

The development, implementation and evaluation of an integrated aquatic vegetation management plan for the control of submersed aquatic vegetation in South African impoundments

BJ Du Plessis



orcid.org 0000-0002-0450-0155

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Promoter: Prof MS Janse van Vuuren

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To my parents, Danie and Olivia (née Pretorius) Du Plessis,
who were my first teachers.

ABSTRACT

South Africa is an arid country with intermittent, unevenly distributed rainfall and experiences amongst the most variable flow regimes in the world. These climatological realities necessitate careful strategic planning by water resource managers to ensure an equitable distribution of water to all users. This situation has led to substantial investments in the damming of rivers for industrial, agricultural and hydro-electric purposes and the construction of complex inter-basin water transfer schemes to augment water from surplus catchments to catchments where the demand exceeds supply.

The Usutu-Vaal Phase II Inter-Basin Water Transfer Scheme, located in the eastern-central area of South Africa, experienced operational problems caused by nuisance submersed aquatic vegetation (SAV) for many years. Aquatic vegetation interfered with the operation of high-capacity water transfer pumps and other infrastructure of the scheme which resulted in downtime with substantial economic implications. Over the past decades the focus in South Africa was mainly on the control of floating declared aquatic weeds, such as water hyacinth (*Pontederia crassipes* Mart.). The control of SAV was not a high priority and as a result insufficient information on the management of SAV in South Africa is currently available. The only information on larger scale SAV management operations in the country is the control of SAV in two waterbodies with a full surface area (FSA) of approximately 60ha (Germiston Lake and Potchefstroom Dam) with sterile grass carp as biocontrol agent and in addition to this, the herbicidal control of SAV and macroscopic algae in irrigation canals. Prior to this study, no integration of different control methodologies on large scale SAV management was documented in South Africa.

The study area includes the Usutu-Vaal Phase II Inter-Basin Water Transfer Scheme which comprises the Heyshope Dam (FSA=5,023ha), Geelhoutboom balancing dam (FSA=36ha) and two concrete-lined conduits, Geelhoutboom Canal (21.1km length) and the Balmoral Canal (4.6km length). Water is pumped from Heyshope Dam in the Usutu River catchment via the Geelhoutboom Canal to the Geelhoutboom Dam and from there over the escarpment to the Balmoral Canal which spills into the neighbouring Vaal River catchment. As all components of the scheme experienced significant operational problems with indigenous nuisance SAV, mainly *Potamogeton schweinfurthii* A. Benn., *Stuckenia pectinata* (L) Börner and *Lagarosiphon muscoides* Harv., it was necessary to implement an Integrated Aquatic Vegetation Management Plan (IAVMP) to manage problematic aquatic vegetation in order to ensure a sustainable water supply to the Vaal River System.

The IAVMP on the Usutu-Vaal Phase II Inter-Basin Water Transfer Scheme was developed around an herbicidal component, with a diquat-based herbicide, and sterile grass carp (*Ctenopharyngodon idella* Val.) as the biological control component, in addition to mechanical adaptations to structures to preclude SAV from entering pumping station forebays and to prevent the biocontrol agent from escaping the target areas.

The primary purpose of the study was to develop and implement tools to prevent nuisance SAV from impacting on the water transfer scheme's ability to sustain an uninterrupted water supply from the Usutu River catchment to the neighbouring Vaal River System. Certain management objectives or aims were set to achieve the goals of the IAVMP. The first management objective was to implement a programme of total aquatic vegetation control during all periods in the Geelhoutboom balancing dam as this was the area experiencing the most significant SAV problems. The aim was to eliminate SAV interference with the operation of the high-capacity pumps (5m³/s) at the Geelhoutboom Pumping Station. The second management objective was to implement a programme of total aquatic vegetation control at all operational periods in both the conduits by securing the integrity of the water conveyance system from Heyshope Dam to Geelhoutboom Dam (Geelhoutboom Canal) and from the Geelhoutboom Dam to the Vaal River System (via the Balmoral Canal). The third management objective was to implement a programme of only partial aquatic vegetation control in Heyshope Dam, with the aim to reduce the original SAV infestation in the impoundment from 700ha to 70ha and to decrease contamination from the impoundment to the rest of the water transfer system. The challenge in Heyshope Dam was to see if the partial control of SAV was achievable with sterile grass carp. The final objective of the study was to develop an IAVMP that can be extrapolated and site-specifically adapted to impoundments experiencing similar problems with nuisance SAV with maximum effectiveness on the target plants and minimum interruption of the receiving environment (non-target fauna and flora).

Several hundreds of hectares of nuisance aquatic vegetation were treated with a diquat-based herbicide and 36,000 sterile grass carp individuals were stocked in the Heyshope Dam and 1,400 individuals in Geelhoutboom Dam. This translates to 51 units per infested area (hectares) in the Heyshope Dam and 38 fish per ha in Geelhoutboom Dam. Mechanical adaptations to infrastructure at the Geelhoutboom Canal outlet into the balancing dam and the forebay grids and overflow were also implemented to accommodate the biocontrol agent and to prevent aquatic vegetation entering the forebays of water transfer pumps.

The IAVMP proved to be successful as the area of SAV infestation was reduced from 700ha in 2001 to 375ha in 2006, and 69ha in May 2008, an area slightly smaller than the set management objective of 70ha, which calculates to 1.5% of the FSA of Heyshope Dam. No pump failures were experienced due to interference by aquatic vegetation over the total study period and unscheduled downtimes could not be attributed to nuisance aquatic vegetation blockages of grids or water transfer pumps. Savings in pump maintenance were found to be significant and Department of Water and Sanitation (DWS) officials were of the opinion that the programme was cost-effective and worth the investment.

As part of the ecological component of the monitoring programme, ecological sensitive areas in Heyshope Dam were identified, demarcated and protected as far as possible from interference by the aquatic vegetation control activities. When the aim of a 70ha reserve of SAV in Heyshope Dam was reached in the winter of 2008, a moratorium was placed on any further stockings of sterile grass carp in the impoundment and herbicidal treatments were restricted to a demarcated area of 11ha near the pump abstraction location at the dam wall area. The SAV survey of May 2010 however, revealed that the SAV surface area was further reduced from 69ha calculated in 2008 to a mere 1ha. It was clear that the anticipated impact of piscivores on the fingerling/juvenile sized grass carp survival at the initiation of the programme was overestimated and the palatability of the hardy, fibrous *P. schweinfurthii*, as grass carp nourishment, was underestimated.

Although the Heyshope Dam is an unnatural constructed reservoir, the altered habitat created after construction (from a lotic to a lentic ecosystem) has a definite conservation value as the impoundment plays refuge (especially during drought periods) to many waterbird species frequenting the numerous wetlands in the larger catchment. The conservation value of the adapted aquatic ecosystem should be protected as far as possible and the impact of the IAVMP on non-target species should be kept to a minimum without compromising the original intentions for construction of the scheme, i.e., water augmentation to the Vaal River System.

In addition to the SAV management programme, the effect of the IAVMP on the receiving environment (i.e., non-target fauna and flora) was monitored and evaluated in the Heyshope Dam with the aim to generate enough information to develop a protocol for IAVMP's to be applied to other impoundments, with similar nuisance SAV problems. This was done by monitoring the water quality of the tributaries and the two impoundments, evaluating the trophic status of Heyshope Dam, and monitoring the effect of the removal of SAV on macroinvertebrates, fish and waterbird communities.

