops	38	Yes					
2	Knysna	37	Yes	X				
3	Berg	36	No	X				
4	St Lucia	35	No	X				
5	Durban Bay	35	No					
6	Bot	34	No		X			
7	Olifants	34	No		X			
8	Kromme	33	No	X				
9	Richards Bay	32	Yes					
10	Mhlanga	32	Yes		X			
11	Swartvlei	32	Yes	X				
12	Wilderness	32	No					
13	Mfolozi	31	No	X				
14	Bushmans	31	Yes					X
15	Verlorenvlei	31	No		X			
16	Mgeni	31	No		X			
17	Gamtoos	30	No		X			
18	Breede	30	No	X				
19	Mtamvuna	29	Yes				X	
20	Keurbooms	29	No				X	
21	Piesang	29	No					
22	Heuningnes	29	Yes					X
23	Klein	29	Yes				X	
24	Mtanfufu	28	No				X	
25	Kowie	28	No					
26	Groot Brak	27	Yes					X
27	Mlalazi	26	Yes		X			
28	Mpenjati	26	No		X			
29	Uilkraals	26	No					X

PRIORITY ACCORDING TO THE NUMERICAL MODEL	ESTUARY	FINAL SCORE	SUBJECTIVE PRIORITISATION DURING 2008 WORKSHOP	MONITORING COMMENCED OR PLANNED				
				2012	2013	2014	2015	2016
30	Palmiet	26	Yes					
33	Zinkwazi	25	No	X				
34	Mdlotane	25	No		X			
41	Nonoti	23	No	X				
53	Gouritz	19	No					
71	Mdloti	18	Yes				X	
99	Orange	16	Yes				X	

Table 11 Sampling frequency for different sampling tiers of the NESMP.

TIER	SAMPLING FREQUENCY
Tier 1	Monthly during first year on a spring high tide, starting one to three hours after the onset of high tide to determine the extent of the saline intrusion. Thereafter, dependent on findings of first year, a minimum of at least during high flow and low flow or stable open and stable closed phase, depending on the type of estuary. The temporal scale does however need to be as frequent as practical possible within the limitations of the available budget and human resources.
Tier 2	Twice every 3 to 5 years during the high and low flow or stable open and closed phase dependent on the type of estuary. A minimum of once during a stable phase, should there be budget limitations.
Tier 3	Situation specific dependent on the objective of the study. Usually more frequent sampling over a shorter period.

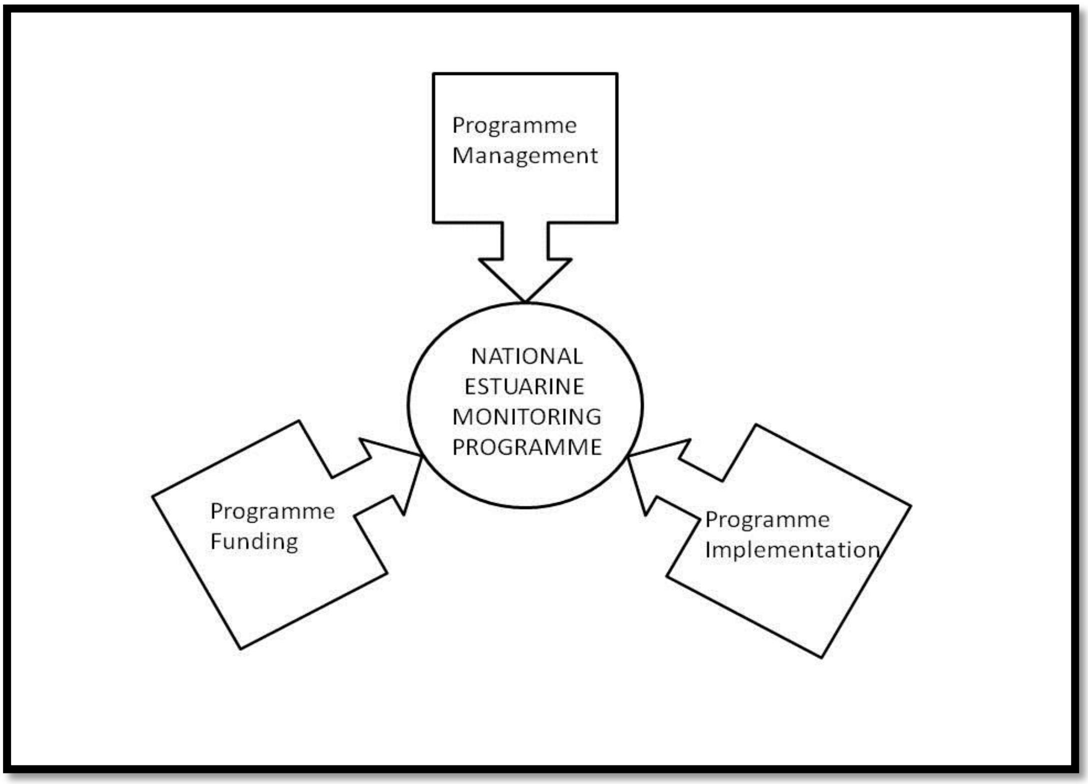


Figure 13 Three main activities form the core of the NESMP. Different parties have different and sometimes overlapping responsibilities within the NESMP framework.

Table 12 Roles and responsibility for the different organisations associated with the estuaries selected for pilot testing of the NESMP between 2012 and 2015.

ESTUARY	CAPITAL EQUIPMENT	SAMPLING	WATER QUALITY ANALYSIS	DATA MANAGEMENT	REPORTING
Subtropical					
St Lucia; Mfolozi	DWS, Ezemvelo / KZN Wildlife	Ezemvelo / KZN Wildlife, SAEON	DWS, SAEON	DWS, SAEON	DWS, Ezemvelo / KZN Wildlife, iSimangaliso Wetland Park Authority
Mlalazi	DWS, Ezemvelo / KZN Wildlife	Ezemvelo / KZN Wildlife,	DWS	DWS	DWS, Ezemvelo / KZN Wildlife
Nonoti; Zinkwazi; Mdlotane	DWS, Zinkwazi / Blythdale Conservancy	Zinkwazi / Blythdale Conservancy	DWS	DWS	DWS
Mhlanga; Mdloti; Mgeni; Mpenjati; Mtamvuna	DWS, Ezemvelo / KZN Wildlife	Ezemvelo / KZN Wildlife	DWS	DWS	DWS Ezemvelo / KZN Wildlife
Mtafufu	DWS	Mtafufu estuary management forum	DWS	DWS	DWS
Warm temperate					
Swartkops	DWS, Nelson Mandela Bay Municipality, SAEON	Nelson Mandela Bay Municipality, SAEON	DWS, Nelson Mandela Bay Municipality	DWS	DWS
Kromme	DWS, SAEON	SAEON	DWS	DWS, SAEON	DWS
Keurbooms	DWS	DWS, Eden District Municipality	DWS, Eden District Municipality	DWS	DWS Eden District Municipality
Knysna; Swartvlei	DWS, SANPARKS	SANPARKS	DWS	DWS	DWS
Gouritz	DWS	SAEON	DWS	DWS	DWS
Groot Brak	DWS, Eden District Municipality	Eden District Municipality	DWS, Eden District Municipality	DWS	DWS Eden District Municipality
Breede	DWS, DAFF	Lower Breede River Conservation Trust	DWS	DWS, DAFF, Lower Breede River Conservation Trust	DWS, DAFF
Cool temperate					
Heuningnes; Uilkraals	DWS	Cape Nature	DWS, Overberg	DWS	DWS

ESTUARY	CAPITAL EQUIPMENT	SAMPLING	WATER QUALITY ANALYSIS	DATA MANAGEMENT	REPORTING
			District Municipality		
Klein; Bot	DWS	Cape Nature, DAFF, The Shark Conservancy	DWS, Overstrand Local Municipality	DWS	DWS
Berg; Verlorenvlei; Olifants	DWS, West Coast District Municipality	West Coast District Municipality	DWS, West Coast District Municipality	DWS	DWS
Orange	DWS	DAFF, Endangered Wildlife Trust, Northern Cape Environmental Affairs	DWS	DWS	DWS

During the initial pilot testing phase of the programme the roles and responsibilities did change as a result of 1) limitation of the available manpower to do the sampling, 2) a decrease in the available operational budget, 3) changed mandates or priorities by entities involved, 4) administrative complications as a result of these changed mandates or priorities, and 5) organizational and personal conflict.

3.3.6 Programme Management

The management structure consists of a national, regional and local management level (Figure 14). This is to ensure that the management structure is simple and practical with a minimal chance for ambiguity in programme implementation and reporting.

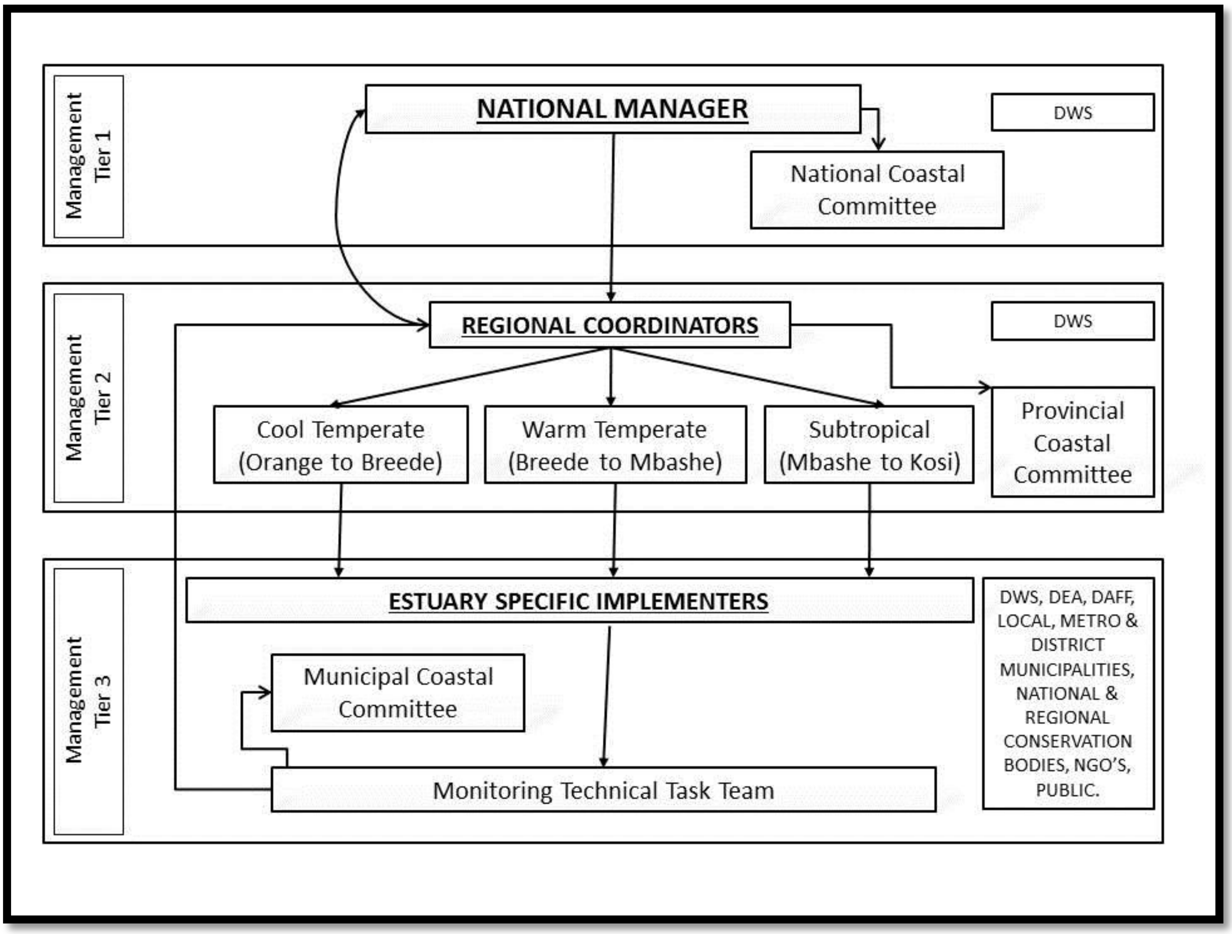


Figure 14 The management structure for the estuarine monitoring programme is divided into three distinguishable levels.

The national level management is the responsibility of RQIS of the DWS, in Pretoria. This directorate is mandated to design and implement all DWS national water resource monitoring programmes in terms of the NWA (Act No 36 of 1998). Although DWS is the national manager, other relevant government departments and para-statals are also consulted as part of the national management through a NESMP reference group. These government departments include Department of Environment Affairs, Department of Science and Technology through the South African Environmental Observation Network, Department of Agriculture, Forestry and Fisheries and the CSIR.

Currently engagement with other national departments and institutions takes place through the parliamentarian Working Group 8, tasked specifically with Oceans and Coast. Working Group 8 also acts as the National Coastal Committee. This working group meets once a quarter and discuss issues of joint interest between the different roleplayers. During these meetings DWS provide feedback on the NESMP through the Working Group 8 chair.

Reporting to the National manager are the regional coordinators, who are responsible for the implementation and operation of the programme in the three biogeographical regions. The subtropical region covers Water Management Area 3, 4 and part of WMA 7 (from Mzimvubu to Mbashe Estuary). The warm temperate region covers part of WMA 7 (from Mbashe to Keiskamma Estuary) and part of WMA 9 (Keiskamme to Breede Estuary). The cool temperate region covers part of WMA 9 (Breede to Cape Point), WMA 8 and WMA 6. The regional coordinators are officials from the DWS based at RQIS and liaise with relevant regional roleplayers including government departments, para–statals and NGOs and report back to the provincial coastal committees when needed. The relevant Provincial Coastal Committee (PCC) are the reporting forum in accordance with ICMA.

The estuary specific implementers are responsible for undertaking the monitoring in line with the NESMP protocol, through a monitoring technical task team, which is responsible for overseeing the estuary specific operational aspects of the monitoring programme. A core group forms the monitoring technical task team. They are responsible for co-ordinating the sampling on a specific estuary, addressing the logistical requirements including sampling equipment, sample collection and delivery and liaison with the main funders including DWS. This task team comprises members from different organisations where possible, including government departments, para-statals, the private sector and volunteer civilians in their personal capacity. In most instances the monitoring team consists of two members, but ideally there should be at least four individuals, to ensure that there is an alternative team that can undertake the sampling should it be required. This group provides feedback to the regional coordinators and to the Municipal Coastal Committee (MCC) on a quarterly base. There is overlap of roles and responsibilities between the NESMP implementing organisations and coastal management organisations as required in terms of the ICM Act. To prevent a duplication of meetings and subsequent effort, the structure as proposed for integrated coastal management through the ICM Act is synergized with the management structure for the NESMP (Table 13).

The largest difficulty with a national water quality monitoring programme is the availability of funding for water quality analysis, procurement of capital equipment and operational costs. In view of this being a DWS initiative, the bulk of the operational funding is budgeted for by DWS. However, in view of the scale of the programme, additional funding and support streams should be solicited though collaboration.

Table 13 The National Estuarine Monitoring Programme management structure in relation to the proposed coastal management structure mandated through the Integrated Coastal Management Act (Act No 24 of 2008).

LEVEL	NESMP Management Structure	ICMA Management Structure
NATIONAL	National Manager	National Coastal Committee / Working Group 8
REGIONAL	Regional Coordinators - Subtropical - Kosi to Mbashe (WMA 3,4,7) - Warm Temperate – Mbashe to Breede (WMA 7, 9) - Cold Temperate – Breede to Orange (WMA 6, 8, 9)	Provincial Coastal Committees - KZN - Eastern Cape - Western Cape - Northern Cape
LOCAL	Estuary Specific Implementers - Monitoring Technical Task team - Sampling team	Municipal Coastal Committees (On district municipal level)

In view of various roleplayers' mandated involvement with water resource monitoring there is an opportunity to pool resources ensuring the most effective use of available funding and manpower. Different estuaries have different role players, each with their own strengths and weaknesses. The success of the programme is based on making use of the available human and financial resources at each estuary and not applying a single stringent operational philosophy. This is achieved by coordinating the monitoring effort efficiently and ensuring constant open lines of communication between role players. The national manager is critical in coordinating this collaboration and giving it effect through the regional coordinators and the estuarine specific implementers.

Data management is a critical pathway in the NESMP. Without proper data management all the effort going into programme coordination, management and sample collection will be ineffectual. A simple bottom up, top down data management process ensures that the data are collected, stored and information generated and disseminated in a seamless fashion. Four parties are involved with data collection, management and dissemination (Figure 15).

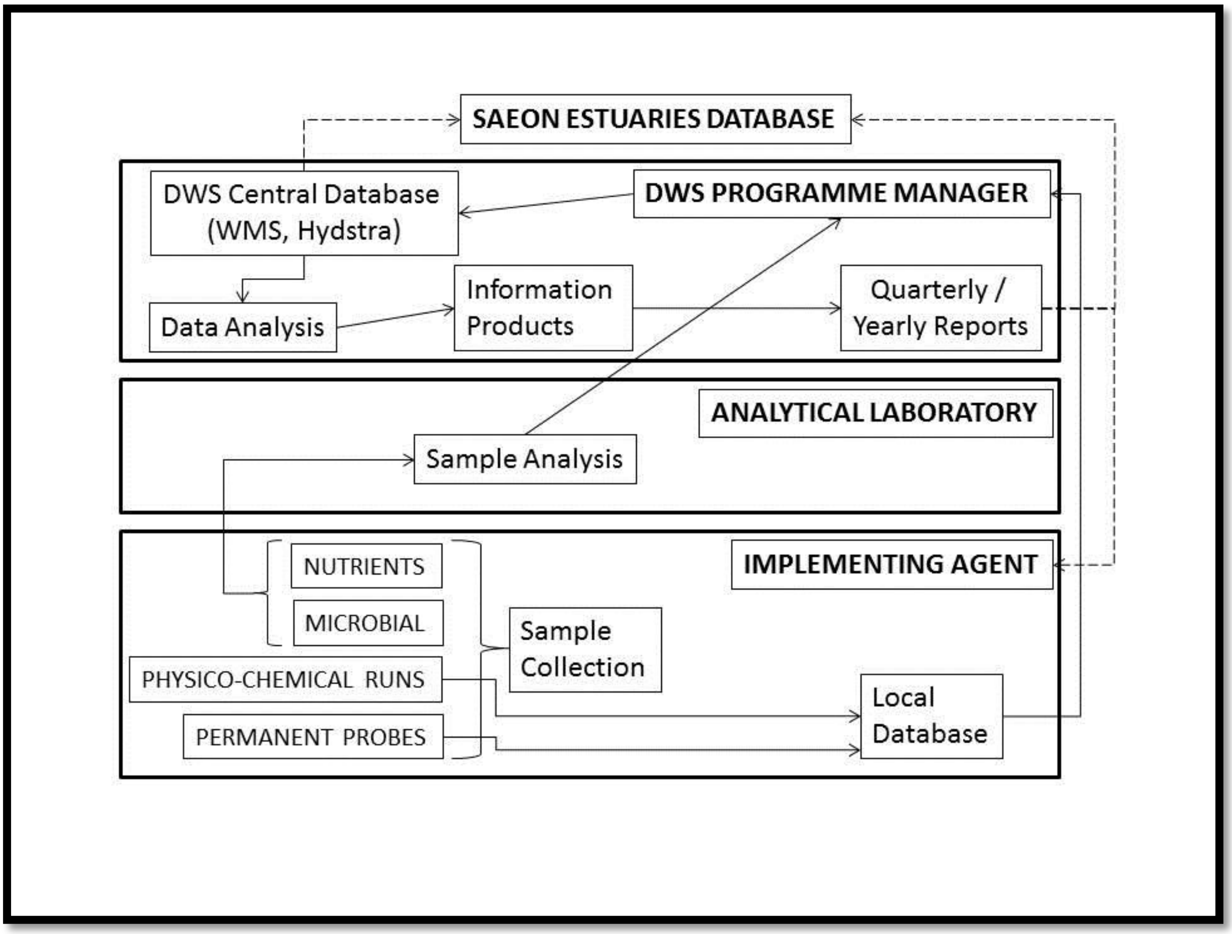


Figure 15 The data management process of the NESMP. Solid lines indicate data collection, data archiving and analysis. Dotted line indicates data and information product dissemination.

The implementing agency is responsible for collecting water samples, the associated physico-chemical variables and any other relevant data. The water samples are submitted to the analytical laboratory for analysis, whilst a simple standardised Excel based database is kept by the implementing agency on a local computer for the physico-chemical variables and other relevant data. This Excel spreadsheet is submitted monthly to the DWS programme manager, who is responsible for loading the data into the appropriate DWS database. The data from the water sample analysis are directly submitted by the relevant analytical laboratory to the DWS programme manager. These data are also available to the implementing agency if requested. The information on this database is also submitted in parallel to SAEIS at the SAEON Elwandle Node by the DWS programme manager.

The DWS programme manager is responsible for ensuring the compilation of information products in the form of quarterly and annual reports that are submitted to the implementing agents. The implementing agents are then responsible for providing these to all the stakeholders. These reports are then also deposited in the SAEIS.

3.3.7 *Limitations and gaps*

Globally, the economic downturn of the past decade has implications for environmental management. This is also relevant to South Africa where government spending on monitoring water resources have systematically stagnated as the allocated budget does not keep up with the demand for water resource monitoring and associated information. This has worsened over the past two years as a result of substantial budget cuts within DWS for operations and human resource expansion. Therefore the largest limitation to the effective implementation of the NESMP as proposed in this study is the availability of funds to undertake a programme of this national scale. Linked to this are the available human resources to ensure that sampling, sample analysis, data management and reporting takes place.

Currently DWS are responsible for seven national monitoring programmes, which are not operating optimally, even with the assistance of internal roleplayers in the form of DWS regional offices and CMA's. To make DWS solely responsible to undertake the entire NESMP from sampling to information generation has major challenges and is not viable with the existing constraints.

In order to address the limited resources within DWS, the foundation of the NESMP is collaboration with other role-players that have a vested interest in the generated data and information. This collaboration has sampling by external parties as the main objective. This is a labour intensive activity, for which DWS do not have the man power or budget to pay for. Hence, the requirement from external parties to commit human resources to undertake sampling without compensation. In turn DWS provides sampling hardware, training, data analysis and information. The information generated through this collaboration is fed back to the collaborators to assist them with their different mandates. These collaborators are also exposed to similar financial and human resource constraints as is the case with DWS. Therefore, the collaboration is dependent on the goodwill of other parties that also have similar constraints. This requires focussed and efficient coordination and support from DWS to facilitate this collaboration. This in itself is a labour intensive action that requires commitment from DWS staff.

3.4 CONCLUSION

A three tiered monitoring approach is followed in the NESMP addressing both biotic and abiotic driver and response indicators. The proposed indicators are aligned with the EHI and the requirements of ecological reserve and classification studies. This ensures that data collected are robust enough to provide relevant long-term information on the state of South African estuaries. This approach also ensures that the data can be used for other relevant management activities, including EWR baseline studies and EWR audits. The proposed NESMP protocol also ensures that the data generated during *ad hoc* assessments of specific issues, including pollution incidents and impacts associated with development pressure, can contribute to the long-term data sets for estuaries in South Africa. The NESMP protocol provides for standardization of sampling methods, aligned with current sampling practices in South Africa (Taljaard et al., 2003) to ensure national comparisons of the emanating information. The proposed NESMP protocol will therefore ensure that data are collected in a consistent repeatable manner, thereby ensuring that the state of South African estuaries can be evaluated on a national scale. The standardized spatial and temporal orientation of sampling will further facilitate the comparison of these data. Through this process, management recommendations based on robust scientific data can be made.

Management is central to the success of any water resource monitoring programme. The proposed NESMP provides for a tiered approach to management of the programme on a national, regional and local level. This ensures that data are collected and comparable on a national scale, but usable for regional and local intervention. Finally, the roles and responsibilities are also identified for the different role-players to ensure smooth implementation of the programme.

The success of the programme should constantly be evaluated in line with strategic adaptive management in order to ensure that the necessary changes in the sampling and management protocol takes place when needed. The programme should however, in line with the DWS monitoring guidelines be formally re-evaluated on a 5 year cycle. During this review, all relevant parties that have an interest in the NESMP should be consulted. The aim and objectives of the NESMP should also be reassessed during this review ensuring that the monitoring remains remain relevant to the changing natural environment. This chapter showed that a single monitoring programme could be designed for South African estuaries. The implementation of the NESMP is however based on collaboration due to the financial and human resource constraints. Subsequent chapters test the collection of Tier 1 (abiotic) data based on this central principal of collaboration to investigate how these data can inform management decisions.

CHAPTER 4. TESTING OF THE MONITORING PROGRAMME USING THE BERG AND BREEDE ESTUARIES AS CASE STUDIES

4.1. INTRODUCTION

Pilot testing of new monitoring programmes is a requirement of DWS (DWAF, 2004b). This ensures that the assumptions being made during the design phase of the programme are tested and the programme refined for final implementation. This however does not preclude the reassessment of the programme on a five year cycle to re-evaluate the success of the programme as required by DWS (DWAF, 2004b). The main objective is to make the required adjustments to ensure the effectiveness of the monitoring programme in line with strategic adaptive management. The NESMP has been tested on 28 estuaries (Appendix C) on the South African coast between 2012 and 2016. This testing focussed on Tier 1 of the protocol as described in Chapter 3. Due to time and budget constraints Tier 2 and 3 could not be assessed as part of this study. Table 14 summarises the implementation of the NESMP on a national scale for this period. From this it is clear that Tier 1 monitoring continued on 72 % of the estuaries during the first four years of testing the NESMP. The highest success rate between 2012 and 2016 for the implementation of Tier 1 of the NESMP was achieved through the use of municipalities and multiple organisations as implementation agents through the establishment of MoUs. The highest fail rate (80 %) was experienced where NGOs were solely responsible for the sampling. This is mainly as a result of human and financial constraints and the absence of MoUs. These organisations are dependent on donor funding, which is becoming scarcer as a result of the global economic downturn currently being experienced. This shortage in donor funding has implications for the financial sustainability of these organisations over the long run and subsequent commitment to the NESMP through a MoU. The second highest failure rate (27 %) was observed where conservation bodies were solely responsible for sampling. This was as a result of human capacity limitations and logistical support from DWS. The required logistical support could not be met by DWS as a result of procurement problems, resulting in a delay in getting water quality analysis contracts in place. This has resulted in the conservation body having to redeploy limited human resources to priority tasks in light of this constraint. The use of universities resulted in 16% failure of the monitoring effort. This was as a result of a lack of students to continue with the sampling.

Table 14 Summary of the implementation of the NESMP between 2012 and 2016 by different roleplayers.

ORGANISATION	NUMBER OF ESTUARIES INITIATED (2012-2016)	NUMBER OF ESTUARIES DISCONTINUED (2012 – 2016)	REASON FOR DISCONTINUATION
Municipalities	3	0	N/A
Conservation bodies	11	3	Human resource limitations and logistical support
NGOs	5	4	Human and financial resource limitations
Universities	6	1	Human resource limitations
Government departments	5	0	N/A
Multiple organisations	4	0	N/A

This chapter evaluates the data collected during the pilot testing of Tier 1 of the NESMP for the Berg and Breede estuaries. These two estuaries were selected due to the different parties responsible for implementation of the NESMP on each estuary. The Berg Estuary was sampled by the West Coast District Municipality (WCDM) staff for which there is a formal MoU between DWS and the WCDM. The Breede Estuary was selected as an NGO, the Lower Breede River Conservancy Trust (LBRCT) does the sampling. There is no formal agreement in the form of a MoU between DWS and the LBRCT. Although these systems are both permanently open systems, the objective of this chapter is not to only test the methodology, but also to test the implementation through different roleplayers.

Although the NESMP was designed with the primary objective of collecting long-term data to determine status and trends in estuarine health on a national scale, these trends need to be translated into local management actions. A secondary objective of the NESMP data isare therefore to audit the Resource Quality Objectives and associated Ecological Reserve for estuaries and recommend management intervention within the context of the NWA and ICMA. Through this the value chain of data collection, interpretation and information generation is taken a step further by identifying required management interventions.

The Threshold of Potential Concern (TPC) is the trigger that is used to ensure that the Ecological Specifications are met (Figure 16). The Thresholds of Potential Concern (TPC) are measurable end points related to specific abiotic and biotic indicators that if reached, prompt management action. The TPCs are therefore early warning signals of potential non-compliance with the ecological specifications.

4.2. PROBLEM STATEMENT

The success of a new water resource monitoring programme needs to be evaluated by testing the implementation of the programme over an extensive period. DWS advises that new monitoring programmes should be tested for at least a three year period (DWS, 2004b). This is to evaluate if the objectives of the monitoring programme are achieved with the collected data. Without evidence, the successful design of the monitoring programme cannot be evaluated and the programme refined.

The objective of this chapter is to investigate the implementation of the NESMP on the Berg and Breede estuaries during the first three years of the programme (2012 to 2015) by 1) evaluating the collected data in terms of long-term trends, within the context of the NWA and ICMA, 2) evaluating the use of the collected data to compare against the TPCs that were set in the Berg Estuary Environmental Water Requirements study (DWA, 2012) and 3) in the absence of TPCs, set TPCs for the Breede Estuary; and 4) make recommendations regarding the programme implementation as well as the setting and use of TPCs for estuaries. Due to time and space constraints, this chapter only address case studies on the Tier 1 monitoring on the Berg and Breede estuaries. The research question that this chapter addressed was “Are the data collected as part of the NESMP adequate to provide a national overview of estuary health and address the local management issues that need to be resolved?”

4.3. STUDY AREA

The Berg Estuary (Figure 17) is located 130 km from Cape Town on the west coast of South Africa and is one of three permanently open estuaries on the Atlantic seaboard. It is one of the largest estuaries in the country with a surface area of 61 km^2. It is also one of the most important estuaries in South Africa for conservation purposes, due to its habitat diversity of which the extensive floodplains in the middle and upper reaches are unique in the south-western Cape. It has been identified as an important bird area and a desired protected area (Barnes, 1998; Turpie *et al.*, 2002; Turpie, 2004; Turpie and Clark, 2007). The mouth of the estuary is used as an important national fishing harbour. Tidal oscillation is propagated upstream for a distance of 69 km, although the saline intrusion only extends to a distance of approximately 45 km from the mouth (DWA, 2012). The mouth is 200 m wide but the channel becomes smaller and shallower further inland from the mouth. The average depth is between 3 and 5 m although deeper areas of up to 9 m do exist (DWA, 2012). The total volume of the estuary is approximately 12 Mm^3. The catchment receives most of its precipitation in the winter. The Berg River originates in the Jonkershoek Mountains and is 294 km long with a catchment area of 7715 km^2. The catchment is characterised by small to medium urban areas (Paarl, Wellington, Piketberg, Hopefield and Veldrif) and agricultural activities. There are four major dams namely Wemmershoek (storage capacity = 60 Mm^3), Voëlvlei (storage capacity = 170 Mm^3), Misverstand (storage capacity = 7.9 Mm^3) and Berg River Dam (storage capacity = 130 Mm^3). Various smaller dams are also present. Supplement Schemes divert water from the Dwars River to the Berg River Dam. The present day mean annual runoff (MAR) of the Berg River has been estimated to be around 520 Mm^3a^{-1}. This is approximately 46 % lower than under natural conditions (DWA, 2012).

The Breede Estuary (Figure 18) is located 220 km east of Cape Town on the south coast of South Africa. It is also one of the largest estuaries in the country stretching from Witsand to a point 10 km north-west of Malgas (DWAF, 2003). The channel is incised with a depth that varies between 3 to 6 m and deeper. The tidal influence stretches to a point approximately 52 km from the mouth (DWAF, 2003). The mouth is permanently open to the ocean as a result of the relative high run-off and the volume of tidal exchange. The Breede River is the largest river in the Western Cape and originates in the Ceres Basin (DWAF, 2003). The catchment covers a drainage region of approximately 12 600 km^2 with a MAR of 1800 million m^3/a and is mainly characterised by agricultural land use with fruit, wine and grain production being the focus. The Brandvlei and Theewaterskloof are the largest dams in the catchment, used for irrigation purposes and water supply to the Cape Town metropolitan area. They have a storage capacity of 342 million m^2 and 434 million m^2 respectively. A network of channels supplies water for irrigation purposes to the Breede Valley. The main water use in the catchment (66%) is for agricultural purposes. The main tributaries to the Breede River include the Molenaars, Hex, Kogmanskloof, Riviersonderend and Buffeljags River. The main urban areas are Ceres, Worcester, Robertson, Bonnievale and Swellendam. The Breede River is situated in the winter rainfall area receiving most of its precipitation between April and September (DWAF, 2003). Annual rainfall varies between 400 mm (north of the Langeberge) and 2300 mm (upper Riversonderend). The water quality of the Breede River has been mainly impacted by agricultural return flow resulting in nutrient loading and salinization, specifically of the middle reaches. In recent years, wastewater treatment works have resulted in microbial pollution, nutrient loading and associated algal, duckweed and hyacinth blooms in the river.

An important management objective for permanently open estuaries is to maintain the productive river estuary interface zone (REI) in its spatial and temporal extent. The REI zone is generally described as the productive zone where the salinity ranges between 10 and 15 ppt (Bate et al. 2002). Whitfield and Wood (2003) identified the REI zone as the area where the integrated vertical salinity is less than 10 ppt and where specific biological components dominate. This results in unique microalgal, pelagic and benthic invertebrate and fish assemblages in the REI zone (Bate et al., 2002). Due to variability in the freshwater input into estuaries as a result of different rainfall patterns, the REI zone varies between estuaries in both temporal and spatial dimensions. The previous ecological water requirement studies identified this as being a distance of approximately 12- 45 km in the Berg Estuary (DWA, 2012) and from 12-40 in the Breede Estuary (DWAF, 2003). Due to the extensive Breede catchment and associated high runoff, it was indicated that during high winter flows, the REI zone may even extend out to the marine environment and be non-existent during drought conditions (DWAF, 2003).

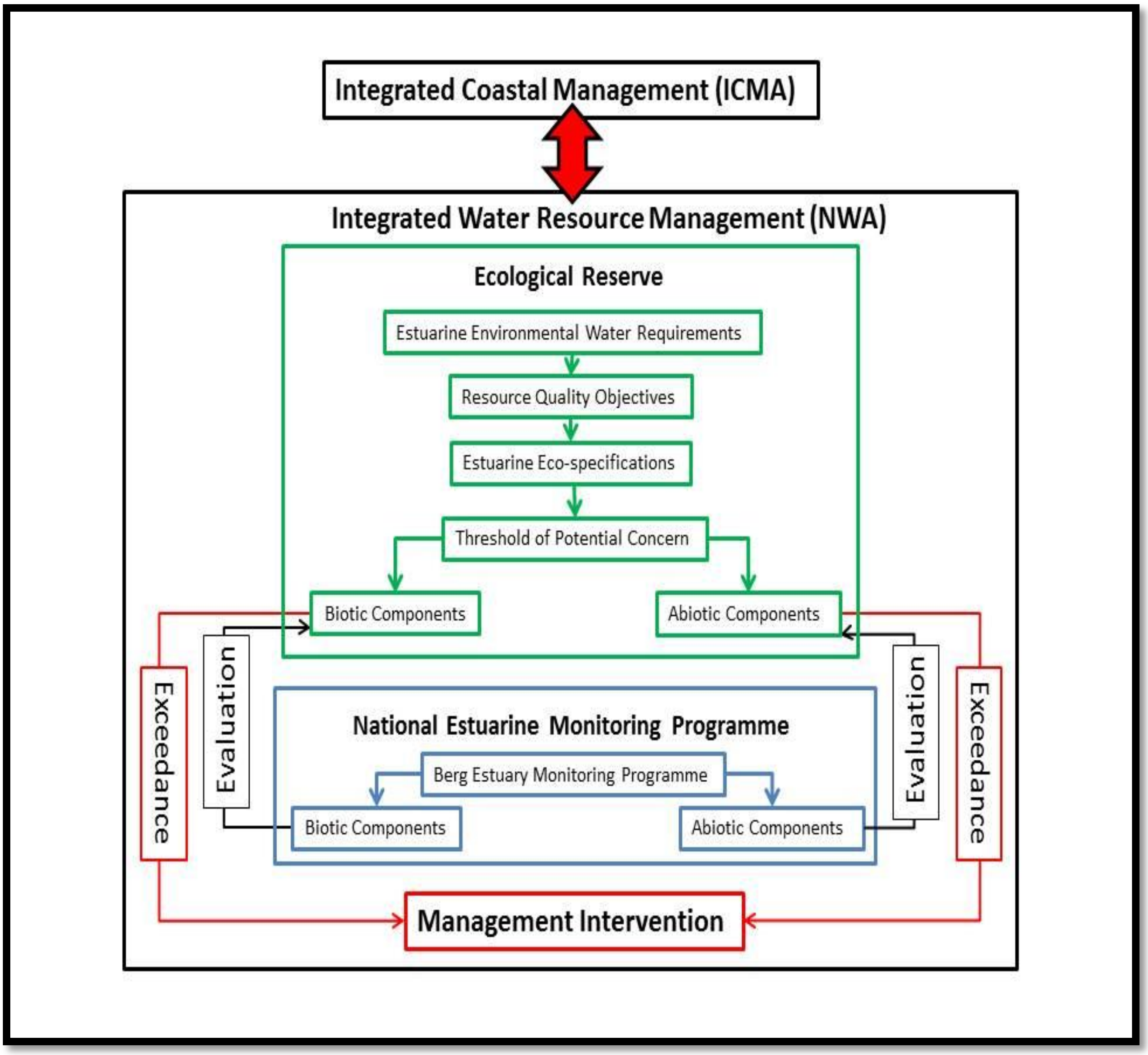


Figure 16 Contextualisation of the Integrated Coastal Management Act (ICMA) and the National Water Act (NWA) in terms of Environmental Water Requirements, Threshold of Potential Concern, the National Estuarine Monitoring Programme and management intervention.

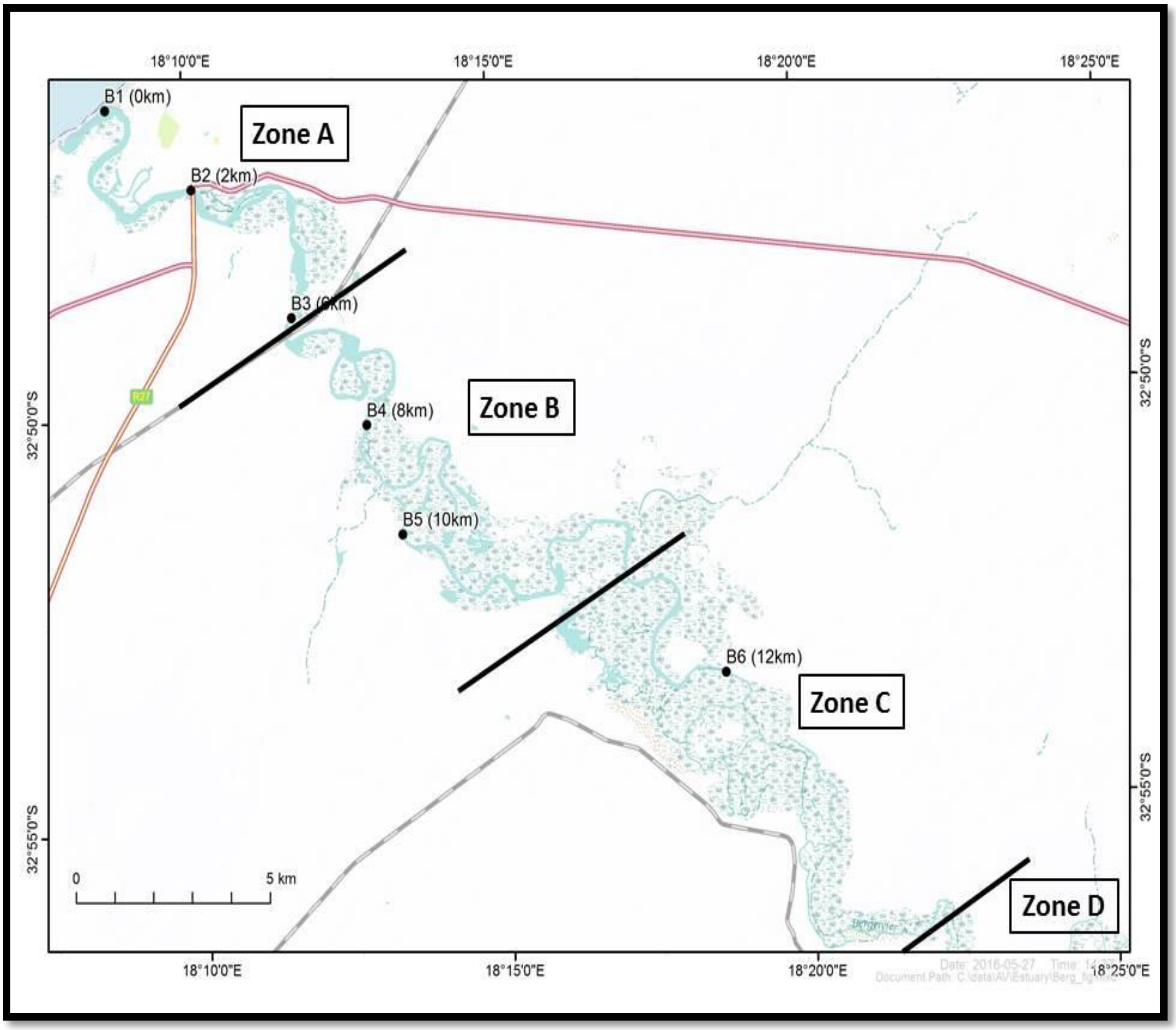


Figure 17 The Berg Estuary with sampling sites used in this study. Sites 1 to 6 were used as system variable and nutrient collection points. Sites 2 and 4 were used as deployment points for *in situ* permanent water quality loggers. The different zones as identified in the Berg Estuary ecological water requirements study (DWA, 2012) are also indicated.

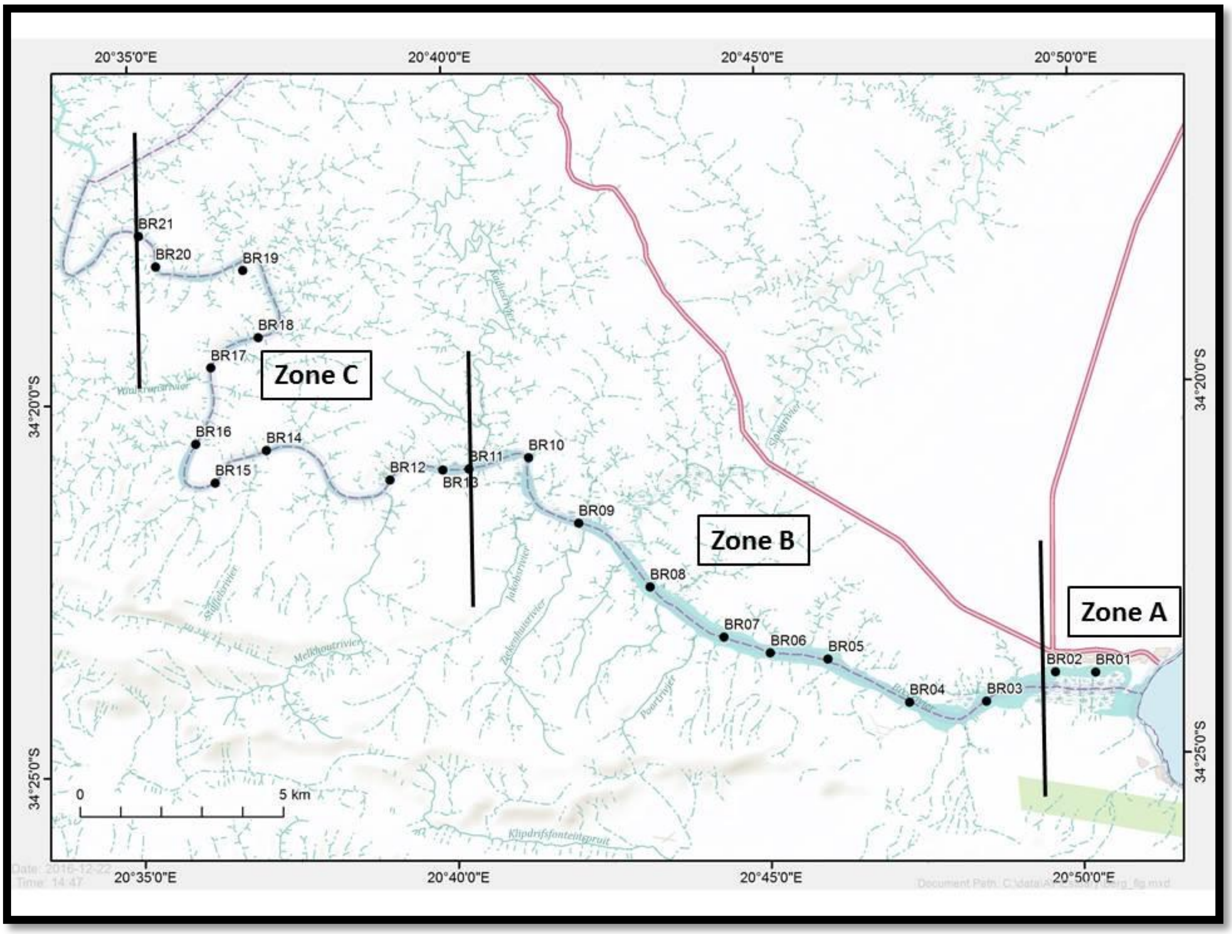


Figure 18 The Breede Estuary with sampling sites used in this study. Sites 1 to 21 were used for system variables and Sites 2, 5, 8, 11, 14, 18 and 21 for nutrient collection points. Site 1 was used as deployment points for *in situ* permanent water quality loggers. Different zones as determined in section 4.5.2 of this study are also indicated.

4.4. METHODS

4.4.1. Flow Data

Hourly flow data, between August 2012 and October 2014, from the DWS flow gauging station (G1H031) situated approximately 120 km from the Berg Estuary mouth at Misverstand were used for comparative purposes. Low flow levels for the Berg Estuary were <5 $m^3 s^{-1}$ and high flows >5 $m^3 s^{-1}$ as per the Berg Estuary EWR study (DWA, 2012). For the Breede Estuary, hourly flow data between January 2012 and August 2015 from the DWS flow gauging station (H7H006), situated approximately 120 km from Witsand at Swellendam were used. Low flows for the Breede Estuary were <10 $m^3 s^{-1}$ and high flows >10 $m^3 s^{-1}$as per the Breede Estuary EWR study (DWAF, 2003).