The results concluded that Heyshope Dam is an oligotrophic, turbid system. It was also clear that grass carp preferred the more palatable softer, finer structured *Stuckenia pectinata* to the more fibrous, hardy *Potamogeton schweinfurthii*, as *S. pectinata* was removed by preference from the impoundment before *P. schweinfurthii*. Twenty-four macro-invertebrate taxa were sampled during April 2000, in comparison to 19 taxa observed during April 2007. Thus, five taxa associated with SAV as substrate were not recorded after the implementation of the IAVMP. Three indigenous fish species; the Bushveld Smallscale Yellowfish (*Labeobarbus polylepis* Boul.), Sharptooth Catfish (*Clarias gariepinus* Burch.), and the Banded Tilapia (*Tilapia sparrmanii* Smith); and three exotic species, Carp (*Cyprinus carpio* L.), Largemouth Bass (*Micropterus salmoides* Lac.) and Mosquitofish (Baird & Girard) were sampled at the selected sites in Heyshope Dam. The only noticeable change in the fish community since the inception of the study was the possible disappearance of the Southern Mouthbrooder (*Pseudocrenilabrus philander* Weber), which needs to be verified in a follow-up monitoring programme.

The positive effects of the implementation of an IAVMP on the fish community is that Small-scale yellowfish numbers increased significantly from 2000 to 2007, and that no evidence could be found of the biocontrol-agent migrating out of the target area. The sterile grass carp stocked in the Geelhoutboom balancing dam in 2002 (400 units) and 2004 (1,000 units) died out towards the end of 2021 as the original target SAV was returning to the waterbody and no grass carp activity was observed in the balancing dam. It can therefore be concluded that the biocontrol agent has a life expectancy of up to 18 years under favourable local conditions.

The introduction of the IAVMP on Heyshope Dam resulted in a sharp decline in the numbers of the two true open water avian herbivores on the impoundment, *Fulica cristata* and *Thalassornis leuconotus*. *F. cristata* aggressively protects its territory and scares away other competitive waterbird species and they are therefore considered to be very strong territorial birds. It is anticipated that the reduction in *F. cristata* numbers may facilitate waterfowl species diversity.

This study was the first on the implementation and evaluation of a large scale IAVMP on SAV in South Africa. The study highlights the successes and shortcomings in the development of an IAVMP for the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme. It is accepted that, with progressive deteriorating surface water quality, problems with nuisance SAV will increase through South Africa. This study will contribute to the knowledge base on the management of SAV in South Africa as it represents the first large scale programme to manage SAV. This thesis provides baseline information for the development of IAVMP's in South Africa and will provide a guideline in the development, implementation and evaluation of IAVMP's on SAV in the country.

KEY TERMS

Biocontrol

Habitat modification

Herbicidal control

Integrated Pest Management

Mechanical control

Sterile grass carp

Usutu-Vaal Phase II Inter-Basin Water Transfer Scheme

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THE ALMIGHTY

ABBREVIATIONS

ABBREVIATION	DESCRIPTION
AVCASA	Association of Veterinary and Crop Associations of South Africa
ASPT	Average Score Per Taxon
CHL <i>a</i>	Chlorophyll <i>a</i>
CPU	Catch Per Unit
CPUE	Catch Per Unit Effort
CWAC	Coordinated Waterbird Counts
CWT	Code Wire Tags (sterile grass carp ID)
DO	Dissolved Oxygen
DWS	Department Water and Sanitation, South Africa
DWAF	Department of Water Affairs and Forestry, South Africa
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
EIA-BAS	Environmental Impact Assessment – Basic Assessment
EMP	Environmental Management Plan
FAO	Food and Agriculture Organisation (United Nations)
FL	Fork length (fish length)
FRAI	Fish Response Assessment Index
FSA	Full Supply Area
FSL	Full Supply Level
GWS	Government Water Scheme
HRAC	The global Herbicide Resistance Action Committee
IAVMP	Integrated Aquatic Vegetation Management Plan
IPM	Integrated Pest Management
IUCN	International Union for Conservation of Nature
MIRAI	Macro-invertebrate Response Assessment Index
NEM:BA	National Environmental Management: Biodiversity Act (Act No. 10 of 2004)
OEMP	Operational Environmental Management Plan
PCO	Pest Control Operator (Certified in terms of Act No. 36 of 1947)
PCSIB	Pest Control Industry Board (of South Africa)
ppm	Parts per million
RQS	Resource Quality Services (Division of DWS)
SANAS	South African National Accreditation System
SASS5	South African Scoring System Version 5 for macro-invertebrate monitoring
SAV	Submersed Aquatic Vegetation
SAVPGA	Submersed Aquatic Vegetation Potential Growth Area

AN INTEGRATED AQUATIC VEGETATION MANAGEMENT PLAN FOR THE CONTROL OF SUBMERSED AQUATIC
VEGETATION IN SOUTH AFRICAN IMPOUNDMENTS

SDS	Safety Data Sheet
T _A	Temperature - ambient
T _W	Temperature - water
TDS	Total Dissolved Salts
TL	Tail length (fish length)
TVA	Target Vegetation Area
WTS	Water Transfer Scheme

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

South Africa is a water scarce country with an average annual rainfall just below 500mm (58% of the world average of 860mm) (Schulze, 1997). The majority of the country (65%) receives less than 500mm rain annually and 21% receives less than 200mm (DWAF, 1988). The eastern- and southern coastal areas of South Africa have considerably higher rainfall than the interior and western coastal areas (DWAF, 2008). Water scarcity resulted in large scale damming of rivers for domestic, industrial, agricultural and hydro-electrical purposes. It also necessitated the establishment of inter-basin water transfer schemes to augment catchments where demand exceeds availability (DWAF, 1988; King et al., 2011).

Large petroleum industries, such as SASOL II and III near the town of Secunda and ESKOM's power stations on the Highveld, play a major role in the macroeconomy of South Africa. These industries rely on an uninterrupted water supply from the Vaal River System (Envirokonsult, 2000). To meet this growing demand, the Department of Water and Sanitation (DWS) had to augment the available water supply of the Vaal River from other catchments. The Usutu-Vaal Inter-basin Water Transfer Scheme was one of several inter-basin water transfer schemes, initiated in the 1970's by the DWS, to satisfy this demand. The second phase of the Usutu-Vaal Inter-basin Water Transfer Scheme, transferring water from the Usutu River catchment to the Vaal River catchment, was implemented during 1984, after completion of the Heyshope Dam and its conduits.

During early 2000, submersed aquatic vegetation (SAV) blocked the forebay grids of the pumping stations and the cooling systems of the high-capacity water transfer pumps of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme. SAV interfered with the normal operation of the scheme to such an extent that pump failures occurred on a weekly basis (Envirokonsult, 2000). This resulted in interrupted water supply to the Vaal River System, as well as irregular electricity consumption regimes which in turn, led to a significant escalation in maintenance costs and a loss of income for the DWS.

A site-specific aquatic vegetation control programme was implemented in 2000 in the Geelhoutboom Dam to guarantee a sustainable water supply to the Vaal River System. This balancing dam has a full surface area (FSA) of 36ha. The programme incorporated a once-off herbicidal application with a diquat-based herbicide and biological control with sterile (triploid) grass carp (*Ctenopharyngodon idella* Val.). Excellent results were obtained after the initial stocking of 400 fish during 2002 and another 1,000 during 2004. However, the intensity of the SAV infestation, and problems with SAV blocking the water transfer pumps at Heyshope Dam, necessitated the expansion of the control programme to include the source of the nuisance plants. After consultation with the Department of Agriculture, Conservation and Environment and Mpumalanga Parks Board, it was decided to incorporate Heyshope Dam in the aquatic vegetation control programme (Envirokonsult, 2000).

The SAV species encountered in the water transfer scheme, namely *Potamogeton schweinfurthii* Benn., *P. nodosus* (Fisch.), *Stuckenia pectinata* (L.) Börner, *Lagarosiphon major* (Ridley), *L. muscoides* (Harv.), and *Najas marina* (L.) are all indigenous to South Africa (Cook, 2004; Van Ginkel and Cilliers, 2017). The target species mainly responsible for interference with the operation of the scheme were *P. schweinfurthii*, *S. pectinata* and *L. muscoides*. The first significant problems experienced with nuisance SAV in South Africa were described by Schoonbee (1991) in Germiston Lake and Potchefstroom Dam (both relatively small dams with an FSA of approximately 60ha) and in local irrigation canals in the early to mid-1990's (Du Plessis and Davidson, 1995). Either biocontrol with triploid grass carp or herbicidal control with diquat was applied to manage SAV infestations in South Africa, but no integrated control strategies were used.

A wealth of information on the management of SAV in waterbodies is available internationally, especially in the United States of America (USA). Over the past decades intensive research has been done in the USA to develop strategies and techniques for environmentally and scientific sound management, conservation, and restoration of aquatic ecosystems (Madsen, 2000; Lembi, 2003; Pípalová, 2006; Cassani et al., 2008; Cuda et al., 2008; Helfrich et al., 2009; Gettys et al., 2014; Stallings et al., 2015). These studies focused *inter alia* on different aquatic vegetation species, methodologies of control and impact assessments.

Prior to this study (conducted from 2006 to 2010) the control of nuisance SAV in South Africa was mainly addressed on an *ad hoc* basis with the focus on herbicidal treatments. No integrated aquatic vegetation management strategies were applied and local literature

on SAV management is limited. Local experience with biological control, using grass carp as biocontrol agent, is limited to minor applications in mostly small recreational ponds, irrigation canals (one study) and larger urban impoundments (two case studies) (Schoonbee, 1991; Du Plessis and Davidson, 1995).

With the deterioration of water quality of South African surface waters, aquatic vegetation management is becoming an essential component of water resource management. The official DWS policy of addressing pollution at the source (DWAF, 1988) proved to be inadequate. Furthermore, it became clear that the change in the political dispensation in South Africa necessitated a symptomatic approach to restore the secondary effects of surface water pollution caused by an increase in eutrophication. The experience gained from the study on the Usutu Vaal Phase II Inter-basin Water Transfer Scheme identified the urgent need to develop an Integrated Aquatic Vegetation Management Plan (IAVMP) for South African impoundments.

This study focuses on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme, which consists of the Heyshope Dam, Geelhoutboom Balancing Dam and two concrete-lined canals. The Heyshope Dam Pumping Station pumps water to the Geelhoutboom Canal, which gravitates to the Geelhoutboom Dam. From this dam, the water is pumped by the Geelhoutboom pumping station, over the watershed, via the Balmoral Canal to the Klein Vaal River, from where it gravitates to the Grootdraai Dam, situated in the neighbouring Vaal River catchment (see Figures 3.1 and 3.2 for map of study area).

Geelhoutboom Dam, the concrete-lined Geelhoutboom Canal (20.1km in length), as well as the Balmoral Canal (4.6km in length) are considered man-made water conduits which should be kept in an optimal operational condition (clean and free of all aquatic and terrestrial vegetation) at all times. Although initially constructed for the sole purpose of water delivery to the Vaal River System, the Heyshope Dam is regarded as a waterbody with a specific ecological value, as it provides refuge to many waterbirds in wetlands of the Wakkerstroom area, renowned for its rich birdlife.

The presence of SAV in a natural aquatic ecosystem with conservation value is essential as it plays an important role in the food chain and provides protection, attachment, spawning and nourishment for many species of aquatic fauna (Rozas and Odum, 1998). Phytoplankton forms the base of the aquatic food chain (Krull, 1970; Lembi, 2003), while macrophytes, such as SAV, provide habitat and shelter for fish, waterfowl, and other wildlife. In addition, macrophytes provide food for insects, some fish species, waterfowl

and mammals (Lembi, 2003). However, the excessive proliferation of SAV can cause numerous problems. These include: Interfering with potable water quality (Bruwer, 1979; Helfrich et al., 2009), resulting in recreational (Lembi, 2003) and aesthetical problems; increasing the risk of flooding, causing health effects because it acts as a substrate for vectors of waterborne diseases (Bruwer, 1979; Lembi, 2003; Melaram et al., 2022); inducing fish kills by removing dissolved oxygen in shallow, isolated areas (Wetzel, 1983; Wilcove et al., 1998; Simon and Townsend, 2003); enhancement of siltation (Envirokonsult, 2012; Du Plessis, 2020); interfering with irrigation (Du Plessis and Davidson, 1995) as well as bulk water delivery as in the case of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme.

It was anticipated that any aquatic vegetation control programme in Heyshope Dam could have an impact on the ecology of the impoundment and possibly also its catchment. It was therefore decided that an Environmental Impact Assessment (EIA) should be conducted prior to the incorporation of the impoundment into the aquatic vegetation management programme (Envirokonsult, 2000).

1.2 PROBLEM STATEMENT

Large infestations of SAV in the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme resulted in interrupted water supply to the Vaal River System, as well as irregular electricity consumption regimes and a significant escalation in the maintenance cost at the two high-capacity pumping stations at Heyshope Dam and at the Geelhoutboom balancing dam. As these SAV infestations interfered with the optimal operation of the Usutu Vaal Phase II Inter-basin Water Transfer Scheme, it had to be addressed by implementing an IAVMP in the scheme to ensure a sustainable, uninterrupted water supply to the Vaal River System.

1.3 AIMS OF STUDY

The overall aim of the study was to develop an IAVMP for the water transfer scheme, by developing and implementing a SAV management strategy for all the components of the system, and to evaluate the success of the strategy on target vegetation in the scheme, as well as the impact thereof on the receiving aquatic ecosystem (non-target fauna and flora) in the Heyshope Dam.

The primary purpose of the IAVMP, initiated in the Geelhoutboom balancing dam in 2001 and extended to the Heyshope Dam, was to develop and implement tools to prevent nuisance aquatic vegetation to impact on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme's ability to sustain an uninterrupted water supply to the Vaal River System. This has led to the development of an IAVMP, with the following aims:

Aim 1: Maintain and operate the Geelhoutboom balancing dam free of all aquatic vegetation on a permanent basis. As the Geelhoutboom Dam was constructed with the sole purpose to impound water to generate capacity for the 5m³/s water transfer pumps of the Geelhoutboom Pumping Station, the balancing dam was regarded to be of no ecological conservation value. Thus, total aquatic vegetation control was required in the Geelhoutboom balancing dam.