4.4.2. Monthly Sampling

This study is limited to water quality as part of the abiotic component of Tier 1 of the NESMP (Figure 12). System variable data including pH, temperature, oxygen concentration, turbidity and salinity and were collected at 6 sites on the Berg Estuary (Figure 17) and 21 sites on the Breede Estuary (Figure 18) with the use of a YSI multiprobe. Secchi depth values were also collected in the Berg Estuary as a surrogate for turbidity. System variable data from August 2012 to July 2014 on the Berg Estuary and from March 2012 to November 2014 are the subject of this study. The data were downloaded onto a computer and stored as Excel spreadsheets. The data were scrutinised for anomalies associated with equipment malfunction or calibration errors (readings not typically expected and repeated across the system) and subsequently cleaned, by removing outlier data points to ensure data quality. Time series graphs were drawn up in MS Excel. Data were plotted on a graph with the variable level / concentration on the y-axis and sites as reflected in distance from mouth on the x-axis. The objective of these graphs was to indicate spatial and temporal changes in the physico-chemical variables and analysed constituents over the study period for each system. The Data Analysis Toolpack in Excel was used for descriptive data analysis (Appendix D). Subsurface water samples were collected in clean plastic bottles at all six sites on the Berg Estuary between November 2013 and December 2014; and on the Breede Estuary at seven sites from March 2013 to November 2014. These samples were filtered through a 0.45 micron glass fibre filter and then through a 0.2 micron filter. The samples were placed on ice and frozen upon return from the field. The water samples were analysed at an accredited laboratory for Soluable Reactive Phosphate (SRP) and Dissolved Inorganic Nitrates (DIN). All data were evaluated based on flow conditions and divided into low flow and high flow conditions. The analysis was specifically not based on seasons as the TPCs were set based on flows.

4.4.3. *Permanent Loggers*

Data were collected with the use of two In Situ Aquatroll permanently deployed loggers that measure water level variation, salinity and temperature. On the Berg Estuary, one logger was deployed at Site 2 situated 6 km from the mouth and one at Site 4 approximately 20 km from the mouth (Figure 17). On the Breede Estuary a permanent logger was deployed at Site 1 at the mouth (Figure 18). Measuring intervals were set hourly for the data from 21 August 2012 to 1 November 2015 on the Berg Estuary; and 9 February 2013 to 16 February 2016 on the Breede Estuary. The loggers were deployed at constant depths but not surveyed in, therefore the data reflect relative water level changes and not absolute changes in relation to mean sea level. The loggers were cleaned and calibrated on a monthly basis when the data were downloaded onto a laptop and stored as Excel spreadsheets. The data were scrutinised for anomalies and cleaned to ensure data quality. Time series graphs were drawn up with Excel and the Data Analysis Toolpack in Excel was used to do descriptive data analysis (Appendix D).

4.4.4. *Thresholds of Potential Concern*

The data collected on the Berg Estuary were evaluated against the Thresholds of Potential Concern (TPC), as set in the Berg Estuary Ecological Water Requirement Assessment (DWA, 2012). The results are expressed as the percentage exceedance of the TPC for the different constituents over the entire study period. An alternative set of TPCs were calculated making use of the data set collected in this study on the Berg Estuary and compared against the TPCs that was set in the EWR study (DWA, 2012). The rationale behind this is to evaluate TPCs set intuitively by specialists with limited historical data, against TPCs that have been set using a larger verified data set. The alternative TPCs were calculated making use of the 10th and 90th percentile calculation in the Excel Data Analysis Toolpack. Although the 50th percentile may be more indicative of the actual impacted (non-pristine) condition of South African estuaries, the 10th and 90th percentiles were selected as they support a precautionary approach for the environmental conditions in South African estuaries in context of the NWA. The 10th percentile was used as the lower limit for constituents that have lower limits (oxygen content and secci depth) and the 90th percentile for constituents that only have an upper limit (salinity, TDS, DIN and SRP). The 10th and 90th percentile was used for constituents that have a range (pH).

Thresholds of Potential Concern have not been determined for the Breede Estuary and the 10th and 90th percentile for the data collected in this study, between 2012 and 2015, were used to set the TPCs in a similar manner as for the alternative TPCs for the Berg Estuary. The different abiotic states for the Breede Estuary, as defined in the EWR study (DWAF,

2003) were used as a foundation for setting the TPCs, across the estuary for the low and high flow conditions. The results are expressed as the percentage exceedance of the TPC for the different constituents over the entire study period. In order to determine the REI zone the salinity data collected in the study were compared against the flow data from the DWS flow gauging weir H7H006 at Swellendam. The salinity data were divided into high flow data (>10 m^3 s^{-1}) corresponding to typical winter flow conditions and low flow data (<10 m^3 s^{-1}) typical of summer flow conditions. The data were averaged across the system and this was plotted against distance from mouth. The average vertical profile salinity of <10 ppt was used as an indication of the start of the REI zone as described in Whitfield and Wood (2003).

4.5. RESULTS AND DISCUSSION

4.5.1. Berg Estuary

Flow data

Mean daily flow between August 2012 and October 2014 at the gauging weir G3H031 at Misverstand, on the Berg River is shown in Figure 19. Flow increased in June 2013 and peaked at 842 m^3 s^{-1} on 1 September 2013. Flows subsided and returned to zero at the beginning of December 2013. During 2014 the rainy season started in May. Mean flow for the entire study period was 31.8 m^3 s^{-1}. A standard deviation of 75.7 m^3 s^{-1} and upper range of 842 m^3 s^{-1} indicates that there was a large variation in flow during the study period as expected (Appendix D).

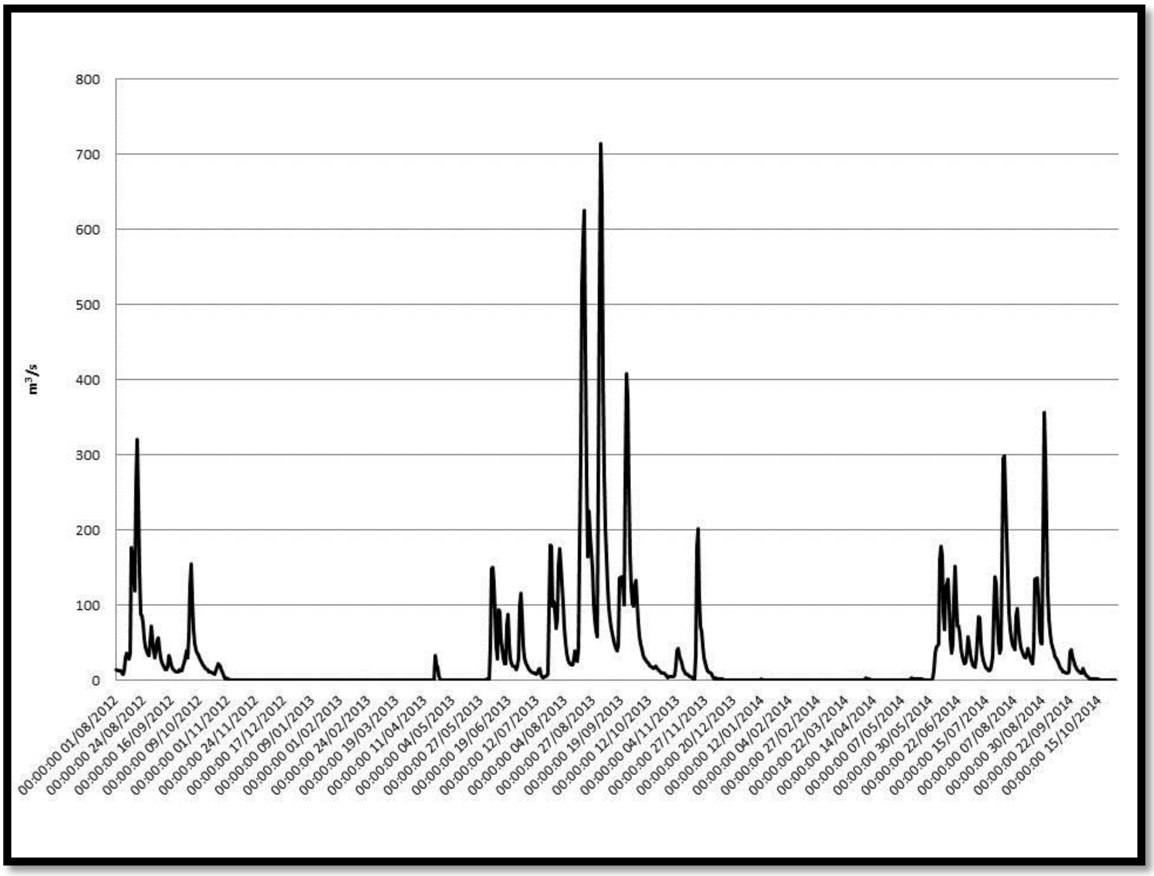


Figure 19 Mean daily flow data for the period August 2012 to October 2014 from the DWS flow gauging station G1H031 on the Berg River at Misverstand (n=820).

Monthly Sampling

Temperature. During the high flow conditions between August 2012 and July 2014 the data (n = 108) show a constant pattern between Site 1 at the mouth and Site 6, 40 km from the mouth (Figure 20). This is indicative of the stabilising effect of cold water as a result of winter rainfall in the catchment on the Berg system, flowing from the upper reaches to the lower reaches, where cold marine water from the Benguela current is already present.

During the low flow conditions for the same period, the water temperature showed a pattern of increase from Site 1 at the mouth to Site 6, 40 km from the mouth. Low flows occur during the summer, when the cold marine water enters further into the estuary, resulting in colder water at the mouth with warmer water in the upper reaches of the estuary. The higher temperatures further upstream in the estuary are a result of the water column being heated as a result of the higher ambient temperature. This increased temperature is further enhanced by the shallower nature of the estuary in the upstream areas. An anomaly is observed at Site 2, situated 6 km from the mouth, where the temperatures measured during the low flow condition of the entire study generally was lower than that at Site 1 at the mouth and the rest of the upstream sites. This is probably a result of the sampling site being situated in the shade of a road bridge crossing the Berg Estuary. Higher water temperatures are also noted at Sites 3, 4, 5 and 6 during a specific high flow sampling run. This is as a result of a chance high flow event associated with a storm during a time when the ambient temperatures were high as a result of the onset of summer. Therefore this high flow event did not take place during the winter which is the typical high flow season in the Western Cape.

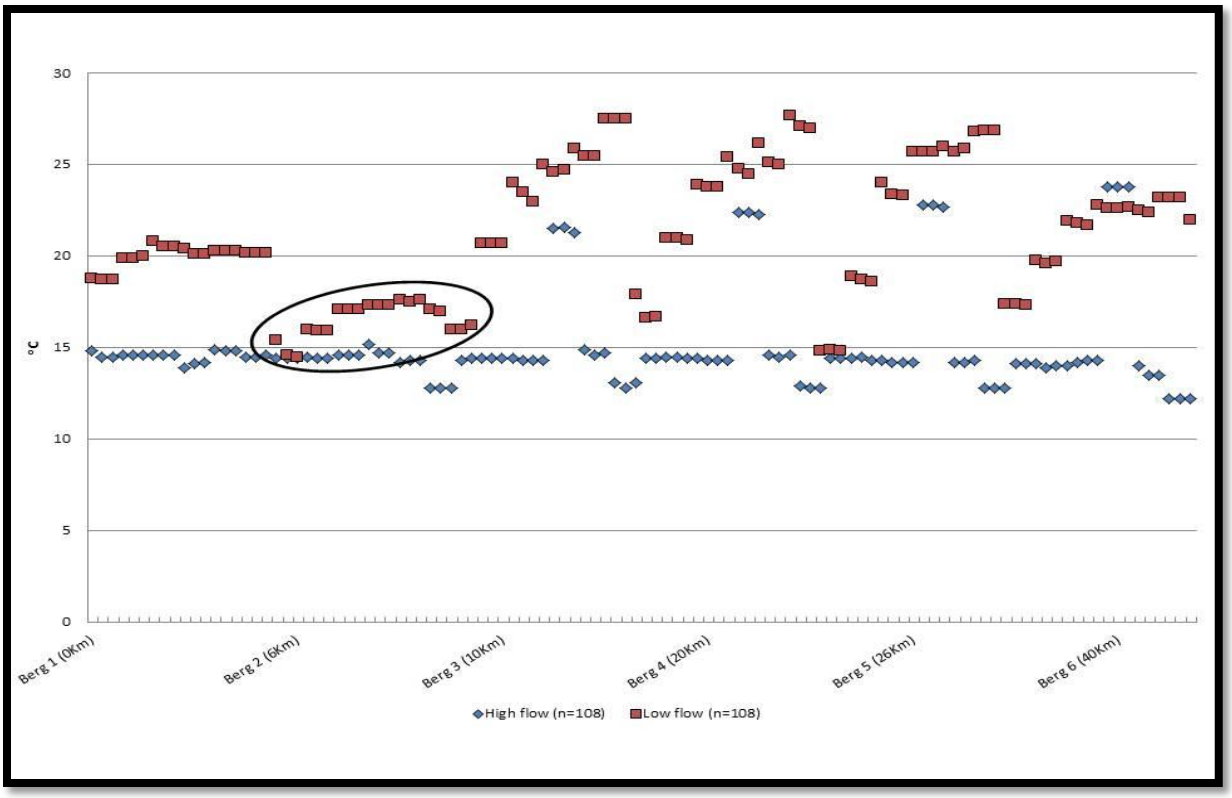


Figure 20 Temperatures recorded between Site 1 (at the mouth) and Site 6 (40 km from mouth) on the Berg Estuary between August 2012 and July 2014. Red squares (n=108) indicate low flow conditions (<5 m^3 s^{-1}) and blue diamonds (n=108) indicate high flow conditions (>5 m^3 s^{-1}). Ellipse indicate observed anomaly with the rest of the system.

Salinity. During the high flow conditions between August 2012 and July 2014 the salinity data (n = 102) also show a constant pattern between Site 1 at the mouth and Site 6, 40 km from the mouth (Figure 21). Higher salinity was observed from the mouth to Site 3. This is indicative of freshwater inflow from the catchment, although the tidal influence is still present during the high flow conditions in the lower reaches of the estuary.

During the low flow conditions for the same period, the salinity showed a systematic trend of decrease from Site 1 at the mouth to Site 6, 40 km from the mouth (n=106). Low flows occur during the summer, when saline marine water enters further into the estuary, resulting in an extension of the salinity wedge into the upper reaches of the estuary. It is clear from the data that salinity up to 28 ppt was recorded during drought conditions as far as 40 km from the mouth.

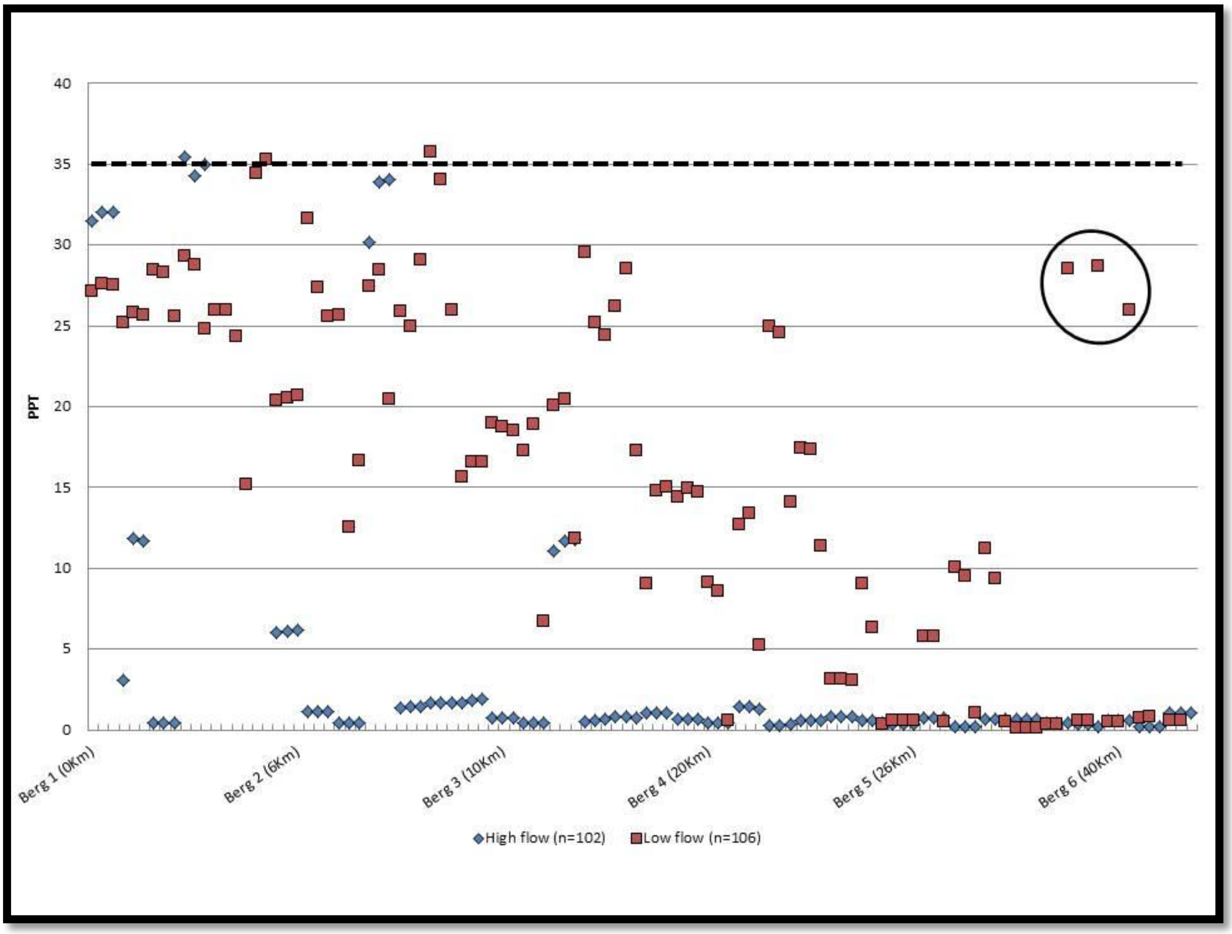


Figure 21 Salinity recorded between Site 1 (at the mouth) and Site 6 (40 km from mouth) on the Berg Estuary between August 2012 and July 2014. Red squares indicate low flow conditions (<5 m^3 s^{-1}) (n=106) and blue diamonds indicate high flow conditions (>5 m^3 s^{-1}) (n=102). Circle indicates high saline levels recorded at Site 6 during drought conditions. System variable TPCs: Black dashed line = salinity >35 ppt.

Oxygen. During the high flow conditions between August 2012 and July 2014 the oxygen data (n = 55) also show a constant pattern between Site 1 at the mouth and Site 6, 40 km from the mouth (Figure 22). This is indicative of freshwater inflow from the catchment, resulting in increased turbulence and subsequent higher oxygen levels across the system. The colder water, as a result of colder ambient temperatures, also has the ability to absorb more oxygen, resulting in the general higher observed oxygen levels during the high flow / winter conditions. During the low flow conditions for the same period, the oxygen levels showed a systematic trend of decrease from Site 1 at the mouth to Site 6, 40 km from the mouth (n=77). Low flows occur during the summer, when higher water temperatures result in a decrease in the oxygen content of the water column. There was an increase in temperature at the upper sites of the estuary (Figure 20). During summer, upwelling of cold nutrient rich water from the Atlantic Ocean takes place because of land based winds. This results in an increase in primary productivity in the coastal zone and subsequent occurrence of red tide. Red tide results in a decrease in the oxygen content of water and may result in the development of anoxic conditions. This was observed on the west coast during January 2014 and its movement into the Berg Estuary can be observed in a drop of the oxygen levels to below 4 mg/l even at Site 6, 40 km from the mouth (Figure 22).

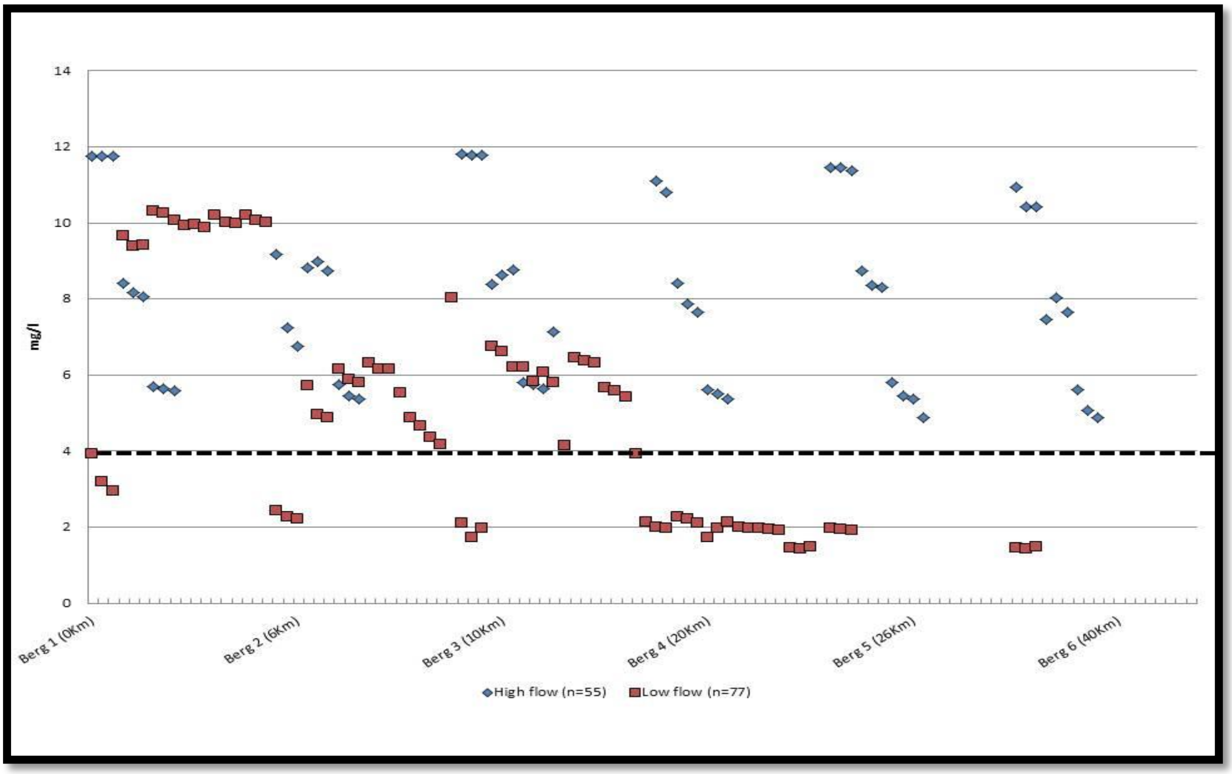


Figure 22 Oxygen content recorded between Site 1 (at the mouth) and Site 6 (40 km from mouth) on the Berg Estuary between August 2012 and July 2014. Red squares indicate low flow conditions (<5 m^3 s^{-1}) (n=132) and blue diamonds indicate high flow conditions (>5 m^3 s^{-1}) (n=77). System variable TPCs: black dashed line = [O_2] <4 mg/l.

Turbidity. During the high flow conditions between August 2012 and July 2014 the turbidity data (n = 107) show a pattern of increase between Site 1 at the mouth and Site 6, 40 km from the mouth (Figure 23). This is indicative of the increased flow, resulting in increased sediment resuspension and sediment wash off from the catchment causing higher turbidity. Generally, turbidity is lower at the mouth because of clearer marine water ingress due to tidal action and the larger grain size of the marine sand at the mouth in comparison with finer sediment further upstream in the estuary. During the low flow conditions for the same period, the turbidity is far lower and more constant. Low flow conditions result in the settling out of sediment and therefore lower turbidity levels as observed.

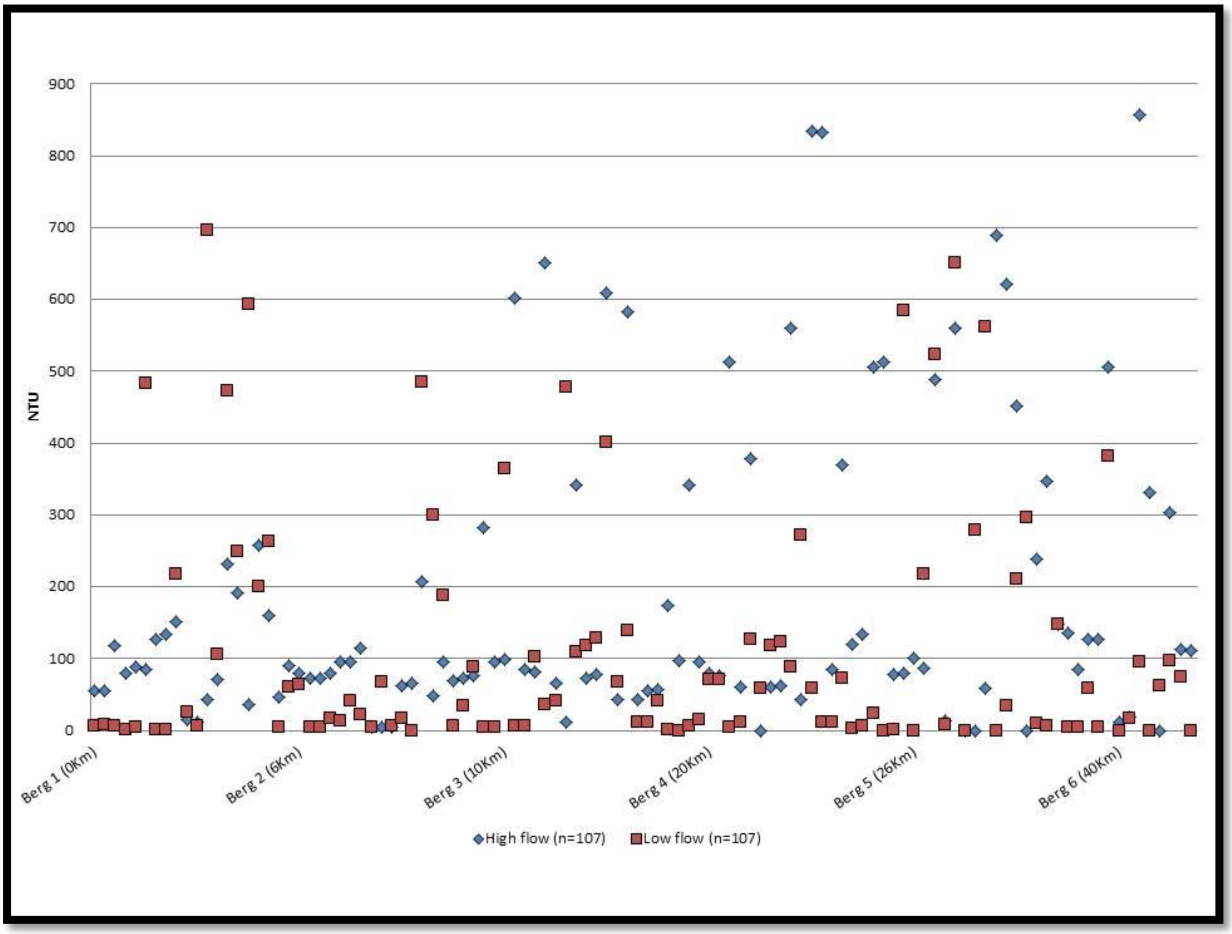


Figure 23 Turbidity recorded between Site 1 (at the mouth) and Site 6 (40 km from mouth) on the Berg Estuary between August 2012 and July 2014. Red squares indicate low flow conditions (<5 m^3 s^{-1}) (n=107) and blue diamonds indicate high flow (n =107) conditions (>5 m^3 s^{-1}) (n=107).

pH. During the high and low flow conditions between August 2012 and July 2014 the pH data (n = 107) show a consistent pattern between Site 1 at the mouth and Site 6, 40 km from the mouth (Figure 24).

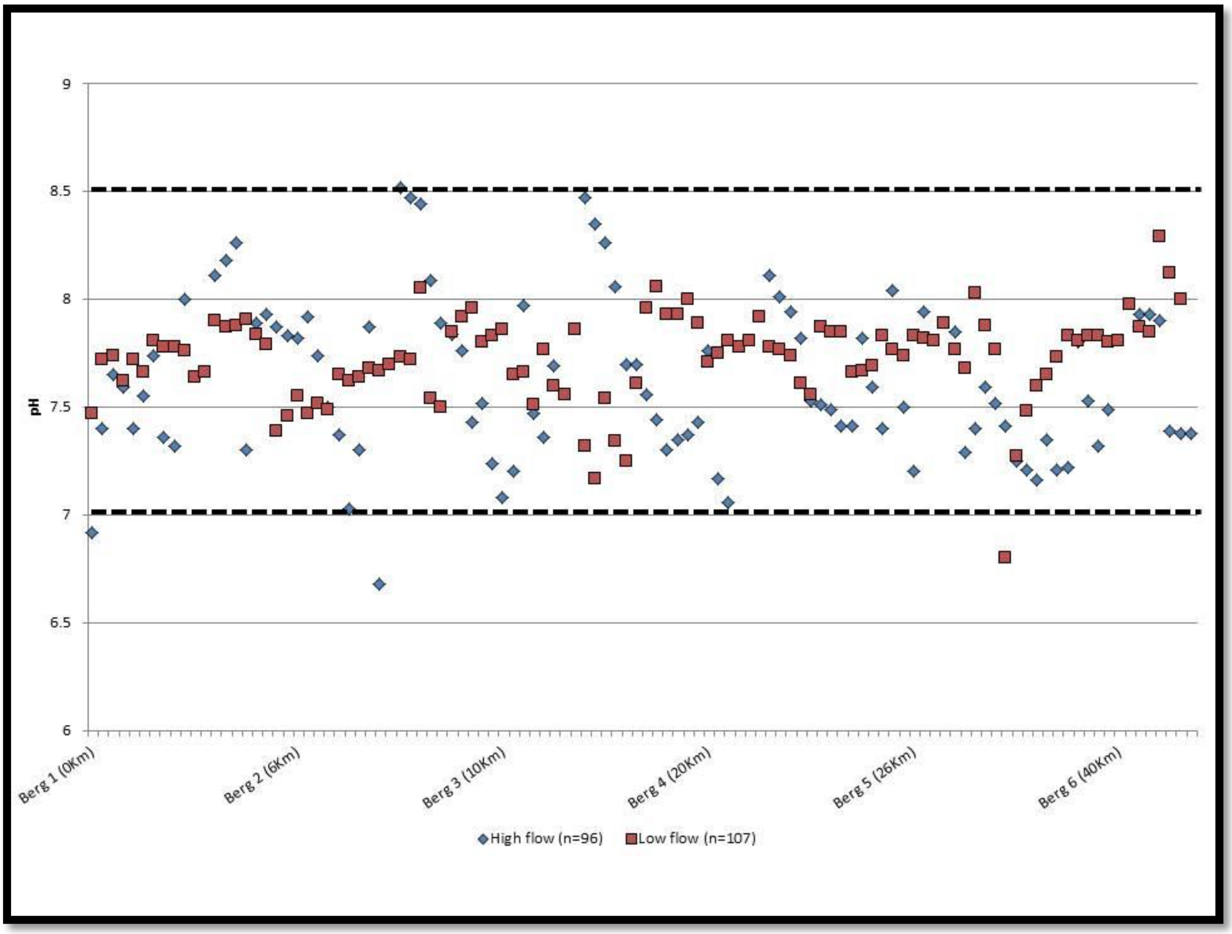


Figure 24 pH recorded between Site 1 (at the mouth) and Site 6 (40 km from mouth) on the Berg Estuary between August 2012 and July 2014. Red squares indicate low flow conditions (<5 $m^3 s^{-1}$) (n=107) and blue diamonds indicate high flow conditions (>5 $m^3 s^{-1}$) (n=96). System variable TPCs: black dashed lines 7<pH>8.5.

Dissolved Inorganic Nitrogen. DIN varied between 5 µg/l and 126 µg/l during the low flow conditions, with a clear distribution of the higher levels in the middle reaches of the estuary (Figure 25). This may be indicative of a nutrient "plug" being formed during summer, resulting in an increase in nutrients in the lower and middle reaches of the Berg Estuary. During the high flow conditions the DIN varied between 4 µg/l and 104 µg/l. There is a tendency that the DIN levels were higher at the mouth in comparison to the upstream sites.

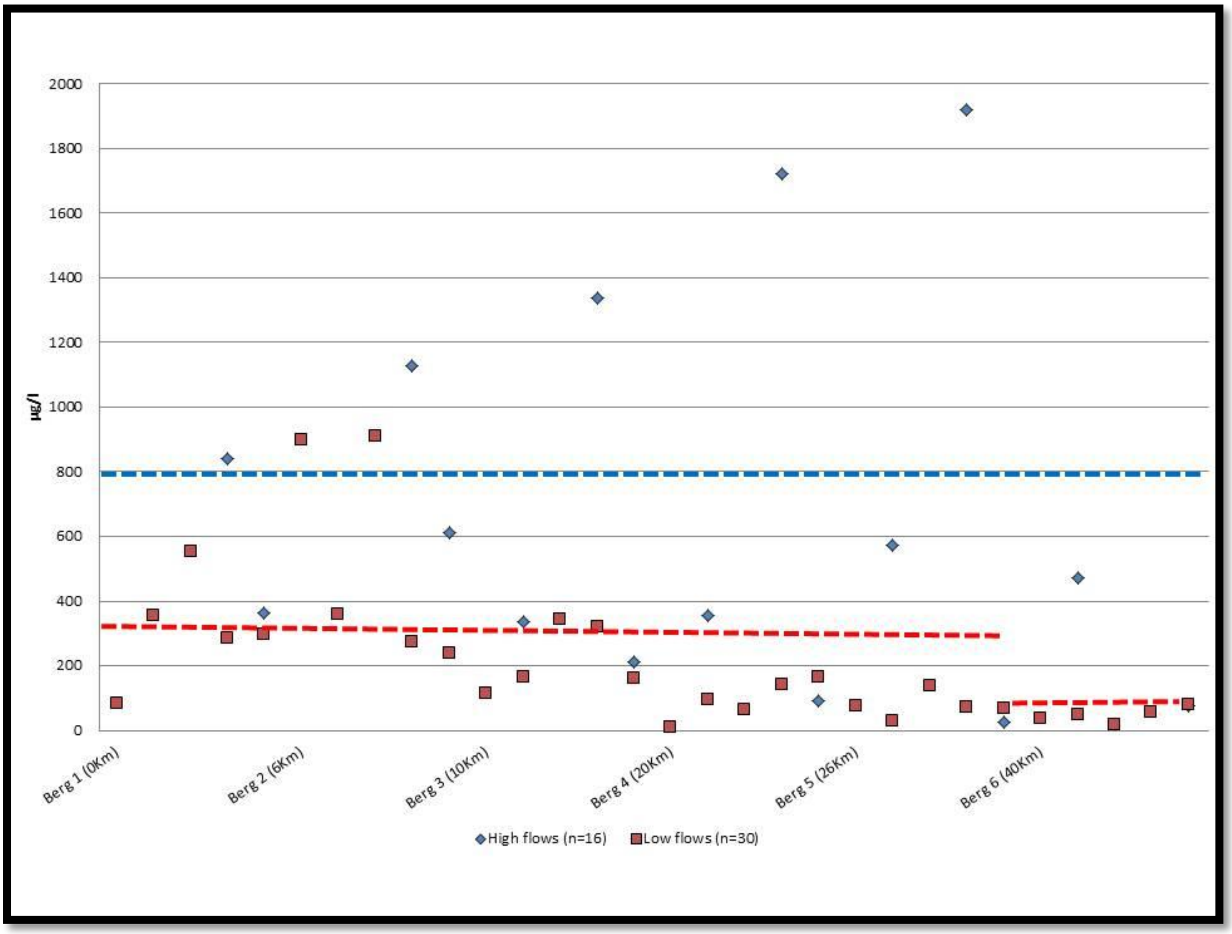


Figure 25 Dissolved Inorganic Nitrogen levels recorded form 6 sites on the Berg Estuary during high and low flow conditions between November 2013 and December 2014 (n=34). TPCs for low flows = red dashed line. TPCs for high flows = blue dashed line.

Soluble Reactive Phosphate: SRP varied between 12 µg/l and 909 µg/l during the low flow conditions, with a clear distribution of the higher levels in the bottom reaches of the estuary (Figure 26). This may be indicative of upwelling from the Benquela current during summer and / or phosphate loading in the lower reaches of the estuary as a result of the industrial activities associated with the harbour at Laaiplek and Veldrift. During the high flow conditions the SRP varied between 24 µg/l and 1921 µg/l with the highest levels being recorded from the upstream sites, indicating catchment based loading of SRP into the system.

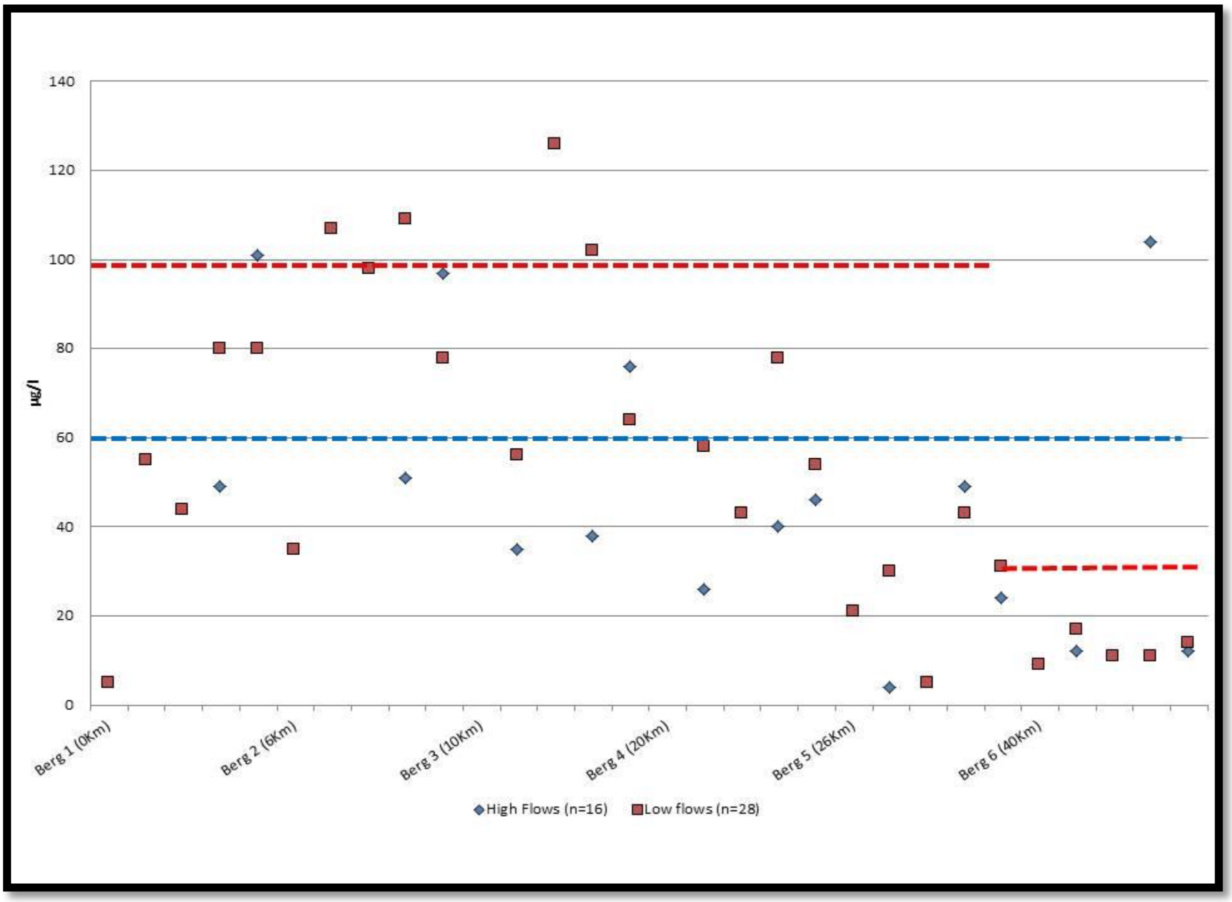


Figure 26 Soluble Reactive Phosphate levels recorded form 6 sites in the Berg Estuary during high and low flow conditions between November 2013 and December 2014 (n=32). TPCs for low flows = red dashed line. TPCs for high flows = blue dashed line. Outliers of 909 µg/l during low flow at Site 2 and 1921 µg/l during high flows at Site 6 not reflected on graph..

Permanent Loggers

Figures 27 and 28 indicate seasonal changes in temperature and salinity during the entire study period at a distance of 6 km (Site 2) and 20 km (Site 4) from the mouth in the Berg Estuary. Water temperatures at both sites were lower during winter with a concomitant decrease in salinity as a result of increased rainfall and associated freshwater inflow from the catchment. The mouth however remained saline for longer periods during summer and winter as can be observed from the Site 2 data (Figure 27). The only occurrence of a prolonged freshwater state at the mouth was during the winter flood events in August and September 2013. Various shorter freshwater states did occur during September and October 2012, October and December 2013 and May and June 2014.

The results at Site 4, 20 km from the mouth, show that marine water does not penetrate as far into the estuary during winter, as is the case during the summer (Figure 28). The water remains fresh at this site for up to 7 months during winter when rainfall results in increased flows in the system (Figure 19). Between 13 August 2013 and 25 September 2013 three major floods moved through the system with flows peaking at 842 m^3 s^{-1}. These flood events are reflected as three distinct periods of higher than normal water levels from the Aquatroll data (Figure 29).

An example of daily variation in salinity as a result of tidal exchange during late summer at a distance of 20 km from the mouth is indicated in Figure 30. Slight changes in the levels can also be observed during this period. On 18 April 2013 a freshet moved through the system, with a resulting decrease in the salinity levels.

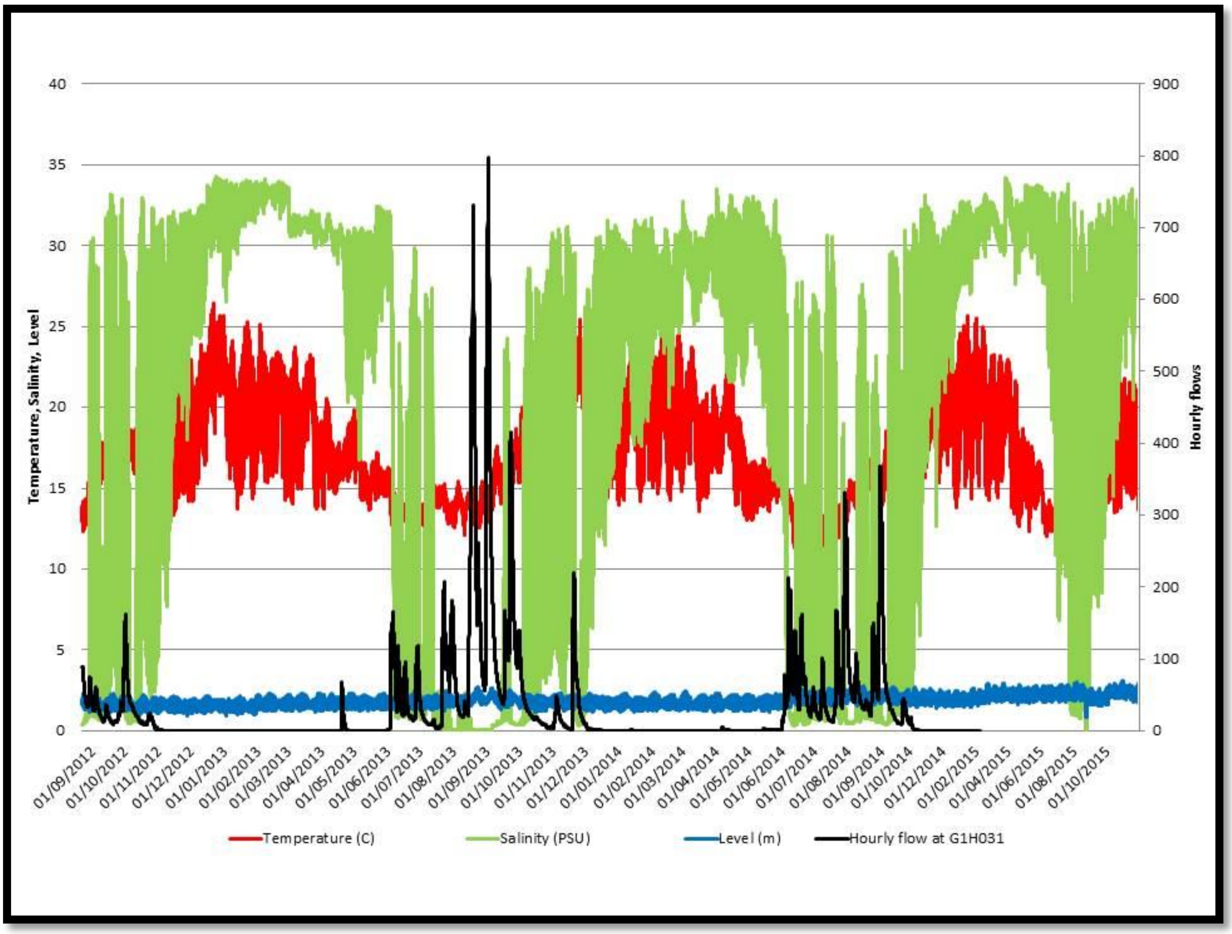


Figure 27 Time series graph of water level, salinity and temperature from a permanent deployed logger at a distance of 6 km from the Berg Estuary mouth (Site 2). Flows from flow gauging station G1H31 are overlaid on the logger data.

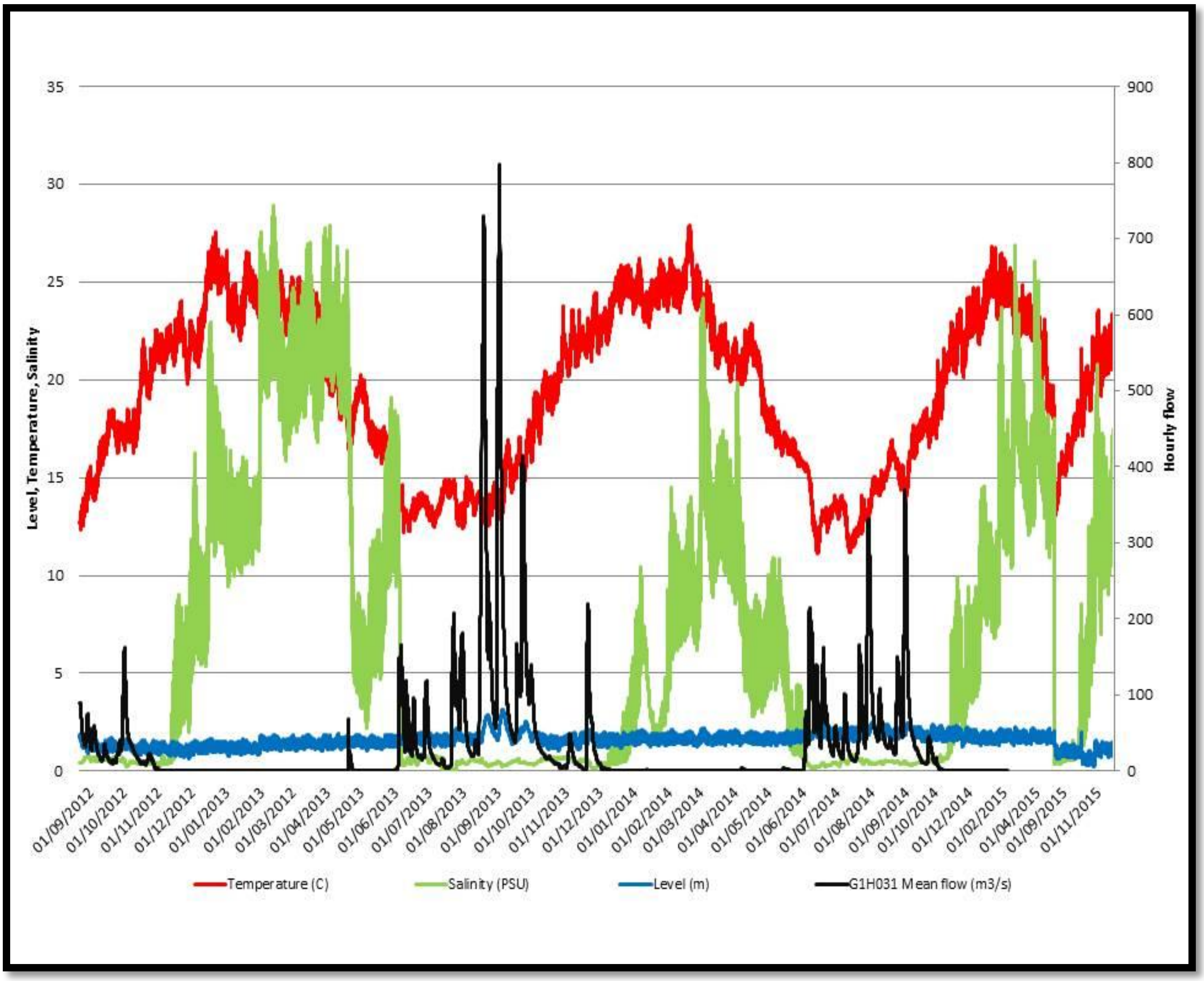


Figure 28 Time series graph of water level, salinity and temperature from permanent deployed logger at a distance of 20 km from the Berg Estuary mouth (Site 4). Flows from flow gauging station G1H31 are overlaid over the logger data.

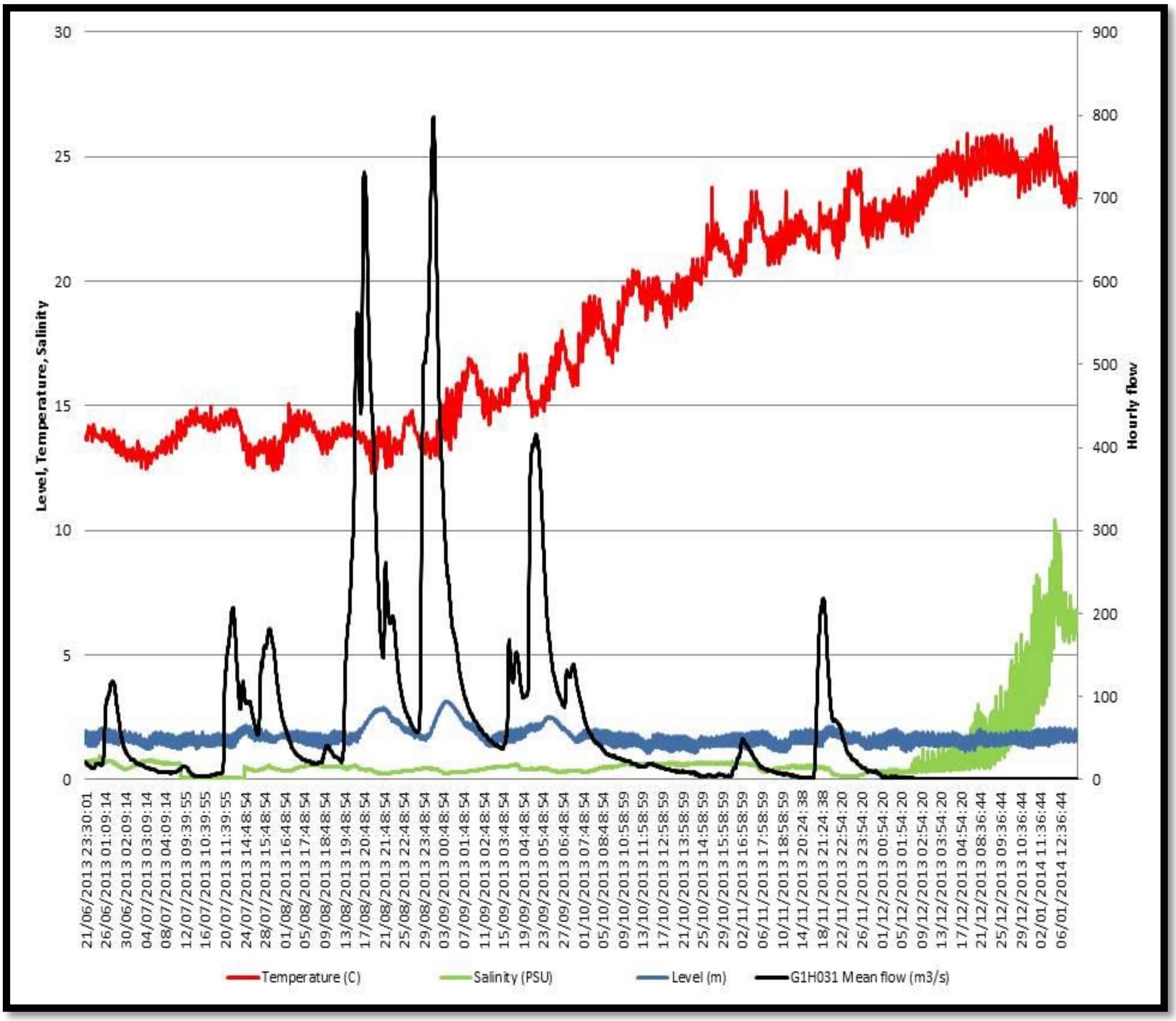


Figure 29 Time series graph of water level, salinity and temperature from permanent deployed logger at a distance of 20 km from the Berg Estuary mouth (Site 4). Flows from flow gauging station G1H31 are overlaid over the logger data.

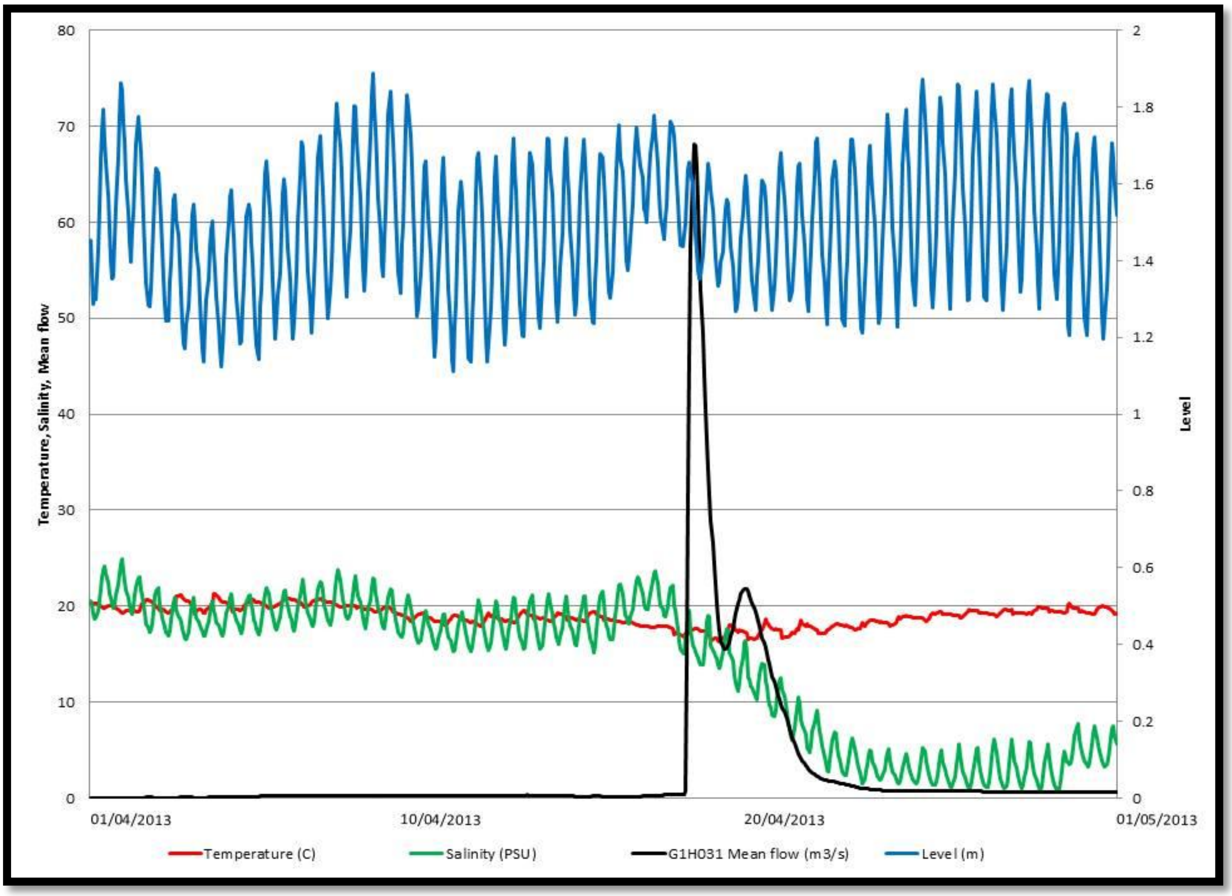


Figure 30 Water level, salinity and temperature from a permanent deployed probe between 15 April 2013 and 22 April 2013 at a distance of 20 km from the mouth (Site 4). Flows from flow gauging station G1H31 are overlaid over the logger data.

Figure 31 indicates the salinity, level and temperature data for the period 15 January 2014 to 15 February 2014 from both permanent loggers. During the salinity measurements that took place on 29 January 2014, very low oxygen levels were recorded (Figure 22) across the entire system due to a red tide event on the west coast. Two weeks before the salinity survey of 29 January 2014 a systematic decrease in flow is observed (Figure 19). This period was also associated with spring tides, larger fluctuations in tidal exchange and salinity at Site 2 (Figure 27). The low freshwater inflow condition and increased tidal fluctuation, results in an increase in salinity from 0 ppt to 5-15 ppt at Berg Site 4, starting on 29 January 2016. Salinity levels at Berg Site 2, 6 km from the mouth were higher during the same period (18 - 32 ppt) and oscillated with tidal exchange. Tidal exchange and low freshwater inflow, resulted in the red tide extending further into the estuary with associated low oxygen levels (Figure 22). Neap tide sets in 4 days later around 1 February 2014 and is observable as a smaller fluctuation in salinity at both sites. Temperature at Site 2 was lower, but fluctuated more than that at Site 4. This is also a function of the exchange of cold marine water with the tides in comparison with constant warmer water at Site 4.

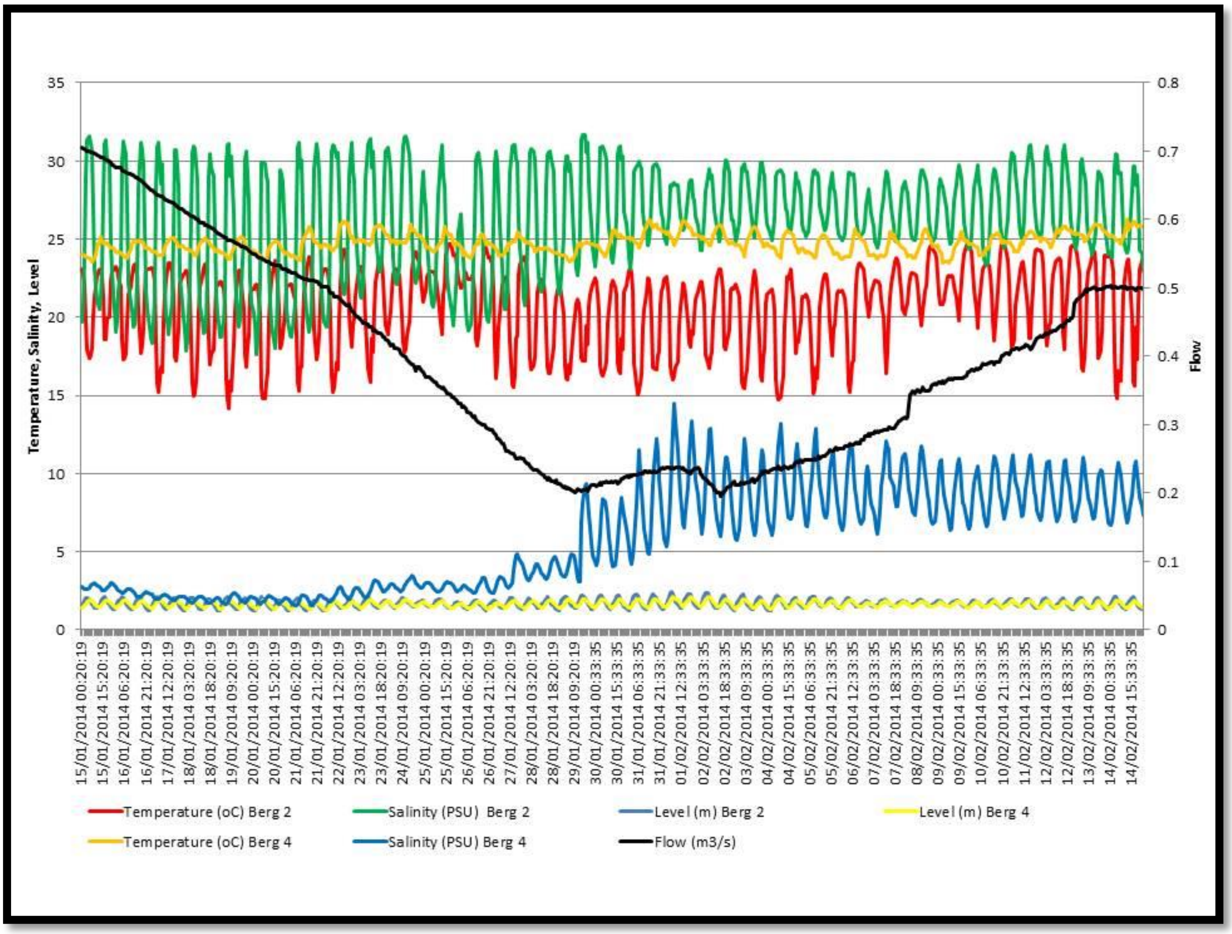


Figure 31 Hourly logger data from Sites 2 and 4 with associated flow data from flow gauging station G1H31 for period 15 January 2014 to 15 February 2014.

Threshold of Potential Concern

The TPCs for the Berg Estuary, as determined in the Ecological Water Requirements Assessment (DWA, 2012), as well as the alternative TPCs calculated with the data from this study, are summarised in Table 15. The percentage exceedance of both sets of TPCs are compared in Figures 32 and 33.

The alternative TPCs for salinity and pH at various distances from the mouth were similar to those set in the EWR study. The alternative TPC for TDS at the river inflow was 1731 mg/l in comparison with EWR study value of 3500 mg/l (DWA, 2012). This is substantially lower than the EWR study TPC. The 10th percentile TPC for oxygen concentration was 2.3 mg/l. This is substantially lower than the TPC of 4 mg/l set in the EWR study (DWA, 2012). By default the level of 4 mg/l should remain as the TPC as this generally indicates the onset of anoxic conditions.

Table 15 The TPC for system variables and nutrients of the Berg Estuary as determined in the Ecological Water Requirements Assessment (DWA, 2012) and the alternative TPCs calculated with the 10th and 90th percentile for data from this study. The percentile that acts as calculated TPC in bold. Number of data points used for 10th and 90th percentile calculation indicated in brackets.

TPC'S: BERG ESTUARY EWR STUDY (DWA, 2012)	ALTERNATIVE TPCS		DIFF-ERENCE BETWEEN TPCs
	10TH PERCEN-TILE	90TH PERCEN-TILE	
Salinity			
Continuous 25 ppt at 11 km from mouth (n = 45)	0.6	**28.8**	3.8
> 35 ppt in estuary (n = 260)	0.4	**29.6**	-5.4
> 0 ppt above 40 km from mouth (n = 44)	0.2	**1.0**	1
TDS (n = 44)			
> 3500 mg/l at river inflow	239	**1371**	-2129
pH			
River: 7< pH >8.5 (n = 42)	**7.2**	**8.0**	n/a
Estuary: 7< pH >8.5 (n = 253)	**7.3**	**8.1**	n/a
DO			
DO<4 mg/l (n = 169)	**2.3**	10.8	n/a
Secci Disk (n = 66)			
< 1 m in zone A to B during low flows (<1 $m^3 s^{-1}$)	**0.08**	1	0
DIN			
River: DIN > 80 µg/l during LF (<1 $m^3 s^{-1}$) (n = 7)	50	**357**	277
River: DIN > 800 µg/l during HF (<5 $m^3 s^{-1}$) (n = 2)	216	**1731**	931
Estuary: DIN > 300 µg/l during LF (<1 $m^3 s^{-1}$) Zone A-B (n = 21)	139	**729**	429
Estuary: DIN > 80 µg/l during LF (<1 $m^3 s^{-1}$) Zone C-D (n = 12)	33	**335**	255
Estuary: DIN > 800 µg/l during HF (< 5 $m^3 s^{-1}$) Zone A-D (n = 30)	86	**557**	-243
SRP			
River: SRP >20 µg/l during LF (<1 $m^3 s^{-1}$) (n = 7)	5	**37**	17
River: SRP >60 µg/l during HF (<5 $m^3 s^{-1}$) (n = 3)	27	**47**	-13
Estuary: SRP >100 µg/l during LF (<1 $m^3 s^{-1}$) Zone A-B (n = 20)	35	**108**	8
Estuary: SRP >30 µg/l during LF (<1 $m^3 s^{-1}$) Zone C-D (n = 11)	5	**58**	28
Estuary: SRP >60 µg/l during HF (<5 $m^3 s^{-1}$) Zone A-D (n = 13)	37	**97**	37

There was a substantial difference between the alternative TPCs for DIN and those postulated in the Berg EWR study (-243 and 931 µg/l); the highest being almost 1000 µg/l for DIN input from the river during high flows. This is indicative of the current level of nutrient loading in the system as a result of catchment activities. The small sample size (between 2 and 21 samples) also contributes to this large difference. Additional surveys, hence a larger sampling size, will provide a better reflection of the actual nutrient loading in the system. A difference in the alternative TPCs and the Berg EWR study TPC for SRP was also observed, but was not as pronounced (between -13 and 37 µg/l) as was the case for DIN.

The percentage exceedance of the TPCs for system variables, as set in the Berg Estuary EWR study and the alternative TPCs are summarised in Figure 32. The highest exceedance (66%) of system variable TPCs were for secchi disk readings <1 m in Zone A to B during low flow events. This was followed by DO with an exceedance of 18% across the entire system, TDS > 3500 mg/l with 11% exceedance at the freshwater inflow (Site 6), salinity > 0 ppt 40 km with 7% and salinity >35 ppt in estuary with 5% exceedance. The TPC for pH was not exceeded for the estuary or river (7< pH >8.5). The % exceedance of system variables for the alternative TPCs were similar to those set during the EWR study (DWA, 2012). Only TDS at the river inflow were marginally higher with 11% exceedance against the EWR value exceedance of 8%.

The highest exceedance of nutrient TPC (67%) was for river DIN during high flows (winter) followed by estuary SRP during low flows (summer) in Zone C to D >30 µg/l (Figure 33). This was followed by 50% exceedance of estuary DIN >80 µg/l during low flows (summer) in zone C-D, 38% for river DIN >800 µg/l during high flows (winter) in Zone A-B and river SRP >60 µg/l with 33% during high flows (winter). Estuary DIN >300 µg/l during low flows (summer) in zone A to B were exceeded for 38% of the time and estuary DRP>100 µg/l during low flows (summer) in zone A to B with 20%. River DIN >80 µg/l during low flows (summer) were exceeded 29% of the time and estuary SRP>60 µg/l in zone A to D during high flows (winter) with 23%.

The alternative and EWR TPCs showed the largest differences for nutrients in the estuary zone of the Berg Estuary. Generally the alternative TPCs were lower than those set in the EWR study. This is indicative that the EWR TPCs were the more conservative, set following a precautionary approach. In the river part of the system the alternative TPCs and the EWR TPCs were generally similar for DIN, but differed for SRP. The alternative SRP for the river during low flows were. The high levels of especially SRP exceedance are probably because of failing wastewater treatment works. The Berg River municipality Green Drop score decreased in 2011 from 73.8% to 48.9% in 2013 (DWA, 2013). The main reasons for this decrease were operational shortcomings, insufficient design capacity, absence of compliance monitoring regimes and lack of pump station maintenance.

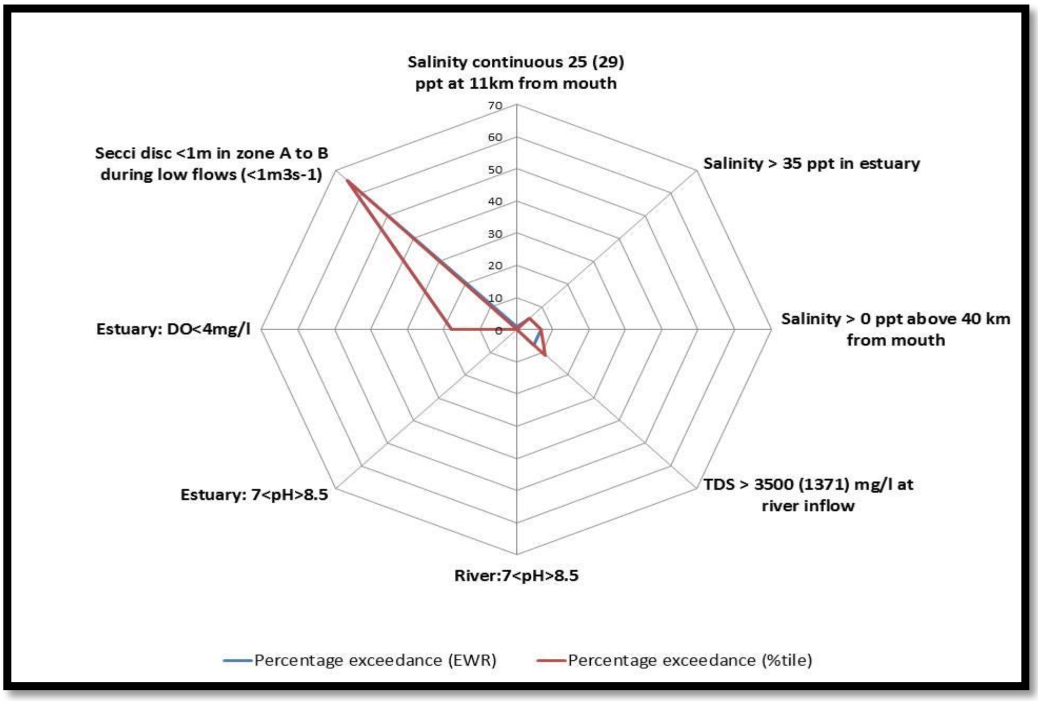


Figure 32 Comparison of percentage exceedance of system variable TPCs, between the Berg Estuary EWR study TPCs (DWA, 2012) and the alternative TPCs (in brackets if different) calculated with the data from 2012 to 2014.

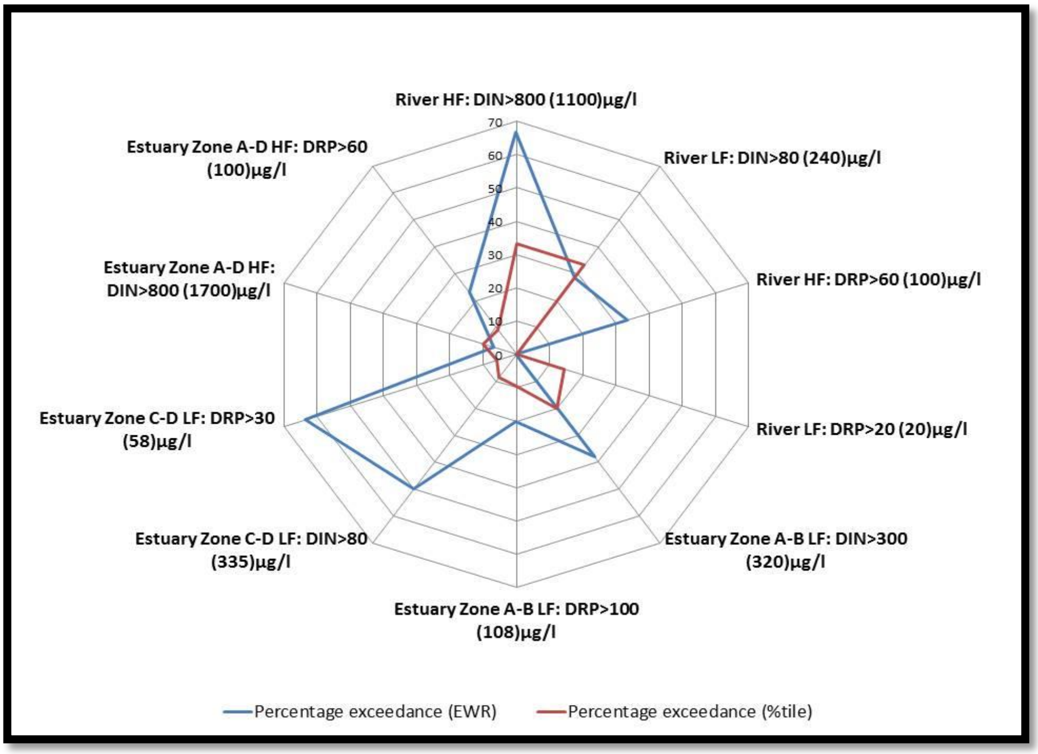


Figure 33 Comparison of percentage exceedance of nutrients TPCs between the Berg Estuary EWR study (DWA, 2012) and the alternative TPCs (in brackets), calculated with the data from 2012 to 2014.

4.5.2. Breede Estuary

Flow data

Mean flow at the gauging weir H7H006 on the Breede River at Swellendam, from January 2012 to August 2015 is shown in Figure 34. Flow increased in June 2013 and peaked at 402 $m^3 s^{-1}$ on 9 August 2012. Flow decreased during the summer and peaked again on 19 August 2013 at 818 $m^3 s^{-1}$, on 30 July 2014 at 425 $m^3 s^{-1}$ and at 251 $m^3 s^{-1}$ during 27 July 2015. The peaks were interspersed with periods of low flows, which never decreased to below 0.01 $m^3 s^{-1}$. Mean flow for the entire study period was 46 $m^3 s^{-1}$. A standard deviation of 85 $m^3 s^{-1}$, and upper range of 818 $m^3 s^{-1}$ indicates that there was a large variation in flow during the study period (Appendix D).

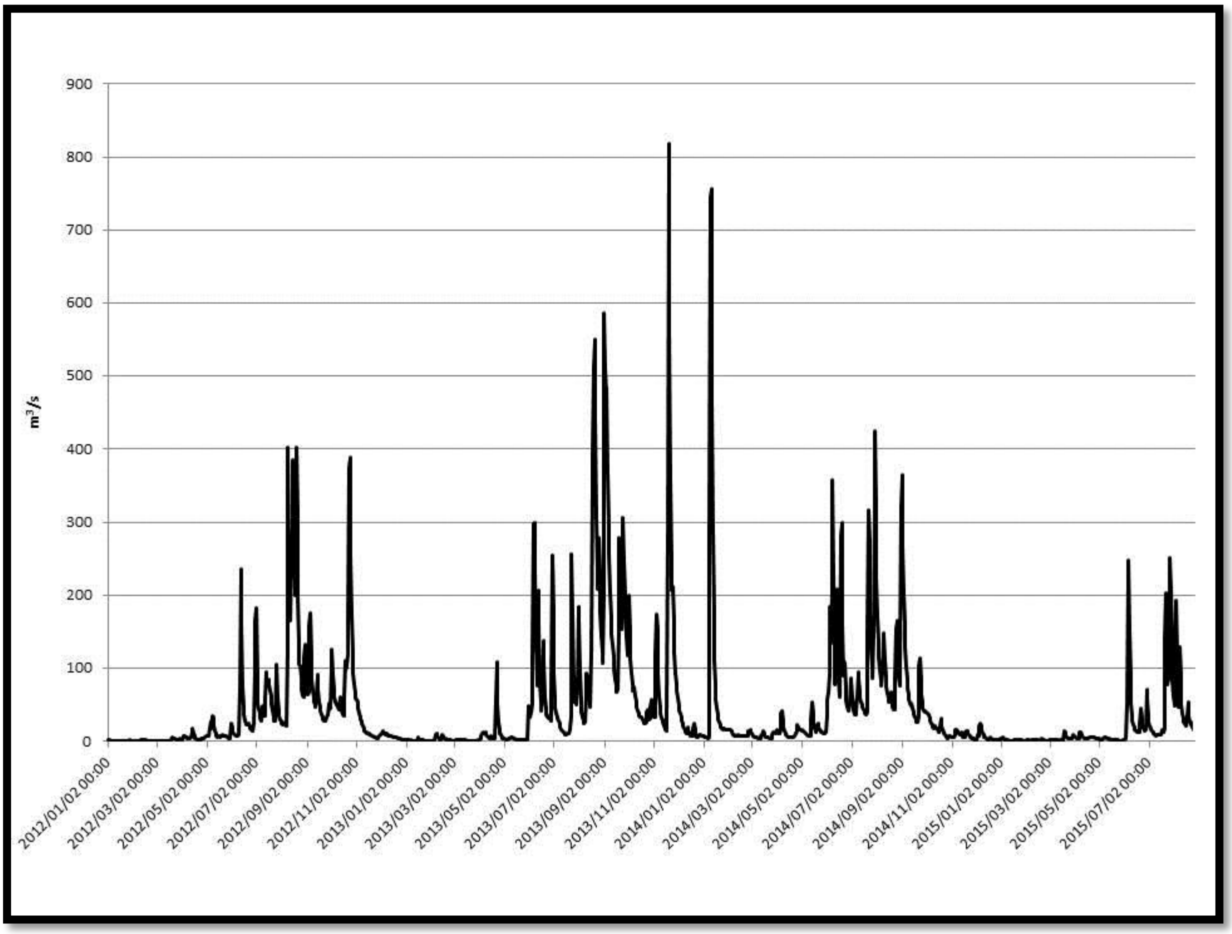


Figure 34 Flow data from the DWS flow gauging station G7H006 on the Breede River at Swellendam for the period January 2012 to August 2015 (n=1332).

Monthly Sampling

Temperature. During the high flow conditions between March 2012 and November 2014 the data (n = 1644) show a constant pattern between Site 1 at the mouth and Site 21, 39 km from the mouth (Figure 35). There was however a larger spread of the data between lowest

(11.3 °C) and highest values (27.1 °C) with a standard deviation of 3.89 during the high flow conditions. This is higher than the standard deviation (3.01) calculated for the low flow conditions when the temperature varied between 16.6°C and 25.1°C (n=626). This indicates that high flow conditions also take place during the summer months when the higher ambient temperature results in higher water temperatures. Generally, there is an increase in water temperature form Site 1 at the mouth to Site 21 situated 39 km from the mouth. This is indicative of the influence of cold marine water from the lower reaches of the estuary and warmer, catchment derived water in the upper reaches.

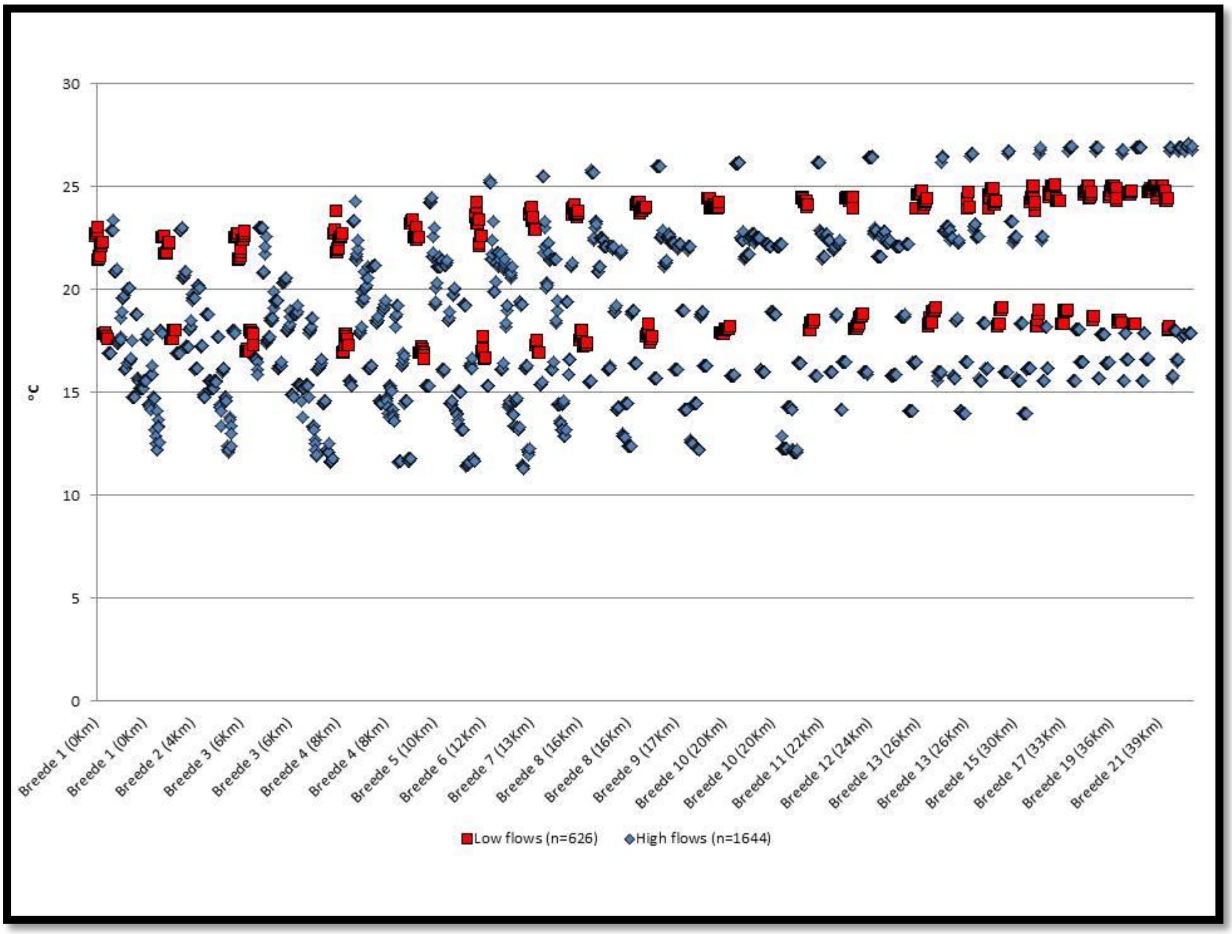


Figure 35 Temperatures recorded between Site 1 (at the mouth) and Site 21 (39 km from mouth) on the Breede Estuary between March 2012 and November 2014. Red squares indicate low flow conditions (<10 $m^3 s^{-1}$) (n=1644) and blue diamonds indicate high flow conditions (> 10 $m^3 s^{-1}$) (n=626).

Salinity. During the high flow conditions between March 2012 and November 2014, the salinity data (n = 1644) also show a constant pattern between Site 1 at the mouth and Site 21, 39 km from the mouth (Figure 36). Higher salinity occurred at the mouth and decreased towards the upstream sites indicative of freshwater inflow from the catchment. Tidal influence was still present during the high flow conditions in the lower reaches of the estuary.

During the low flow conditions for the same period, the salinity showed a systematic decrease from Site 1 at the mouth to Site 21, 39 km from the mouth (n=626). Low flows occur during the summer, when saline marine water penetrates further into the estuary, resulting in an extension of the salinity wedge into the upper reaches of the estuary. It is clear from the data that salinity up to 8 ppt was recorded during low flow conditions as far as 39 km from the mouth.

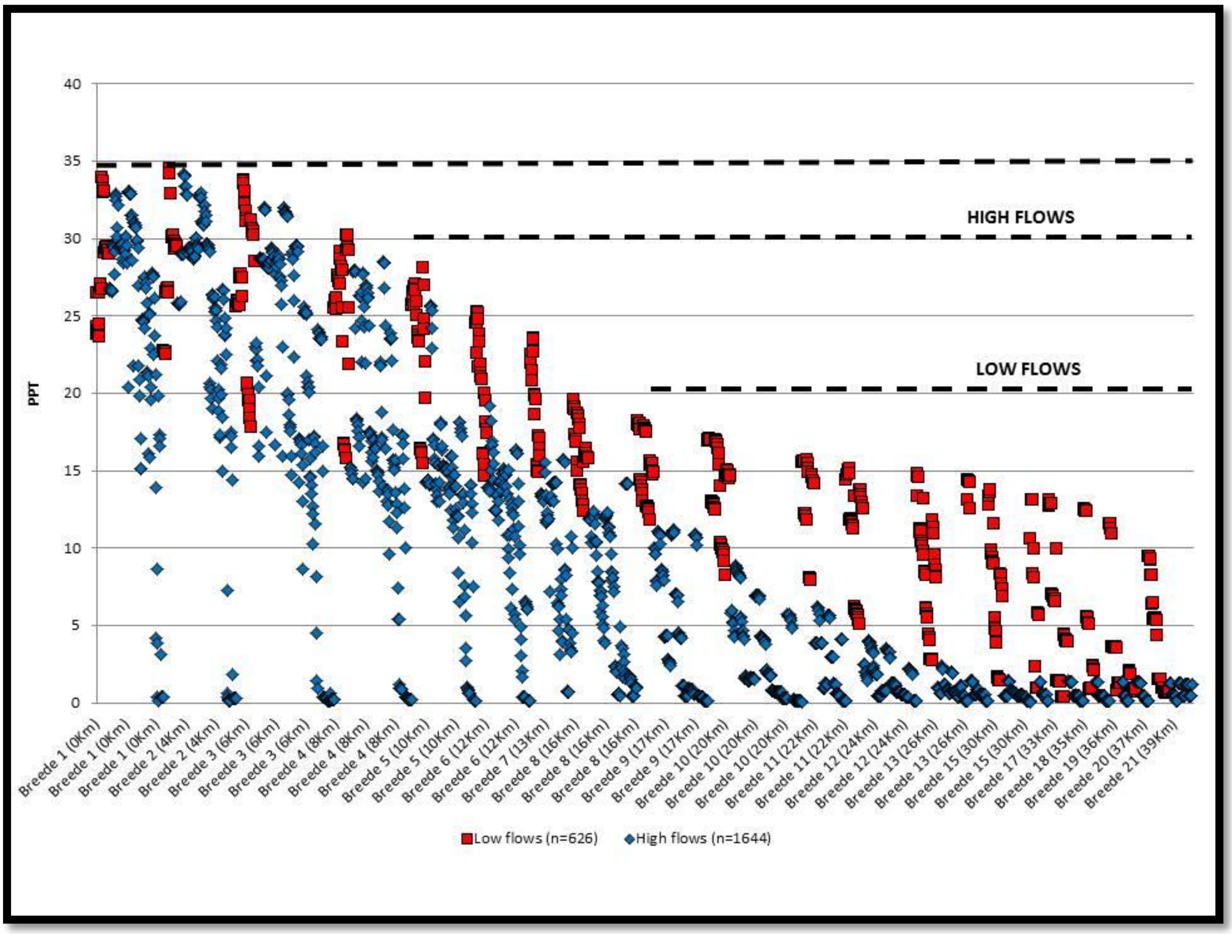


Figure 36 Salinity recorded between Site 1 (at the mouth) and Site 21 (39 km from mouth) on the Breede Estuary between March 2012 and November 2014. Red squares indicate low flow conditions (<10 m3 s-1) (n=1644) and blue diamonds indicate high flow conditions (>10 m3 s-1) (n=626). System variable TPCs: black dashed line = salinity.

Oxygen. During the high flow conditions between March 2012 and November 2014, the oxygen data (n = 1625) also show a fairly constant pattern between Site 1 at the mouth and Site 21, 39 km from the mouth (Figure 37). This is indicative of freshwater inflow from the catchment, resulting in increased turbulence and subsequent higher oxygen levels. The colder water, associated with winter and the higher flows, also has the ability to absorb more oxygen, resulting in the general higher oxygen levels during the high flow / winter conditions.

During the low flow conditions for the same period, the oxygen levels decrease from Site 1 at the mouth to Site 21, 39 km from the mouth (n=628). Low flows occur during the summer, when higher water temperatures result in a decrease in the oxygen content of the water column. There was an increase in temperature at the upper sites of the estuary (Figure 37). No anoxic conditions (oxygen concentration < 4 mg/l) were recorded during the entire study period.

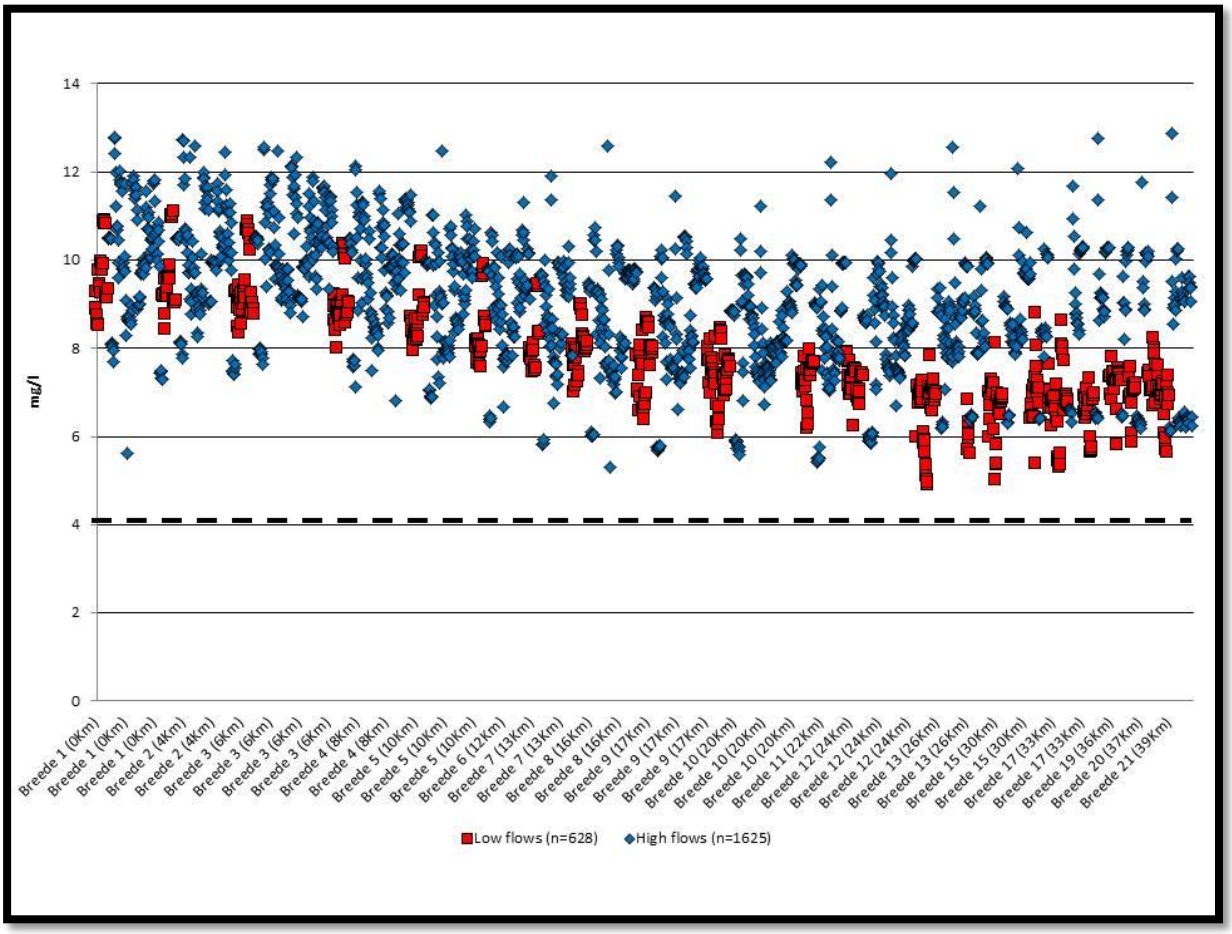


Figure 37 Oxygen content recorded between Site 1 (at the mouth) and Site 21 (39 km from mouth) on the Breede Estuary between March 2012 and November 2014. Red squares indicate low flow conditions (<10 m3 s-1) (n=628) and blue diamonds indicate high flow conditions (>10 m3 s-1) (n=1625). System variable TPCs: black dashed line = [O2] > 4 mg/l.

pH Between March 2012 and November 2014, the pH data show a consistent pattern between Site 1 at the mouth and Site 21, 39 km from the mouth (Figure 38), during both the high flow (n=1644) and the low flow (n=626) conditions. At the upstream sites above 30 km, there is a marked decrease in pH during the low flow conditions, with levels dropping below 6 to as low as 3.3 at Site 21 during certain times. This is probably as a result of local anthropogenic activities immediately adjacent to the sampling stations, where agricultural activity and small scale residential developments occur. The system is however well buffered as the low pH levels are not observed elsewhere in the estuary.

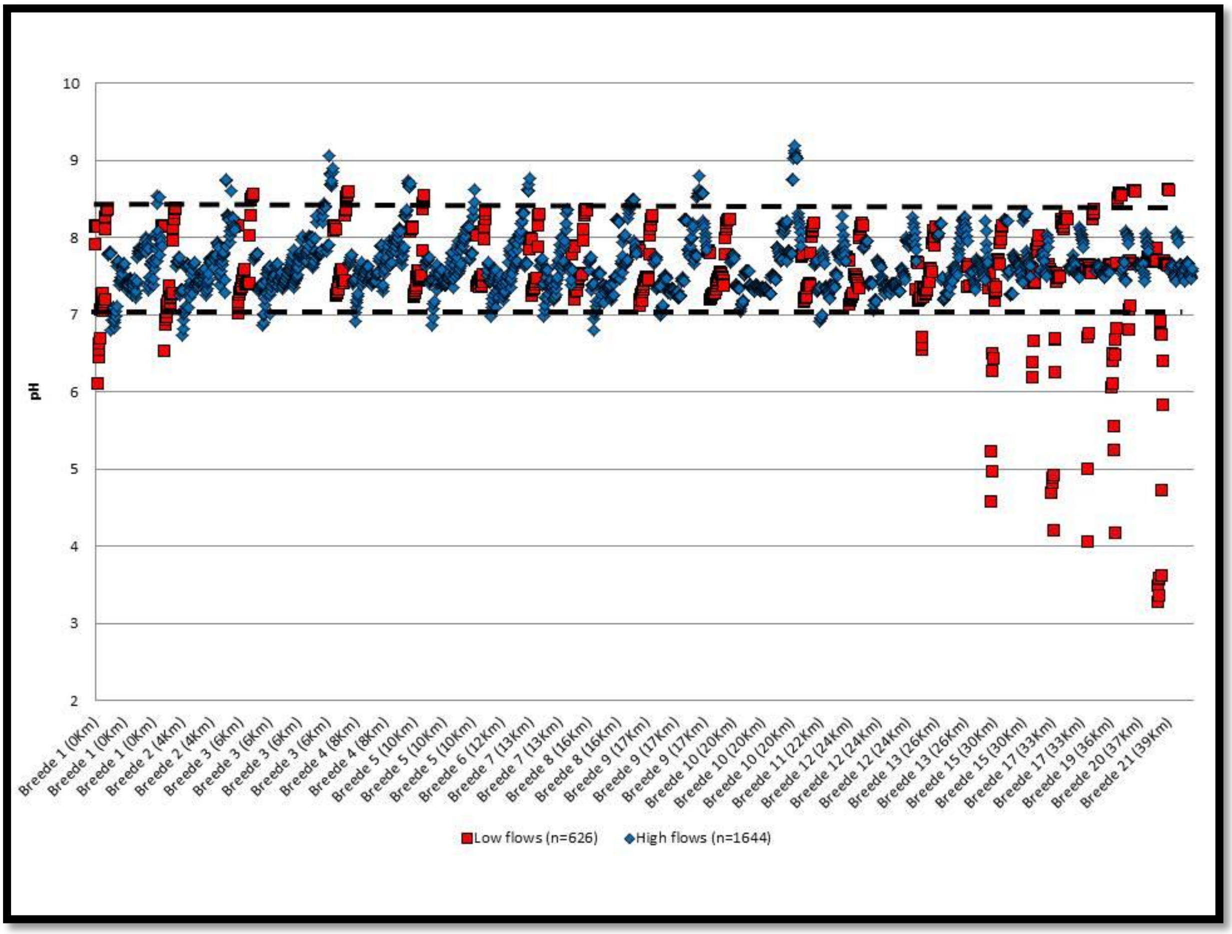


Figure 38 pH recorded between Site 1 (at the mouth) and Site 21 (39 km from mouth) on the Breede Estuary between March 2012 and November 2014. Red squares indicate low flow conditions (<10 m3 s-1) (n=1644) and blue diamonds indicate high flow conditions (>10m3 s-1) (n=626). System variable TPCs: black dashed line 7<pH>8.5.