Aim 2: Maintain both the Geelhoutboom and Balmoral canals free of terrestrial and aquatic vegetation on a permanent basis. As these concrete-lined canal structures are regarded as man-made structures without any ecological conservation value, total aquatic and terrestrial vegetation control was required in both.

Aim 3: Reduce the infestation of nuisance SAV (700ha in year 2000) in Heyshope Dam to 10% (70ha) of the original infestation. As Heyshope Dam is considered a water body with an ecological conservation value, the aim was to manage nuisance aquatic vegetation to such an extent that the biomass did not interfere with the operation of the water transfer pumps at the dam wall or contaminate the downstream Geelhoutboom Dam and the two canals with nuisance aquatic vegetation. Thus, only partial aquatic vegetation control was required in the Heyshope Dam with the aim to minimise the impact of the SAV rehabilitation measures on non-target fauna and flora in the impoundment.

Aim 4: Monitor and evaluate the success of the IAVMP on the target vegetation in the Heyshope Dam, Geelhoutboom Dam and the two conduits and supply recommendations to optimise the programme.

Aim 5: Monitor and evaluate the impact of the IAVMP on the non-target fauna and flora in the Heyshope Dam and recommend measures to mitigate negative impacts on the receiving environment.

Aim 6: Present an IAVMP for the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme which can be applied as a blueprint to be extrapolated with site-specific adaptations to other impoundments experiencing similar problems with nuisance SAV.

1.4 STRUCTURE OF THE THESIS

The thesis is structured into 10 chapters. Chapter 1 presents the need (problem statement) and context, together with the scope, aims and objectives of the study. A comprehensive literature review on the history of aquatic vegetation management in South Africa, factors that play a role in SAV growth and the management of aquatic vegetation internationally are presented in Chapter 2. A detailed description of the study area, which comprises the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme from the tributaries of Heyshope Dam in the Usutu River catchment to the Vaal River catchment and a general description of the climatology of the area, are presented in Chapter 3. The methodologies applied to develop the IAVMP for the scheme and to evaluate the effect thereof on the target species as well as the receiving environment (non-target species) in especially Heyshope Dam, are presented in Chapter 4. The results of the monitoring programme are discussed in two sections of Chapter 5. The first section covers the environmental assessment to establish the impact of the IAVMP on the receiving environment, while the second section evaluates the overall success of the implemented IAVMP on the scheme. In Chapter 6 the developed IAVMP for the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme is presented, whilst the dynamics of an IAVMP in Heyshope Dam is debated in Chapter 7. General conclusions and recommendations for further research are made in Chapters 8 and 9 respectively, and the thesis is finalised with the cited references in the final chapter, Chapter 10.

Because South Africa is not blessed with any significant natural lakes, the terms “impoundment”, “dam” and “reservoir” are used throughout the thesis to describe the artificially constructed lentic waterbodies. In conclusion, this study is the first large scale aquatic vegetation management programme on SAV in the history of South Africa and aims to set a baseline IAVMP for South African impoundments that could be site-specifically adjusted to include other impoundments experiencing similar problems with nuisance SAV.

CHAPTER 2

LITERATURE REVIEW

The aim of this chapter is to present a broad overview of the (1) history of integrated aquatic vegetation management in the Republic of South Africa, (2) problem forming submersed aquatic plant species in South African waterways, with particular reference to the target species encountered in the study area, (3) impact of the overabundant proliferation of submersed aquatic vegetation (SAV) on the receiving environment, (4) management options available to control of SAV and their impact on target and non-target aquatic fauna and flora, and (5) place of integrated aquatic vegetation management plans in water resource management in the Republic of South Africa.

As the availability of herbicides for the management of SAV is limited in South Africa, only the formulations available are discussed in more detail.

2.1 HISTORY OF INTEGRATED AQUATIC VEGETATION MANAGEMENT IN SOUTH AFRICA

South Africa is one of the most biodiverse countries in the world, containing an estimated 8% of the world's vascular plants, three global biodiversity hotspots and approximately 21,000 plant species (SANBI, 2018). The Western Cape region of South Africa is recognised as one of the six floral kingdoms of the world (Cape Floristic Region). Seventy percent of the Cape Floral Kingdom's 9,000 plant species are found nowhere else on earth (SANBI, 2018).

Botswana, Lesotho, Swaziland, and the Republic of South Africa supports about 600 species of wetland plants, including 114 endemic taxa (Cook, 2004). Although South Africa is rich in indigenous aquatic plants (Glen et al., 1999; Cook, 2004; Glen et al., 2007; Van Ginkel and Cilliers, 2017), nuisance aquatic plants are increasingly disrupting the balance of aquatic ecosystems. Some of these nuisance aquatic plants have attained "declared weed status" and their control is enforced by local environmental legislation (Henderson, 2001).

Guillarmod (1979) reported that introduced aquatic weeds have become serious pest plants in fresh and brackish water systems of southern Africa in the 1950's, although in the case of *Pontederia crassipes* Mart. (syn. *Eichhornia crassipes* (Mart.) Solms) (water hyacinth), a warning of what was likely to happen was printed as early as 1913. The catalyst for coordinated aquatic vegetation control in the Republic of South Africa was the proliferation of the number one aquatic weed in the world, water hyacinth. Water hyacinth was reported in South Africa since around 1900 (Du Plessis et al., 2007).

In the late 1970's South Africans realised the necessity for coordinated aquatic weed control when water hyacinth infested more than 80% of the full surface area (FSA) of the 2,062 hectare (5,095 acres) Hartbeespoort Dam in the North West Province (Steyn et al., 1979). The infestation was controlled with aerial herbicide applications of terbutryn (Kluge, 1978; Ashton et al., 1979; Scott et al., 1979; Steyn et al., 1979). In 2015 water hyacinth was still controlled annually in the Hartbeespoort Dam by the Department Water and Sanitation (DWS) with herbicides and biocontrol-agents.

In the mid 1980's the DWS realised that the herbicidal control operations on *P. crassipes* had to be adapted to incorporate natural enemies of the plant to optimise control efforts. The Plant Protection Research Institute of the Agricultural Research Council in Pretoria was contracted in 1985 by the DWS to look into the feasibility of controlling nuisance aquatic weeds with the plant's natural enemies (biological control agents). The concept of "integrated aquatic vegetation management" was born in South Africa.

The Vaal River System, which is regarded as the "economic vein" of South Africa experienced significant *P. crassipes* infestations from the 1970's. This was controlled by glyphosate applications from boats and spraying from the shore. However, by 1981 the *P. crassipes* population had increased significantly and spread downstream from the Vaal Barrage (a coffer dam downstream of the Vaal Dam) to Regina Bridge near the town of Parys. The *P. crassipes* infestation has grown to infest a 300km river reach. In late 1982 it was decided to chemically control *P. crassipes* on the Vaal River System with mainly glyphosate using aerial spraying by helicopters and fixed wing aircrafts. Follow-up treatments were done

from the riverbanks by sprayers or motorised herbicide sprayers on boats (Du Plessis et al., 2007).