Dissolved Inorganic Nitrogen. DIN varied between 0 µg/l (below detection limit) and 1026 µg/l during the low flow conditions, with higher levels in the upper reaches of the estuary (Figure 39). During the high flow conditions the DIN varied between 0 µg/l (below detection limit) and 700 µg/l. There is a tendency that the DIN levels were higher at the upstream sites of the estuary. This is indicative of catchment related nutrient loading from various sources.

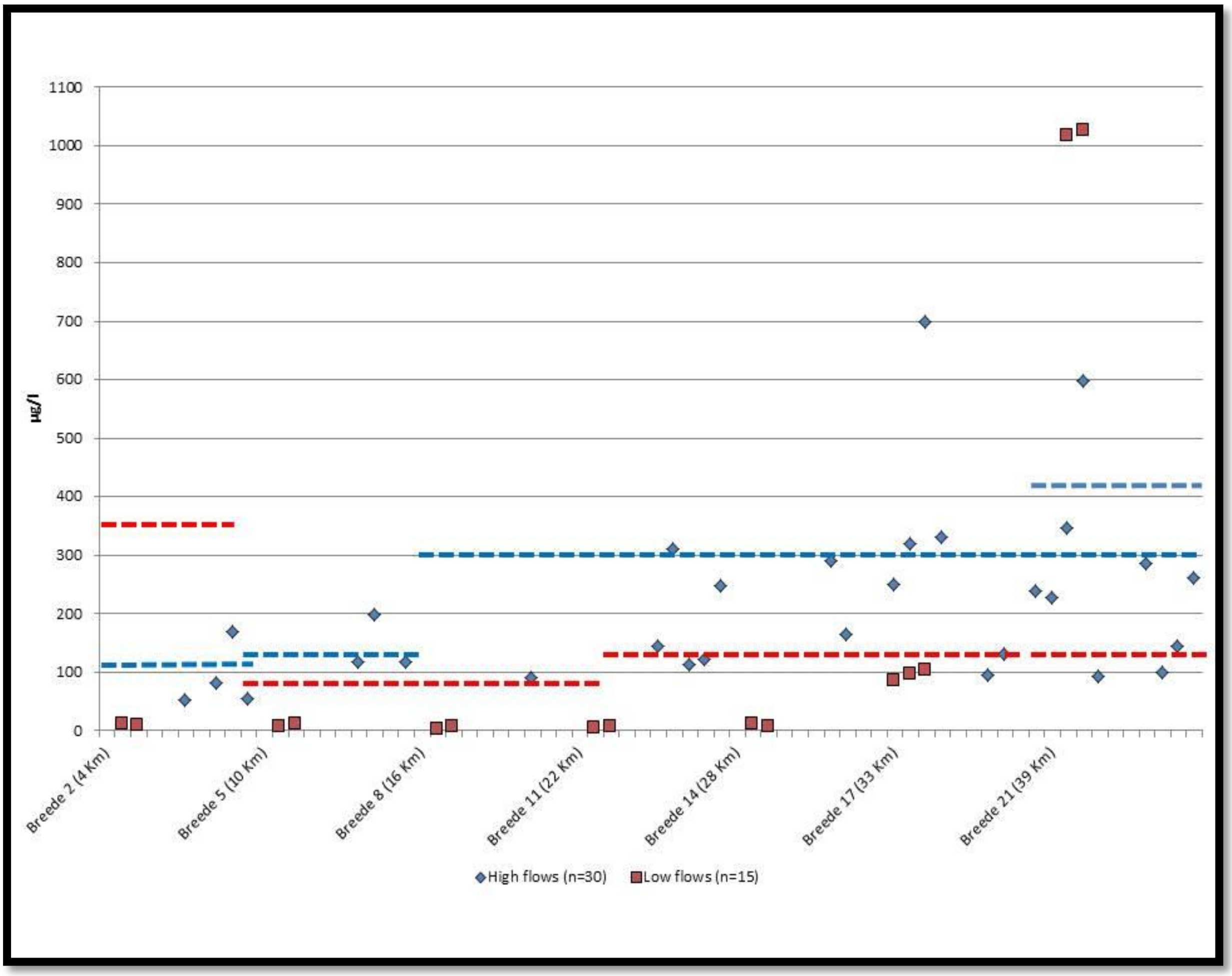


Figure 39 Dissolved Inorganic Nitrogen levels recorded form 7 sites on the Breede Estuary during high and low flow conditions between May 2013 and September 2014 (n=49). TPCs for low flows = red dashed line. TPCs for high flows = blue dashed line.

Soluble Reactive Phosphate. SRP varied between 0 µg/l (below detection limit) and 22 µg/l during the low flow conditions, with no clear distinction of areas with elevated concentrations (Figure 40). During the high flow conditions the SRP varied between 0 µg/l (below detection limit) and 657 µg/l and were recorded from the upstream sites, indicating catchment based input of SRP into the system. The high TPC calculated is however as a result of a single outlier datapoint of 657 µg/l recorded at Site 14, 28 km from the mouth during a high flow period.

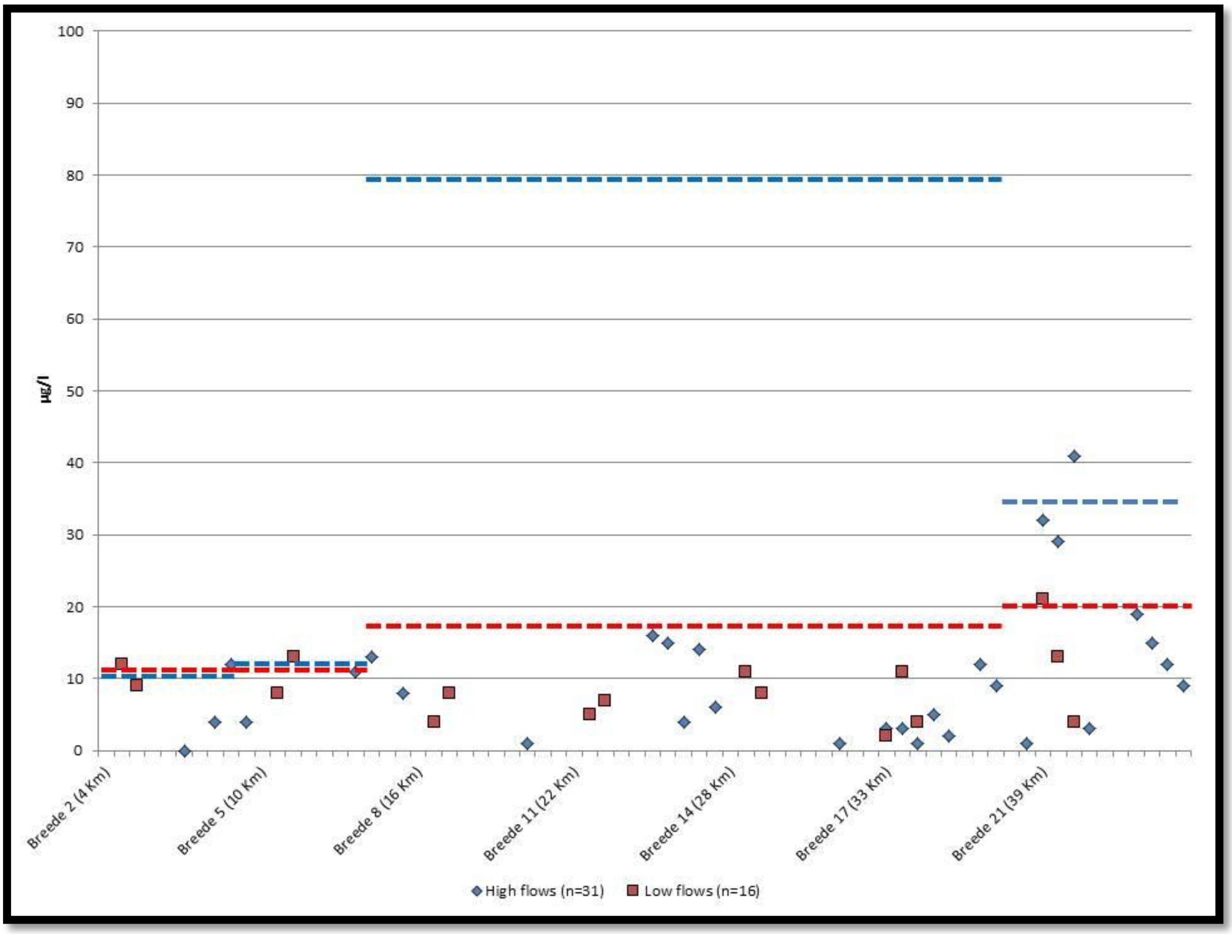


Figure 40 Soluble Reactive Phosphate levels recorded from 7 sites on the Breede Estuary during high and low flow conditions between May 2013 and September 2014 (n=41). TPCs for low flows = red dashed line. TPCs for high flows = blue dashed line. Highest level of 657 µg/l at Site 14 not indicated.

Permanent Loggers

The permanent probe data for Site 1 on the Breede Estuary are indicated in Figure 41. There is a clear seasonal pattern observable for salinity and temperature. Water level changes at this site were between 0 and 0.9 m and were associated with freshwater inputs and tidal exchange. This can be seen from the flood data between 1 June 2015 and 30 June 2015. There was a pronounced drop in salinity from more than 30 ppt on 3 June 2015 to fresh (0 ppt) on 5 June 2015, when a small flood moved through the system (Figure 42). During the same time temperatures dropped, as a result of the freshwater input and the water levels increased as a result of a larger volume of water in the system (Figure 42). This returned to the pre-flood levels, with clearer tidal variation after 12 June 2015, when the salinity systematically returned to the pre-flood levels.

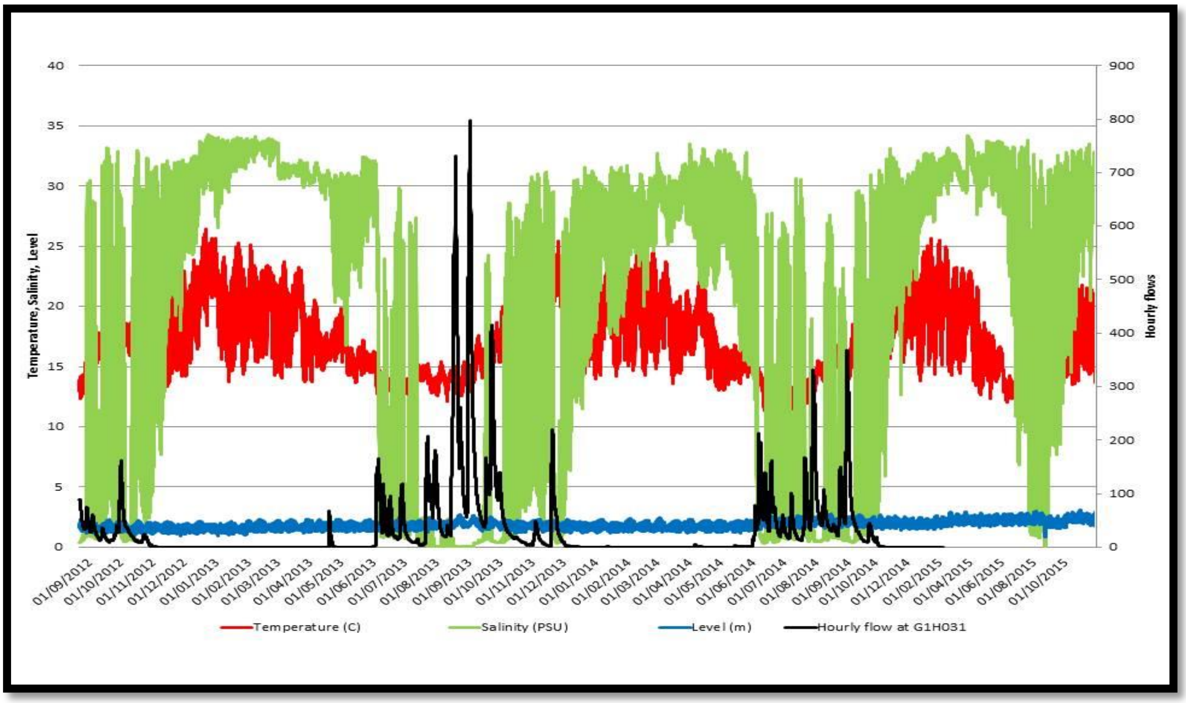


Figure 41 Time series graph of water level, salinity and temperature from permanent deployed logger at the mouth of Breede Estuary (Site 1) between 24 October 2013 and 1 February 2016.

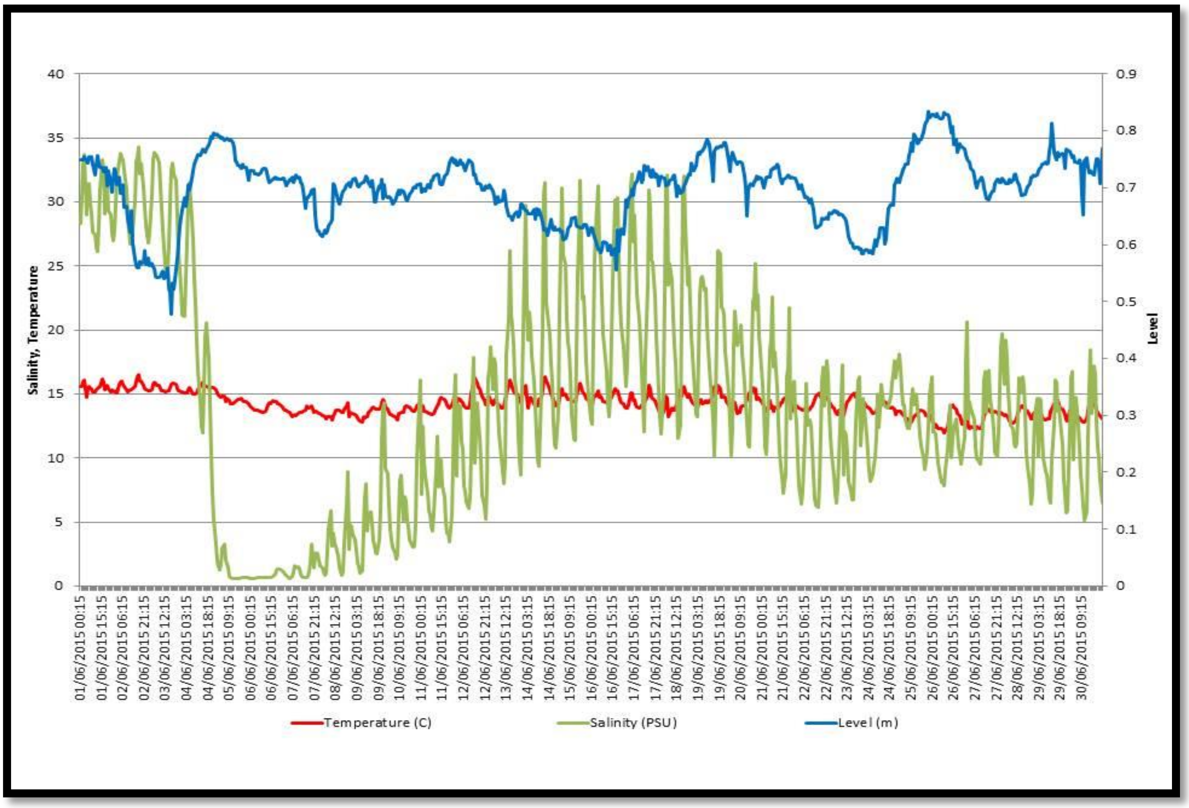


Figure 42 Hourly logger data from Site 1 between 1 June 2015 and 30 June 2015. Flood conditions between 3 June and 7 June 2015 indicated by low salinity and temperature.

Figure 43 indicate the logger data between 25 September 2015 and 25 November 2015. There is marked drop in salinity between 8 October 2015 and 25 November 2015. This was not as a result of salinity changes in the system, but as a result of a calibration error when the data were downloaded and the probe recalibrated. This is also observable in Figure 41. This is indicative of the importance of quality control of the data, training of samplers and constant liaison between programme managers and the sampling team for troubleshooting.

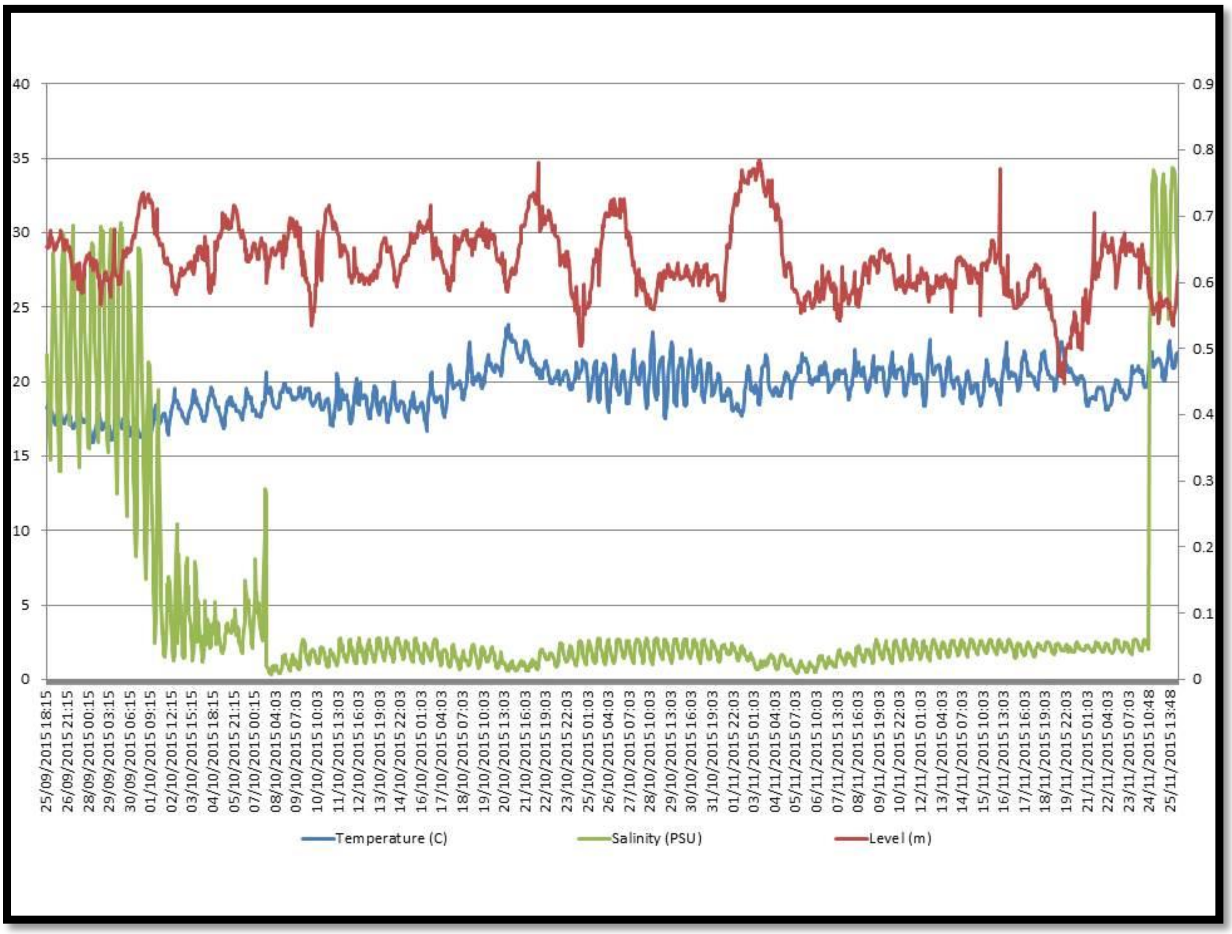


Figure 43 Logger data from Site 1 between 25 September 2015 and 25 November 2015.

Threshold of Potential Concern

The different abiotic states were described, although TPCs for the Breede Estuary were not set in the Resource Directed Measures study (DWAF, 2003). The REI zone was determined for the different high flow (winter) and low flow (summer) scenarios based on the data collected in this study (Figure 44). The REI zone for the high flow condition starts at a distance of 10 km from the mouth at Site 5. During the low flow conditions, the REI starts at a distance of 20 km from the mouth at Site 10.

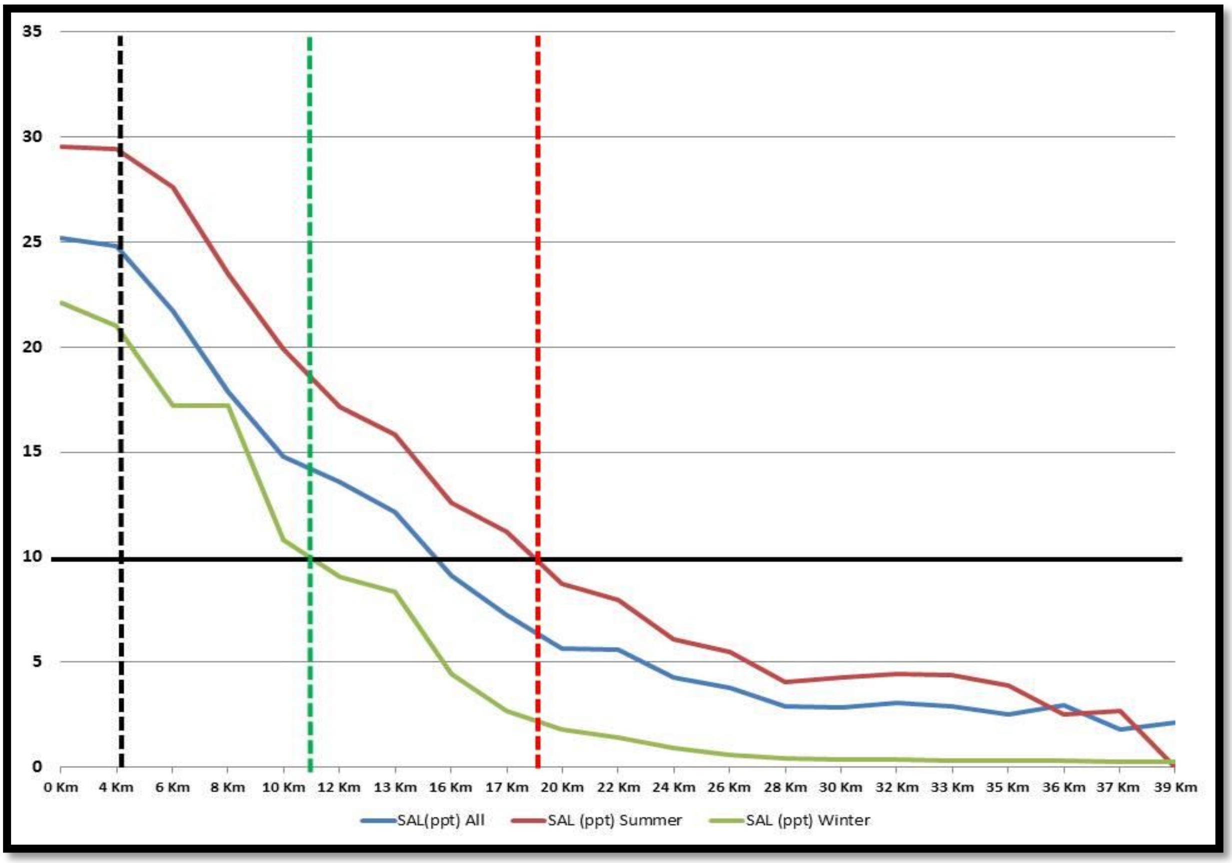


Figure 44 Average salinity during high and low flow conditions, recorded at the sites on the Breede Estuary between 2012 and 2015 (n=2270). The REI zone cut-off at 10 ppt is indicated with the different salinity zones during the high and low flow scenarios.

The Breede is divided into three distinct zones based on the average salinity patterns observed from the data collected in this study (Figure 44). Zone A is where the recorded salinity was between 20 and 35 ppt and presents the marine zone. This corresponds to the area between the mouth and a distance of 4 km from the mouth during both seasons. Zone B stretches from a distance of 4 km from the mouth to the start of the REI zone. During high flow conditions this zone ends at a distance of approximately 11 km from the mouth and during low flow conditions, at a distance of approximately 18 km from the mouth. Zone C represents an area where the average salinity is below 5 ppt and presents the area of freshwater dominance. This represents the area from a distance of 22 km from the mouth inland. It therefore represents the entire REI zone in summer and part there-off in winter.

TPCs were set with guidance of the different states as described in the Intermediate Ecological Water Requirement study (DWAF, 2003) and the data from this study and is summarised in Table 16. The percentage exceedances of these TPCs are summarised in Figures 45 and 46.

Table 16 The TPCs for system variables and nutrients of the Breede Estuary as calculated with the 10th and 90th percentile for data from this study. Number of data points used for 10th and 90th percentile calculation indicated in brackets. High flows >10 m3 s-1 and low flows <10 m3 s-1 based on DWAF (2003).

CONSTITUENT	DATA FROM THIS STUDY		TPC	TYPICAL STATE ACCORDING TO BREEDE ESTUARY RDM STUDY (2003)
	10TH PERCEN-TILE	90TH PERCEN-TILE		
Salinity (n = 2270)				
REI: Winter (Flows > 10 m^3 s^{-1})	0	30	Average of 10 ppt at a distance of 10 km from mouth REI = 10 to 40 km	0 – 40 km from mouth
REI: Summer (Flows < 10 m^3 s^{-1})	0	20	Average of 10 ppt at a distance of 20 km from mouth REI = 20 to 40 km	20 – 40 km from mouth
Estuary	n/a	n/a	> 35 ppt	0 - 35 ppt
> 50 km from mouth	n/a	n/a	> 0 ppt	0 ppt
TDS (n = 44)				
> µg/l at river inflow (n=159)	220	1581	>1600 µg/l	-
pH				
River (n = 159)	7.3	8.6	7<pH>8.5	7<pH>8
Estuary (n = 2270)	7.3	8.1	7<pH>8.5	7<pH>8
DO (n = 2253)				
River and estuary	6	11	<4 mg/l	Well oxygenated
Secchi Disk				
River and estuary	No data	No data	10 µg/l <suspended solids >30 µg/l	10 µg/l <suspended solids > 30 µg/l
DIN (µg/l)				
River: High flows (n = 8)	97	422	>425	200-500
River: Low flows (n = 15)	34	133	>135	20-200
Estuary Zone A (<4 km) High flows (n = 8)	0	107	>110	0-100
Estuary Zone B (5-10 km)	0	134	>135	120-470

CONSTITUENT	DATA FROM THIS STUDY		TPC	TYPICAL STATE ACCORDING TO BREEDE ESTUARY RDM STUDY (2003)
	10TH PERCEN-TILE	90TH PERCEN-TILE		
High flows (n = 9)				
Estuary Zone C (11-39 km) High flows (n = 15)	0	305	>305	200-500
Estuary Zone A (<4 km) Low flows (n = 4)	15	362	>360	0-100
Estuary Zone B (5-20 km) Low flow (n = 8)	0	83	>85	55-300
Estuary Zone A (21-39 km) Low flows (n = 4)	0	136	>136	55-200
SRP (µg/l)				
River: High flows (n = 8)	11	35	>35	0-20
River: Low flows (n = 3)	5	19	>20	0-20
Estuary Zone A (<4 km) High flows (n = 3)	4	10	>10	0-40
Estuary Zone B (5-10 km) High flows (n = 3)	9	13	>13	15-25
Estuary Zone C (11-39 km) High flows (n = 15)	5	80	>80	0-20
Estuary Zone A (<4 km) Low flows (n = 3)	2	11	>11	0-40
Estuary Zone B (5-20 km) Low flows (n = 4)	5	12	>12	15-25
Estuary Zone A (21-39 km) Low flows (n = 8)	5	17	>17	0-20

The REI zone lies at a distance between 10 to 40 km from the mouth, depending on the flow in the system. This is a result of the speed of water flow that the estuary experiences, the size of the catchment and the permanent open nature of the estuary mouth. This translates into the average salinity during winter not exceeding 10 ppt at a distance of 10 km from the mouth. During the low flow conditions, the REI zone starts at a distance of 20 km from the mouth. The salinity in the entire estuary should not exceed 35 ppt at any time and salinity should always be 0 ppt at 50 km from the mouth. Saline intrusion beyond this point would be an indication of a decrease in flow with implications for habitat diversity and potential changes in mouth state. TDS levels at the river inflow should not exceed 1600 µg/l. pH in both the river and estuary by default has been set between 7 and 8.5. Similarly, an oxygen concentration of >4 mg/l have been set as the default TPC level as levels lower than 4 mg/l indicates the onset of anoxic conditions. No data were available for secchi disk as a surrogate for turbidity. The typical expected secchi depth level of <1m at a distance of 10 km from the mouth during low flow conditions as set in DWAF (2003) is used.

The calculated TPC for DIN levels in the river is 425 µg/l during high flow conditions and 135 µg/l during low flow conditions. The TPC for estuary zone A during high flows was calculated as 110 µg/l, which is slightly higher than the typical 0 - 100 µg/l suggested in DWAF (2003). The TPC for DIN during high flows in Zone B are 125 µg/l, and 305 µg/l in Zone C, which is also in line with the conditions as proposed in DWAF (2003). During low flow conditions the calculated TPC for DIN in Zone A was 360 µg/l, which is substantially higher than the levels (0 - 100 µg/l) described for the abiotic conditions (DWAF, 2003). This could be as a result of nutrient loading associated with the Witsand residential area and upwelling from the Agulhas current. The calculated TPCs for DIN during low flow conditions is Zone B and C were 85 and 136 µg/l respectively and in line with the typical conditions described in DWAF (2003).

The calculated SRP for river inflow during high flow conditions was slightly higher at > 35 µg/l in comparison with the conditions of 0 - 20 µg/l, as defined in DWAF (2003). The low flow TPC for river SRP of >20 µg/l is the same as the abiotic conditions described in DWAF (2003). The calculated TPCs for high flow conditions in Zone A, B and C were >10, >13 and 80 µg/l respectively. This is in line with the abiotic conditions as described in DWAF (2003) for Zone A and B, but substantially higher in Zone C. The low flow TPCs for Zone A, B and C were > 11, 12 and 17 µg/l respectively, which is in line, although generally lower than the abiotic states as described in DWAF (2003).

The percentage exceedance of the calculated TPCs for system variables are reflected in Figure 45. The highest exceedance (17%) of system variable TPCs were for low flow salinity at a distance of 20 km from the mouth, followed by 11% exceedance for high flow salinity at a distance of 10 km from the mouth. Estuarine pH showed 8 % exceedance of the calculated TPC.

The TPCs for the river during low flows for DIN and SRP was both 33% (Figure 46). The high flows exceedance was 13% for both DIN and SRP. The TPC for DIN in all three estuary zones, during high flows were exceeded with 11%. Low flow exceedance of DIN TPCs for Zone A, B and C were 25, 11 and 6% respectively. The TPC for SRP during high flows were exceeded with 33, 25 and 6% respectively for Zones A, B and C, while the TPCs for low flow conditions was exceeded by 33, 25 and 3% respectively.

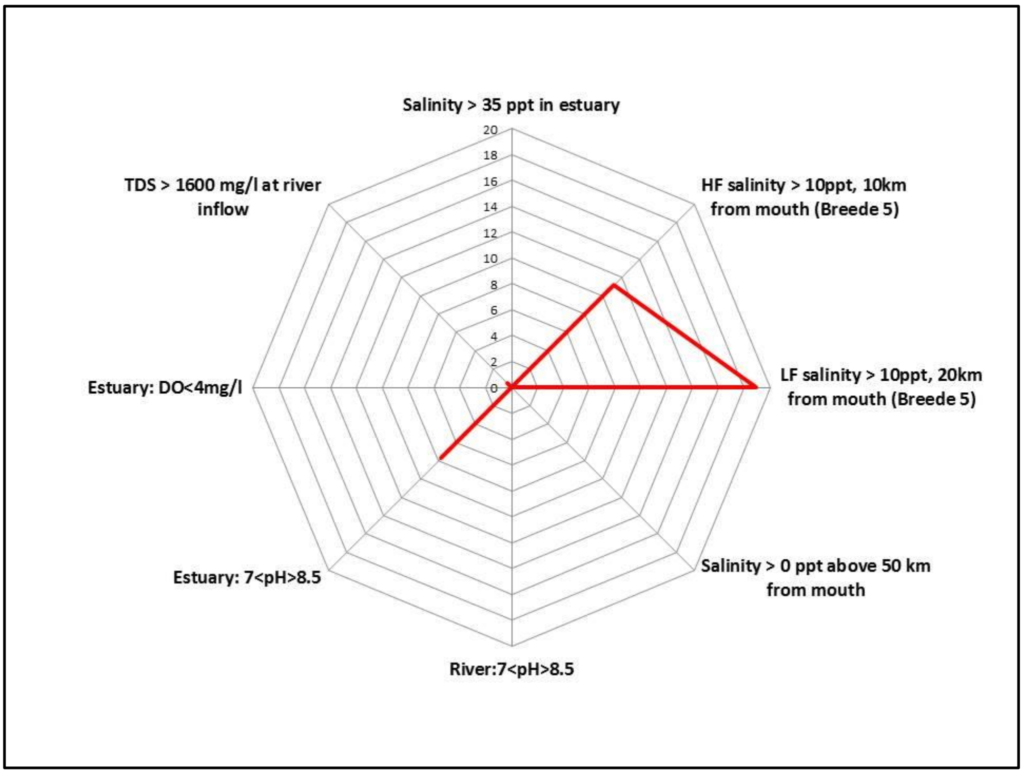


Figure 45 Percentage exceedance of system variable TPCs as calculated for the Breede Estuary for the period 2012 to 2014 (n=160 – 19992). High flow (HF) = >10 m^3 s^{-1}. Low flows (LF) = <10 m^3 s^{-1}.

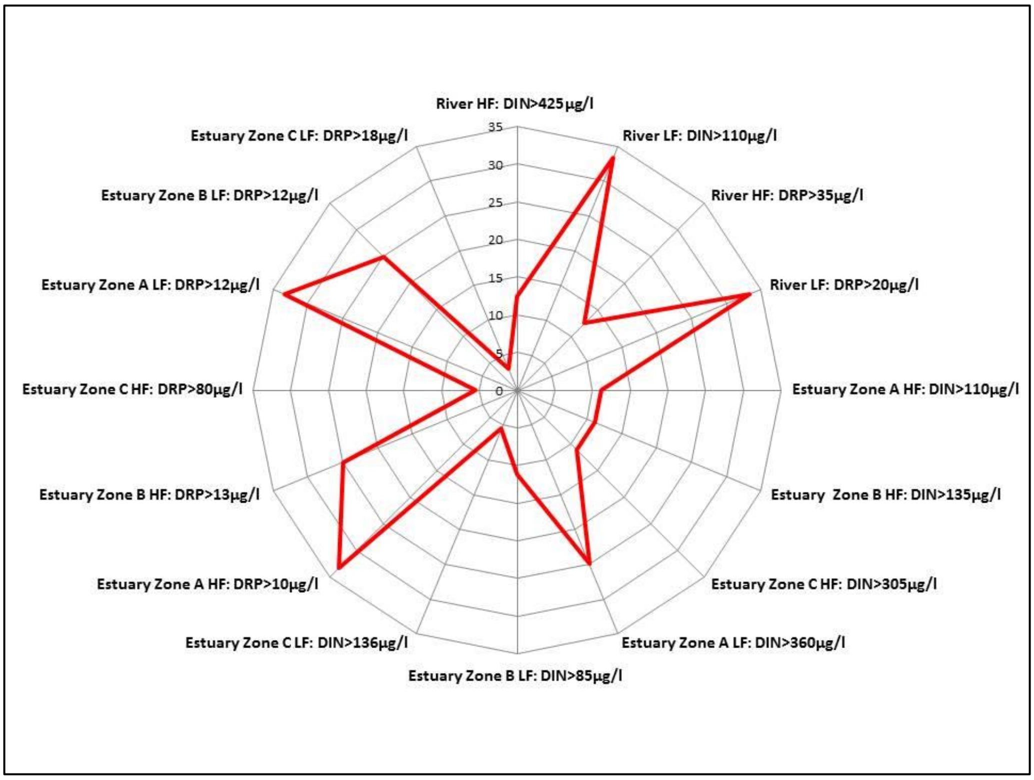


Figure 46 Percentage exceedance of TPCs for nutrient levels as calculated for the Breede Estuary for the period 2013 to 2014 (n=17). High flow (HF): >10 m^3 s^{-1}. Low flows (LF): <10 m^3 s^{-1}.

This nutrient loading in the system indicates the impact of both agricultural and residential development in the catchment, as well as localised residential development on the banks of the estuary. The high exceedance of SRP and DIN in Zone A, during low flow conditions is probably the result of marine upwelling during summer. The localised residential developments around Witsand focus on the holiday market. This probably also plays a role in these elevated nutrient levels during the holiday season (December to February) which falls within the low flow period. The septic tanks used at Witsand have to deal with more sewerage than normal. This may result in septic tank failure as a result of under design and associated localised sewerage pollution. Relatively high exceedance of the TPCs during low flow conditions at the upstream river inflow into the estuary may also reflect localised nutrient enrichment from adjacent residential development in the vicinity of Malgas. This may also be the result from similar under designed or dysfunctional septic tanks. In addition, this also emanate from poorly treated sewerage discharge from the Swellendam wastewater treatment works, which results in increased nutrient loads due to lower water volumes in the system during summer. The system therefore has lower capacity to dilute these pollution loads, resulting in the observed exceedance of the TPCs. The Swellendam wastewater treatment works underwent extensive intervention, which have resulted in its municipal green drop score increasing from 41 % in 2011 to 70.8% in 2013 (DWA, 2013). The report however highlighted that 2 of the 5 plants under control of the Swellendam municipality, exceeded their hydraulic design capacity and none of the 5 plants complied with the effluent quality limits. In addition 3 of the 5 plants did not have sufficient operational monitoring in place. All these factors contribute to nutrient loading of the Breede system and observable in the exceedance of TPCs. During the high flow conditions there is a larger volume of water in the system, resulting in larger dilution. This is observable in a general pattern of lower frequency of exceedance of nutrient TPCs during high flow conditions in comparison with the low flow condition in the Breede system.

4.6. CONCLUSION AND RECOMMENDATIONS

This study showed that the data collected as part of NESMP could provide an overview on some aspects of estuary health and address local management issues particularly relating to water quality. The Berg and Breede estuaries were analysed as case studies. Both estuaries function as typical permanently open systems with a strong tidal prism. A clear seasonal trend, in system variables and nutrients, influenced by the prevailing flow regimes, were observed. There was a salinity gradient from the mouth to a distance of approximately 40 km upstream in both estuaries. The permanently open mouths cause a tide influenced zone in the lower reaches, with relatively consistent changes in salinity, turbidity and DO concentrations. Schumann (2007) indicated a similar salinity regime between 2002 and

2005 for the Berg Estuary, as part of a baseline monitoring study. This study also confirmed the position of the REI zone (10 ppt) in both estuaries to be upstream of 10 km from the mouths. The REI zone will however vary in time and space depending on the amount of freshwater input from the catchment.

The upper reaches of the estuaries were strongly influenced by extensive agriculturally dominated catchments resulting in sediment input to the Berg Estuary and nutrient input to both estuaries. Dissolved Inorganic Nitrogen concentrations were variable for the Berg Estuary ranging from 10 to >1000 µg/l, while SRP levels were mostly below 100 µg/l, which was also observed in the Berg baseline study (DWAF, 2007). During high flow conditions, nutrients concentrations were elevated at the upstream sites in the Berg Estuary and systematically decreased towards the mouth due to nutrient loading from agricultural return flows and urban development and associated wastewater disposal. In the Breede Estuary the DIN varied between 32 and 700 µg/l and SRP between 10 and 675 µg/l. Based on the available data it seems that DIN and SRP levels in the two systems were similar, but that SRP concentrations periodically show elevated levels from the norm. This however needs further investigation due to the limited number of nutrient samples analysed in this study. The data indicate periodic event based nutrient loading of the estuaries, which may not always be measured with monthly sampling. Consistent monitoring is needed to capture both baseline and event conditions to better understand the pressures on these estuaries.

High nutrient conditions exceeding the TPCs in the Berg Estuary, from the mouth of the estuary to a distance of approximately 20 km, were mostly found during the summer (low flow). Nutrient inputs in the lower reaches are from the fish-processing factories and associated industries at Laaiplek and Veldrif. The influence of upwelling from the Benguela current into the Berg Estuary and the Agulhas current into the Breede Estuary allows the ingress of nutrient rich marine water into the lower estuary reaches. An extensive red tide event caused a decrease in oxygen levels in the lower part of the Berg Estuary. Elevated nutrient levels were also observed in the lower reaches of the Breede Estuary, but only extended to a distance of 10 km from the mouth during low flow conditions. This study therefore confirms previous observations (DWAF, 2003; DWAF, 2007) that the Berg and Breede estuaries act as dynamic sinks for the nutrients that enter the systems from the catchment during winter and from upwelling.

The highest exceedance of TPCs on the Breede Estuary occurred during the low freshwater inflow conditions but during the high flow conditions on the Berg Estuary. The average monthly flows in the Breede Estuary have decreased by 21% from reference conditions (DWAF, 2003) and by 46% in the Berg Estuary (DWA, 2012). For the Breede Estuary, the highest exceedance of system variables were for salinity (for both high and low conditions), while the highest exceedance of nutrients was recorded in Zone A (upper reaches) and the river during low flow conditions. This indicates that reduced flow and nutrient loading are significant pressures that require management intervention. The highest exceedance of the TPCs set in the Berg EWR study (DWA, 2012) were for Secchi disk readings, river DIN and DRP during winter and estuarine DIN and DRP in Zone C to D during summer. This confirms that sedimentation and nutrient loading are the pressures requiring management intervention as observed in the Berg EWR study (DWA, 2012).

Based on the data from this study, the percentage exceedance for system variable TPCs from the Berg EWR study and the alternatives were very similar. The percentage exceedance of TPCs for nutrients however varied substantially between the EWR values and the alternative values. The system variable exceedance calculation and setting of alternative TPCs were based on a substantially larger data set (n between 42 and 253) than for nutrients (n between 2 and 16). This indicates the importance of large data sets to calculate TPCs that are robust enough to use for management purposes. This highly variable level of exceedance that was observed on the Berg Estuary between the set EWR TPCs, based on a limited dataset and the alternative TPCs, based on a more extensive dataset, merit that the nutrient TPCs are revisited through further data collection and analysis.

Based on the use of the 10^{th} and 90^{th} percentile for the system variable and nutrient data collected in this study, it was concluded that the TPC that was set for most constituents in the Berg EWR study (DWA, 2012), was robust enough to reflect the actual situation in the system. However, the TPCs set for DIN in the EWR study need to be reviewed, as the data from this study indicate them to be conservative. This however needs to be evaluated against the data from this study reflecting the present day situation and not reference conditions. For now the EWR values are the more conservative values and should be used, until further long term data are available that can be used to refine the results from this study. In a similar fashion the TPCs for the Breede Estuary should also be used for future evaluation of the implementation of the reserve and re-evaluated as new data become available.

The Berg Estuary Management Plan (Anchor Environmental, 2008) and the Breede Estuary Management Plan (SSI, 2011) identified key management objectives. The Berg Estuary Management Plan identified this as

1) Increase awareness through education material and public participation in management;

2) Conserve biodiversity by sustainable use, facilitated through research, monitoring and enhancement of ecosystem function by establishing protected areas;

3) Improve ecosystem health through rehabilitation and setting of freshwater requirements;

4) Ensure harmony through establishment of zonation plans, regulations and associated compliance monitoring;

5) Retain sense of place by limiting development in natural areas; and

6) Maximise economic benefit by promoting nature based tourism and promoting sensitive development.

For the Breede Estuary these were identified as

1) The maintenance of water quantity and quality, thereby ensuring that the estuary remain in a B category as proposed in the Intermediate Reserve study (DWAF, 2003);

2) Protection of biodiversity from direct or indirect impacts;

3) Management of catchment activities, including agricultural activities that may negatively influence the estuary to ensure environmental sustainability, biodiversity and the aesthetics;

4) Ensure co-operative management of the Breede Estuary by involvement of local and district municipality, the Breede Overberg Managament Agency (BOCMA) and relevant government departments through the Breede Estuary Advisory Forum; and

5) Enhance public awareness of the ecosystem services of the Breede Estuary through education and compliance management.

All of these objectives are directly or indirectly informed and supported with the data and resulting knowledge products that emanated from the monitoring on the Berg and Breede estuaries as part of the NESMP. The data are collected and information generated through collaboration with the Lower Breede Conservancy, associated Breede Estuary Advisory Forum and the Berg Management Forum. The information products in the form of presentations and reports that emanate from this collected data, have increased awareness of water resource management and could be used to develop educational material for scholars and the public. These data were provided to the public and roleplayers, through 32 presentations between 2012 and 2015 to the Berg Estuary Management Forum and the Breede Estuary Advisory Forum, the Western Cape provincial coastal committee and meetings with the West Coast District Municipality and Cape Nature. This material, if correctly packaged and promoted will create awareness, support and buy in by the public for management initiatives thereby enhancing collaborative management of the Berg and Breede estuaries by the public as defined in ICMA. This also ensures the sustainable management of the Breede and Berg estuaries through the management of catchment related impacts. Some of these impacts were been verified through the monitoring data from the NESMP.

The data collected in the NESMP facilitates the establishment of a long-term database that assists in developing a better understanding of how the estuaries function and therefore a better understanding of freshwater requirements and future rehabilitation needs. By addressing the water quality issues, biodiversity conservation and protection of sensitive habitats are also addressed. This facilitates the identification and validation of different conservation zones within the estuary thereby identifying and refining areas of importance and therefore sensitive areas. These sensitive areas include areas of biodiversity, dictated by the main abiotic components including tidal exchange and salinity variability. The REI that has been confirmed in this study, is an example of a sensitive area that requires protection. Through enhancement of ecosystem services, which is based on biodiversity conservation and ecosystem health, nature based tourism and sensitive development is facilitated. Through refinement and evaluation of the TPCs, the successful implementation of the freshwater requirement study and the estuary management plan can be evaluated and management interventions identified, thereby improving the ecosystem health. This is in light of the Breede Estuary ranking 18th in South Africa for biodiversity conservation importance and the Berg Estuary the second most important estuary in South Africa (Turpie et al., 2002).

CHAPTER 5. DESIGN OF A DECISION SUPPORT SYSTEM

5.1. INTRODUCTION

Sustainable environmental management has become more complex with the growing recognition of linkages between ecological and socio-political sub-systems (Matthies, 2007). Many spatial problems including water quality management problems are semi-structured and therefore all of their components cannot be measured or modelled (Hopkins, 1984). A Decision Support System (DSS) is a computer based information system that supports decision making for business or organisational purposes (Sprague, 1980). A DSS attempts to provide the water-resources manager with analytical assistance in making rational choices based on objective assessment, thereby reducing the element of subjective opinion (Jamieson, 1996). Decision-making also needs to include economic, environmental and socio-political considerations, quantitatively wherever possible. Therefore, a DSS can be regarded as a form of artificial intelligence in which computers are used not only to predict what is likely to happen given various assumptions but also to supplement management experience in decision-making. Jamieson (1996) indicated that besides the obvious advantage of assisting water-resource managers in determining the appropriate course of action, the benefits of using a DSS include: 1) Making mathematical modelling more accessible to users; 2) Enabling rational use of the analytical facilities without the necessity of an in-depth knowledge of modelling techniques; 3) Enhancing user experience by reference to domain knowledge from elsewhere; 4) Providing an integrated framework in which different models can co-exist and interact with each other, rather than having a series of separate models which are frequently incompatible, at least to some degree; 5) Maintaining upgrade paths for the incorporation of new or improved knowledge; and 6) Facilitating public accountability in the way decisions are reached.

A DSS assists middle and top management with decision making on different problems, usually when there is very little time for extended analysis of data and information. Sage (1986) indicated that a database, model-base and dialogue generation system are the principal components of a DSS. Database and model-base are common components of DSS, while dialogue management has evolved into broader considerations of user experience of data manipulation, model construction, DSS construction and calibration, execution, analysis and reporting (Argent et al., 2008).

In order to make a DSS useable by various technical and non-technical users, including environmental managers, conservation authorities, DWS officials, a simple, readily available and generally used platform is required. In addition, this platform also needs to facilitate easy changes to the core operation of the DSS. Large datasets are best stored and cleaned in database programmes, but these programmes are not readily available to all estuarine managers. Even a generally used database programme, for instance MicroSoft Access, is not a standard software programme available in all MicroSoft packages. Excel is however generally used and available in most MicroSoft packages. Excel statistical capabilities have also grown considerably, resulting in most requirements for long-term data analysis and interpretation being met. The visual presentation of the data in graphs and tables are also simple and user friendly with the minimum training requirements. Excel was therefore chosen as the foundation of the NESMP DSS, due to its wide use in practice, its ease of use, and its analytical, statistical and visualisation capabilities.

The main objective of the NESMP is the collection of long-term data on the health of South African estuaries. These data need to be converted into management information, to facilitate sustainable use and effective management of estuaries (Figure 47). DWS, DEA, local authorities and conservation bodies have limited human capacity to deal with management of estuaries. There is a need to address this shortage of human capital on a national, regional and local level by facilitating quick decision making on estuary specific management issues, including water quality deterioration. The use of a DSS can facilitate this lack of capacity. Dealing with large complex datasets, as is the case with the NESMP, necessitates a structured manner in which to archive data, extract and analyse data and ultimately make decisions based on the data.

Chapter 3 of the NWA provides for the protection of water resources by apportioning a certain amount of water of a certain quality to maintain the natural functioning of a system in a pre-agreed state. This forms part of the classification studies of water resources in South Africa that entail 1) classification of the water resource, 2) setting Resource Quality Objectives 3) and determining the Ecological Reserve by determining the EWR. Different water use scenarios are compared against each other to decide on an acceptable future condition for various aquatic ecosystems, including estuaries (DWAF, 2007; Dollar, 2008). The TPCs are a result of the classification study and associated Resource Quality Objective, which are gazetted. Therefore, once gazetted, the RQO's and associated TPC have legal standing and acts as the objective towards which estuaries should be managed. In order to ensure that management action takes place to maintain an estuary in a specific condition class, a trigger is needed. The TPCs are the trigger that is used to ensure that the Ecological Specifications are met, once measurable end points related to specific abiotic and biotic indicators are reached. The TPCs are therefore early warning signals of potential non-compliance with the Ecological Specifications. The TPC was selected as the focus around which the NESMP DSS was designed. The central question to be answered by the NEMP DSS is the following: 1) What are the TPCs, where none exists; 2) What is the percentage exceedance of the TPCs; and 3) What management intervention is required once the TPCs are exceeded?

The NESMP DSS is in support of Chapter 3 of the NWA that address the protection of water resources through the classification process and prevention of pollution. Chapter 4 that addresses the use of water and Chapter 14 that addresses monitoring, assessment and information (Figure 48) are also supported through the DSS. The DSS is therefore central to three relevant chapters of the National Water Act (Figure 48). Data collected through the NESMP is founded on Chapter 14 of the NWA, which addresses water quality monitoring and water information management. The data collected through the NESMP, which is managed and evaluated with the DSS informs the EWR and associated classification process (Path A in Figure 48) and therefore the protection of water resources through Chapter 3 of the NWA. The monitoring data can also be used to audit the RQO's, with the use of TPCs where these have been set or preliminary TPCs need to be set (Path B in Figure 48). The information generated with the DSS can also be used to assist with water use protection through pollution prevention (Path C in Figure 48) and corrective action through the water use authorisation process (Chapter 4 of NWA) - path D in Figure 48. Water resource planning, which is central to water use authorisation (Chapter 4 of the NWA), is also supported with the use of the DSS through path E in Figure 48.

5.2. PROBLEM STATEMENT

In order to track the condition of an estuary, monitoring data are needed. The monitoring data however need to give rise to information that can be used for management purposes. The need for a DSS originated from this need to create useable management orientated information from the extensive data being collected during the pilot testing of the NESMP between 2012 and 2015. The purpose of a DSS therefore would be to facilitate completing the information value chain; from data to data analysis and interpretation to information that leads to informed management decisions (Figure 47). The objective of this chapter was to develop a practical DSS for estuary management using an easily accessible spreadsheet model approach. The research question was “Is it possible to use a spreadsheet model approach, using a generally available software programme (in this case Excel) to develop a suitable DSS to facilitate data analysis, data interpretation and information generation?”

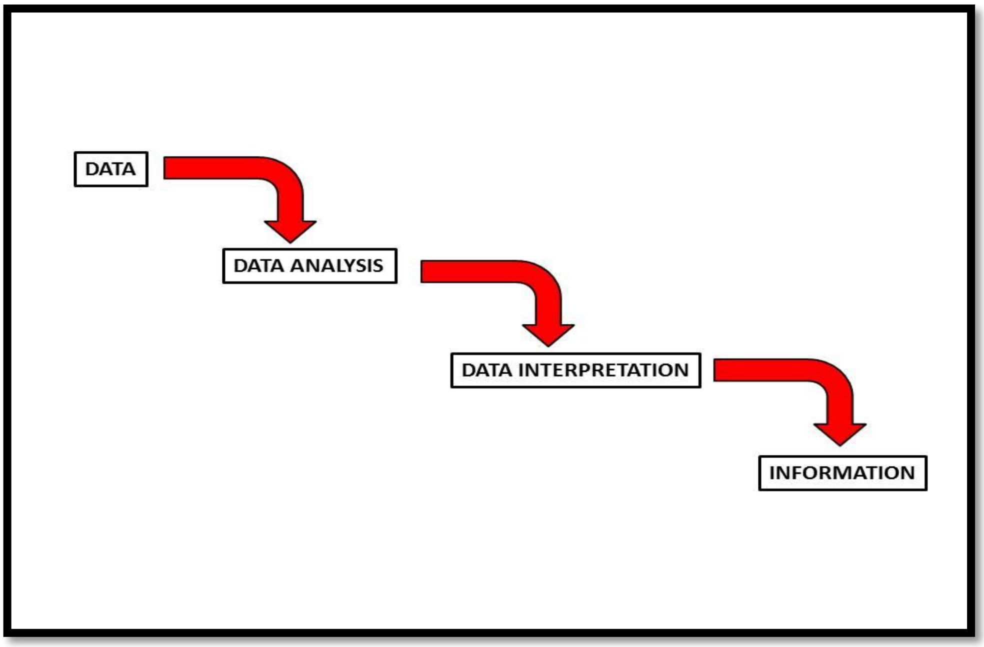


Figure 47 The information value chain.

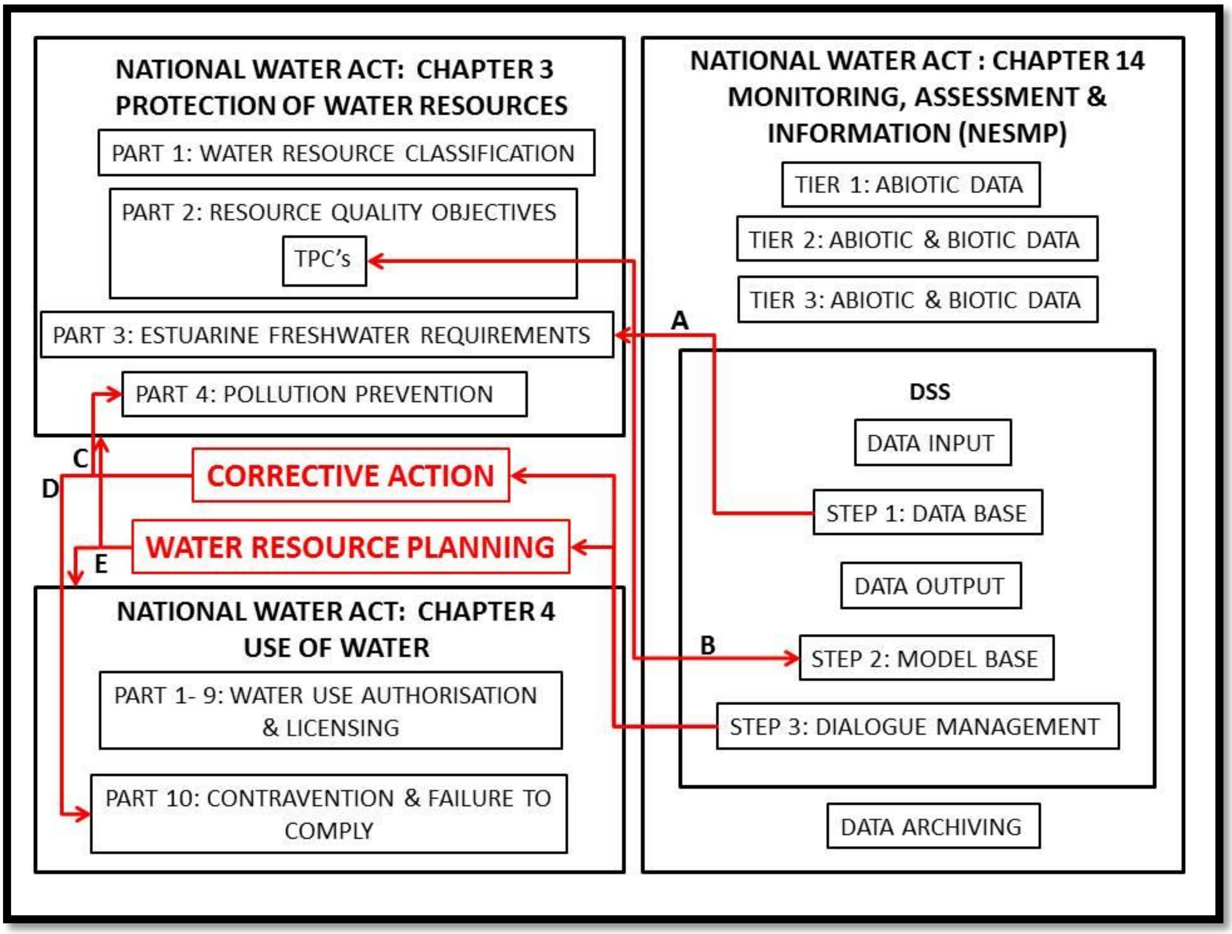


Figure 48 The NESMP DSS in context of Chapter 3, 4 and 14 of the NWA.

5.3. METHODS

5.3.1 Study Approach

The basic design philosophy of the NESMP DSS is the classical data analysis process of data input, data analysis, data interpretation and information generation (Figure 47). This chapter only focusses on a Tier 1 DSS based on the data which have been collected and reflected on in this study. A Tier 2 DSS will eventually be developed and incorporated into a larger NESMP DSS, once Tier 2 data becomes available. It is anticipated that the components of the Tier 2 DSS will mirror those of the Tier 1 DSS, although the input will be of a biological nature. The chapter objective and associated research questions are addressed through a number of research activities, aligned with the typical design questions of a DSS and are:

1. A critical review of international DSS systems, i.e. what can be learned from other systems, for application in the South African estuary management context.
2. Evaluate the objectives of the NESMP in the context of required management decisions and intervention relevant to South African estuaries.
3. Evaluate to what extent the NESMP data, can answer management questions and inform the required management decisions
4. Evaluate the use of Excel and associated data analysis tools to answer these management questions.
5. Identify the most appropriate method for data archiving for use in the proposed DSS
6. Identify the most appropriate method to integrate complex data and link associated answers into an integrated answer for management intervention.

5.3.2 Framework for proposed NESMP DSS

The foundation for the NESMP and therefore the proposed NESMP DSS is adaptive management. This entails the typical design, evaluate, refinement process. Linked to this is the completion of the information value chain (Figure 49). The DSS is constantly updated and refined as new information becomes available through implementation of the NESMP in this interactive process. The DSS provides answers that will then support the adaptive management process of relevance to the specific estuary.

Most of the method development on the design of DSS in water resources has taken place in the 1990's. Subsequent to this these DSSs have been implemented and refined to address specific management objectives. According to Sprague (1980), a DSS is designed as an iterative manner as part of a process (Figure 50). This typically entails 1) analyses of the problem that need to be addressed – in this case estuary health with specific reference to water quality management, 2) design - what the DSS should address, in this case evaluation of estuarine monitoring data, 3) construction - how it should look and work, the objective of this chapter, 4) implementation through testing and refinement of the DSS – in this case the subject of the NESMP data reflected on in Chapter 4. The DSS should be designed in such a manner that changes can easily and quickly be incorporated. This ensures that the system is adaptive to changing environments and the need for adaptive management in the context of estuarine management is addressed.

Most DSS have been developed to address large scale planning and management issues on a catchment scale, where many stakeholders are involved. These large scale DSS addresses various economic, social and environmental considerations. Although estuaries are influenced by a multitude of catchment related activities and various stakeholders are involved with the management of estuaries, the objective of the NESMP DSS is solely focused on the bio-physical results that emanate from the NESMP.

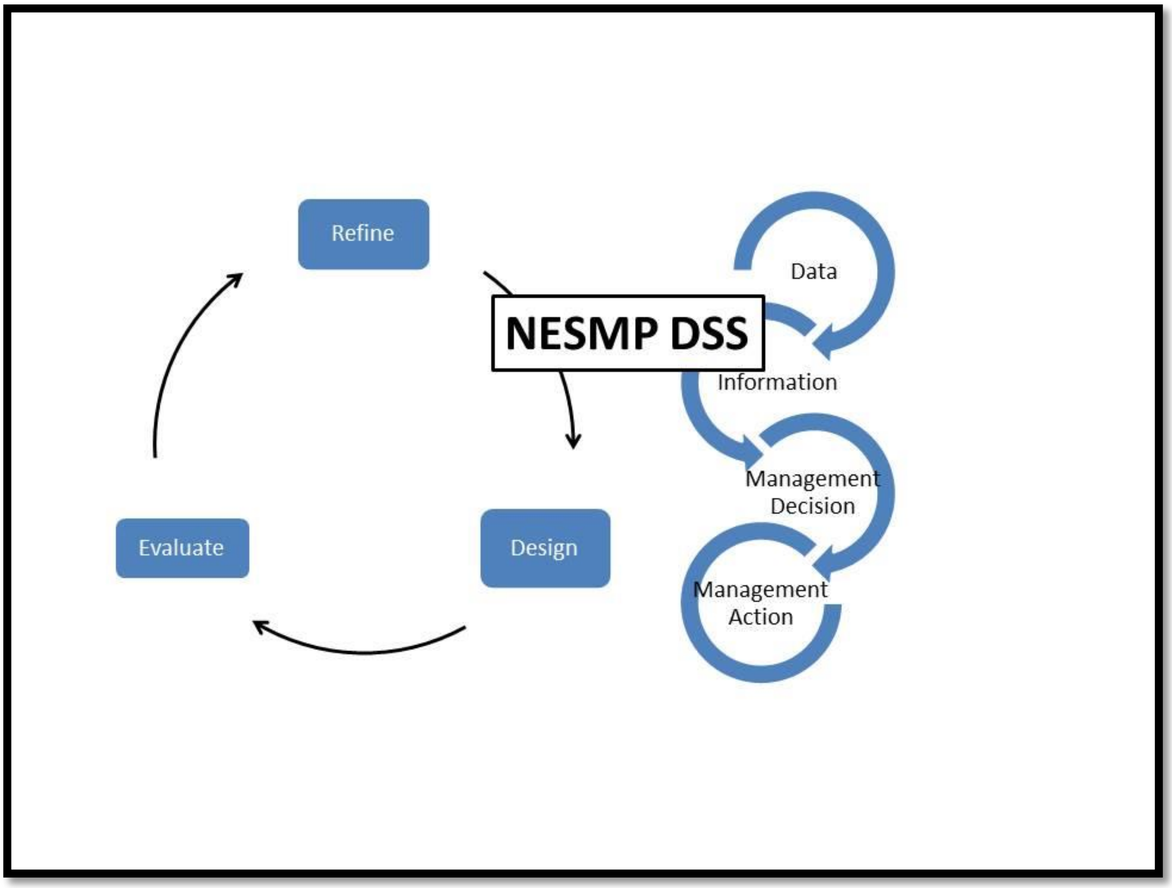


Figure 49 The NESMP DSS in context of the adaptive management process and the information value chain.

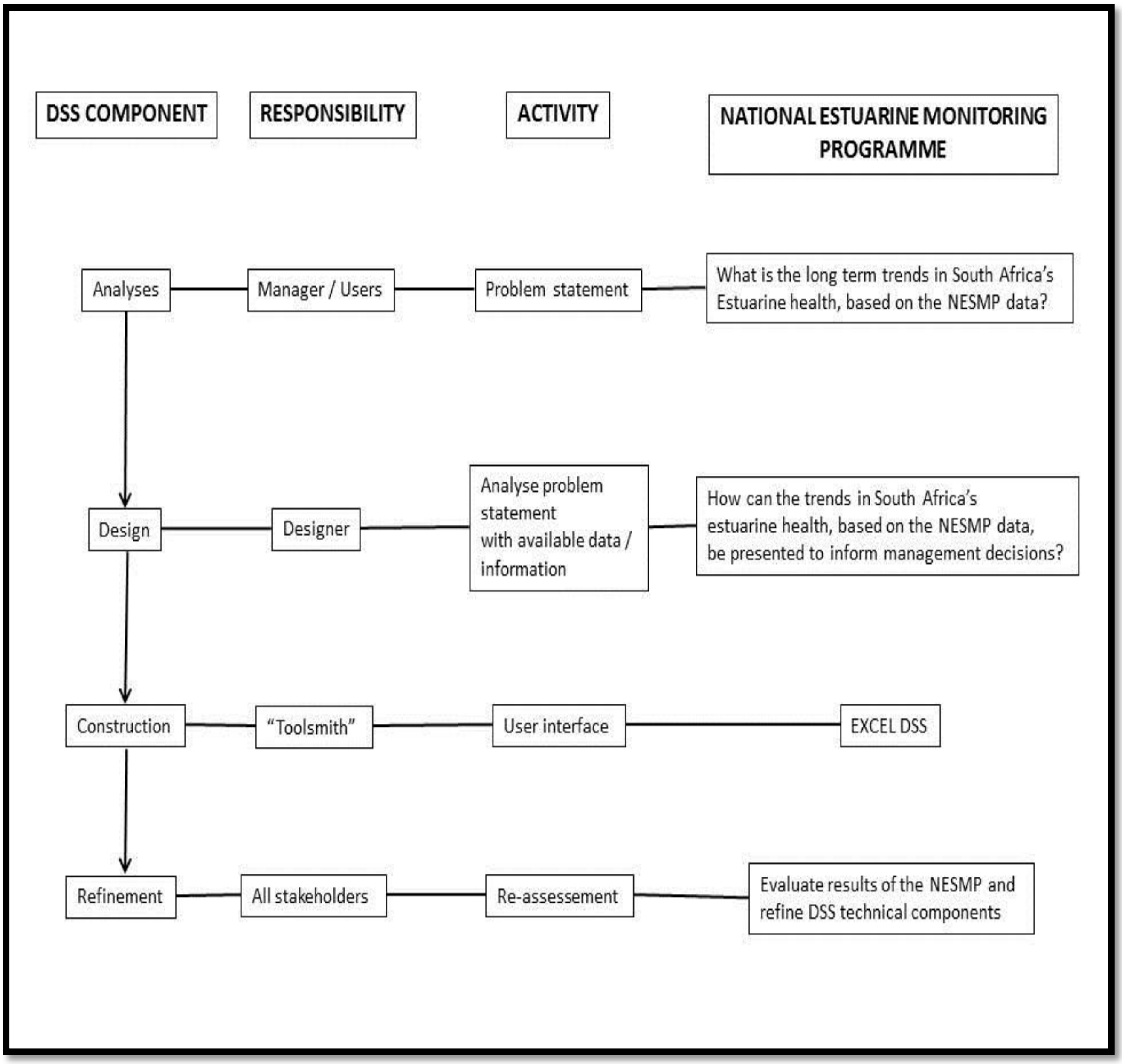


Figure 50 DSS design and implementation process after Sprague (1980) in the context of the NESMP.

5.4. RESULTS AND DISCUSSION

5.4.1 Critical Review of International DSS

Decision support systems have been developed and used for water resource management over the past three decades. In no way can this overview discuss all of these DSS, but rather provide an indication of the process that need to be followed in the development of DSS for water resource management. Sustainable environmental management has become more complex with the growing recognition of linkages between ecological and socio-political sub-systems (Matthies, 2007). Many spatial problems including water quality management problems are semi-structured and therefore all of their components cannot be measured or modelled (Hopkins, 1984). Fedra (1996) discussed the development of DSS in the water resource management field in detail. It was indicated that initially DSS mostly focussed on specific issues of water resource management that required intervention, but a need was identified for integrated river-basin management. This is in line with integrated water resource management which is central to the NWA and ICMA and therefore of relevance to the NESMP. GIS technology is a powerfull tool that can be used to address the integration of various components of water resource management into a single DSS, with a simple understandable interface for resource managers. GIS technology has developed substantially over the past two decades, but still requires human resources with the necessary technical skills to operate these systems. However, most government departments, municipalities and NGOs have GIS sections that focus on the use of this technology, as it is critical for management and planning purposes.

Andreu et al. (1996) discussed the use of the AQUATOOL DSS that was developed to be used during the planning stage of decision making within complex river basins in Spain. This DSS was later developed to include modules for operational stage decision making. To ensure the successful planning and operational management of complex systems, it is essential that the most advanced tools available are used. There is however an unavoidable gap between state of the art water resource systems analysis and usage by practisioners under real world conditions. Andreu et al., (1996) concluded that recent improvements in hardware and software allow the creation and easy use of computer-based DSS, which are the best if not the only means of dealing successfully with complex water-resource systems. As a result of the development and implementation of AQUATOOL a number of prerequisites to ensure the successful use of a DSS have been identified. This is 1) a need for effective communication between the DSS developers and the technicians who will use it in practise and the guarantees that the final product will address the real problems; 2) Adopting an approach which does not try to solve all the problems at once, but progresses from simple questions to more complex ones. In this way, the development of tools in the DSS responds to the priorities of the final users, rather than becoming an academic exercise; and 3) Comprehensive documentation of the developed tools must be available. This includes an overarching user's manuals for the DSS and for each mathematical model separately. Technical manuals and worked examples are also central to understanding and implementation of the DSS.

The Water Ware DSS was developed as an easy to use DSS for river-basin planning (Jamieson and Fedra, 1996) for use by government agencies and river-basin commissions. This DSS integrated GIS, database technology, modelling, optimisation and expert systems. The aim of this system was to integrate complex information into a system that produces robust scientific based answers. Water resource management in South Africa is taking place in a similar complex environment with similar challenges. During the design of the Water Ware DSS, emphasis was placed on the importance of a DSS being both comprehensive and easy to use, with all the complexity being hidden from the user. Although flexibility demands greater user awareness, this was compensated by user-support facilities in the form of embedded expert systems to help quantify input variables and hypertext guides to assist progress. WaterWare required detailed set up of the catchment based models used in the DSS in order for it to be useable. Although this required effort, the benefits of adopting a comprehensive, integrated approach to river-basin planning (catchment based in the South African context) rather than considering the basin in a fragmented, piecemeal fashion, far outweigh the initial investment (Jamieson and Fedra, 1996). This integrated approach is also the departure point for catchment management in South Africa, although the implementation is in its initial phase with the establishment of only two CMA's. The rest of the CMA's are in the process of being established through establishment of proto-CMA's.

Dunn et al. (1996) indicated that the NELUP DSS has been developed to quantify what the main economic and environmental impacts are of rural land-use changes at a river basin scale in the United Kingdom. This mathematically complex system integrates different models of economics, ecology and hydrology with relational and spatial databases. The NELUP DSS consists of a regional component (NUARNO) and a local component (SHETRAN). This supports local evaluation within a larger catchment wide assessment, which is also the premise of the NESMP. This results in a system that allows interactive evaluation of different future scenarios, through a graphics interface. Due to the complexity of the problem, a multi-disciplinary team was responsible for the development of this DSS. These multi-disciplinary teams are critical for the development of a complex DSS, and in the South African context are dependent on a small pool of experts, specifically for estuaries.

Similarly, the MULINO DSS has been developed for the implementation of the EU Water Framework Directive (Giuponni, 2007). This DSS integrate environmental, social and economic concerns, making use of the DPSIR (Driver, Pressure, State, Impact and Response) process. The application of this tool for use with real world management problems was evaluated through feedback by project partners and external and internal end users. Feedback on the NESMP DSS will also be required and is aligned with the re-evaluation of the NESMP through SAM. The lack of this feedback on the implementation and associated refinement of a DSS was indicated as the reason why many DSS fail (Giuponni, 2007). This study also found that although a feedback process was in place for users of the DSS, very few responded. In addition it was indicated that the MULINO DSS was used mainly by academic institutions and not by the target users, namely competent authorities. This is also a potential reality in South Africa as databases and DSS generally are not used in the long-term by government departments, due to a lack of capacity and staff turnover resulting in a loss of consistency in the use of these management tools. The success of the MULINO DSS were evaluated based on: 1) The DSS development process – were future users involved in the design, was the system requirements and beneficiaries identified?; 2) DSS components – were the relevant components included, model precision, were suitable technologies identified for data management?; 3) Decision process – was a logical process followed when using the DSS, is internal communication adequate, are alternatives explored? 4) Decision outputs – is there profit or loss from the use of the DSS, was consensus reached amongst roleplayers, is there consistency in the solutions?; and 5) User satisfaction – was there confidence in the results obtained from the DSS, is there acceptance of these results, correspondence with respect to the DSS and continual use, capacity building and understanding of the models and DSS? Similar indicators will facilitate the evaluation of the success of the NESMP DSS. The final success of the DSS will be measured by the continual use of the DSS by relevant management authorities.

It was concluded by Giuponni (2007) that there is a need for methodologies and tools to put IWRM principles into practice. The ongoing implementation of the WFD throughout Europe has given momentum to this need. Various methods and tools, such as modelling, environmental impact assessment and DSS have been shown to provide sound insights into the problems to be addressed. In an assessment by Giuponni (2007) of the use of the MULINO DSS in the implementation of the WFD, it was concluded that a methodological approach and DSS tool can contribute towards coping with the general problem of IWRM implementation. In the case of the WFD, in particular this would be facilitated by supporting: 1) the integration of different disciplinary approaches and models; 2) the management of the complexity of decision contexts typical of IWRM; 3) the management of large amounts of multi-sector and multi-disciplinary information; 4) the communication between the scientific and policy sectors, and between decision makers and stakeholders; 5) the implementation of the preferences of the various actors involved in the planning process.

Jamieson and Fedra (1996) discussed the need for DSS that integrate various components of water resources management including water pollution, water yield, groundwater contamination to address integrated water resource management. The NESMP DSS is one component that should to be incorporated into a larger DSS for estuary and eventually catchment management.

Decision Support Systems have been developed and are used widely in the environmental management field, addressing specific problems, but generally have a fixed structure or a defined set of data processing and model connection pathways (Argent et al., 2008). Different disciplines use different modelling techniques and models to address their specific needs. This creates problems when component models need to be changed or model operation need to be adjusted to meet the needs of new situations. This is especially of relevance in the South African capacity context due to the limited expertise in water resource modelling and associated DSS. This use of modelling and associated DSS development in South African estuary management is also hampered by the limited long-term data available on the basic biotic and abiotic components of the estuaries in South Africa. The basic premise of the NESMP DSS is therefore to be a non-static system, which evolves as new data and information becomes available through the implementation of the NESMP, relevant projects and social learning. This evolution should take place through continual updating and refinement of individual components within the DSS.

Decision Support Systems are used on various scales from strategic catchment planning, incorporating socio-economic and financial components to site specific scientific DSS. Decision Support Systems can incorporate various technological developments including GIS interfaces, databases and expert systems, to derive a practical solution to water resource management challenges. The interface should however be fairly simple to ensure ease of use, with the complex data analysis and integration components being hidden from the user. Finally, it is crucial that the design of any DSS should be critically evaluated by the users with feedback to the developers to refine and adjust the DSS as needed.

5.4.2 Design of NESMP DSS

The data and information to be generated by the NEMSP lends itself to incorporation into a DSS. The foundation of a DSS consists of three layers, as described by Argent et al. (2008) and indicated in Table 17. The specific DSS allows the manager to search, explore and experiment with the problem area, estuarine health in this case. It is the prerogative of the user to cluster multiple sampling results (per quarter, season or year) together, or use data for each sampling survey individually. By doing this the results can be viewed in different temporal resolutions, depending on the question being asked. With time, as changes occur in a task (estuarine water quality management), the environment (the bio-physical confines of a specific estuary) and the users (DWS and other stakeholders) behaviour, the specific DSS will accommodate these changes. These changes are facilitated through the generation of more monitoring data and information by the NESMP. This results in the reconfiguration of the elements in the DSS with the aid of the DSS builder or "toolsmith" (Figure 50).

Table 17 Contextualisation of the NESMP data, information and actions within the principle components of a DSS as described in Argent et al. (2008).

DSS COMPONENT (According to Argent et al. 2008).	NESMP DSS COMPONENT	ACTION	OUTCOME
Data input and output	Data sheet	Capturing raw data (biotic and abiotic) into DSS	1) Data archiving 2) Data presentation – temporal and spatial scale
Modelling engine	Results sheet	Data analysis with DSS	1) Set, evaluate and refine TPCs if not available 2) Evaluation of monitoring data in terms of TPCs
User interface layer / dialogue manager	Intervention sheet	Evaluate results from data analysis.	1) Provide descriptive management actions

The NESMP DSS focuses only on the operational stage of estuary management (monitoring in this case), as it is assumed that the larger catchment focussed planning has taken place during the EWR studies, the setting of resource quality objectives (RQO's) and associated thresholds of potential concern (TPCs). However in certain instances, no RQO's with associated TPCs have been set. In order to ensure consistency in the use of the NESMP data to inform management decisions, the setting of interim TPCs is an additional function of the DSS. The setting of interim water quality TPCs is based on the 10th and 90th percentile calculation, which is a generally used method of evaluating water quality data in South Africa. This is in line with a precautionary approach to water resource management to support the maintenance of natural ecosystems in South Africa. In certain countries, including the USA, where water resources have been degraded substantially with limited scope for rehabilitation, the approach is more practical towards the status quo. Water resources are managed in terms of what can be achieved, given the degraded state. In these instances the 20th and 80th, even up to the 50^{th} percentile are used to evaluate water quality. These 10th and 90th interim TPCs can then be used as a departure point for the setting and gazetting of TPCs as part of the RQO studies (Figure 48). Therefore, a constant exchange of data and information takes place between the NESMP and the classification studies through the NESMP DSS (Figure 48).

The NESMP DSS consists of a series of five colour coded worksheets organised into different modules (Figure 51 and Table 18). A combination of these worksheets together, forms the different modules that address specific aspects of the data that are collected (Figure 51).

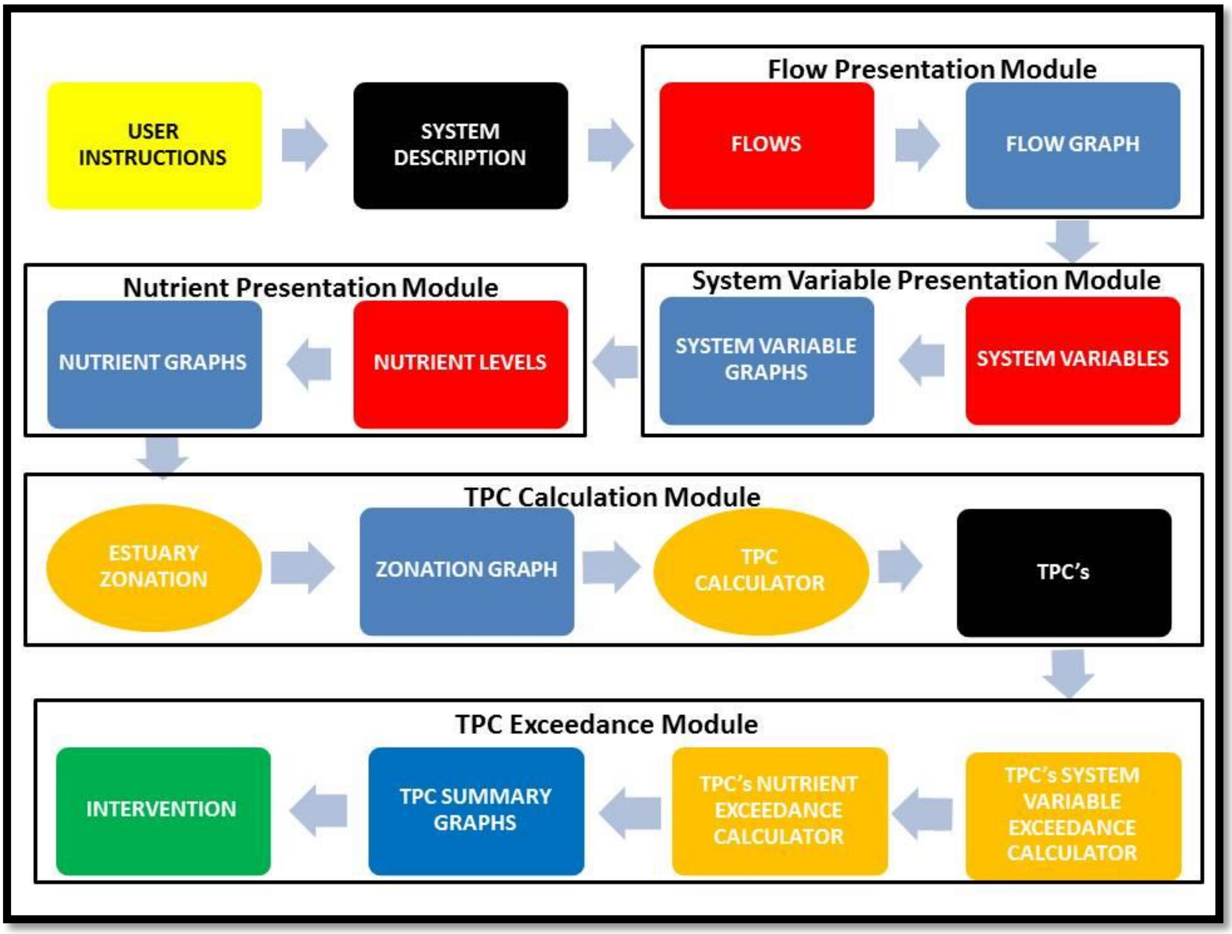


Figure 51 The different modules and worksheets within the NESMP DSS.

Table 18 Description of the different modules, with their supporting worksheets, colour codes and sheet types within the NESMP DSS.

MODULE	WORKSHEET	COLOUR	SHEET TYPE
	User Instructions	Yellow	Information Sheet
	System Description	Black	Descriptive Sheet
FLOW PRESENTATION MODULE	Flows	Red	Data Sheet
	Flow Graph	Blue	Result Sheets
SYSTEM VARIABLE PRESENTATION MODULE	System Variables	Red	Data Sheet
	System Variable Graph (SVddmmyy)	Blue	Result Sheets
NUTRIENT PRESENTATION MODULE	Nutrients	Red	Data Sheet
	Nutrient Graph (Nddmmyy)	Blue	Result Sheets
TPC CALCULATION MODULE	Estuary Zonation Salinity	Orange	Result Sheets
	Estuary Zonation Graph	Blue	Result Sheets
	TPC SV Calc High and Low Flow	Orange	Result Sheets
	TPC Nutr Calc Estuary High & Low flow	Orange	Result Sheets
	TPC Nutr Calc River	Orange	Result Sheets
	TPCs	Black	Descriptive Sheet
TPC EXCEEDANCE MODULE	TPC Exc Calc SV	Orange	Result Sheets
	TPC Exc Calc Nutr	Orange	Result Sheets
	TPCs Sum Graph	Blue	Result Sheets
	Intervention	Green	Intervention Sheet

Information sheet

This sheet provides guidance to the user for the use of the DSS and is coloured yellow.

Descriptive Sheet

The descriptive sheets are black and provide a description of 1) the system and 2) the TPCs. They therefore inform the user and the models that are subsequently used for the

Exceedance of TPCs calculations. The information in these sheets is semi-fixed, with the data that is populated in this sheet describing components of the system that will not change regularly. The data in these sheets form part of the foundation against which the different modules are run. The TPC sheet is also a descriptive sheet where the TPC that have been set in relevant RQO studies are summarised and used as input into subsequent TPC Exceedance module. In cases where TPC do not exist, the TPC are explicitly described, based on the results from the TPC Calculation Module (Figure 51).

Data Sheet

The Data sheets are coloured red and act as the depository for the data collected through the NESMP. The data are used for running the different models which feed into the Results and Intervention sheets. The data sheets ensure that the data are archived with DWS, through a submission cycle of the DSS for each estuary to DWS. The data sheets not only act as a data archive for input into the WMS database of DWS, but are also used for the creation of graphs in the Presentation Modules. The data collected through the NESMP need to be cleaned and verified, before they are copied into the sheets. One data input sheet is used for each module. Together the data input sheet and the associated graphs form the different Presentation Modules.

Results Sheet

The results sheets are blue and orange as two types of results emanate from the DSS. The blue sheets provide graphs that are used for data presentation, while the orange sheets are the calculation sheets. The blue sheets form part of the presentation modules and the orange sheets the calculation modules. The calculation sheets assist in determining TPCs or calculate exceedance of TPCs, depending on the iteration that is used. The TPC are calculated based on flows. Low flow conditions are highlighted in the calculation sheets with red, while high flow conditions are highlighted in green. The TPC may have been set already during the Classification study as part of the Resource Quality Objectives component. In these instances this is set as part of the Resource Quality Objectives, which is gazetted in the Government Gazette. As such it has legal standing and used as the official convention for the minimum condition in which an estuary needs to be kept through management intervention. These gazetted TPCs are manually fed into the TPC summary sheet to calculate the percentage exceedance. In cases where the TPCs have not been set yet, the TPCs are set with the use of the 10th and 90th percentile generated from the data collected through the NESMP in the TPC Calculation Module. In the absence of gazetted TPCs, and as long as NESMP data is collected, the TPC can constantly be updated. This information should then also be used in support of setting TPC that is gazetted as part of the Resource Quality Objectives.

Intervention Sheet

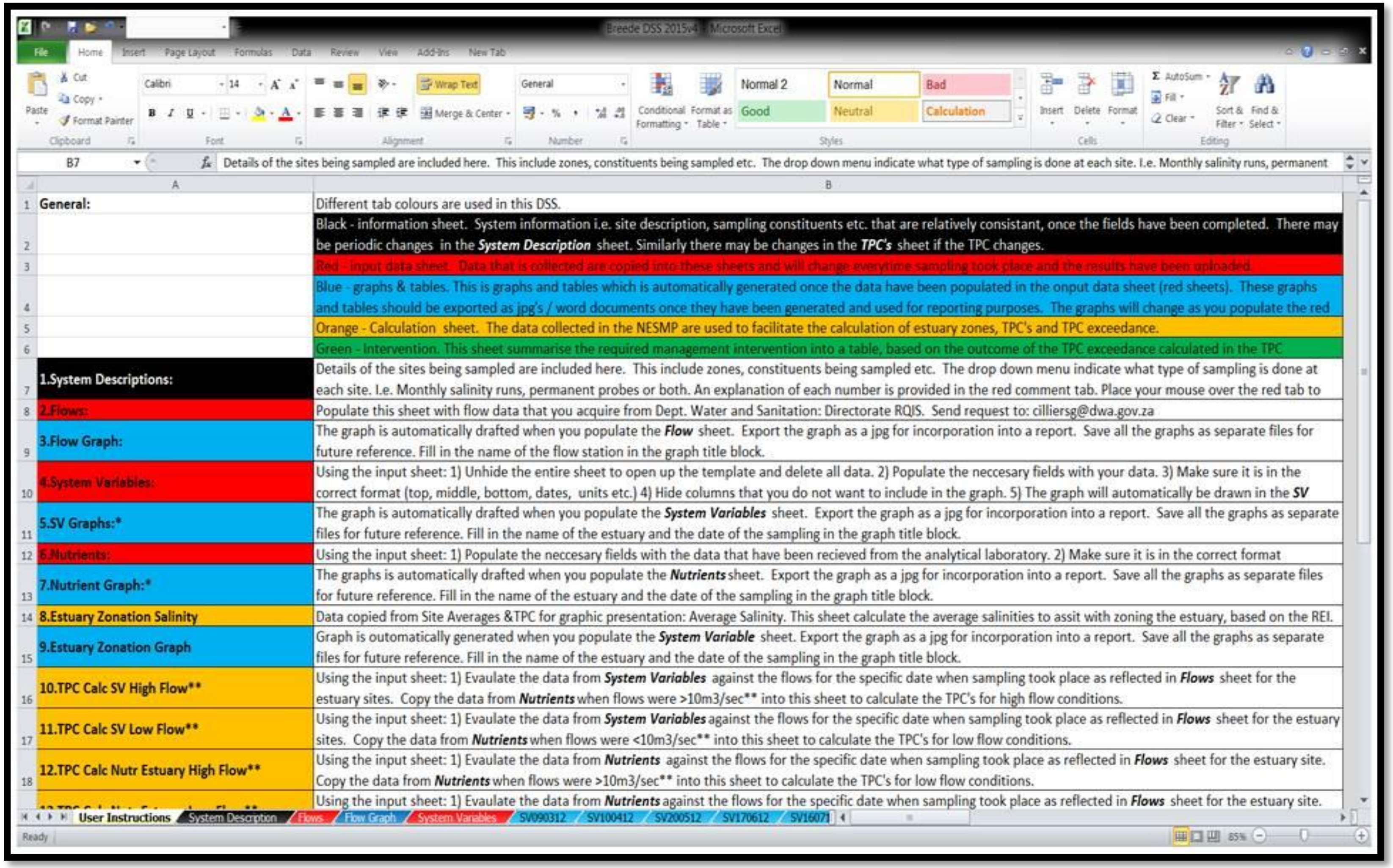
The intervention sheet is green and provides guidance on management actions that should be taken once the TPCs have been exceeded. The intervention sheet addresses the problem identified in broad terms, providing only guidance on potential sources of the problem, intervention scenarios and contact details of management authorities that are responsible for specific aspects that need to be addressed. The interventions proposed should also be revisited periodically by the programme manager, in consultation with experts on a particular system. This will ensure more relevant intervention, as more knowledge of the system becomes available. The interventions are automatically highlighted once the TPCs are exceeded. The nature of the problem may require detailed knowledge of the system. In these instances the interventions should be specific and based on expert opinion of scientists and resource managers with knowledge of the catchment.

5.5. CASE STUDY: BREEDE ESTUARY

A case study on how the NESMP DSS is used to determine the TPCs and the exceedance of these TPCs for the Breede Estuary, based on the 2012 to 2015 NESMP data follow below. The case study discusses each worksheet within the NESMP DSS. Narrative on the use of the different worksheets is included. This case study focuses on high flow and low flow conditions for oxygen concentration and SRP as examples of system variable and nutrient data. This case study illustrates the entire process from data capture through calculating TPCs to identifying management intervention through the use of the NESMP DSS.

5.5.1. User Instructions

This is a summary of how to use the NESMP DSS and each of the worksheets (Figure 52). The user instructions are therefore embedded in the DSS to facilitate quick referencing when using the DSS. This sheet is protected and therefore cannot be changed by the user. Changes to this sheet will only take place if the operation and use of the DSS changes and will be done by the DSS builder.



	A	B
1	**General:**	Different tab colours are used in this DSS.
2		Black - information sheet. System information i.e. site description, sampling constituents etc. that are relatively consistant, once the fields have been completed. There may be periodic changes in the ***System Description*** sheet. Similarly there may be changes in the ***TPC's*** sheet if the TPC changes.
3		Red - input data sheet. Data that is collected are copied into these sheets and will change everytime sampling took place and the results have been uploaded.
4		Blue - graphs & tables. This is graphs and tables which is automatically generated once the data have been populated in the onput data sheet (red sheets). These graphs and tables should be exported as jpg's / word documents once they have been generated and used for reporting purposes. The graphs will change as you populate the red
5		Orange - Calculation sheet. The data collected in the NESMP are used to facilitate the calculation of estuary zones, TPC's and TPC exceedance.
6		Green - Intervention. This sheet summarise the required management intervention into a table, based on the outcome of the TPC exceedance calculated in the TPC
7	1.System Descriptions:	Details of the sites being sampled are included here. This include zones, constituents being sampled etc. The drop down menu indicate what type of sampling is done at each site. I.e. Monthly salinity runs, permanent probes or both. An explanation of each number is provided in the red comment tab. Place your mouse over the red tab to
8	2.Flows:	Populate this sheet with flow data that you acquire from Dept. Water and Sanitation: Directorate RQIS. Send request to: cilliersg@dwa.gov.za
9	3.Flow Graph:	The graph is automatically drafted when you populate the ***Flow*** sheet. Export the graph as a jpg for incorporation into a report. Save all the graphs as separate files for future reference. Fill in the name of the flow station in the graph title block.
10	4.System Variables:	Using the input sheet: 1) Unhide the entire sheet to open up the template and delete all data. 2) Populate the neccesary fields with your data. 3) Make sure it is in the correct format (top, middle, bottom, dates, units etc.) 4) Hide columns that you do not want to include in the graph. 5) The graph will automatically be drawn in the ***SV***
11	5.SV Graphs:*	The graph is automatically drafted when you populate the ***System Variables*** sheet. Export the graph as a jpg for incorporation into a report. Save all the graphs as separate files for future reference. Fill in the name of the estuary and the date of the sampling in the graph title block.
12	6.Nutrients:	Using the input sheet: 1) Populate the neccesary fields with the data that have been recieved from the analytical laboratory. 2) Make sure it is in the correct format
13	7.Nutrient Graph:*	The graphs is automatically drafted when you populate the ***Nutrients*** sheet. Export the graph as a jpg for incorporation into a report. Save all the graphs as separate files for future reference. Fill in the name of the estuary and the date of the sampling in the graph title block.
14	8.Estuary Zonation Salinity	Data copied from Site Averages &TPC for graphic presentation: Average Salinity. This sheet calculate the average salinities to assit with zoning the estuary, based on the REI.
15	9.Estuary Zonation Graph	Graph is outomatically generated when you populate the ***System Variable*** sheet. Export the graph as a jpg for incorporation into a report. Save all the graphs as separate files for future reference. Fill in the name of the estuary and the date of the sampling in the graph title block.
16	10.TPC Calc SV High Flow**	Using the input sheet: 1) Evaulate the data from ***System Variables*** against the flows for the specific date when sampling took place as reflected in ***Flows*** sheet for the estuary sites. Copy the data from ***Nutrients*** when flows were >10m3/sec** into this sheet to calculate the TPC's for high flow conditions.
17	11.TPC Calc SV Low Flow**	Using the input sheet: 1) Evaulate the data from ***System Variables*** against the flows for the specific date when sampling took place as reflected in ***Flows*** sheet for the estuary sites. Copy the data from ***Nutrients*** when flows were <10m3/sec** into this sheet to calculate the TPC's for low flow conditions.
18	12.TPC Calc Nutr Estuary High Flow**	Using the input sheet: 1) Evaulate the data from ***Nutrients*** against the flows for the specific date when sampling took place as reflected in ***Flows*** sheet for the estuary site. Copy the data from ***Nutrients*** when flows were >10m3/sec** into this sheet to calculate the TPC's for low flow conditions.
19		Using the input sheet: 1) Evaulate the data from ***Nutrients*** against the flows for the specific date when sampling took place as reflected in ***Flows*** sheet for the estuary site.