It was soon realised that there was a need to expand the herbicide component of the water hyacinth control efforts on the Vaal River to include biological control agents to assist in the control programme. An integrated control plan, concentrated on using herbicide and biological control methods to complement each other, was introduced. An integrated water hyacinth management plan/manual for the Vaal River System was compiled and implemented (Campbell et al., 1996). This integrated water hyacinth management plan was used as a generic blueprint and each DWS regional office had to adapt the management plan to accommodate their own site-specific conditions (Cilliers, 1995; Campbell et al., 1996; Cilliers et al., 1996; Findlay and Jones, 1996).

An inter-departmental advisory committee (DACAW) on aquatic weed control was founded in November 1998 (Du Plessis et al., 2007). The primary aim was to coordinate the existing expertise on the control of aquatic weeds in South Africa and to exchange knowledge on how to cost effectively control aquatic weeds, especially *Eichhornia crassipes*. In addition to water hyacinth control plans, this committee rolled out integrated management strategies for other problem aquatic weeds such as *Azolla filiculoides* Lamarck (red water fern), *Myriophyllum aquaticum* (Velloso) Verdcourt (parrot's feather), *Myriophyllum spicatum* Linnaeus, *Pistia stratiotes* Linnaeus (water lettuce) and *Salvinia molesta* Mitchell (Kariba weed).

Problems with nuisance aquatic vegetation was however not restricted to declared aquatic weeds. Du Plessis and Davidson (1995) reported that indigenous submersed aquatic plants such as *Stuckenia pectinata*, *Potamogeton* species and also filamentous algae (*Cladophora glomerata*) were contributing to major operational problems in South African water conveyance systems. Irrigation canals were treated with the lowered-pH method (sulphuric acid and copper sulphate) in the 1990's (Du Plessis and Davidson, 1995). Later, aquatic vegetation in irrigation canals was managed with chelated copper products and eventually with acrolein, an organic herbicide (Envirokonsult, 2010). As it was too expensive to treat large balancing dams to control aquatic vegetation on irrigation schemes with acrolein, sterile Chinese grass carp (*Ctenopharyngodon idella* Valenciennes) was introduced to assist as a non-selective biological control agent in these structures.

The first integrated aquatic vegetation management plan (IAVMP) to manage SAV and algae in an irrigation scheme was introduced on the Orange-Riet River irrigation scheme near the town of Jacobsdal (central South Africa) in 2012 (Envirokonsult, 2012). Thereafter, many IAVMP's were designed and implemented on irrigation schemes through South Africa with acrolein as the main chemical (herbicidal) control agent in lotic waters and sterile *C. idella* as the biological control agent in lentic waters. Where necessary, the chemical and biological control techniques were complemented with mechanical and physical control options (Envirokonsult, 2014).

With increasing eutrophication experienced in many South African catchments, the proliferation of SAV (exotic and indigenous) also reached problem proportions in many larger dams and reservoirs. For many years, nuisance SAV was only addressed on a small scale and only in the immediate area of a water body where it caused operational or recreational problems. The need for integrated aquatic vegetation plans for affected dams and reservoirs were realised by the DWS when significant and costly operational problems were experienced in the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme where submersed vegetation blocked the grids of the fore bay of the 5m³/s water transfer pumps, as well as their cooling systems. This resulted in costly repairs and interrupted water supply to clients. The remediation actions to combat the problems experienced in the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme led to the development of the first IAVMP for the control of plants in larger South African dams and formed the basis of this study.

2.2 THE EFFECT OF EUTROPHICATION ON WATER RESOURCES

Eutrophication is a term that needs little introduction to limnologists. Eutrophication is primarily associated with the natural ageing process of lakes but is often accelerated by the activities of man. The ontogeny of lake ecosystems is governed by many interacting causal mechanisms that affect the autotrophic productivity of a water body (Wetzel, 1983). The transition of a well-defined lake to a swamp, marsh and eventually a dry terrestrial ecosystem is accelerated by a progressive increase in eutrophication.

Hutchinson (1973) gave a detailed history of the development and use of the term “eutrophication” since Weber (1907) first introduced the term to describe the appearance of wetlands. Naumann (1919) introduced the general classification of lakes through the concepts of oligotrophy and eutrophy, and distinguished them on the basis of phytoplankton populations. Oligotrophic lakes contain few planktonic algae and a eutrophic lake contains a higher concentration of phytoplankton. Naumann (1919) emphasised that chemical variables, especially phosphorus, combined with nitrogen and calcium, were the primary determining factors of the trophic status of a water body.

Boland (1976) reported that the term “eutrophication”, originally limited to the concept of changing nutrient levels, has been gradually expanded to include the consequences or symptoms of nutrient enrichment. Stewart and Rohlich (1967) distinguished between pollution and eutrophication as many forms of pollution, such as heavy metals, acid mine drainage, crude oil, petroleum products and pesticides, do not lead or contribute to eutrophication.

The OECD (1982) classified eutrophication as the “nutrient enrichment of waters which results in the stimulation of an array of symptomatic changes, amongst which increased production of phytoplankton and aquatic macrophytes, deterioration of water quality and other symptomatic changes are found to be undesirable and interfere with water uses”.

Eutrophication is characterised by excessive aquatic plant and algal growth due to the increased availability of one or more limiting growth factors needed for photosynthesis (Schindler, 2006). Eutrophication occurs naturally and progresses over centuries as lakes age and are progressively filled with sediments (Carpenter, 1981). However, human activities have accelerated the rate and extent of eutrophication through both increasing point-source discharges and non-point loadings of limiting nutrients, such as nitrogen and phosphorus, into aquatic ecosystems (i.e., cultural eutrophication), with significant consequences for drinking water sources, fisheries, and recreational water bodies (Carpenter et al., 1998).

Eutrophication was recognised as a water pollution problem in European and North American lakes and reservoirs in the mid-20th century (Rodhe, 1969; Schindler, 2006). Since then, the occurrence of eutrophication has become more widespread

throughout the world (Schindler, 2006). Surveys from the late 20th century indicated that 54% of lakes in Asia are eutrophic; in Europe, 53%; in North America, 48%; in South America, 41%; and in Africa, 28% (ILEC, 1993). In South Africa, a remote sensing study has shown more than 60% of the dams surveyed in South Africa were eutrophic (Matthews and Stewart, 2015). Some South African scientists believe that this figure may be higher (Harding, 2015), with the main contributing source being dysfunctional sewage works that produce more than 4 billion litres a day of untreated, or at best partially treated, sewage effluent that discharges into South African rivers and dams (Turton, 2015).

Under a large majority of lake conditions, the most important nutrients causing the shift from a lesser (oligotrophic) to a more productive state (eutrophic) are phosphorus and nitrogen (Wetzel, 1983). Typical plant organic matter of algae and aquatic macrophytes contains phosphorus, nitrogen and carbon in approximately the following ratios (Vallentine, 1974):

1P : 7N : 40 C per 100 dry weight or

1P : 7N : 40 C per 500 wet weight

If one of the three elements is limiting, and all the other elements are present in excess of the physical needs of the plants or algae, phosphorus can theoretically generate 500 times its weight in living biomass, nitrogen 71 (500:7) times, and carbon 12 (500:40) times (Wetzel, 1983).