Figure 52 User Instruction Sheet.

5.5.2 System Description

The System Description Sheet (Figure 53) describes the different sampling sites in the estuary. The information in this sheet includes GPS points, photos, and constituents being sampled at each site. Other relevant environmental conditions to describe the sites may also be included. This sheet can be changed in order to include additional information, new sites and new constituents. Red information tabs are included in this sheet to explain the codes that describe specific aspects at each site.

*5.5.3 **Flow Presentation Module (FPM)***

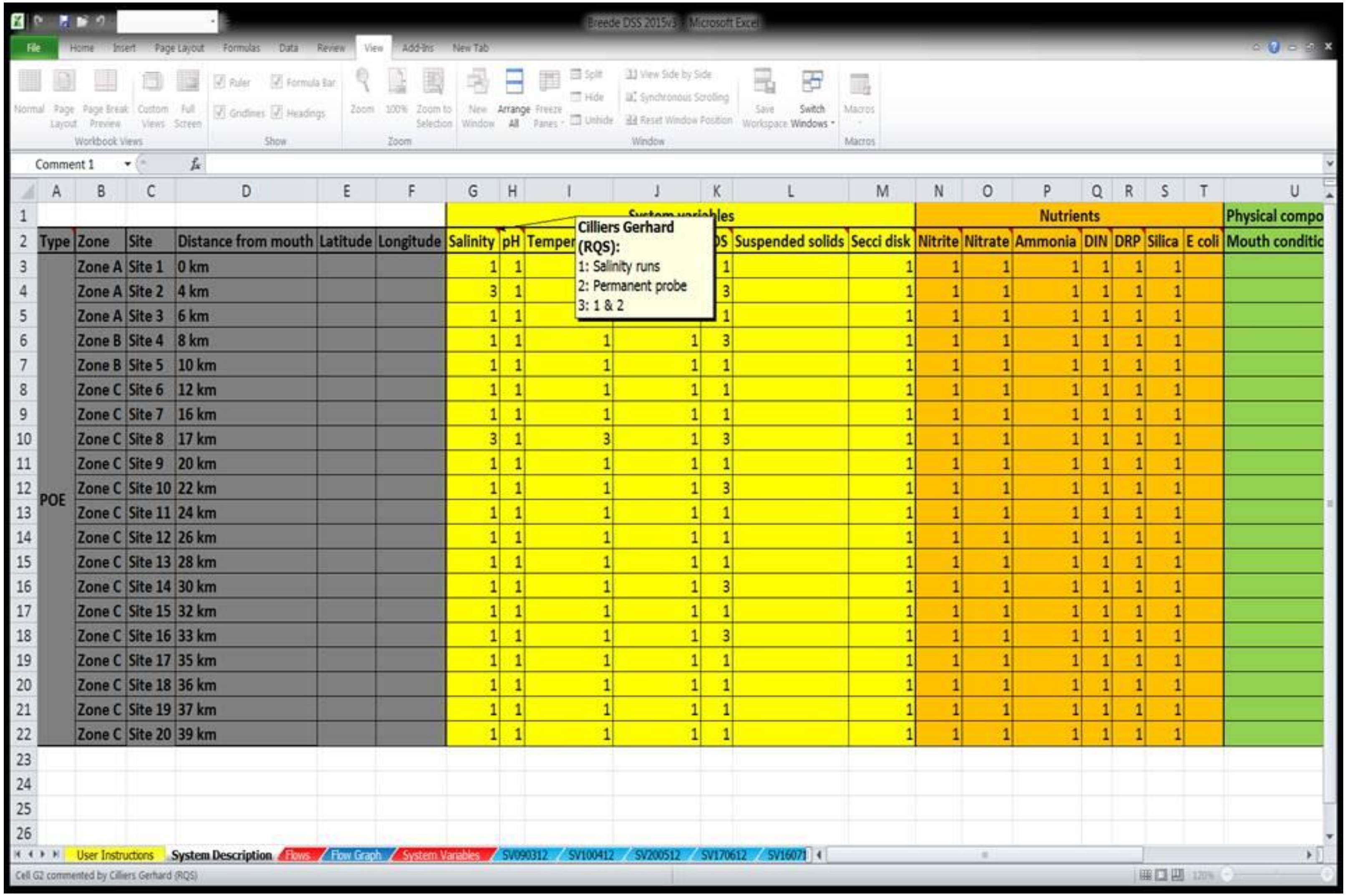
The Flow Presentation Module (FPM) graphically presents the flow data that have been extracted from the HYDSTRA database of DWS for the period under investigation. The HYDSTRA data are extracted and copied into the FPM input sheet (Figure 54) in column B. A graph is automatically generated (Figure 55). The heading of the graph should be changed manually on each graph. The resulting flow graph is used for assistance with the interpretation of other data and should be copied and saved as a JPG or PNG for use in reports.

5.5.4 System Variable Presentation Module (SVPM)

The System Variable Presentation Module (SVPM) graphically presents the system variables that have been collected through the NESMP for the period under investigation. The data is copied into the SVPM input sheet (Figure 56) and automatically graphically presented (Figure 57). The TPCs are also inserted into the relevant column for graphic comparison with the observed data. The heading of the graph should be changed manually on each graph. The resulting system variable graph is used for assistance with the interpretation of data and should be copied and saved as a JPG or PNG for use in reports.

5.5.5 Nutrient Presentation Module (NVPM)

The Nutrient Presentation Module (NPM) graphically presents the nutrient data of the samples that have been collected and analysed through the NESMP for the period under investigation. The data is copied into the NPM input sheet (Figure 58) and automatically graphically presented (Figure 59). The TPCs are also inserted into the relevant column for comparison with the observed data. The heading of the graph should be changed manually on each graph. The resulting nutrient graph is used for assistance with the interpretation of data and should be copied and saved as a JPG or PNG for use in reports.



	System variables							Nutrients							Physical compo
Type	Zone	Site	Distance from mouth	Latitude	Longitude	Salinity	pH	Temper		DS	Suspended solids	Secci disk	Nitrite	Nitrate	Ammonia	DIN	DRP	Silica	E coli	Mouth conditic
POE	Zone A	Site 1	0 km			1	1			1		1	1	1	1	1	1	1		
	Zone A	Site 2	4 km			3	1			3		1	1	1	1	1	1	1		
	Zone A	Site 3	6 km			1	1			1		1	1	1	1	1	1	1		
	Zone B	Site 4	8 km			1	1	1	1	3		1	1	1	1	1	1	1		
	Zone B	Site 5	10 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 6	12 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 7	16 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 8	17 km			3	1	3	1	3		1	1	1	1	1	1	1		
	Zone C	Site 9	20 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 10	22 km			1	1	1	1	3		1	1	1	1	1	1	1		
	Zone C	Site 11	24 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 12	26 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 13	28 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 14	30 km			1	1	1	1	3		1	1	1	1	1	1	1		
	Zone C	Site 15	32 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 16	33 km			1	1	1	1	3		1	1	1	1	1	1	1		
	Zone C	Site 17	35 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 18	36 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 19	37 km			1	1	1	1	1		1	1	1	1	1	1	1		
	Zone C	Site 20	39 km			1	1	1	1	1		1	1	1	1	1	1	1		

Figure 53 System Description Sheet with red tabs explaining the information codes being used.

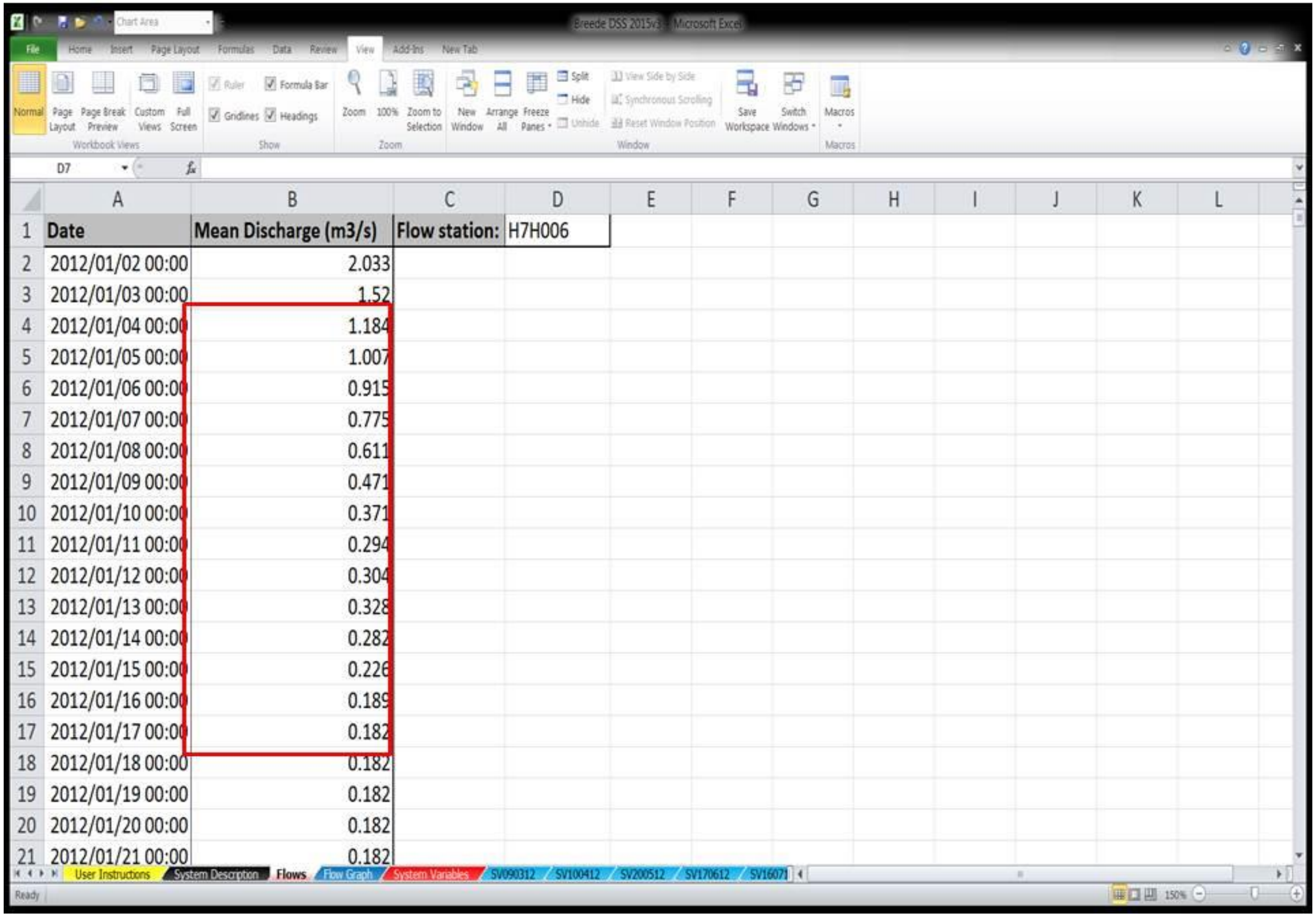


Figure 54 Flow Sheet with copied HYDSTRA data indicated with red box.

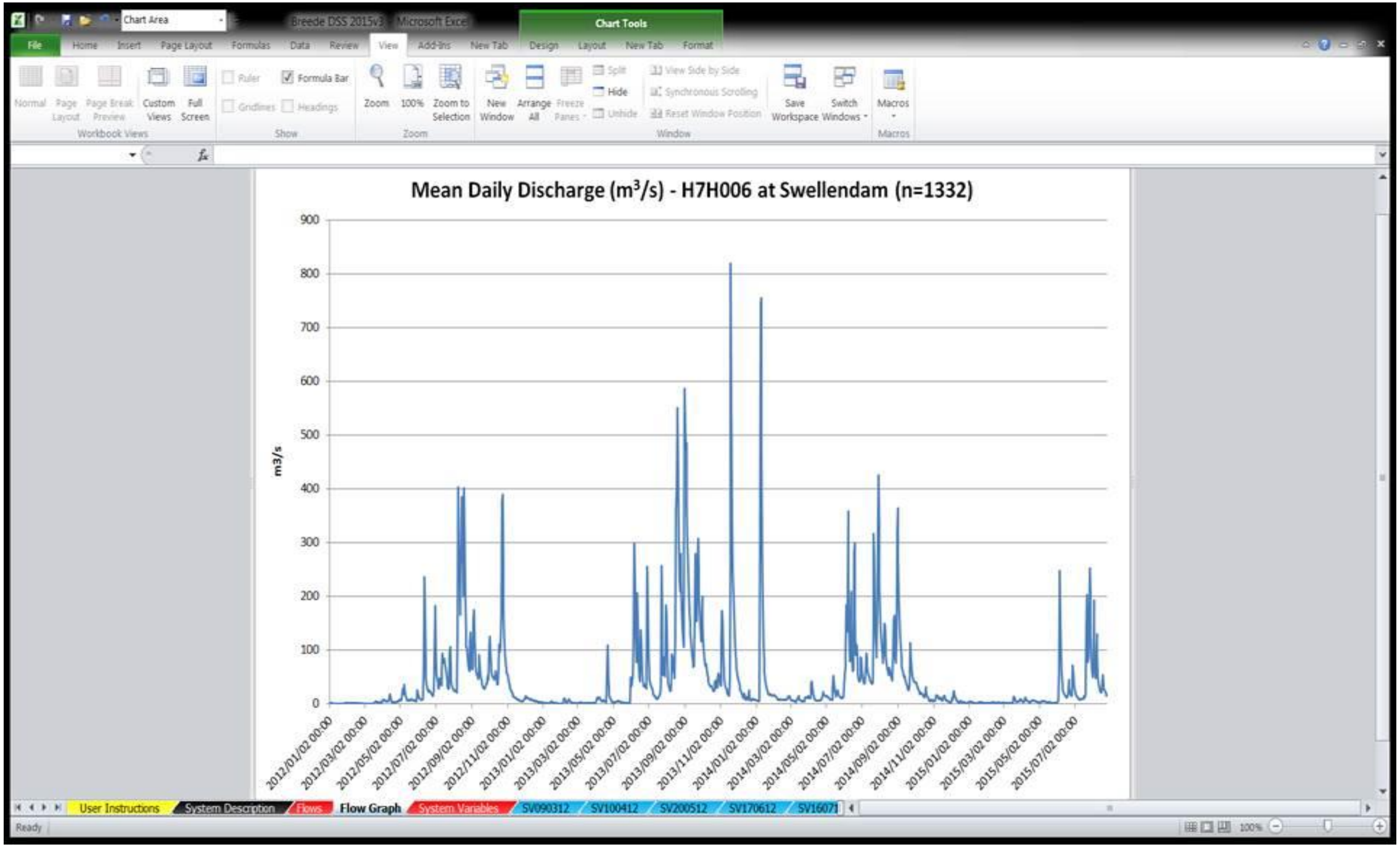
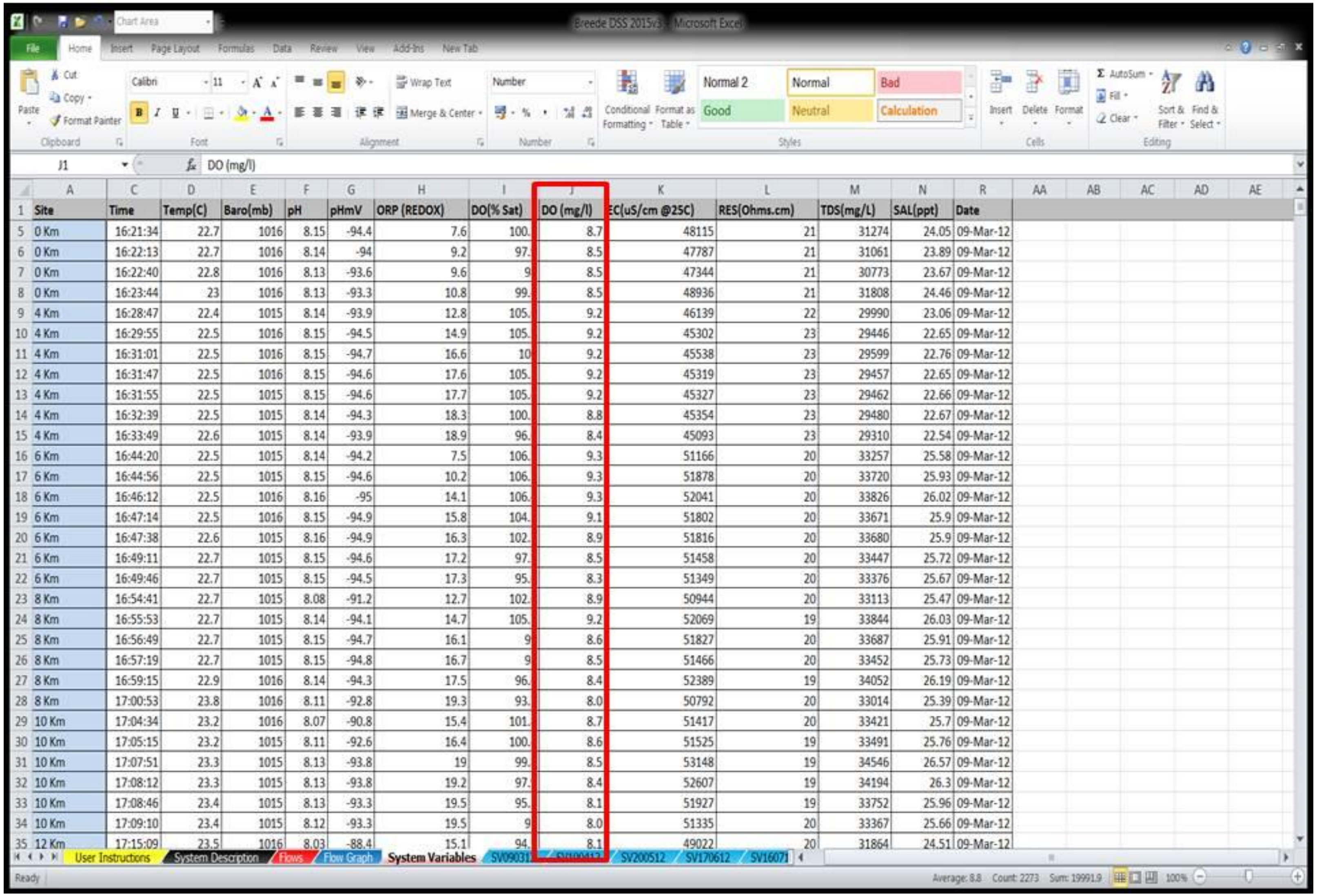


Figure 55 Flow graph emanating from the flow sheet.



	Site	Time	Temp(C)	Baro(mb)	pH	pHmV	ORP (REDOX)	DO(% Sat)	DO (mg/l)	EC(uS/cm @25C)	RES(Ohms.cm)	TDS(mg/L)	SAL(ppt)	Date
5	0 Km	16:21:34	22.7	1016	8.15	-94.4	7.6	100.	8.7	48115	21	31274	24.05	09-Mar-12
6	0 Km	16:22:13	22.7	1016	8.14	-94	9.2	97.	8.5	47787	21	31061	23.89	09-Mar-12
7	0 Km	16:22:40	22.8	1016	8.13	-93.6	9.6	9	8.5	47344	21	30773	23.67	09-Mar-12
8	0 Km	16:23:44	23	1016	8.13	-93.3	10.8	99.	8.5	48936	21	31808	24.46	09-Mar-12
9	4 Km	16:28:47	22.4	1015	8.14	-93.9	12.8	105.	9.2	46139	22	29990	23.06	09-Mar-12
10	4 Km	16:29:55	22.5	1016	8.15	-94.5	14.9	105.	9.2	45302	23	29446	22.65	09-Mar-12
11	4 Km	16:31:01	22.5	1016	8.15	-94.7	16.6	10	9.2	45538	23	29599	22.76	09-Mar-12
12	4 Km	16:31:47	22.5	1016	8.15	-94.6	17.6	105.	9.2	45319	23	29457	22.65	09-Mar-12
13	4 Km	16:31:55	22.5	1015	8.15	-94.6	17.7	105.	9.2	45327	23	29462	22.66	09-Mar-12
14	4 Km	16:32:39	22.5	1015	8.14	-94.3	18.3	100.	8.8	45354	23	29480	22.67	09-Mar-12
15	4 Km	16:33:49	22.6	1015	8.14	-93.9	18.9	96.	8.4	45093	23	29310	22.54	09-Mar-12
16	6 Km	16:44:20	22.5	1015	8.14	-94.2	7.5	106.	9.3	51166	20	33257	25.58	09-Mar-12
17	6 Km	16:44:56	22.5	1015	8.15	-94.6	10.2	106.	9.3	51878	20	33720	25.93	09-Mar-12
18	6 Km	16:46:12	22.5	1016	8.16	-95	14.1	106.	9.3	52041	20	33826	26.02	09-Mar-12
19	6 Km	16:47:14	22.5	1016	8.15	-94.9	15.8	104.	9.1	51802	20	33671	25.9	09-Mar-12
20	6 Km	16:47:38	22.6	1015	8.16	-94.9	16.3	102.	8.9	51816	20	33680	25.9	09-Mar-12
21	6 Km	16:49:11	22.7	1015	8.15	-94.6	17.2	97.	8.5	51458	20	33447	25.72	09-Mar-12
22	6 Km	16:49:46	22.7	1015	8.15	-94.5	17.3	95.	8.3	51349	20	33376	25.67	09-Mar-12
23	8 Km	16:54:41	22.7	1015	8.08	-91.2	12.7	102.	8.9	50944	20	33113	25.47	09-Mar-12
24	8 Km	16:55:53	22.7	1015	8.14	-94.1	14.7	105.	9.2	52069	19	33844	26.03	09-Mar-12
25	8 Km	16:56:49	22.7	1015	8.15	-94.7	16.1	9	8.6	51827	20	33687	25.91	09-Mar-12
26	8 Km	16:57:19	22.7	1015	8.15	-94.8	16.7	9	8.5	51466	20	33452	25.73	09-Mar-12
27	8 Km	16:59:15	22.9	1016	8.14	-94.3	17.5	96.	8.4	52389	19	34052	26.19	09-Mar-12
28	8 Km	17:00:53	23.8	1016	8.11	-92.8	19.3	93.	8.0	50792	20	33014	25.39	09-Mar-12
29	10 Km	17:04:34	23.2	1016	8.07	-90.8	15.4	101.	8.7	51417	20	33421	25.7	09-Mar-12
30	10 Km	17:05:15	23.2	1015	8.11	-92.6	16.4	100.	8.6	51525	19	33491	25.76	09-Mar-12
31	10 Km	17:07:51	23.3	1015	8.13	-93.8	19	99.	8.5	53148	19	34546	26.57	09-Mar-12
32	10 Km	17:08:12	23.3	1015	8.13	-93.8	19.2	97.	8.4	52607	19	34194	26.3	09-Mar-12
33	10 Km	17:08:46	23.4	1015	8.13	-93.3	19.5	95.	8.1	51927	19	33752	25.96	09-Mar-12
34	10 Km	17:09:10	23.4	1015	8.12	-93.3	19.5	9	8.0	51335	20	33367	25.66	09-Mar-12
35	12 Km	17:15:09	23.5	1016	8.03	-88.4	15.1	94.	8.1	49022	20	31864	24.51	09-Mar-12

Figure 56 System Variable sheet with Dissolved Oxygen highlighted

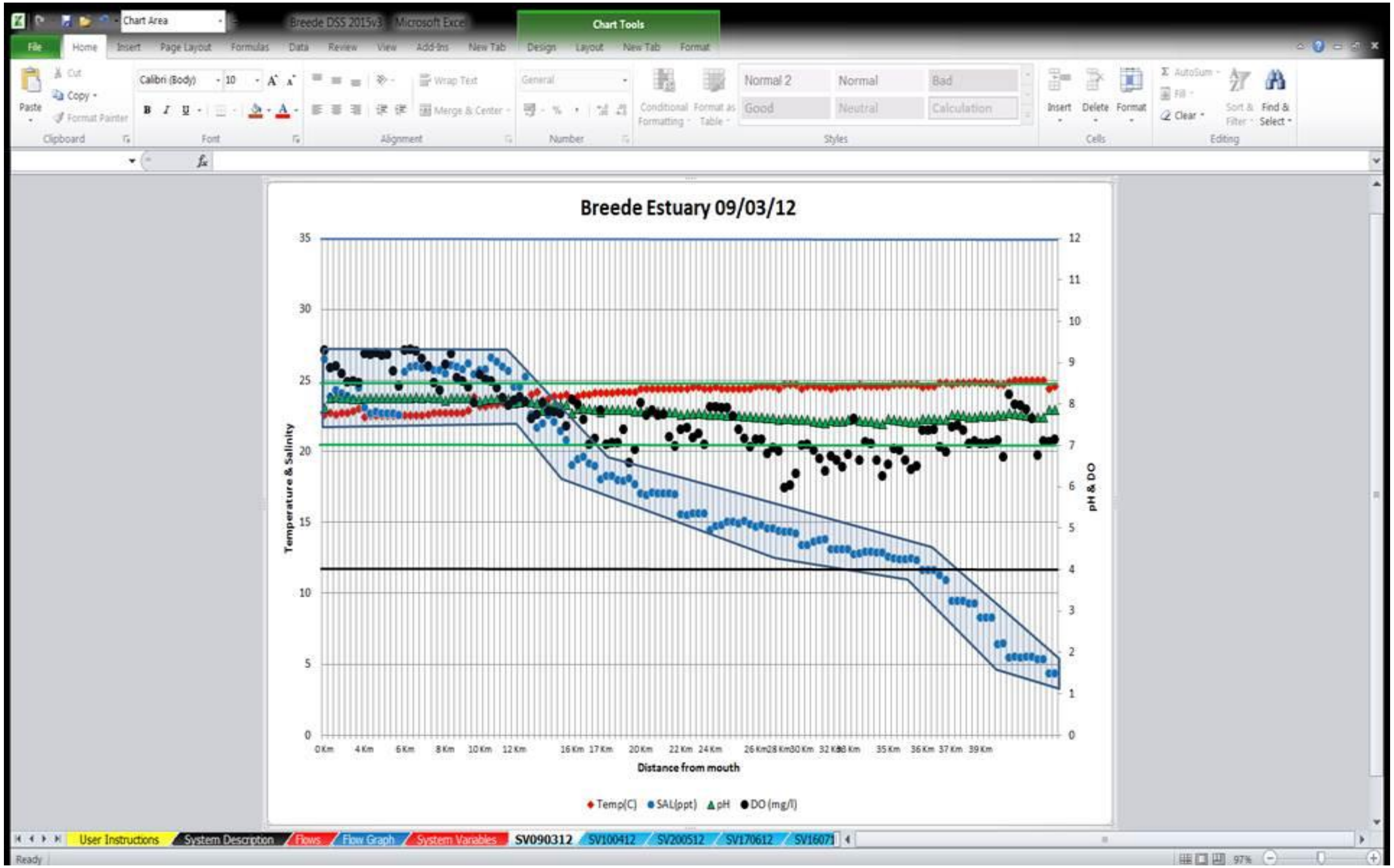
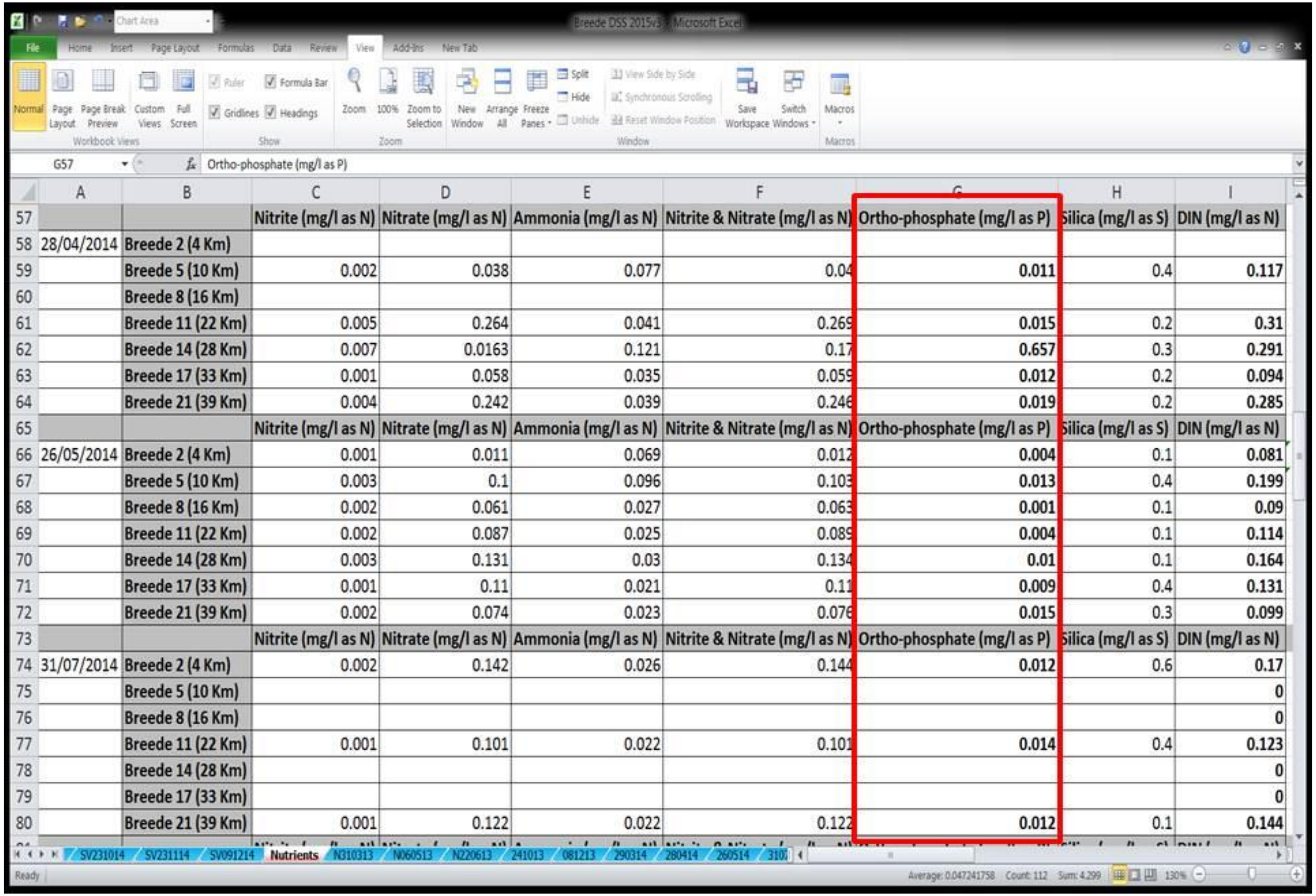


Figure 57 System Variable Graph for Breede Estuary on 09/03/2012



	A	B	C	D	E	F	G	H	I
57			Nitrite (mg/l as N)	Nitrate (mg/l as N)	Ammonia (mg/l as N)	Nitrite & Nitrate (mg/l as N)	Ortho-phosphate (mg/l as P)	Silica (mg/l as S)	DIN (mg/l as N)
58	28/04/2014	Breede 2 (4 Km)							
59		Breede 5 (10 Km)	0.002	0.038	0.077	0.04	0.011	0.4	0.117
60		Breede 8 (16 Km)							
61		Breede 11 (22 Km)	0.005	0.264	0.041	0.269	0.015	0.2	0.31
62		Breede 14 (28 Km)	0.007	0.0163	0.121	0.17	0.657	0.3	0.291
63		Breede 17 (33 Km)	0.001	0.058	0.035	0.059	0.012	0.2	0.094
64		Breede 21 (39 Km)	0.004	0.242	0.039	0.246	0.019	0.2	0.285
65			Nitrite (mg/l as N)	Nitrate (mg/l as N)	Ammonia (mg/l as N)	Nitrite & Nitrate (mg/l as N)	Ortho-phosphate (mg/l as P)	Silica (mg/l as S)	DIN (mg/l as N)
66	26/05/2014	Breede 2 (4 Km)	0.001	0.011	0.069	0.012	0.004	0.1	0.081
67		Breede 5 (10 Km)	0.003	0.1	0.096	0.103	0.013	0.4	0.199
68		Breede 8 (16 Km)	0.002	0.061	0.027	0.063	0.001	0.1	0.09
69		Breede 11 (22 Km)	0.002	0.087	0.025	0.089	0.004	0.1	0.114
70		Breede 14 (28 Km)	0.003	0.131	0.03	0.134	0.01	0.1	0.164
71		Breede 17 (33 Km)	0.001	0.11	0.021	0.11	0.009	0.4	0.131
72		Breede 21 (39 Km)	0.002	0.074	0.023	0.076	0.015	0.3	0.099
73			Nitrite (mg/l as N)	Nitrate (mg/l as N)	Ammonia (mg/l as N)	Nitrite & Nitrate (mg/l as N)	Ortho-phosphate (mg/l as P)	Silica (mg/l as S)	DIN (mg/l as N)
74	31/07/2014	Breede 2 (4 Km)	0.002	0.142	0.026	0.144	0.012	0.6	0.17
75		Breede 5 (10 Km)							0
76		Breede 8 (16 Km)							0
77		Breede 11 (22 Km)	0.001	0.101	0.022	0.101	0.014	0.4	0.123
78		Breede 14 (28 Km)							0
79		Breede 17 (33 Km)							0
80		Breede 21 (39 Km)	0.001	0.122	0.022	0.122	0.012	0.1	0.144

Figure 58 Nutrient sheet with SRP data highlighted.

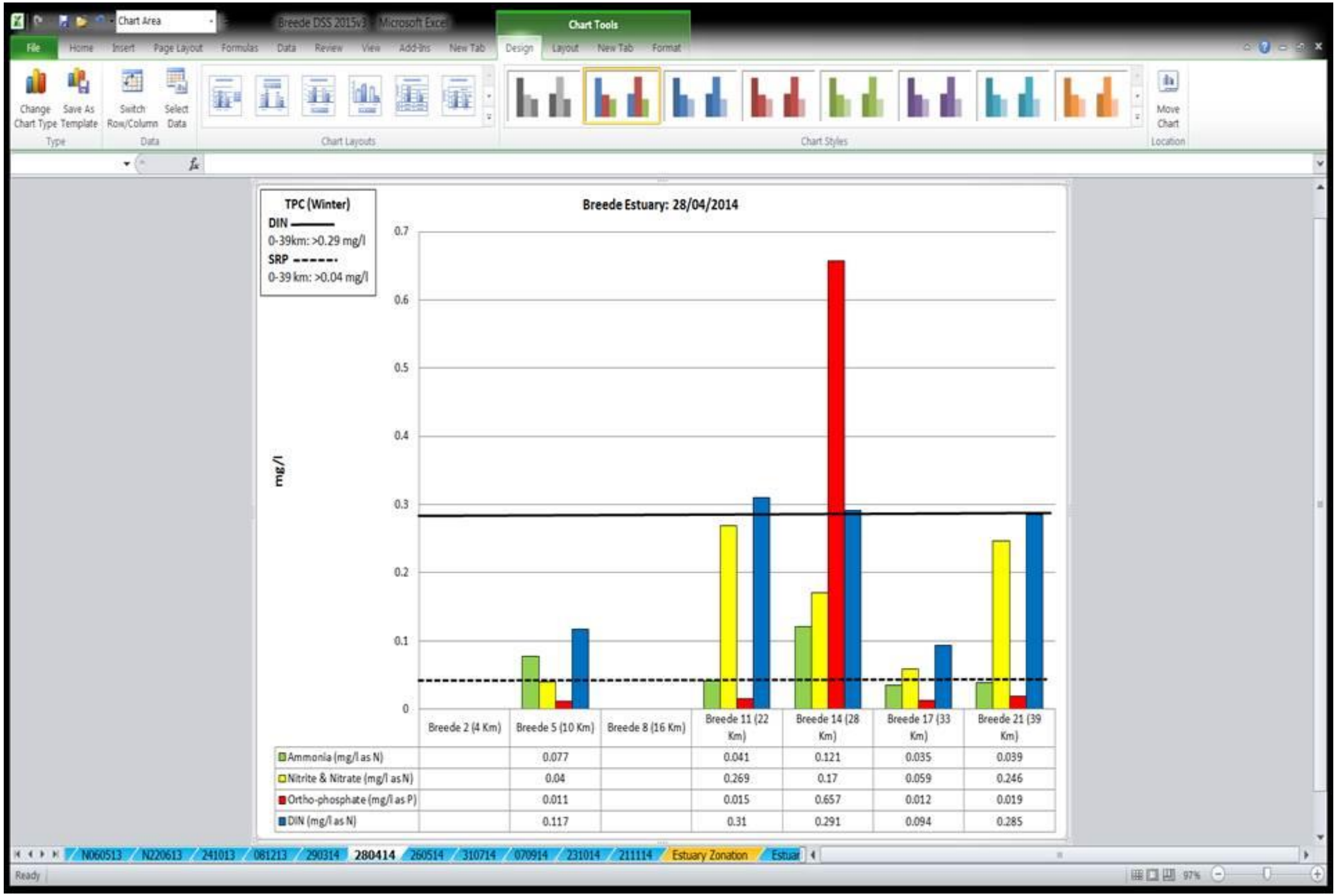


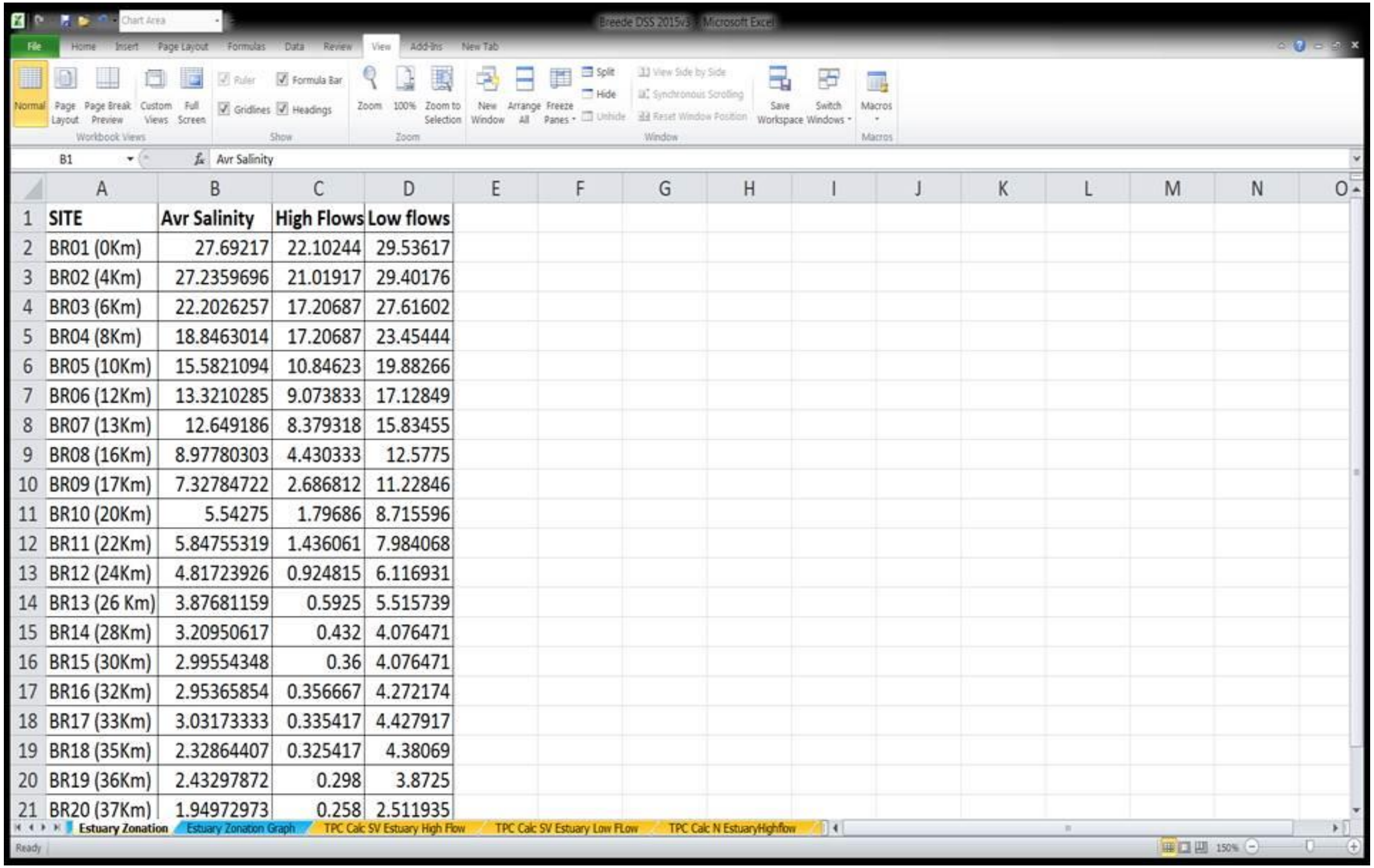
Figure 59 Nutrient Graph for Breede Estuary on 28/04/2014

5.5.6 TPC Calculation Module (TCM)

The TPC Calculation Module (TCM) consists of two components. In order to set TPCs, the estuary needs to be divided into zones based on the main abiotic characteristics. For this purpose the *Estuary Zonation* component is used. Estuary zonation is primarily determined based on the salinity distribution during high and low flow conditions (Figure 60) across the system. The salinity data from each site from the System Variable Presentation Module is used as input into the Estuary Zonation component of this Module. This sheet presents the averages at each site, for high and low flow conditions with the use of the data collected in the NESMP. The results from the Estuary Zonation are graphically presented in the Estuary Zonation Graph (Figure 61) and used for data interpretation and setting of the TPCs with the TPC calculator (Figure 62 to 65). Usually this zonation will also be informed by previous studies and the data from the NESMP. The distribution of different habitats and associated vegetation and geomorphological characteristics should also be used in support of this zonation. The zonation results are used to set the different zones within the different *TPC calculation* sheets (TPC Calc SV Estuary High Flows, TPC Calc SV Estuary Low Flows, TPC Calc N Estuary High Flows and TPC Calc N Estuary Low Flows) as depicted in Figures 62 to 65. The NESMP data are copied into the relevant spreadsheets and then used to calculate the TPC, which is automatically transferred into the TPC description sheet (Figure 66).

5.5.7 TPC Exceedance Module (TEM)

The TPC Exceedance Module (TEM) consists of two components. The *System Variable TPC Exceedance Calculator* (Figure 67) and *Nutrient TPC Exceedance Calculators* (Figure 68) are populated with the relevant NESMP data and relevant TPCs (calculated or already set). In order to calculate the percentage exceedance, the TPCs need to be inserted in the formula cell of the relevant calculator (Figure 69). Once this has been included the TPC exceedance will automatically be calculated and exported to the TPC Sum Graph (Figure 70).



SITE	Avr Salinity	High Flows	Low flows
BR01 (0Km)	27.69217	22.10244	29.53617
BR02 (4Km)	27.2359696	21.01917	29.40176
BR03 (6Km)	22.2026257	17.20687	27.61602
BR04 (8Km)	18.8463014	17.20687	23.45444
BR05 (10Km)	15.5821094	10.84623	19.88266
BR06 (12Km)	13.3210285	9.073833	17.12849
BR07 (13Km)	12.649186	8.379318	15.83455
BR08 (16Km)	8.97780303	4.430333	12.5775
BR09 (17Km)	7.32784722	2.686812	11.22846
BR10 (20Km)	5.54275	1.79686	8.715596
BR11 (22Km)	5.84755319	1.436061	7.984068
BR12 (24Km)	4.81723926	0.924815	6.116931
BR13 (26 Km)	3.87681159	0.5925	5.515739
BR14 (28Km)	3.20950617	0.432	4.076471
BR15 (30Km)	2.99554348	0.36	4.076471
BR16 (32Km)	2.95365854	0.356667	4.272174
BR17 (33Km)	3.03173333	0.335417	4.427917
BR18 (35Km)	2.32864407	0.325417	4.38069
BR19 (36Km)	2.43297872	0.298	3.8725
BR20 (37Km)	1.94972973	0.258	2.511935

Figure 60 Average salinity during high and low flows used for determining the REI and estuary zonation.

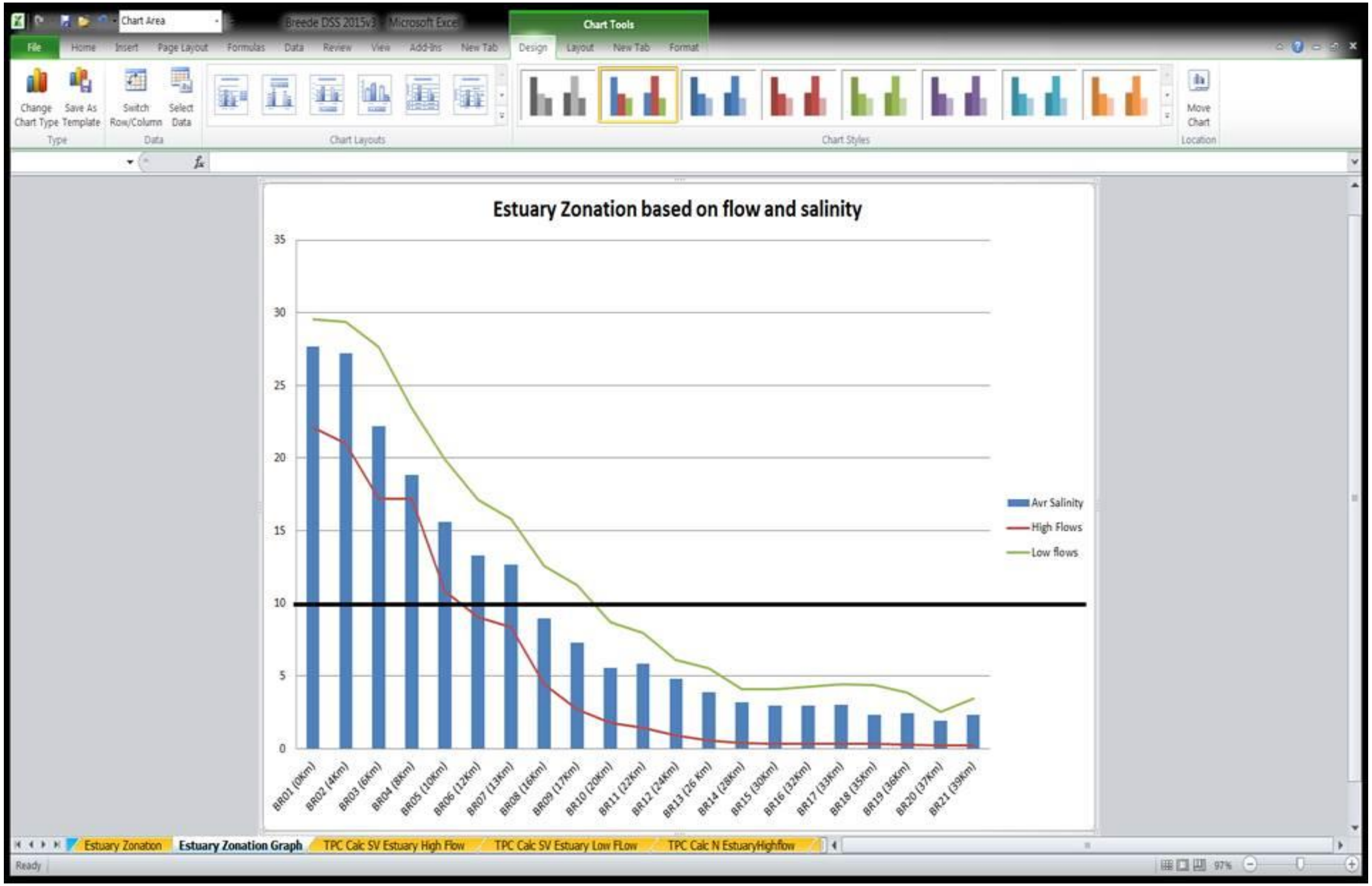
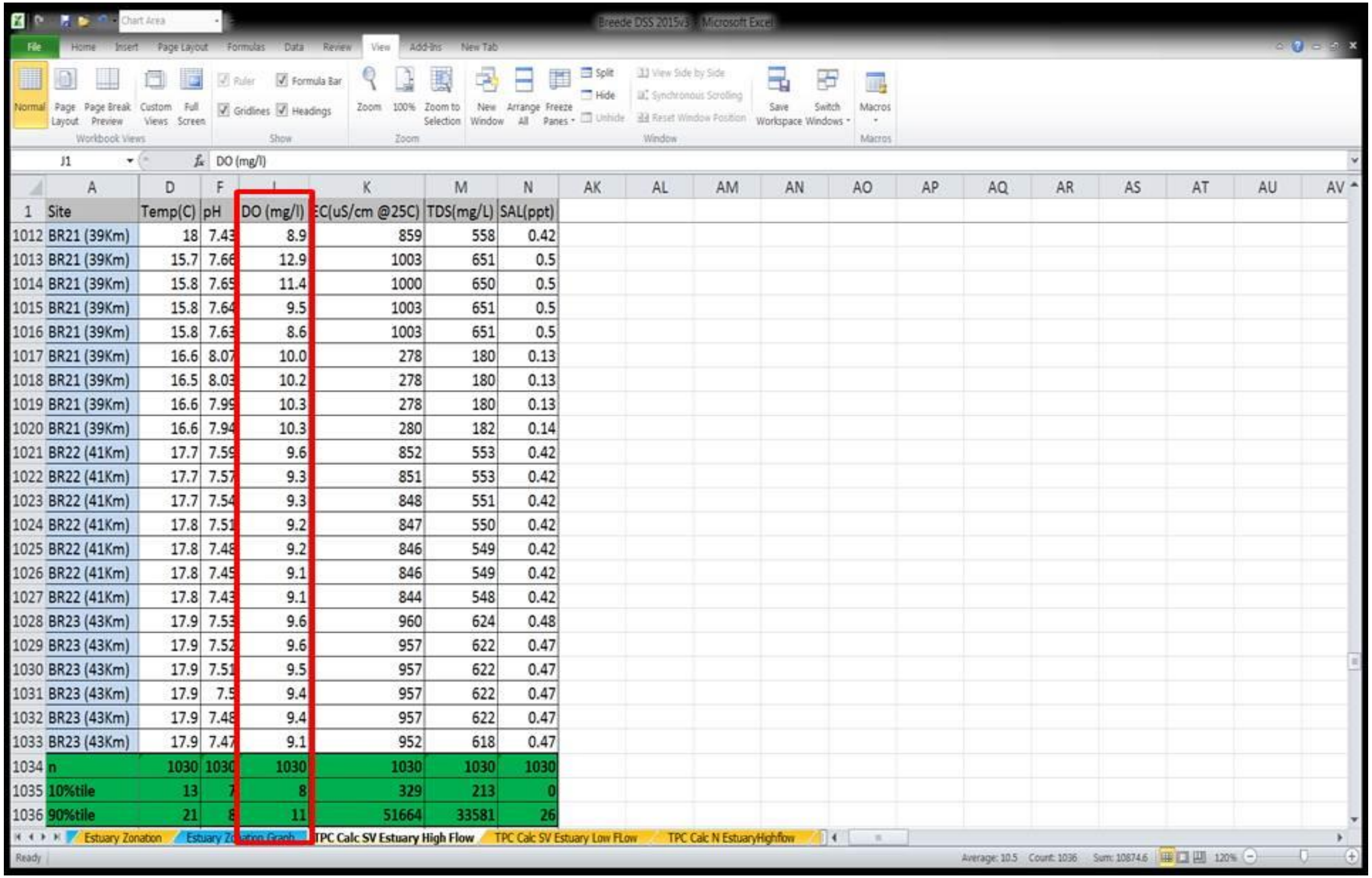
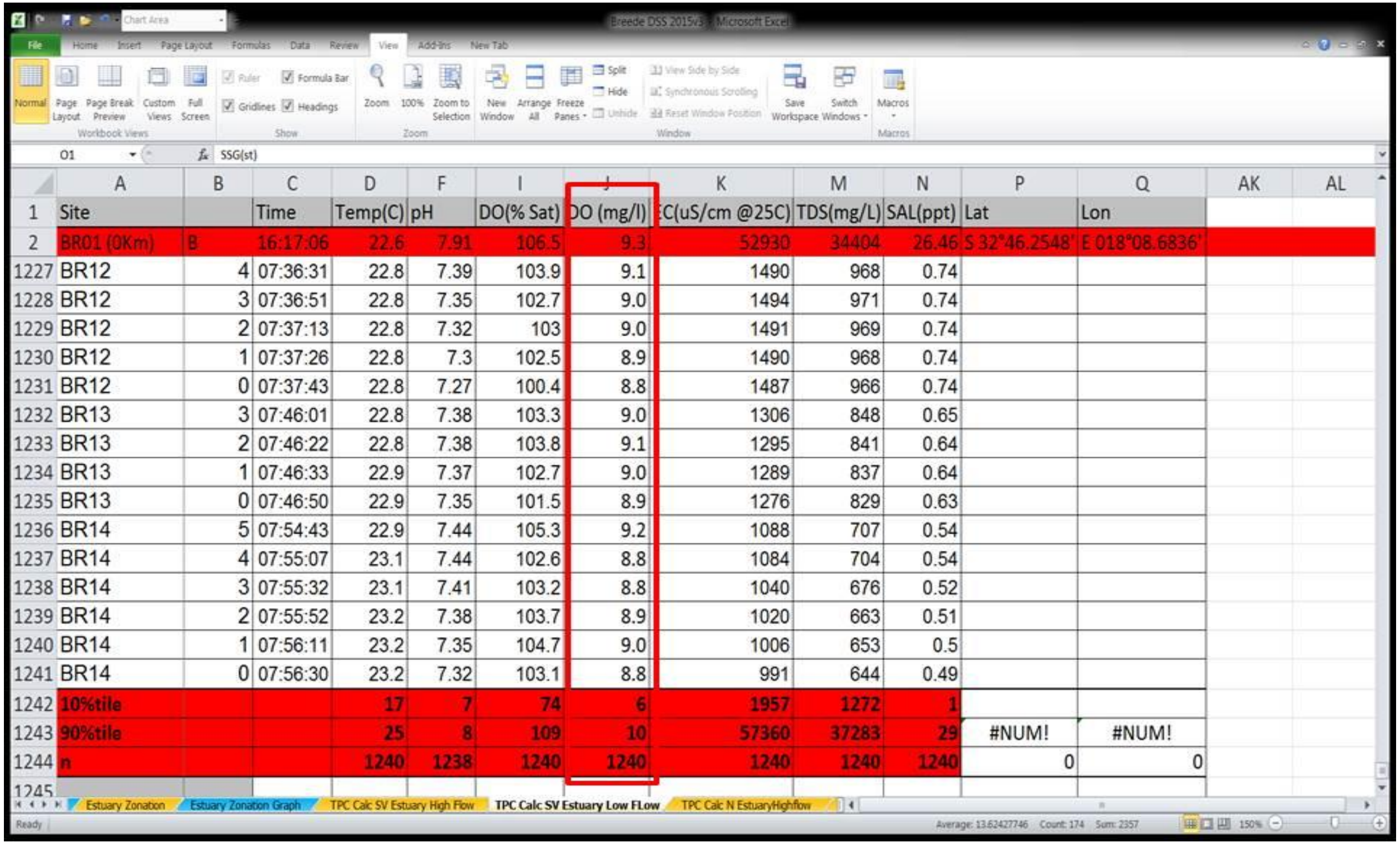


Figure 61 Graphic presentation of the estuary zonation based on the average salinity during high and low flows and the REI (indicated with black line).



	Site	Temp(C)	pH	DO (mg/l)	EC(uS/cm @25C)	TDS(mg/L)	SAL(ppt)
1012	BR21 (39Km)	18	7.43	8.9	859	558	0.42
1013	BR21 (39Km)	15.7	7.66	12.9	1003	651	0.5
1014	BR21 (39Km)	15.8	7.65	11.4	1000	650	0.5
1015	BR21 (39Km)	15.8	7.64	9.5	1003	651	0.5
1016	BR21 (39Km)	15.8	7.63	8.6	1003	651	0.5
1017	BR21 (39Km)	16.6	8.07	10.0	278	180	0.13
1018	BR21 (39Km)	16.5	8.03	10.2	278	180	0.13
1019	BR21 (39Km)	16.6	7.99	10.3	278	180	0.13
1020	BR21 (39Km)	16.6	7.94	10.3	280	182	0.14
1021	BR22 (41Km)	17.7	7.59	9.6	852	553	0.42
1022	BR22 (41Km)	17.7	7.57	9.3	851	553	0.42
1023	BR22 (41Km)	17.7	7.54	9.3	848	551	0.42
1024	BR22 (41Km)	17.8	7.51	9.2	847	550	0.42
1025	BR22 (41Km)	17.8	7.48	9.2	846	549	0.42
1026	BR22 (41Km)	17.8	7.45	9.1	846	549	0.42
1027	BR22 (41Km)	17.8	7.43	9.1	844	548	0.42
1028	BR23 (43Km)	17.9	7.53	9.6	960	624	0.48
1029	BR23 (43Km)	17.9	7.52	9.6	957	622	0.47
1030	BR23 (43Km)	17.9	7.51	9.5	957	622	0.47
1031	BR23 (43Km)	17.9	7.5	9.4	957	622	0.47
1032	BR23 (43Km)	17.9	7.48	9.4	957	622	0.47
1033	BR23 (43Km)	17.9	7.47	9.1	952	618	0.47
1034	n	1030	1030	1030	1030	1030	1030
1035	10%tile	13	7	8	329	213	0
1036	90%tile	21	8	11	51664	33581	26

Figure 62 High flow system variable TPC calculator with the oxygen concentration data and 10 and 90 percentile highlighted.



	A	B	C	D	F	I	J	K	M	N	P	Q	AK	AL
1	Site		Time	Temp(C)	pH	DO(% Sat)	DO (mg/l)	EC(uS/cm @25C)	TDS(mg/L)	SAL(ppt)	Lat	Lon		
2	BR01 (0Km)	B	16:17:06	22.6	7.91	106.5	9.3	52930	34404	26.46	S 32°46.2548'	E 018°08.6836'		
1227	BR12	4	07:36:31	22.8	7.39	103.9	9.1	1490	968	0.74				
1228	BR12	3	07:36:51	22.8	7.35	102.7	9.0	1494	971	0.74				
1229	BR12	2	07:37:13	22.8	7.32	103	9.0	1491	969	0.74				
1230	BR12	1	07:37:26	22.8	7.3	102.5	8.9	1490	968	0.74				
1231	BR12	0	07:37:43	22.8	7.27	100.4	8.8	1487	966	0.74				
1232	BR13	3	07:46:01	22.8	7.38	103.3	9.0	1306	848	0.65				
1233	BR13	2	07:46:22	22.8	7.38	103.8	9.1	1295	841	0.64				
1234	BR13	1	07:46:33	22.9	7.37	102.7	9.0	1289	837	0.64				
1235	BR13	0	07:46:50	22.9	7.35	101.5	8.9	1276	829	0.63				
1236	BR14	5	07:54:43	22.9	7.44	105.3	9.2	1088	707	0.54				
1237	BR14	4	07:55:07	23.1	7.44	102.6	8.8	1084	704	0.54				
1238	BR14	3	07:55:32	23.1	7.41	103.2	8.8	1040	676	0.52				
1239	BR14	2	07:55:52	23.2	7.38	103.7	8.9	1020	663	0.51				
1240	BR14	1	07:56:11	23.2	7.35	104.7	9.0	1006	653	0.5				
1241	BR14	0	07:56:30	23.2	7.32	103.1	8.8	991	644	0.49				
1242	10%tile			17	7	74	6	1957	1272	1				
1243	90%tile			25	8	109	10	57360	37283	29	#NUM!	#NUM!		
1244	n			1240	1238	1240	1240	1240	1240	1240	0	0		
1245														

Figure 63 Low flow system variable TPC calculator with the oxygen concentration data with 10th and 90th percentile highlighted.

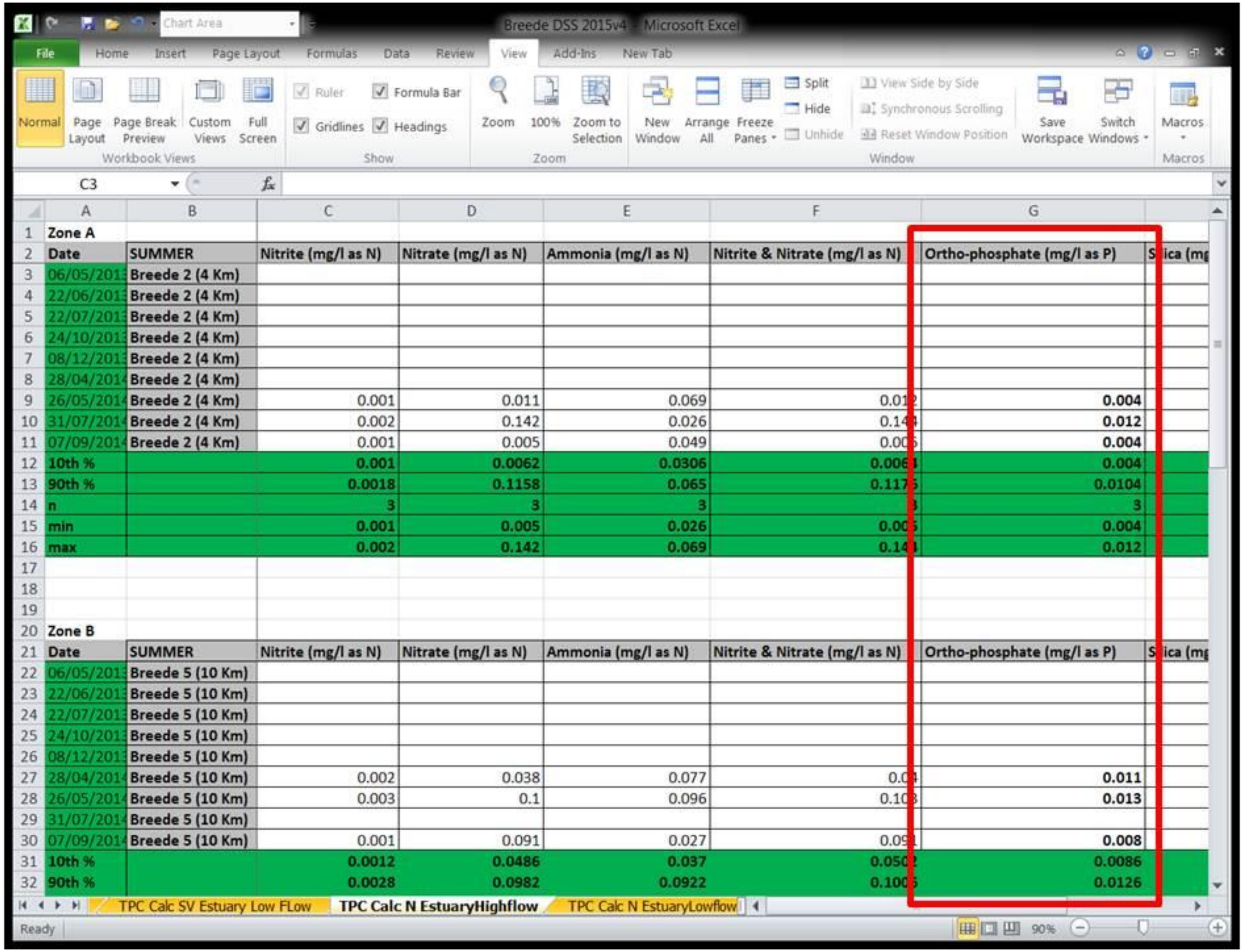


Figure 64 High flow nutrient TPC calculator with SRP data and associated 10th and 90th percentile for each zone highlighted.

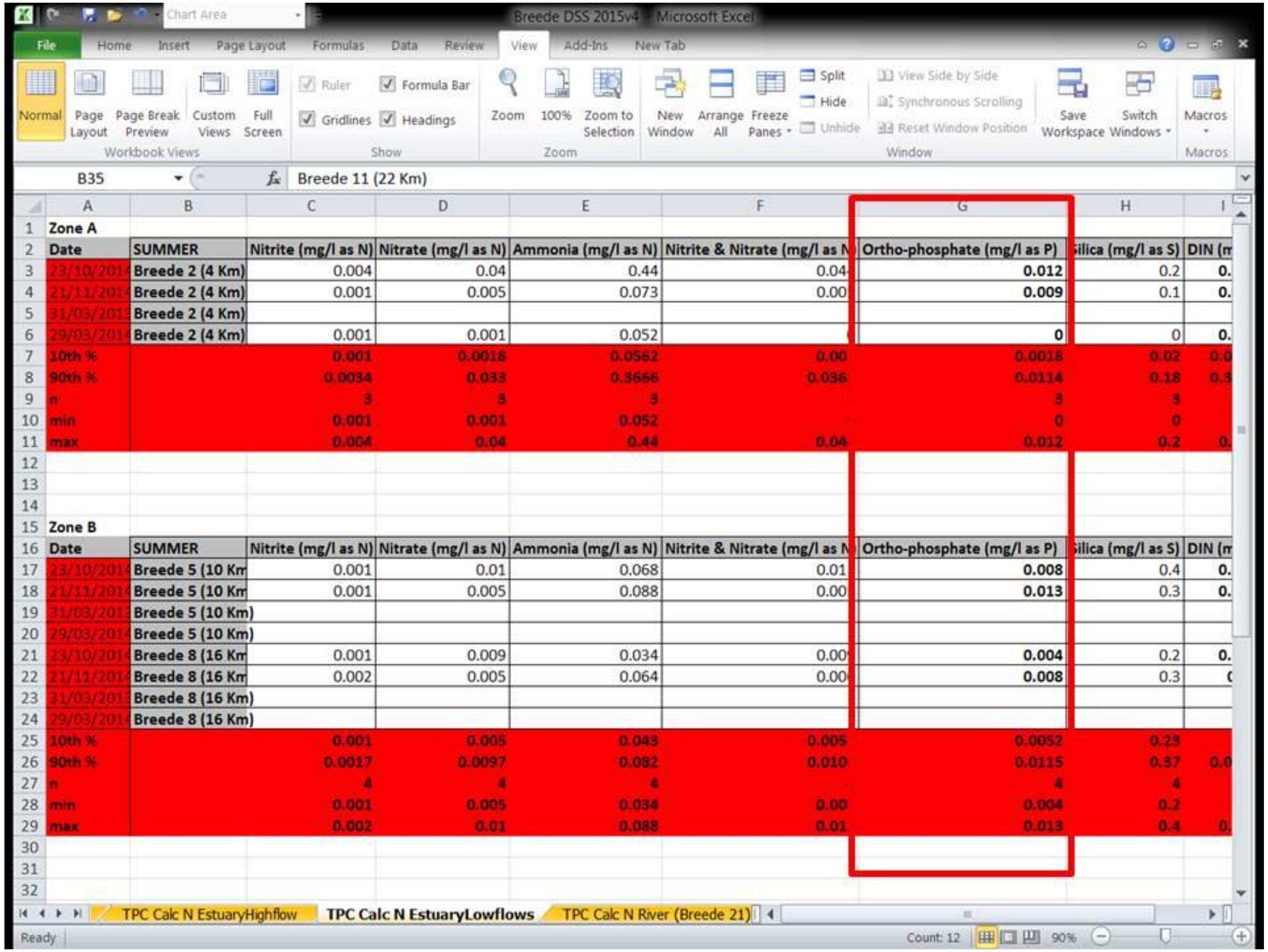


Figure 65 Low flow nutrient TPC calculator with SRP data and associated 10th and 90th percentile for each zone highlighted.

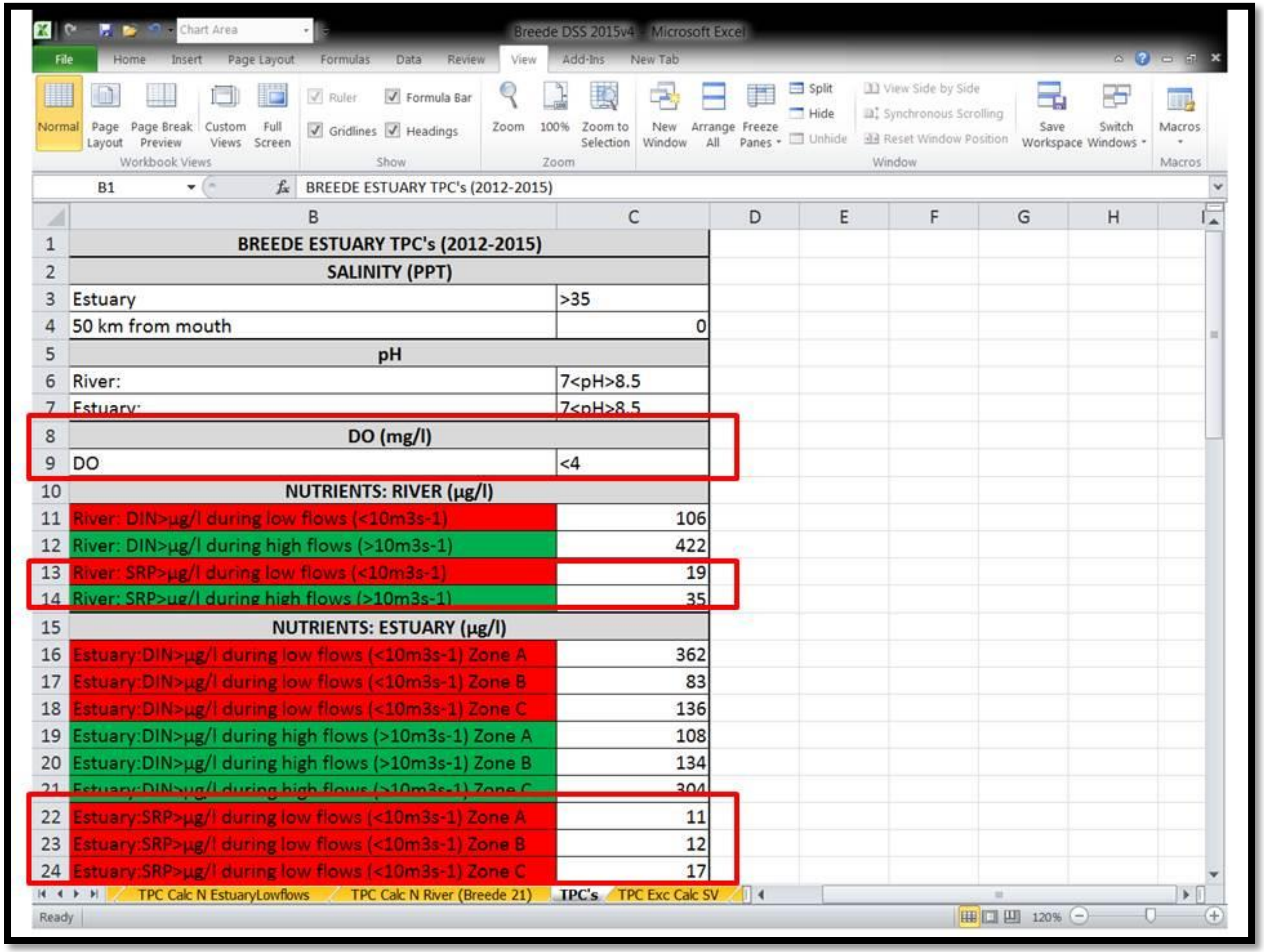


Figure 66 TPC description sheet with Oxygen and SRP TPC indicated

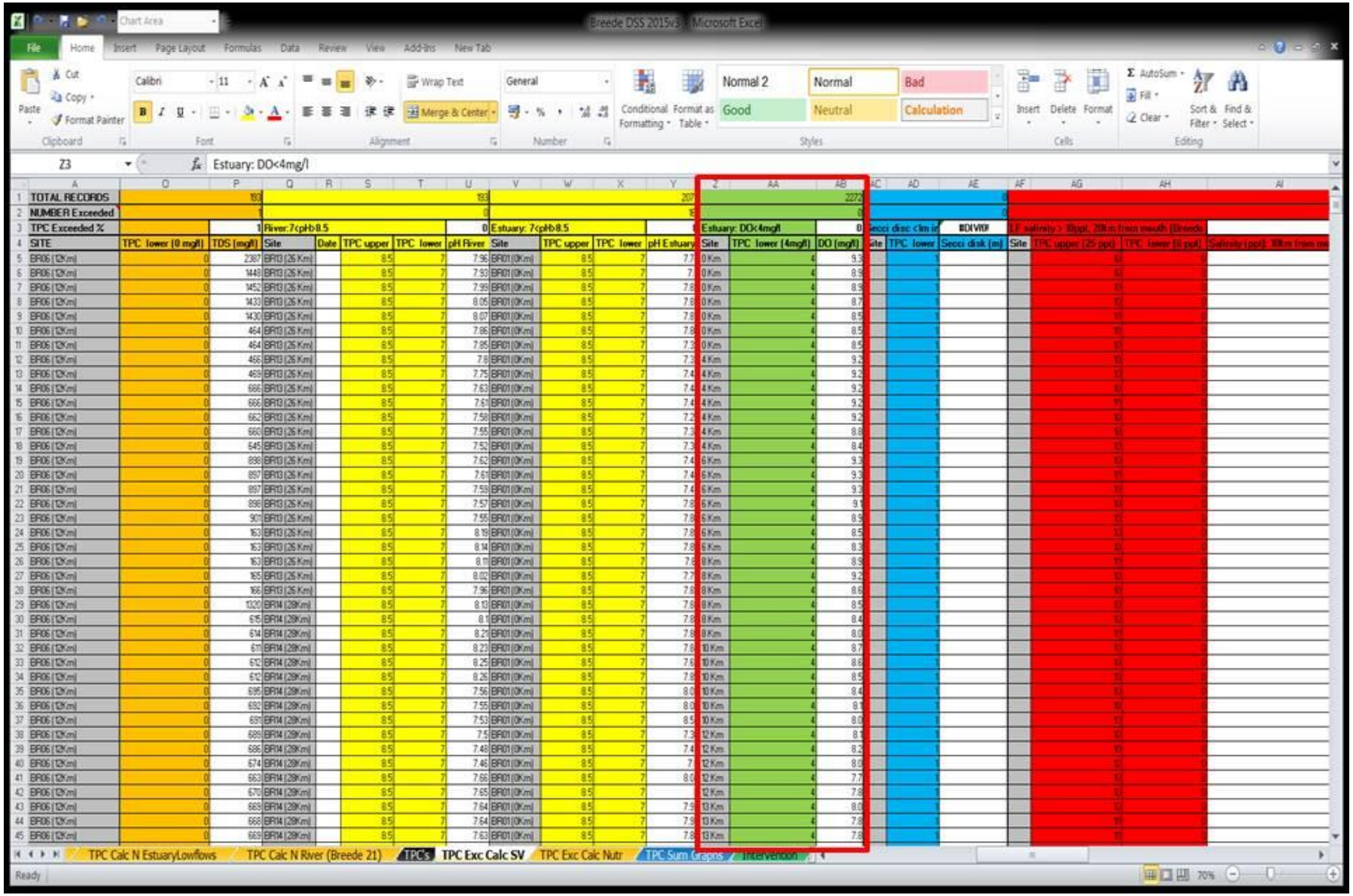


Figure 67 System Variable TPC Exceedance Calculator with data and percentage exceedance of oxygen concentration highlighted.

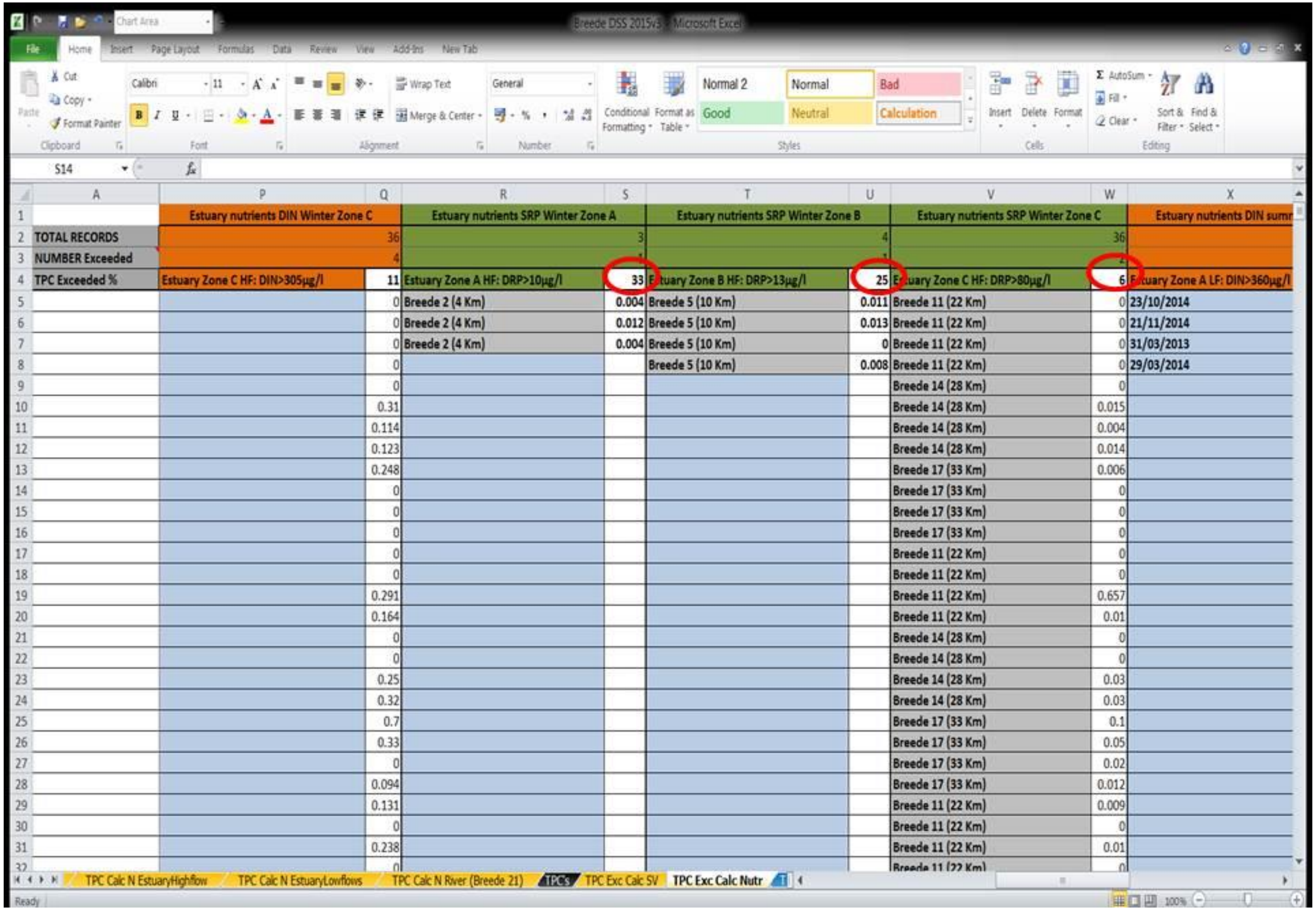


Figure 68 Nutrient TPC Exceedance Calculator with percentage exceedance highlighted with red circles.

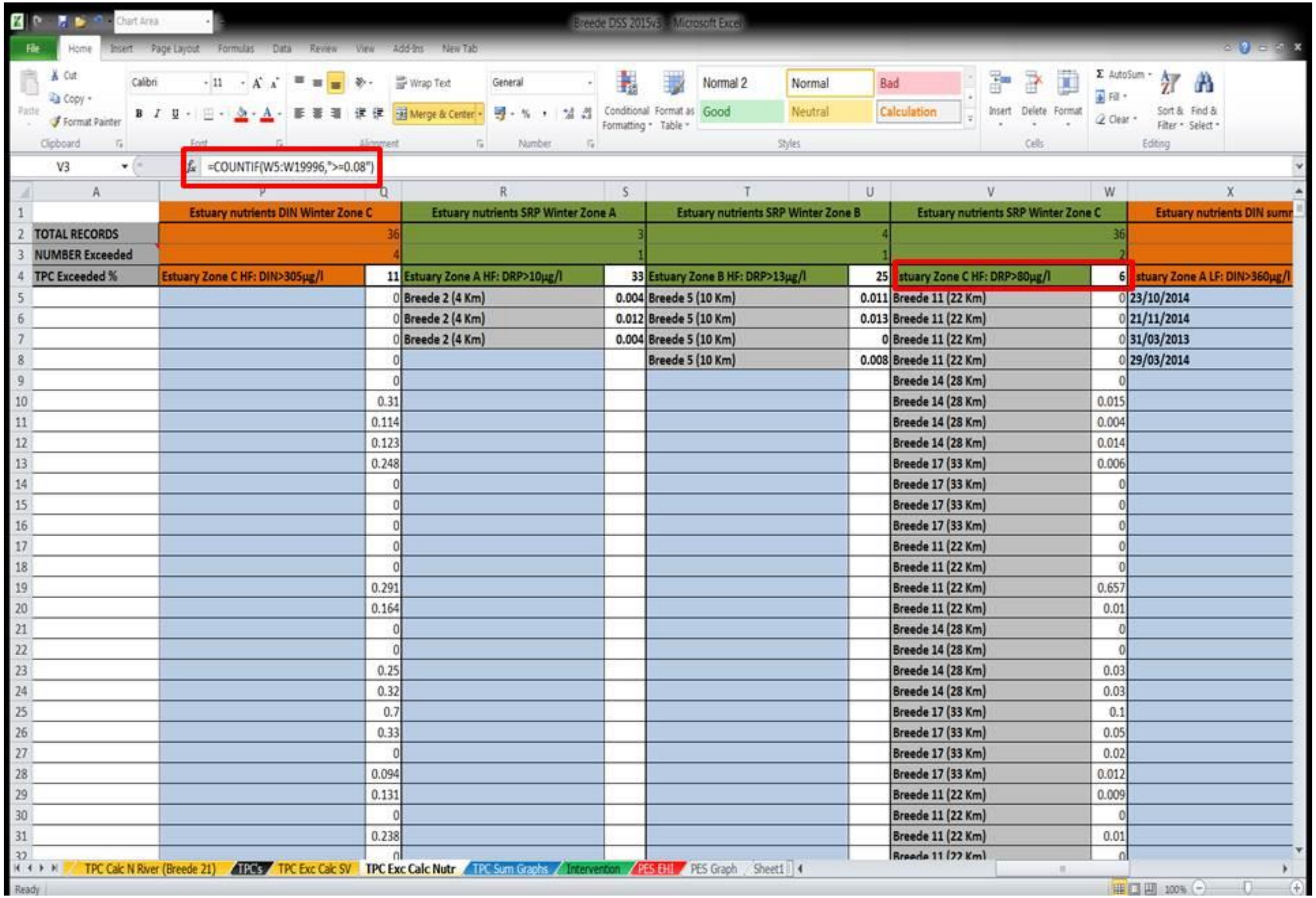


Figure 69 The TPCs are manually inserted into the calculation cell as indicated in red highlight.

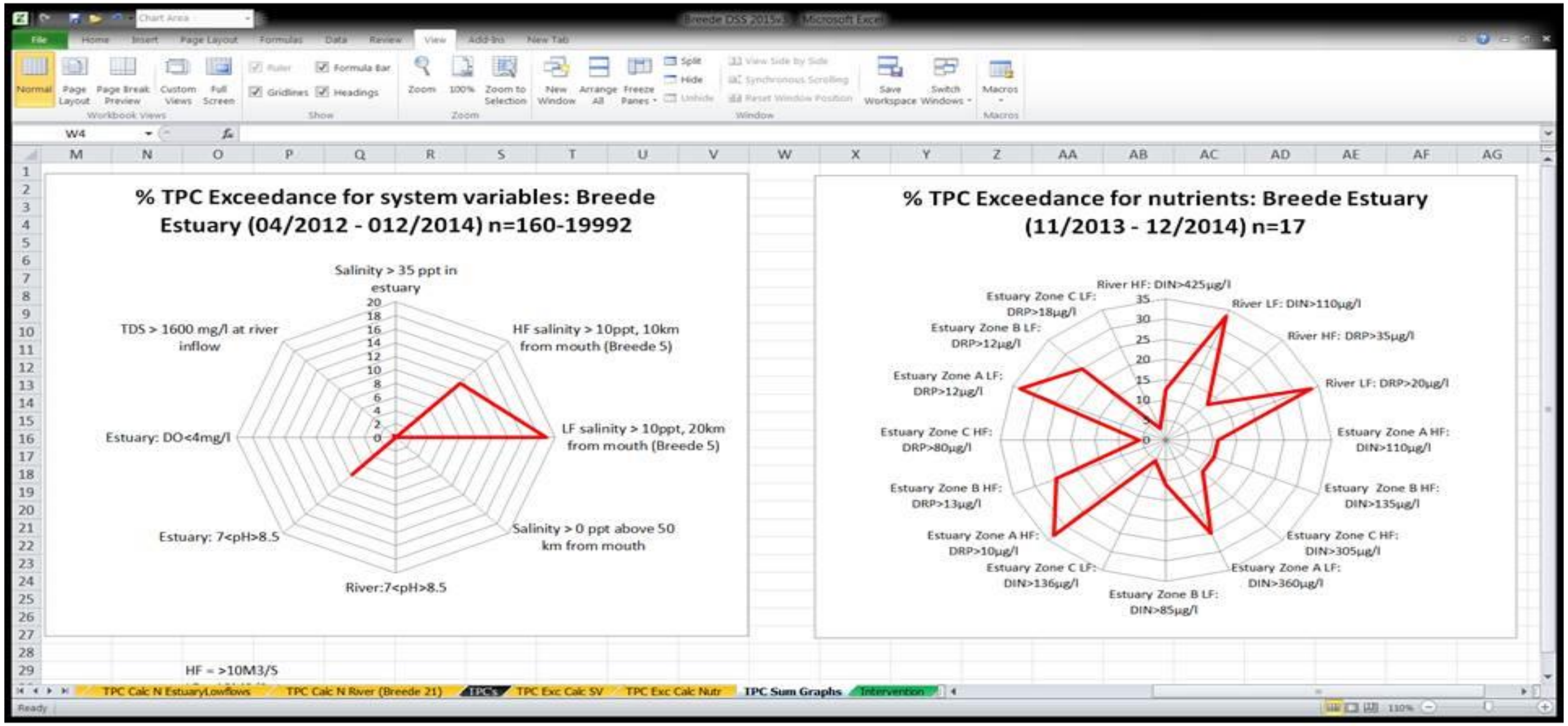
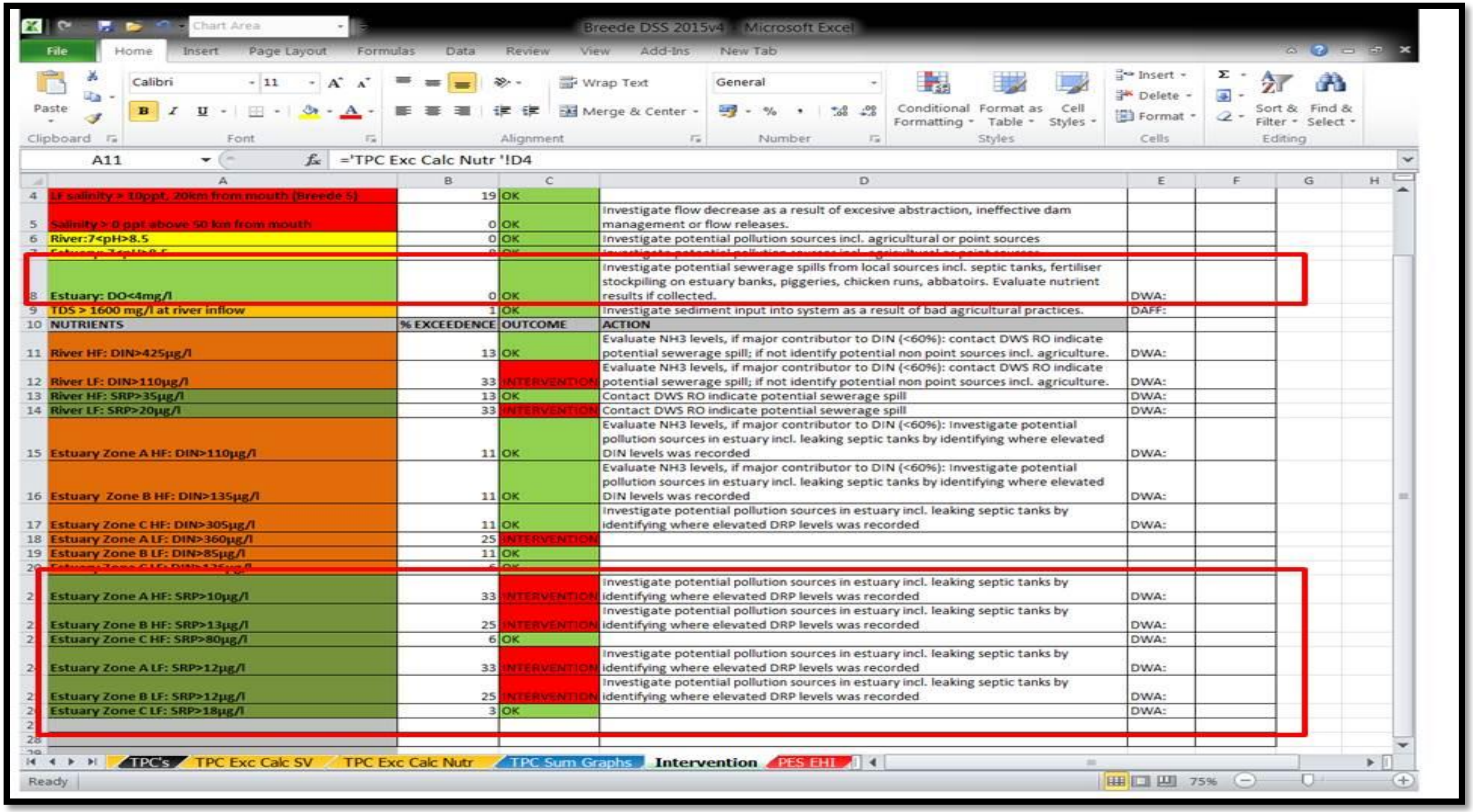


Figure 70 TPC Exceedance Graphs for the Breede Estuary for the period 2012 to 2015.

5.5.8 Intervention Sheet

The Intervention Sheet evaluates the percentage exceedance of the different TPCs and makes management recommendations (Figure 71) when needed. In order to prevent deterioration of estuarine condition, the recommendations from the Intervention Sheet need to be translated into management action. Without resources being allocated to address the identified problem, the deteriorating condition will go unchecked. Two cut off points for percentage exceedance are used to advise on intervention that may be required (Figure 72). When a 10 to 20% exceedance of a TPC is noted the specific constituent is orange flagged for early warning purposes. When this 10 to 20 % exceedance is observed continually for three surveys in a row it is red flagged for intervention. When a 20% exceedance is observed it is red flagged immediately and intervention is required as per the Intervention sheet. The user will however need to evaluate this exceedance in context of the time frame within which the sampling took place. Exceedance during sampling over three consecutive months will result in quicker action, than is the case for three consecutive sampling runs on a quarterly, six monthly or annual base. In instances where there is a 20% exceedance for a six monthly or annual survey, further high frequency surveys may need to be undertaken to increase the resolution of the data, to identify the causes of the problem and associated intervention. For this reason it is proposed that intervention will depend on further surveys for which resources must be made available. Each case should however be evaluated individually, through consultation with relevant stakeholders and estuarine specialists. The Intervention Sheet not only guides the user in the required actions that need to be taken, but also advises on the relevant authority to contact for assistance. This sheet will therefore need to be periodically updated as contacts at relevant authorities change.