In a comprehensive review of literature Vollenweider (1968) empirically deduced that controlling phosphorus inputs, and in some cases nitrogen inputs, to lakes was the primary key to reducing eutrophication in lakes. Studies by Schindler (1977) also concluded that the primary focus in eutrophication management should be to control phosphorus. Hereafter, phosphorus control became the standard policy for eutrophication management in most first-world countries. International efforts to control phosphorus at point sources reduced eutrophication, and hence algal blooms and the growth of aquatic vegetation, in many lakes and reservoirs around the world.

Walmsley and Butty (1980) developed a eutrophication model for South African reservoirs in the early eighties. The model was based on the prediction of the

amount of algal growth within an impoundment in relation to its phosphate loading and chlorophyll a concentration. This work has led to the implementation of a 1mg/l phosphate standard in selected South African catchments in the mid-eighties.

The effects of eutrophication may reduce the beneficial utilisation of water resources. Bruwer (1979), Walmsley and Butty (1980), Wetzel (1983) and Du Plessis et al. (1990) list negative effects which can arise from increased eutrophication:

- Increased phytoplankton biomass;
- Toxic phytoplankton species;
- Increases in blooms of zooplankton;
- Increased biomass of benthic and epiphytic algae;
- Changes in macrophyte species composition and biomass;
- Decreases in water transparency (increased turbidity);
- Colour, smells, tastes, and other water treatment problems;
- Dissolved oxygen (DO) depletion;
- Increased incidences of fish kills;
- Loss of desirable fish species; and
- Decreases in perceived aesthetic value of the water body and adjacent properties.

The presence of high concentrations of nutrients supports the rapid growth and proliferation of algae and macrophytes in a water body. These symptomatic effects of eutrophication have a significant impact on the aquatic health of the water body and as a consequence financial implications. Madsen and Wersal (2017) summarised costs involved with the control of aquatic weeds in the US. The estimated cost of damage mediated by eutrophication in the U.S. alone is approximately \$2.2 billion annually (Dodds et al., 2009). Pimentel et al. (2000) reported that the estimated total cost of invasive aquatic plants in the United States was approximately \$110 million/yr. The cost of aquatic weed control in irrigation districts in 17 western US states was estimated to be in excess of \$50 million/year (Anderson, 1993). Florida state agencies have spent nearly \$250 million to manage *Hydrilla verticillata* in Florida waters over the past three decades; if one accounts for local government and local water management districts, this total approaches \$750 million in management costs associated with hydrilla alone (Schardt, pers. comm. as

cited by Madsen and Wersal, 2017). In South Africa, costs of water hyacinth (*Eichhornia crassipes*) control alone were in the order of R12 million per annum (Du Plessis et al., 2007).

Although many aquatic macrophytes present in South African dams are exotic invasive species (especially the free-floating plants), increasing eutrophication results in the overabundant proliferation of indigenous submersed vegetation, to such an extent that these plants have a significant detrimental impact on the beneficial use of a water body. However, in a review by Bornette and Puijalon (2011), it was highlighted that it is not only eutrophication that is detrimental, as frequently quoted, but most environmental parameters that govern the maintenance and dynamics of aquatic plant communities.

The changing political climate in South Africa has led to the progressive deterioration of sewerage treatment infrastructure which is already manifesting in significantly higher phosphate loading to impoundments, canals, rivers and other waterways. This has necessitated a shift from the previous preventative maintenance at the source of pollution, to the management of the symptoms of eutrophication. In South Africa, SAV needs to be managed as their uncontrolled proliferation may lead to interference with the beneficial uses of a water body, which may result in the ultimate loss of a water resource.

2.3 PROBLEM AQUATIC PLANT SPECIES IN SOUTH AFRICAN WATERWAYS, WITH PARTICULAR REFERENCE TO THE TARGET SPECIES ENCOUNTERED IN THE STUDY AREA

2.3.1 Regulation of weed control in South Africa:

The management of weeds in the Republic of South Africa is regulated by specific legislation, the National Environmental Management: Biodiversity Act, Act 10 of 2004 (NEM:BA) and the Conservation of Agricultural Resources Act, Act No. 43 of 1983 (CARA). This legislation stipulates that the resident and/or owner of land is responsible for the control of declared weeds (listed in the legislation documents).

The CARA is an act of the National Department of Agriculture of the Republic of South Africa and makes provision for the conservation of natural agricultural resources through:

- Maintaining the production potential of land;
- Combating and preventing erosion;
- Preventing the weakening or destruction of the water resources;
- Protecting the vegetation; and
- Combating weeds and invader plants.

Amended Regulations 15 and 16 of CARA legislation were promulgated during 2001. These changes were necessitated by the accelerating deterioration of South Africa's natural resources due to invasion by alien invasive plants, as well as an increased public awareness with regards to environmental matters.

The amended Regulations 15 and 16 of CARA make provision for four groups of problem plants. The first three groups are covered by Regulation 15 and consist of undesirable alien plants which include 122 species of declared weeds (Category 1 plants), 76 species of plant invaders (37 species of Category 2 and 39 species of Category 3 plants). Regulation 16 covers bush encroachment and lists 44 species as indicators of bush encroachment.

According to the NEM:BA Act of 2004, Category 1 plants, or declared weeds, are prohibited plants that are not tolerated on land or water surfaces, neither in rural nor urban areas. These plants may not be planted or propagated, and all trade in their seeds, cuttings or other propagative material is prohibited. These declared weeds may not be transported or be allowed to disperse. Plant species were included in this category because their harmfulness outweighs any useful properties they may have (NEM:BA, 2004). Some of their harmful qualities are that they pose a serious health risk to humans or livestock, cause serious financial losses to land users, are able to invade undisturbed environments and transform or degrade natural plant communities, use more water than the plant communities they replace, or are particularly difficult to control.

2.3.2 Submersed aquatic plant species listed as declared weeds:

The following submersed aquatic plant species are listed as declared weeds according to NEM:BA Section 70(1) (Category 1 plants) in South Africa: *Elodea canadensis* Michx. (Canadian water weed); *Egeria densa* Planch. (Dense water weed) and *Hydrilla verticillata* (L.f.) Royle (hydrilla) (NEM:BA, 2004). All three species are members of the Hydrocharitaceae family (monocots).

2.3.3 Target aquatic plant species in the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme:

None of the declared submersed aquatic weeds were found during the vegetation surveys in the Heyshope Dam or its tributaries. However, three indigenous submersed aquatic plants interfere with the operation and management of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme. These plants are endemic to southern Africa and are known for causing problems with substantial economic implications in water conveyance structures (Du Plessis and Davidson, 1995).

The target submersed aquatic plant species in the study were all monocots:

- *Stuckenia pectinata* (L.) Börner - Fennel-leaved pondweed
- *Potamogeton schweinfurthii* (Benn.) - Broad-leaved pondweed
- *Lagarosiphon muscoides* (Harv.) - Fine oxygen weed

For the purpose of this study these three aquatic plants are briefly discussed.

2.3.3.1 *Stuckenia pectinata* (L.) Börner (Fennel-leaved pondweed)

Alternative names and distribution: *Stuckenia pectinata* was previously classified as *Potamogeton pectinatus* and *Stuckenia pectinatus*, commonly called fennel-leaved pondweed, sago pondweed or ribbon weed (USDA-NRCS, 2018). In South Africa the layman's term for this species in many regions is simply "water grass", but the common name used by South African water resource managers is "fennel-leaved pondweed". In the United States of America the common name is "sago pondweed". For the purpose of this document, the name, "fennel-leaved pondweed" will be used.

S. pectinata is a cosmopolitan, fully submersed aquatic plant that grows in fresh and brackish water on all continents, except Antarctica. It is widely spread throughout southern Africa and is very common in many South African river systems, lakes, dams, irrigation canals and other water conveyance structures (Du Plessis and Davidson, 1995; Du Plessis, 2003; Cook, 2004; Van Ginkel and Cilliers, 2017).

Description: *S. pectinata* is an aquatic herbaceous plant up to 1 meter tall (Bare, 1979). The species is generally completely submersed, except for the reproductive spike that emerges above the water surface when it flowers (Larson, 1993). It is nearly unbranched at the base, becoming freely branched towards the top (Larson, 1993), often growing in very large masses (Godfrey and Wooten, 1979). Leaves are all submersed, linear-filiform, appearing to originate at the top of the sheath, at least 2-12cm long and between 0.2 to 1mm wide, with stipules fused to the blade being up to two thirds as long as the leaf blade (Bare, 1979; Larson, 1993; Holub, 1997). The inflorescence is a spike with 2 to 6 unevenly spaced whorls and is 1 to 5cm long (Bare, 1979). Fruits are yellowish to brown, ovoid with a beak 0.3 to 0.5mm long (Larson, 1993).



PLATE 2.1: *Stuckenia pectinata* (L.) Börner (Fennel-leaved pondweed or sago pondweed) in Heyshope Dam, Mpumalanga Province, South Africa.

Habitat: Fennel-leaved pondweed is common in shallow to moderately deep (<2.5m), fresh to sub-saline permanent water bodies where water is not absent for

periods of more than 3 months (Coetzer, 1987; Kantrud, 1990; Du Plessis and Davidson, 1995; Du Plessis, 2003). In South African concrete-lined irrigation canals fennel-leaved pondweed only grow in areas where soil was deposited on the bottom of the concrete-lined canal or in subsurface areas between adjacent canal slabs. Fennel-leaved pondweed does not attach to the concrete on the bottom of the canal (Du Plessis and Davidson, 1995; Du Plessis, 2003).

Uses: Beneficial uses for fennel-leaved pondweed are many as this species plays an important role in aquatic ecosystems. Waterfowl use, and rely on, fennel-leaved pondweed as a food source, (Kantrud, 1990). The whole plant can be consumed, and parts are utilised by diving, dabbling, whistling ducks, many types of geese and coots (Kantrud, 1990). Red-knobbed coots (*Fulica cristata*) also use *S. pectinata* as building material for their nests on Heyshope Dam and surrounding water bodies. It also serves as nesting for certain fish species and habitat for macroinvertebrates. The wave dampening action of fennel-leaved pondweed can be used for erosion control of shores and dams (Kantrud, 1990).

Weediness: Although classified as “threatened” or “endangered” in some states in the USA (USDA-NRCS, 2018), *S. pectinata* may become weedy or invasive in some regions in the Republic of South Africa and may displace some desirable vegetation if not properly managed. It is especially problematic as it has significant economic implications in water conveyance structures such as irrigation canals, balancing dams and other related water conveyance infrastructure (Yeo, 1967; Kantrud, 1990; Du Plessis and Davidson, 1995; Du Plessis, 2003).

Fennel-leaved pondweed can physically obstruct recreational activities, water flow, and block cooling systems of high-capacity bulk water pumps, water intake ports at power plants and irrigation canals (Peltier and Welch, 1969; Madsen et al., 1988; Envirokonsult, 2000; Du Plessis, 2003). It may also become a substrate that allows nuisance algae to attach. Fennel-leaved pondweed may also cause very low levels of dissolved oxygen (DO) in streams used to transport sewerage effluent.

Management: Water resource managers have tried to manipulate populations of fennel-leaved pondweed for use by waterfowl and wildlife by adjusting water levels. However, results from these trials are variable and depend on water chemistry, water levels, turbidity, geography and other macrophyte competitors (Kantrud,

1990). In some cases, declines in populations have been achieved by partially dewatering of water bodies. In other instances, an increase in fennel-leaved pondweed was observed following partial or full dewatering of water bodies (Kantrud, 1990).

Internationally many herbicides and chemicals have been used in an attempt to control growth of fennel-leaved pondweed. Commercial fertilizers have been recommended to increase phytoplankton in water bodies in order to reduce the clarity or increase the turbidity of the water and preventing fennel-leaved pondweed invasion (Kantrud, 1990). This extreme approach can however not be recommended.

Herbicides used for the control of fennel-leaved pondweed include 2,4D, silvex and sodium arsenite (Davidson et al., 1962; Kantrud, 1990). Copper sulphate, diquat, fenac, dichlobeil, naphthalam, morflurazon, aquathol-K, aquazine, ortho diquat 2,4D buoxethanol ester, arrazine, glycolphosphate, triazine, carbofuran and alachlor have been used to control or inhibit fennel-leaved pondweed growth, targeting various parts of the plant (Kantrud, 1990).

Light exclusion, as well as mechanical and physical removal and control of *S. pectinata* by using rakes, cables, and mechanical harvesters have been used, but have limited or no success and are not economically feasible (Kantrud, 1990; Mitzner, 1978; Engel and Nichols, 1984). *Stuckenia pectinata* was successfully managed with grass carp (Hestand and Carter, 1978; Osborne, 1978; Nall and Schardt, 1980; Miller and Decell, 1984; Van Dyke et al., 1984; Sutton and Vandiver, 1986; Bowers et al., 1987; Leslie et al., 1987; Schoonbee, 1991; Du Plessis, 2003; Gettys et al., 2014).

2.3.3.2 *Potamogeton schweinfurthii* (Bennet) (Broad-leaved pondweed)

Alternative names and distribution: Van Ginkel and Cilliers (2017) listed the following synonyms for *Potamogeton schweinfurthii*: *Potamogeton bunyonyiensis* (Denny and Lye), *Potamogeton capensis* (Schelle ex Hagstr.), *Potamogeton promontoricus* (Hagstr.), *Potamogeton repens* (Hagstr.) and *Potamogeton venosus* (Benn.).

Potamogeton schweinfurthii is present in Portugal, Italy, some Mediterranean islands, North Africa to southern Africa and Madagascar (Landsdown, R.V., 2017; Tamire et al., 2016; Van Ginkel and Cilliers, 2017). Kaplan (2005) reported the first observation of *P. schweinfurthii* in the Mediterranean part of Europe in 2005 and Aymerich et al. (2012) reported the first records of *P. schweinfurthii* in the Iberian Peninsula in 2012. This species has been recorded in waterways in the Limpopo, North West, Mpumalanga and Gauteng provinces in the Republic of South Africa (personal observation). *P. schweinfurthii* is however not as widely spread through southern Africa as *Stuckenia pectinata*. According to Van Ginkel and Cilliers (2017) *P. schweinfurthii* is spread through waterways in the north-eastern, north-western and far-eastern parts of South Africa, central Namibia, as well as in northern Botswana.