	A	B	C	D	E
4	LF salinity > 10ppt, 20km from mouth (Breede 5)	19	OK		
5	Salinity > 0 ppt above 50 km from mouth	0	OK	Investigate flow decrease as a result of excesive abstraction, ineffective dam management or flow releases.	
6	River:7<pH>8.5	0	OK	Investigate potential pollution sources incl. agricultural or point sources	
7	Estuary: 7<pH>8.5	0	OK	Investigate potential pollution sources incl. agricultural or point sources	
8	Estuary: DO<4mg/l	0	OK	Investigate potential sewerage spills from local sources incl. septic tanks, fertiliser stockpiling on estuary banks, piggeries, chicken runs, abbatoirs. Evaluate nutrient results if collected.	DWA:
9	TDS > 1600 mg/l at river inflow	1	OK	Investigate sediment input into system as a result of bad agricultural practices.	DAFF:
10	NUTRIENTS	% EXCEEDENCE	OUTCOME	ACTION	
11	River HF: DIN>425µg/l	13	OK	Evaluate NH3 levels, if major contributor to DIN (<60%): contact DWS RO indicate potential sewerage spill; if not identify potential non point sources incl. agriculture.	DWA:
12	River LF: DIN>110µg/l	33	INTERVENTION	Evaluate NH3 levels, if major contributor to DIN (<60%): contact DWS RO indicate potential sewerage spill; if not identify potential non point sources incl. agriculture.	DWA:
13	River HF: SRP>35µg/l	13	OK	Contact DWS RO indicate potential sewerage spill	DWA:
14	River LF: SRP>20µg/l	33	INTERVENTION	Contact DWS RO indicate potential sewerage spill	DWA:
15	Estuary Zone A HF: DIN>110µg/l	11	OK	Evaluate NH3 levels, if major contributor to DIN (<60%): Investigate potential pollution sources in estuary incl. leaking septic tanks by identifying where elevated DIN levels was recorded	DWA:
16	Estuary Zone B HF: DIN>135µg/l	11	OK	Evaluate NH3 levels, if major contributor to DIN (<60%): Investigate potential pollution sources in estuary incl. leaking septic tanks by identifying where elevated DIN levels was recorded	DWA:
17	Estuary Zone C HF: DIN>305µg/l	11	OK	Investigate potential pollution sources in estuary incl. leaking septic tanks by identifying where elevated DRP levels was recorded	DWA:
18	Estuary Zone A LF: DIN>360µg/l	25	INTERVENTION		
19	Estuary Zone B LF: DIN>85µg/l	11	OK		
20	Estuary Zone C LF: DIN>125µg/l	6	OK		
2	Estuary Zone A HF: SRP>10µg/l	33	INTERVENTION	Investigate potential pollution sources in estuary incl. leaking septic tanks by identifying where elevated DRP levels was recorded	DWA:
2	Estuary Zone B HF: SRP>13µg/l	25	INTERVENTION	Investigate potential pollution sources in estuary incl. leaking septic tanks by identifying where elevated DRP levels was recorded	DWA:
2	Estuary Zone C HF: SRP>80µg/l	6	OK		DWA:
2	Estuary Zone A LF: SRP>12µg/l	33	INTERVENTION	Investigate potential pollution sources in estuary incl. leaking septic tanks by identifying where elevated DRP levels was recorded	DWA:
2	Estuary Zone B LF: SRP>12µg/l	25	INTERVENTION	Investigate potential pollution sources in estuary incl. leaking septic tanks by identifying where elevated DRP levels was recorded	DWA:
2	Estuary Zone C LF: SRP>18µg/l	3	OK		DWA:

Figure 71 The Intervention Sheet.

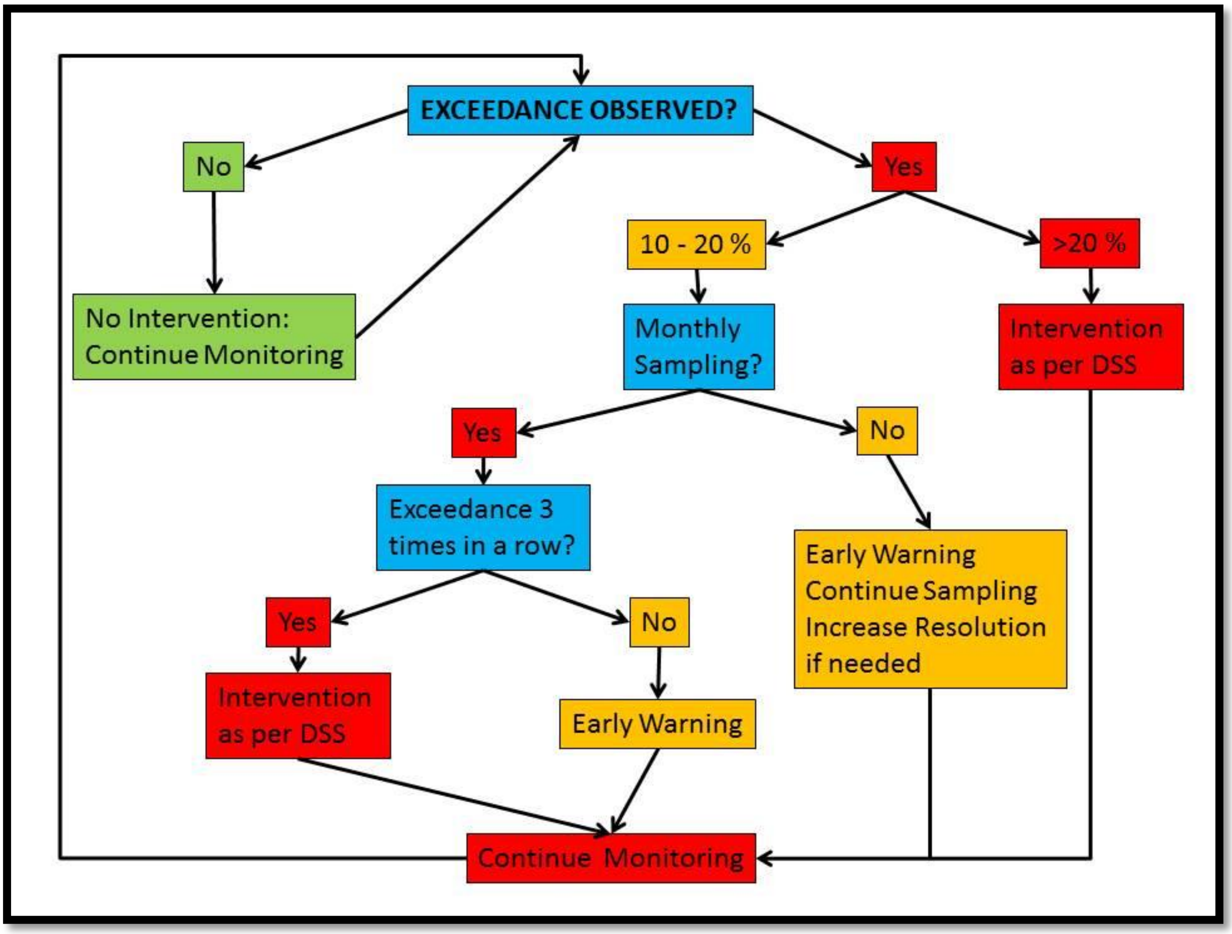


Figure 72 The Percentage Exceedance Decision Tree

5.6 CONCLUSION AND RECOMMENDATIONS

The NESMP DSS is a fairly user friendly system that facilitates the creation of management orientated information, based on scientific complex data generated through the NESMP. It was illustrated in this chapter how this system can be designed with a generally available spreadsheet programme, in the form of MicroSoft Excel. The chapter also indicated that the DSS can evaluate and analyse the NESMP data and provide management guidance for intervention where certain guiding values (TPCs) are exceeded. This does however require that the DSS is set up with the relevant TPCs. The current NESMP DSS only addresses Tier 1 data of the NESMP, focussing largely on the abiotic components. As the NESMP are expanded and eventually cover the biotic component of Tier 2, the DSS needs to evolve to include these components as well. Setting TPC's, and making management recommendations when these TPC's are exceeded, for the biological component of Tier 2 of the NESMP will depend on specialist input. In certain instances the TPC's are set as part of the RQO and classification studies. These TPC's will be readily available as these studies are funded by DWS. Where an estuary has not been the subject of a classification study, the inputs from appropriate specialists will need to be sourced. This will have financial implications, which need to be budgeted for by DWS. There are a limited number of specialists for each of these specific components and this may hamper setting of these TPC's. The objective of the NESMP DSS is to evaluate the data collected in the programme against a specific benchmark, in this case the TPCs, as set in the RQO studies (Figure 48). In the absence of previously determined TPCs the DSS also functions to set these TPCs. This necessitates that a tailor made DSS is required for each estuary as a result of the different levels of information that may be available on different estuaries and the different way in which estuaries respond to natural and anthropogenic impacts. The core DSS however remains standard and acts as the foundation for developing a specific DSS for each estuary. The programme manager and the team responsible for the NESMP should develop the DSS further. This will ensure consistency in the development of the DSS and facilitate capacity building within DWS for DSS development and use. The development of the estuary specific DSS however needs to be evaluated by specialist estuarine ecologists and managers to ensure that there is a quality control component, hence preventing errors. These errors could have dire consequences for maintenance and improvement of estuarine health.

The system has been designed with managers with a certain level of technical and scientific background in estuarine functioning and management in mind. The DSS is only a tool to assist the manager to identify specific problems and guide him / her to potential solutions. The DSS is not a replacement for experienced estuarine managers and/or expert opinion by estuarine specialists. The DSS is therefore in support of estuarine managers to facilitate informed management decisions based on complex scientific data.

The NESMP DSS can assist in making management decisions and support the recommendations with scientific sound facts against a set RQO benchmark with legal standing (when Gazetted). With the use of the NESMP DSS, the success of the proposed management interventions can be evaluated against the long-term management objectives, as set in the estuarine management plan. The DSS therefore also facilitates the auditing and evaluation of the successful implementation of estuarine management plans as defined in the ICMA. The current NESMP DSS, although fairly user friendly should in future go through a redesign process to make the ergonomics and layout less complicated. A "polished" user interface will facilitate more users of the NESMP DSS and it will prevent errors when uploading data and subsequent higher confidence in the results that will emanate from its use.

The NESMP DSS needs to be continually evaluated against its successful use by estuarine managers. There should be a continual refinement, based on feedback by users of the

DSS. As more experience with the use of the DSS is gained and estuary management science progresses further, the DSS should evolve into a system that does not necessarily create simpler answers, but has the capability to incorporate more complex data and information, thereby providing integrated answers for complex estuarine resource management problems.

The NESMP DSS should eventually form part of a larger suite of Decision Support Systems that address integrated water resource management on a catchment scale. The NESMP DSS is therefore not seen as a single stand-alone system that can provide an estuarine manager with all the answers. The socio-economic and environmental forces at play in a catchment are complex. Various other disciplines and stakeholders also have a role to play in the management of estuaries. Estuaries, although seen as the final receiving environment of catchment perturbations before the ocean, form part of a larger mosaic of environmental and socio-economic systems within the larger catchment.

CHAPTER 6. CONCLUSIONS

The objective of this thesis was to design a National Estuarine Monitoring Programme (NESMP) for South Africa. This objective was achieved by: 1) undertaking a detailed literature review in Chapter 2 to provide the background to estuary function and status quo in South Africa and international practise in estuary monitoring; 2) designing the programme making use of the prescribed methods for the design, testing and implementation of monitoring programmes by the Department of Water and Sanitation (DWAF, 2004b; DWAF, 2004c), based on international practise and stakeholder consultation, in Chapter 3; 3) testing the implementation of the programme between 2012 and 2015 on 28 estuaries, of which two case-studies are reflected on in Chapter 4 of this thesis; 4) Developing a decision support system in Chapter 5, to assist with data interpretation of complex data sets and the subsequent creation of management orientated information.

Estuaries have been the subject of basic research for decades (Whitfield and Baliwe, 2013). This research was mostly driven by academic institutions and conservation bodies, with the purpose of developing an understanding of the functioning and conservation of these systems. This basic research paved the way for effective management of estuarine ecosystems. Management however depends on information and information depends on data (DWAF, 2005). The national, regional and local management responsibilities for the coastal zone, including estuaries, have recently been clarified through the promulgation of the Integrated Coastal Management Act (Act No 24 of 2008). This act indicates that the overarching responsibility lies with the Department of Environmental Affairs (DEA). Collaborative management of estuaries is central to the ICMA (DEA, 2014) and therefore addresses the Department of Water and Sanitation's (DWS) role as custodian of all South Africa's water resources, including estuaries, through the National Water Act (Act No 36 of 1998). The DWS have been collecting data on South African water resources since the 1940s. This data collection effort over the years has culminated in the current seven formalised monitoring programmes of DWS. The objectives of these monitoring programmes are primarily to track long-term changes in the quantity and quality of South Africa's water resources and provide management orientated information. All these monitoring programmes have however focused on the freshwater environment. There has not been an overarching national monitoring programme for estuaries in South Africa. Past water resource management projects by DWS relevant to estuaries, including EWR and classification studies, have mostly been informed by existing research studies, once off surveys and associated expert opinion.

The literature review (Chapter 2) undertaken to set the background for the design of the NESMP found that the DWS and DEA are the lead agents for the management and associated monitoring of estuaries. However, sister departments including DAFF and DST, national and regional conservation bodies including SANParks, Ezemvelo / KZN Wildlife, CapeNature, municipalities and parastatals have legal mandates relevant to estuaries to fulfil and therefore play an important role. NGOs including the WWF-SA, conservancies and tertiary education institutions also play an important role because of applied management and research programmes. Finally, it was also concluded in the literature review, that public involvement is key to effective integrated management and monitoring of estuaries. Volunteer programmes in Australia and the USA have played a role in capacity building in civil society in support of estuary monitoring. In South Africa the Adopt a River programme was initially focussed on volunteer involvement with river stewardship and associated civil science. The focus of the programme has however shifted from volunteering to work creation, to the detriment of volunteer involvement. A civil science programme has recently been initiated through the WRC, which includes a revaluation of citizen involvement in coastal monitoring, including estuaries. This civil science programme can easily be linked with the NESMP, as the foundation of the NESMP is also volunteer based involvement and the use of user friendly and practical methods to determine estuarine condition. Fixed point photography, salinity measurements and mouth condition are examples of simple but critical data sets, that can be gathered by the public and which form part of the NESMP Tier 1 and 2 protocol. A large part of the population that live at towns and cities next to estuaries are retirees and or citizens with a keen interest in the environment. Harnessing the interest and energy of these citizens can facilitate the collection of supporting data for the NESMP.

Various international monitoring programmes were investigated as part of the literature review, to set the scene for the design of a monitoring programme for South Africa. This included the National Estuaries Programme (NEP) and associated National Coastal Assessment (NCA) in the USA (U.S. EPA, 1997), the Water Framework Directive (WFD) of the European Union (European Communities, 2000, Borja, et al., 2005) and the Australian National Water Quality Management Strategy (NWQMS) (Hallet et al., 2016a). It was determined that the USA and EU monitoring programmes are founded on a formal national / international legal mandate (the EPA Clean Water Act and the European Union Framework Directive), therefore enforceable, while the Australian monitoring initiatives are a guideline. The guideline focus of the Australian approach has resulted in large divergence in the monitoring initiatives and associated estuarine health indicators used in the different Australian states. This results in the data not being comparable across states for a national perspective. Central to all three of these monitoring initiatives are the alignment of indicators, quality standards for methods, monitoring data, and setting of a benchmark or reference condition against which current and future estuarine conditions can be compared.

Chapter 3 of this study provides the NESMP protocol. The design process was based on the methods for the design, testing and implementation of monitoring programmes by the Department of Water and Sanitation (DWAF, 2004b; DWAF, 2004c). Stakeholder consultation took place at a workshop in 2008, to determine the technical and managerial requirements of the NESMP from key stakeholders. In addition, direct personal engagements were undertaken and recorded with individuals from tertiary institutes, NGOs and government departments to solicit further opinion on the design and implementation of the NESMP. This part of the study indicated that there is consensus between roleplayers on the importance of a national monitoring programme for South African estuaries. In certain instances, monitoring data supports basic research by academic institutions. There is also a need for basic monitoring data in support of applied research and associated government funded consultancies including, water resource classification studies and associated EWR studies by the private sector. It was however observed that different roleplayers have different objectives for the programme, based on vested interests of academic and/or commercial / financial nature. This required that the objectives of a national monitoring programme be identified and ring-fenced at an early stage of the study.

The primary role of the NESMP is to support water resource management decisions by DWS, though capacitating internal or external parties. In order to steer the monitoring programme form the onset, clear objectives were set, through consultation with all stakeholders as mentioned above. This included water resource managers and research scientists. The objective was stated as:

To measure, assess and report on a regular basis on the status and trends of the nature and extent of the health or condition of South African estuaries in a manner that will support strategic management decisions in the context of fitness for use of estuaries and aquatic ecosystem integrity, and be mindful of financial and capacity constraints, yet be scientifically sound.

The programme has therefore been designed to address the collection of abiotic and biotic data of relevance to the South African Estuarine Health Index (EHI) of Turpie et al. (2012) as it addresses both abiotic and biological components of estuaries. The abiotic component, as per Tier 1 of the NESMP protocol, was the subject of the case study in this thesis. The South African EHI is also used as the basis for classification and EWR studies. By using the South African EHI as the foundation for the NESMP, the data collected will not only provide input on the estuarine health on a national scale, but will also act as baseline data for future classification studies.

The NESMP follows a tiered approach to collect basic information to understand the biotic and abiotic functioning of a specific estuary. The methods required to undertake these three tiers of monitoring are in line with the EWR methodologies of DWS (DWAF, 2008), which is based on the EHI (Turpie et al., 2012). The use of approved EWR methodologies as the basis of the NESMP ensure that data and information from historic studies can be used and ensure that data from future EWR studies can add to the pool of knowledge on South African estuaries. The programme's tiered approach will ensure that data from different spatial and temporal scales, with different, but overlapping objectives can be deposited in a central database. This is in support of 1) long-term trend analysis on estuarine health condition 2) filling data gaps on systems that requires future intermediate and comprehensive EWRs; and 3) auditing the implementation of the EWR and associated classification system through TPCs. The programme will therefore address management requirements of estuaries in line with the NWA and ICMA.

This data and information may also be used to inform the Integrated Environmental Management (IEM) process as part of Environmental Impact Assessments (EIA) of development on estuaries, regulated by the regional offices of DEAT. The Environmental Management Plans that result from the EIAs need to be in line with the Estuary Management Plans (EMP) as required in ICMA. The local authorities, DWS and conservation bodies have the opportunity to raise concerns regarding a proposed development and make recommendations in terms of the site specific Environmental Management Plan. Data and information that inform these EMPs may also be sourced from the NESMP, for use in specific EIAs. This is already the practise with the data generated through DWS freshwater monitoring programmes and supports additional decision making outside the mandate of DWS by other authorities, including DEA, conservation entities and municipalities. This overarching data and knowledge management resulting from the NESMP will therefore facilitate management decisions on various levels.

A numeric model was also developed in Chapter 3 to objectively prioritise estuaries for national implementation of the NESMP. Basing the prioritisation model on the practicality of establishment of a monitoring programme of a specific estuary prevents ineffective implementation of the NESMP on a national scale. Practicality, being dictated by the availability of a sampling team with a vested interest in the resulting data from sampling a specific estuary, was the main driver for this prioritisation model. This however does not preclude identification of estuaries that may have priority as a result of specific conservation of management issues to be addressed through a monitoring programme. This is also of relevance to potential impacts as a result of climate change and uncertainty regarding trajectories of change. For these specific cases financial resources however need to be solicited, which in the current South African, and global economic climate may be challenging. Therefore, the need to establish the NESMP initially on estuaries where it is practical was identified. Illustrating the success of the NESMP could then be used to solicit the required financial support for other priority estuaries, where the NESMP cannot be implemented on a volunteer base. The NESMP are based on collaboration and volunteer involvement by relevant parties that have a vested interest in the data. There is no financial gain by these implementers. This however requires that DWS should provide the necessary logistical and technical support to the local implementers. This indicates commitment from DWS and fosters commitment from the implementers. This logistical and technical support includes provision of equipment (sampling boats, sampling material, *in situ* water quality probes), training in sampling protocols, monitoring equipment and troubleshooting of equipment and associated operational issues. DWS as the manager of the programme is also responsible for water quality sample analysis when required. This requires that the necessary human and financial resources from DWS are available to assist on a technical and managerial level.

Central to the success of the programme is a strong management component. Without management and associated financial and logistical support, the programme would not have been successfully designed, tested and refined for implementation. The management component consists of a national, regional and local component. Nationally, the programme is managed by DWS as the custodian of South African water resources, through the monitoring mandate set by the NWA. The DEA also have a key role to play as the ICMA mandate this department has for coastal management. A need for a strong working relationship on a national level between the two sister departments has been identified in this study. The establishment and maintenance of this relationship is critical to coordinate monitoring efforts and ensure clear communication channels and has been the focus since the onset of the design of the NESMP. This collaboration takes place on a strategic level in the form of the National Coastal Committee (NCC) as defined by the ICMA. Currently the NCC is implemented through Working Group 8, which convenes every quarter between all governing role players involved with coastal management. This is overseen by DEA, with participation by DWS, DAFF, local and regional municipalities and other relevant stakeholders. Working Group 8 acts as the forum for the national reporting structure on the NESMP. This group also report directly to the South Africa Parliament on coastal matters including estuaries. There is however no formal agreement between DWS and DEA which may result in complications in implementation of the programme as a result of overlapping mandates and ill-defined roles and responsibilities. The collaborative foundation set by the NWA and ICMA can however initiate such a formalised agreement through a nationally focused MoU.

The South African coast is divided into three biogeographical zones. This is a natural division of the coast, based on biophysical characteristics into sections that also make logical sense for the regional management of the NESMP. On this level the regional offices of DEA, DWS and associate CMAs, regional conservation agencies and regional municipalities play a role with the regional management of the NESMP. The NESMP makes provision for a scientist per coastal zone, to manage the NESMP. They ensure regional coordination of the NESMP and provide feedback to the national management body via the programme manager on the regional implementation of the NESMP. This is critical for regional implementation of the programme, due to the multiple role players with different mandates in each region. It also ensures effective communication between the local implementers and the nation management body and vice versa. Regional management may however result in complications for implementation on a local scale. This is due to misalignment between the three coastal regional zones and the municipal boundaries associated with the coast. This may result in the municipal and conservation role players involved with future monitoring initiatives, having to liaise with two different NESMP regional managers. This can however be resolved by not being stringent with the NESMP regional allocation of estuaries to NESMP regional managers. The requirement for three regional managers / scientists also has challenges with regards to available human resources within DWS. Currently only two posts are dedicated to the NESMP by DWS. Currently, the programme manager is responsible to oversee the programme on a national level and is also responsible for the regional management of the Cool Temperate region. A scientist is responsible to oversee the Warm Temperate and Subtropical coastal regions. Both these resources also provide scientific support to the programme over and above the management and coordination roles. The scientific responsibilities include data management, data analysis and reporting.

The local coordination of the NESMP is critical for implementation of the programme on an estuary based level. Without local logistical coordination and management support for the programme, the actual monitoring on each estuary will not take place. The estuary management forums and associated estuary management plans are pivotal to the successful collection of data. The establishment of a monitoring technical task team (MTT) within each estuary management forum ensures that all issues relating to the monitoring programme can be resolved locally. The members on the MTT consist of a representative of at least the DWS and DEA and other relevant parties including, but not limited to conservation bodies, local or regional municipalities and the public. The members will vary from estuary to estuary, depending on the availability of estuaries role players. This study indicated that at a local estuary based level the programme is the most at risk of failure. This has been illustrated by various levels of success with the testing of the NESMP on 28 estuaries since 2012. A strong estuary based implementation team is therefore pivotal to the success of the programme. Ensuring the sustainability of the programme is critical to safeguard return on the financial and human resource investment in the programme. The use of volunteer organisations, whether governmental, para-statal, NGO or civilian poses some difficulties in terms of sustainability of the programme. It was found that the programme was most successful where the implementing agents had a vested interest in the data and where there was collaboration with government authorities with a clear environmental management or conservation mandate. This includes the West Coast District Municipality where the NESMP is being implemented on the Olifants, Verlorenvlei and Berg estuaries since 2012; Ezemvelo KZN Wildlife responsible for successful monitoring of the uMtamvuna, uMpenjati, uMgeni, uMhlanga and uMlalazi and St Lucia estuaries since 2013. The success of the programme on these systems are a result of a formal Memorandum of Understanding (MoU) being in place between DWS and the implementing agents. Through the MoU, roles and responsibilities are clarified. It also assists if the responsibilities of implementing agents are also reflected in the relevant local officials work plans. In cases where no MoU was in place as was the case with NGOs like the the Zinkwazi and Nonoti estuaries, the programme started off successfully through participation by the local conservancy and Wildlands Conservation Trust. The programme on these two systems was however not sustainable as the contract funding from Wildlands Conservation Trust ended, resulting in the sampling team not being employed anymore. A similar situation was experienced on the Orange River Estuary where funding constraints resulted in the WWF having to end support for the programme after 6 months. The use of NGOs, as implementers of the NESMP, could be incorporated into future refinement of the prioritisation model, but at a risk of discarding potential successes with the monitoring effort. Currently collaboration with NGO's are cautiously approached as sustainability of the programme on an estuary specific basis is paramount to the success of the programme. The involvement of NGO's could however act as seed for further collaboration and support for the estuary specific monitoring by the NGO in question or alternative organisations.

This study investigated the implementation of the abiotic component of the NESMP on the Berg and Breede estuaries between 2012 and 2016 (Chapter 4). The objectives were to identify trends in system variables and nutrient levels in the Berg and Breede estuaries, evaluate the Threshold of Potential Concerns (TPCs) set for the Berg Estuary against alternative TPCs, set TPCs for the Breede Estuary, and evaluate the observed trends against the TPCs of both systems. The TPCs as determined for the Breede Estuary in this study should be used with caution as this only illustrated how the data collected on a long term base, through the NESMP, may be used for future TPC setting. These TPCs still need to be further refined with the use of additional data collected through the NESMP and expert opinion. Although there is limitation to making use of a two or three year data sets to establish TPCs, this needs to be evaluated against TPCs that have been set in the past on a single survey and associated expert opinion and knowledge of a system. It was shown that the NESMP will be able to describe trends in estuary health, or components of it, on a local and national scale, by using the data collected through the NESMP to inform the Estuarine Health Index, which forms the foundation for the National Estuarine Health Assessment on a periodic base. The data collected were used to confirm information from the EWR studies conducted on both systems in 2003 and 2008 (DWAF, 2003; DWA, 2012). The study indicated that the previous described key water quality drivers are still relevant. Both the Berg and Breede estuaries are flow driven, with changes in the system variables and nutrient loads being dictated by winter rainfall in the catchments and summer upwelling from the Benguela and Agulhas currents. There is a pattern of nutrient loading in the lower part of both estuaries during low flow states as a result of marine upwelling and anthropogenic inputs from Laaiplek and Veldrif in the case of the Berg Estuary and Witsand and scattered residential developments on the banks of the Breede Estuary, between Witsand and Malgas. The observed increase in nutrient concentrations is associated with 1) the main holiday season in South Africa which culminates with the low flow season in summer, resulting in decreased flushing of the estuaries; and 2) catchment runoff.

The Berg Ecological Water Requirement TPCs were evaluated against alternative TPCs that were set making use of the data collected from this study. This indicated that the system variable TPCs were very similar but the nutrient TPCs differed. This merits the future re-evaluation of the nutrient EWR TPCs when further data become available through the NESMP. Current indications by DWS are that the gazetted RQOs and TPCs may be re-evaluated every five years. Through the NESMP, this re-evaluation will be based on scientific sound information. In the absence of TPCs from the EWR study on the Breede Estuary, TPCs were set based on the data collected in this study. Evaluation of the 2012 to 2015 data indicate that sedimentation, nutrient loading and flow reduction are the major management concerns for the Berg system based on evaluation of the percentage exceedance of the TPCs. Nutrient loading and freshwater inflow, as reflected by the saline intrusion upstream, is of concern for the Breede Estuary. It was demonstrated in this study that the NESMP is successful in the collection of long-term data that can be utilised to fill data gaps – both EWR studies were based on limited available data and relied on expert opinion. The NESMP could also inform management decisions through setting and evaluation of TPCs.

The case study data collected during the pilot testing phase (Chapter 4) were also used to test a DSS for the NESMP. This DSS was designed (Chapter 5) to assist with making relevant management decisions, based on the data collected with the NESMP. Through the use of this DSS, which incorporates TPCs, ecological reserve and classification studies can be audited to determine if the objectives of the classification study are being met through reserve implementation. This closes the data – information - management cycle and adds value to the NESMP. This is critical for re-evaluation of information in line with strategic adaptive management on which the management of the estuaries are based. Although a DSS has been designed to address the interpretation of the NESMP data into management information, estuaries are influenced by larger catchment activities. The DSS does identify these larger catchment related perturbations and makes recommendations based on the results from the estuary specific NESMP data. Even though collaboration and integrated water resource management are the foundation of the NWA and the ICMA, the reality is that there are still catchments where this is not fully implemented. There are areas where there is a gap between localised estuarine specific management and larger catchment management. This includes the Wild Coast / east coast of South Africa. The establishment of localised estuary management forums, catchment forums and CMAs, however, shows promise for collaboration and integrated water resource management. The NESMP DSS should therefore form part of a larger suite of DSS to support effective estuary management on a catchment base. This includes DSS that address socio-economic issues including resource use and allocation, environmental economics and development planning.

The required flexibility of the DSS demands greater user knowledge of estuarine functioning. This is addressed by user-support facilities in the form of embedded information to help quantify input variables and associated TPC exceedances. The DSS also provides guidance for management intervention. The DSS does not make estuary experts from managers with limited estuarine knowledge. This is not the objective of the DSS and therefore expert opinion may still be required in certain instances. The DSS does however guide the user in this regard to the relevant institutions / management authorities. The use of a DSS by non-specialists was the departure point of the design of the NESMP DSS. This is also the premise of various international DSS that have been designed to address water resource management. The lack of this feedback on the implementation and associated refinement of a DSS was indicated as the reason why many DSS fail (Giuponni, 2007). This study also found that although a feedback process was in place for users of the DSS, very few responded. In addition it was indicated that the MULINO DSS was used mainly by academic institutions and not by the target users, namely competent authorities. This will therefore merit the active marketing, training and capacity building of the NESMP DSS. This will also have implications for the future refinement of the DSS in a similar way that the River Ecostatus Models has been refined over the past 10 years in South Africa (Kleynhans and Louw, 2009).

The NESMP will also provide opportunities to develop and test new methods for estuarine water resource monitoring and management. This was shown with the deployment of permanent data recorders / probes on 10 estuaries across South Africa as part of this study (Chapter 4). These probes were deployed on the St Lucia, uMhlalazi, Keurbooms, Breede, Klein, Bot, Berg, Verlorenvlei, Olifants and Orange estuaries. The hourly data collected with the use of these probes fill data gaps and add information in between detailed monthly sampling. The data generated with the use of these permanent probes forms part of a larger long-term view of system response to natural and anthropogenic induced changes. Remote sensing technology is currently being used to verify water use and eutrophication of freshwater systems and shows promise for use in estuary monitoring. This includes monitoring mouth condition, sediment deposition, vegetation changes and the level of human activity, and can act as an early warning system of environmental degradation. Such an early warning system can then be used to determine where more detailed monitoring is required, thereby prioritizing management intervention within estuaries.

Deployment of real time data recorders within estuaries will also be a cost effective way to record principal water quantity and quality variables in estuaries and act on incidents in a timely fashion. These real time data recorders log variables include water flow, water depth and salinity amongst others. The deployment of these real time data recorders, although potentially cost effective, still requires a substantial amount of capital layout, and they are not completely automated.

Water resource monitoring requires that sufficient financial provision is made to establish monitoring programmes and to ensure the operation thereof. These expenses include the procurement of equipment for sampling including boats, in situ water quality instruments, permanent probes and sampling material. Currently the procurement processes of government are cumbersome, resulting in the delay of procuring critical equipment and services. In order to ensure more efficient monitoring programmes, the procurement process of government, with specific reference to technical equipment and services needs to be streamlined. In support of this, proper planning of the programme over the medium term in 3 to 5 year cycles, will prevent unnecessary delays in implementation of monitoring. Financial resources are also needed to provide measuring equipment and infrastructure for critically important information on flows within estuaries, on which all system functions depend.

Monitoring water resources is a labour intensive activity. The operational model being used in the NESMP depends on co-operation with stakeholders including government departments, conservation bodies, NGOs and the public. This is as a result of DWS not having the human capacity to undertake the sampling on an estuary specific level. Harnessing resources from stakeholders that have a vested interest in the management of estuaries addresses this lack of departmental capacity. The role of non-technical information gathering, through citizen science, will also support the programme by enhancing the available data. Human capacity does however not only entail the requirement for data collection, but also the management of the programme. Currently the programme is managed with national oversight from DWS through the Directorate Resource Quality Information Services. Within the programme a staff compliment of at least four scientists is required for the effective implementation of the programme. This is the programme manager and three regional coordinators. This is due to the constant liaison and coordination of various parties that are responsible for the data collection, requiring dedicated and focussed involvement. The regional coordinators are also responsible for data analysis, data interpretation and information generation through technical reports. Due to the scale and complexity of this task this is a minimum requirement.

In order to ensure that data are collected in a sustainable manner, logistical support from the responsible department i.e. DWS is required. This logistical support includes equipment maintenance, provision of sampling material, training and trouble shooting. Without this support, the data collection through co-operation and volunteerism will not be sustainable. This is in view of the collaborators not gaining financially from the programme. Their gain is through the generation of information that is of management relevance to these parties. Therefore, logistical support from DWS provides evidence of the commitment of DWS to the effort and resource investment by these collaborators.

To ensure that the momentum of the programme is maintained, efficient communication between the estuary specific implementing teams in the regions, and the programme management body is required. This communication entails standard electronic and telecommunication, but also personal interaction with the local sampling teams and their respective managers. This indicates DWS commitment and facilitates the building of long-term relationships, thereby ensuring the sustainability of the programme.

The data collected should be converted into useable management information to ensure successful estuary management. This management information should be available, shortly after sampling took place to ensure effective intervention. By completing the information value chain quickly, the efforts of the sampling teams can be converted into tangible management evidence, thereby ensuring the momentum of the monitoring programme is maintained and sustained. The findings of the monitoring programme should be communicated to all stakeholders, through newsletters, presentation at meetings, forums and workshop and annual technical reports.

In conclusion, this study formalised a national estuarine monitoring programme for South Africa. It identified the objective of a national programme within the boundaries of the DWS management mandate of South Africa's water resources. The NESMP makes use of existing monitoring protocols ensuring the use of historic data and standard monitoring protocols already being used by DWS and other roleplayers in the management of estuaries. A limitation of the study was that it only addressed abiotic rather than biotic monitoring. The latter requires specialist input that is not readily available in DWS. Thus only Tier 1 was assessed and future studies will be needed to provide information on the practical implementation of Tier 2 and Tier 3 assessments.

Another shortcoming of the thesis was that it could only present data on and test the protocol for the Berg and Breede estuaries. Although the NESMP protocol was tested on 28 estuaries between 2012 and 2015, time and space constraints did not allow for inclusion of a critical analysis from all these systems. The use of two permanently open estuaries in the Western Cape limited the evaluation scope of the NESMP to a single biogeographical area (Cool Temperate Zone) and a single estuary type. Evaluation of the NESMP on a temporarily open-closed system may have added further knowledge on the effectiveness of the monitoring programme on different estuary types. The testing of the NESMP however alluded to the practical implications of the NESMP protocols in the field, thereby facilitating the refinement of the implementation of the NESMP.

The study also tested the RQOs that have been set for the Berg Estuary, paving the way for future auditing of RQOs through TPCs. This study compared the use of expert set TPCs, based on limited data with the use of much more extensive data collected through the NESMP. This indicated that the TPCs based on relevant experts are similar to those based on 10^{th} and 90^{th} percentile calculation using more extensive datasets. The study therefore provides new knowledge on an approach to be used on the setting of future TPCs in a statistical orientated manner. Recommended future studies could investigate different methods for determining TPCs using NESMP data. In addition the future use of volunteers in a sustainable manner, especially in light of the potential use of citizen science in estuary monitoring, needs to be investigated further. This may make an important contribution to the future sustainability of the NESMP developed in this study.

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APPENDIX A

EWR / MONITORING METHODS: EXAMPLE OF LONG-TERM RESOURCE MONITORING PROGRAMME PROPOSED FOR THE BERG RIVER ESTUARY AFTER IMPLEMENTATION OF THE RESERVE (DWS, 2012)

ECOLOGICAL COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations
BIRDS	Undertake counts of all water associated birds. All birds should be identified to species level and total number of each counted.	Winter and summer survey, yearly	Entire estuary
FISH	Conduct fish surveys using both seine and gill nets as primary gear.	Two years after implementation conduct summer and winter survey, followed by summer and winter survey every 3 years thereafter	Entire estuary (40+ stns)
INVERTEBRATES	Zooplankton: Collect quantitative samples using a flow meter after dark, preferably during neap tides (mid to high tide). Sampling to be done at mid- water level, i.e. not surface. (Include chlorophyll a measurements on benthic microalgae and water column chlorophyll as to establish feeding links)	Same as for fish Entire estuary	(10-15 stns)
	Benthic invertebrates: Collect (subtidal) samples using a Zabalocki-type Eckman grab sampler with 5-9 randomly placed grabs (replicates) at each station. Collect intertidal samples at spring low tide using core sampling.	Same as for fish Entire estuary	(10-15 stns)
	Macrocrustaceans: Collected quantitative samples during neap tides (mid to high tide), at the same stations used for zooplankton, using a benthic sled with flow meter.	Same as for fish Entire estuary	(10-15 stns
MACROPHYTES	Use aerial photographs to quantify area covered by different macrophyte habitats and produce a vegetation map. Conduct ground survey to: 1) verify areas covered by different macrophyte habitats 2) check the spread of alien vegetation, 3) check the spread of aquatic weeds (upper reaches) and macroalgae in the lower estuary reaches 4) check the extent of bare ground in the halophytic and xeric floodplain, depth to groundwater and groundwater salinity. 5) Check the distribution of reeds and sedges up the length of the estuary in relation to the longitudinal salinity gradient and the area covered by the sensitive sedge pan habitat. Measurements of macrophyte cover along permanent transects in	Annually	Entire estuary

ECOLOGICAL COMPONENT	MONITORING ACTION	TEMPORAL SCALE (frequency and when)	SPATIAL SCALE (No. Stations
	relation to flooding, sediment water content, water depth, sediment salinity, depth to groundwater and groundwater salinity.		
MICROALGAE	Phytoplankton: Conduct water column chlorophyll a measurements and counts of dominant phytoplankton group.	5Same as for fish Entire estuary	(8 stns)
	Benthic microalgae: Conduct benthic chlorophyll a measurements	Same as for fish Entire estuary	(8 stns)
WATER QUALITY	Collect data on conductivity, temperature, suspended matter/turbidity, dissolved oxygen, pH, inorganic nutrients and organic content in river inflow	At least monthly	At Jantjiesfontein
	Monitor inorganic nutrient inflow from agricultural return flow in upper reaches (e.g. bore hole sampling)	At least monthly	3-5 stns along upper Banks
	Collected longitudinal salinity and temperature profiles (*in situ*)	Continuous *in situ* salinity probe To be measured when biotic surveys require information for interpretation	At 11km: Kliphoek (G1H024), new gauge at 40 km
	Water quality measurements taken along the length of the estuary (surface and bottom samples) for salinity, pH, dissolved oxygen, suspended solids/turbidity and inorganic nutrients.		Entire estuary (10-15 stns)
	Baseline data set for pesticides/herbicides accumulation in Sediments	Every 3 – 6 years	Focus on depositional Areas
HYDRODYNAMICS	Water level recordings s	Continuou	2 km: Laaiplek (G1H074), 11km: Kliphoek (G1H024), 51 km: Jantjiesfontein G1H023) New gauge at 40 km
	Improved Flow gauging of low flow (< 5 m^3S^{-1}) and 8.1	Continuous	Near Misverstand
	Aerial photographs of estuary (spring low tide)	Annually	Entire estuary
SEDIMENT DYNAMICS	Bathymetric survey: Series of cross-section profiles and a longitudinal profile collected at fixed 500 m intervals, but more detailed in the mouth (vertical accuracy better than 300 mm)	Every 3-6 years, depending on time scale of dominant sedimentation/erosion processes in an estuary, as well as after flood events.	Entire estuary
	Set sediment grab samples (at cross section profiles) for analysis of particle size distribution (PSD) and origin (i.e. using microscopic observations)		Entire estuary
	Daily sampling of suspended sediment (and organic matter)	Daily	Sishen-Saldanha train bridge

APPENDIX B

SUMMARY OF DIFFERENT COMPONENTS OF THE MONITORING PROGRAMMES USED IN THE US

Index	Indicators	Ecological Condition by Site	Ranking by NEP Estuary or Region
Water Quality Index	1) Dissolved Inorganic Nitrogen [DIN]; 2) Dissolved Inorganic phosphorous [DIP]; 3) Chlorophyll a; 4) Water clarity; and 5) Dissolved Oxygen.	**Good:** No indicators are rated as poor & maximum of 1 indicator is rated fair. **Fair:** One indicator is rated poor or 2 or more indicators rated fair. **Poor:** Two or more indicators are rated poor.	**Good:** Less than 10% of NEP estuarine area is in poor condition & more than 50% of NEP estuarine is in good condition. **Fair:** 10% to 20% of the NEP estuarine area is in poor condition or more than 50% of the NEP estuarine area is in combined poor and fair condition. **Poor:** More than 20% of the NEP estuarine area is in poor condition.
Sediment Quality Index	1) Sediment toxicity; 2) Sediment contaminants; and 3) Sediment total organic carbon [TOC].	**Good:** No component indicators are rated poor & the sediment contaminants indicator is rated good. **Fair:** No component indicators are rated poor & the sediment contaminants indicator is rated fair. **Poor:** One or more component indicators are rated poor.	**Good:** Less than 5% of the NEP estuarine area is in poor condition &more than 50% of the NEP estuarine area is in good condition. **Fair:** 5% to 15% of the NEP estuarine area is in poor condition or more than 50% of the NEP estuarine area is in combined poor & fair condition. **Poor:** More than 15% of the NEP estuarine area is in poor condition.
Benthic Index	1) Benthic community diversity; 2) Presence & abundance	Determined using regionally dependent benthic index scores.	**Good:** Less than 10% of the NEP estuarine area has a poor benthic index score, & more than 50% of the NEP

Index	Indicators	Ecological Condition by Site	Ranking by NEP Estuary or Region
	of pollution-tolerant species; and 3) Presence & abundance of pollution-sensitive species.		estuarine area has a good benthic index score. **Fair:** 10% to 20% of the NEP estuarine area has a poor benthic index score, or more than 50% of the NEP estuarine area has a combined poor and fair benthic index score. **Poor:** More than 20% of the NEP estuarine area has a poorbenthic index score.
Fish Tissue Contamination Index	**Good:** For all chemical contaminants listed in Table below, composite fish tissue contaminant concentrations are below the EPA Advisory Guidance* concentration range. **Fair:** For at least one chemical contaminant listed in Table 4 composite fish tissue contaminant concentrations are within the EPA Advisory Guidance concentration range. **Poor:** For at least one chemical contaminant listed in Table 4, composite fish tissue contaminant concentrations are above the EPA Advisory Guidance concentration	**Good:** Less than 10% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition, and more than 50% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in good condition. **Fair:** 10% to 20% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition, or more than 50% of the fish samples analyzed (Northeast Coast region)	**Good:** Less than 10% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition, and more than 50% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in good condition. **Fair:** 10% to 20% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition, or more than 50% of the fish samples analyzed (Northeast Coast region)or the monitoring stations where fish were caught (all other regions) are in combined poor and fair condition.

Index	Indicators	Ecological Condition by Site	Ranking by NEP Estuary or Region
	range.	or the monitoring stations where fish were caught (all other regions) are in combined poor and fair condition. **Poor:** More than 20% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition.	**Poor:** More than 20% of the fish samples analyzed (Northeast Coast region) or the monitoring stations where fish were caught (all other regions) are in poor condition.

APPENDIX C

SUMMARY OF THE IMPLEMENTATION OF THE NESMP ON DIFFERENT ESTUARIES IN SOUTH AFRICA BETWEEN 2012 AND 2017. IMPLIMENTATION AGENCIES INDICATED WITH BOLD HAVE FORMAL AGREEMENTS WITH DWS IN THE FORM OF AN MoU.

	ESTUARY	**ESTUARY TYPE**	**DATE COMMENCED**	**DATE ENDED**	**IMPLEMENTATION AGENCY**				
					MUNICIPALITY	**CONSERVATION BODY**	**NGO**	**UNIVARSITY**	**GOVERNMENT DEPARTMENT**
1	St Lucia	TOCE	2013			X			X
2	Mlalazi	Permanently open	2013			**X**			
3	Mvoti	River mouth	2016					X	
4	aMathikula	Permanently open	2016					X	
5	Nyoni	Permanently open	2016					X	
6	Zinkwazi	TOCE	2013	2015			X		
7	Mdlotane	TOCE	2013	2015			X		
8	Nonoti	TOCE	2013	2015			X		
9	Thukela	River mouth	2016					X	
10	Tongati	TOCE	2016					X	
11	Mhlanga	TOCE	2013			**X**			
12	Mdloti	TOCE	2013	2014		**X**			
13	Mgeni	TOCE	2013			**X**			
14	Mpenjati	TOCE	2013			**X**			
15	Mtamvuna	TOCE	2013			**X**			

	ESTUARY	ESTUARY TYPE	DATE COMMENCED	DATE ENDED	IMPLEMENTATION AGENCY				
					MUNICIPALITY	CONSERVATION BODY	NGO	UNIVARSITY	GOVERNMENT DEPARTMENT
16	Mtentu	Permanently open	2017			**X**			
17	Mzimkaba	Permanently open	2017			**X**			
18	Mtanfufu	Permanently open	2015			**X**			
19	Bushmans	Permanently open	2015	2016				X	
20	Gamtoos	Permanently open	2013						**X**
21	Kromme	Permanently open	2013						**X**
22	Keurbooms	Permanently open	2016						X
23	Knysna	Estuarine Bay	2016			X	X		
24	Swartvlei	Estuarine lake	2013	2014		X			
25	Wilderness	TOCE	2013	2014		X			
26	Groot Brak	TOCE	2016	2016					X
27	Klein Brak	TOCE	2016	2016					X
28	Breede	Permanently open	2012				X		
29	Heuningnes	TOCE	2017			**X**			
30	Klein	TOCE	2016			**X**	X		
31	Bot	TOCE	2016			**X**	X		
32	Berg	Permanently open	2012		**X**				
33	Verlorenvlei	TOCE	2013		**X**				
34	Olifants	Permanently open	2013		**X**				

	ESTUARY	ESTUARY TYPE	DATE COMMENCED	DATE ENDED	IMPLEMENTATION AGENCY				
					MUNICIPALITY	CONSERVATION BODY	NGO	UNIVARSITY	GOVERNMENT DEPARTMENT
35	Orange	River Mouth	2016	2016			X		

APPENDIX D

EXAMPLE OF THE DESCRIPTIVE STATITISTICS OF DATA COLLECTED BETWEEN 2012 AND 2015 ON THE BERG ESTUARY (THE ENTIRE DATABASE CAN BE ACCESSED THROUGH THE DWS WEBSITE http://www.dwa.gov.za/iwqs/)

SALINITY (PPT)

	Berg 1 (0Km)	*Berg 2 (6Km)*	*Berg 3 (10Km)*	*Berg 4 (20Km)*	*Berg 5 (26Km)*	*Berg 6 (40Km)*
Mean	24.9	18.3	13.4	9.5	4.7	1.2
Standard Error	1.6	2.0	1.8	1.5	0.9	0.4
Median	27.6	24.6	16.1	7.7	0.8	0.5
Mode	0.5	0.4	0.4	0.4	0.6	0.3
Standard Deviation	10.8	13.6	11.7	10.3	6.1	2.4
Sample Variance	116.2	184.7	136.7	105.6	37.3	5.9
Kurtosis	0.4	-1.7	-1.2	0.0	2.3	11.9
Skewness	-1.2	-0.2	0.3	0.9	1.7	3.6
Range	35.9	35.3	37.3	36.3	23.8	11.4
Minimum	0.5	0.4	0.4	0.3	0.2	0.2
Maximum	36.4	35.7	37.7	36.6	24.0	11.6
Count	44.0	44.0	44.0	44.0	44.0	44.0