PLATE 2.2: *Potamogeton schweinfurthii* (Benn.) (Broad-leaved pondweed) in the Heyshope Dam, Mpumalanga Province, South Africa. The broader leaf structure of this species can be seen in the inset photograph.

Description: Kaplan (2005) gave the following description: *P. schweinfurthii* is a large aquatic, submersed and perennial herb. The stem consists of a slender stolon, somewhat woody, circular structure, occasionally developing terminal bulb-like tubers. The leaves are yellowish to brownish, translucent, submerged or occasionally floating; leaf blades narrowly lanceolate to oblong-elliptic; margins minutely toothed and flat or wavy; bases tapering, tips sharp. Leaves are 65-250mm in length and 3-28mm in width. Inflorescence consists of many flowers,

rigid, emergent spikes; slightly thicker than the stem; developing in the axils of the submerged leaves. The flowers are small, green and inconspicuous on swollen stalks. Fruits are drupelets ovoid, the beak less than 0.5mm long, with a distinct dorsal keel with an overall length of 3.0-4.0mm.

Habitat: *P. schweinfurthii* is found in still or flowing water up to 3m deep, preferring clear water - found at altitudes up to 1,560m (Van Ginkel and Cilliers, 2017).

Uses: Tamire et al. (2016) found an allelopathic interaction between *Potamogeton schweinfurthii* and the phytoplankton population in Lake Ziway in Ethiopia and postulated that extract of *P. schweinfurthii* may be useful for controlling phytoplankton blooms in lakes. In Heyshope Dam the plant also serves as habitat for certain fish species as well as macroinvertebrates.

Weediness: *P. schweinfurthii* may become a problem in some affected water conveyance structures and in dams and lakes where it may impact on water abstraction, structure capacity, flow obstruction and boating. It causes significant problems in the Heyshope Dam and Geelhoutboom Balancing Dam where it blocks the fore bay grids to the water transfer pumps and reduces the capacity of balancing dams.

Environmental concerns: *P. schweinfurthii* is not considered a problematic aquatic plant in the natural environment (Van Ginkel and Cilliers, 2017). It is however problematic in South African water conveyance systems, where it impacts on the flow and capacity of canals and cause operational problems. *P. schweinfurthii* may also interfere with recreational uses, where it causes problems for motorboats and swimming (Du Plessis, 1998).

Management: At the time of this study only two herbicides, diquat and acrolein, were registered in the Republic of South Africa for the chemical control of *P. schweinfurthii*. In addition to herbicidal control, the plants can be removed by physical and mechanical means from water conveyance structures. With the exception of grass carp, no other biological control method for the management of *P. schweinfurthii* is currently available.

2.3.3.3 *Lagarosiphon muscoides* (Harv.) (Fine oxygen weed)

Alternative names and distribution: Six species of *Lagarosiphon* are found in southern Africa: *Lagarosiphon cordofanus* (Casp.), *L. ilicifolius* (Oberm.), *L. major* (Ridl.), *L. muscoides* (Harv.), *L. rubellus* (Ridl.) and *L. verticillifolius* (Oberm.) (Cook, 2004). They are very similar but can roughly be divided into two groups: (1) Plants with soft, only slightly recurved, narrow leaves, 0.5-2mm broad, and (2) plants with firmer, stronger recurved leaves, 2-3mm broad. *L. muscoides* (common name: Fine oxygen weed) belongs to group (1), but can be distinguished from the other two members of the group by its leaves having a very narrow, colourless margin. Other species in this group have leaves that are green up to the margin.

Alternative names for *L. muscoides* are: *Hydrilla dregeana* Prest; *Hydrilla muscoides* (Harv.) Planch.; *Lagarosiphon muscoides* f. *breviolia* Wager; *Lagarosiphon schweinfurthii* Casp. (Van Ginkel and Cilliers, 2017). The plant is found widespread throughout the summer rainfall region of southern Africa. It extends to Botswana and tropical East Africa (Cook, 2004; Van Ginkel and Cilliers, 2017; SANBI, 2018).



PLATE 2.3: *Lagarosiphon muscoides* (Harv.) (Fine oxygen weed). The fine leaf structure can be seen in the inset photograph.

Description: *Lagarosiphon muscoides* (Harv.) is a submerged aquatic plant densely covered with slightly recurved, strap-shaped leaves. Its rather slender

stems sprout from a rhizome and are up to 1 meter long and 0.5-2.0mm thick. The leaves are soft and thin, about 10mm long and up to 1.5mm broad with minute teeth along the margin. The white to pink flowers are only a few millimeters across and float on the water surface. Male flowers break loose from the plant, while female flowers remain attached by long, slender stalks. The narrow egg-shaped fruit is 5-10mm long and contains about 4-8 seeds (Cook, 2004).

Habitat: *L. muscoides* thrives in both still and slow flowing water, 0.5-1.5m deep, and may form dense masses (Cook, 2004). It propagates by seeds and by regenerating from broken-off portions of the plant (BRI, 1980).

Weediness: *L. muscoides* may become a pest at times by overgrowing shallow dams and rivers.

Environmental concerns: Monocultures may occur in shallow dams and in river shorelines as a result of outcompeting other less aggressive plants, thereby preventing a diverse plant population to establish in the water body.

Management: At the time of this study only two herbicides, diquat and acrolein, were registered in the Republic of South Africa for the chemical control of *L. muscoides*. In addition to herbicidal control, the plants can be removed by physical and mechanical means from water conveyance structures. With the exception of sterile grass carp (*Ctenopharyngodon idella*), no other biological control method for the management of *L. muscoides* is currently available.

2.4 THE IMPACT OF THE OVERABUNDANT PROLIFERATION OF SAV ON WATER RESOURCE MANAGEMENT

2.4.1 The benefits of SAV:

Many species of aquatic fauna are directly dependent on aquatic vegetation for refuge, attachment, spawning and food (Rozas and Odum, 1998). The size of the littoral zone of lakes, dams and streams varies greatly in relation to the open-water pelagic region and depends on the geomorphology of the basin and the sedimentation rate since inception of the lake or dam. In shallow lakes, the littoral

flora contributes significantly to the productivity, and may regulate the metabolism of the entire lake ecosystem (Wetzel, 1983).

The presence of SAV in an aquatic ecosystem is essential as it plays an important role in the food chain and provides refuge, attachment, spawning and food for many species of aquatic fauna (Rozas and Odum, 1998). Microscopic algae (phytoplankton) form the base of the aquatic food chain. The macrophytes (larger algae and flowering plants) provide habitat and shelter for fish, waterfowl, and other wildlife. Macrophytes provide food for insects, some fish species, waterfowl and mammals (Lembi, 2003).

Algae and macrophytes produce oxygen as they photosynthesise during the day. Photosynthesis is the major source of oxygen for aquatic fauna (Krull, 1970; Lembi, 2003). Rooted plants stabilise shorelines and bottom sediments; uprooting these plants can lead to shoreline erosion and increased turbidity in a body of water (Smart et al., 1998). Aquatic plants can trap excessive nutrients and detoxify chemicals (Helfrich et al., 2009). A diversity of aquatic plant life, both in and around the water, can add visual interest and beauty to a water body (Lembi, 2003). Because of many benefits, aquatic plant growth is always desirable in an ecosystem. Therefore, the goal of aquatic vegetation management should never be to totally eliminate indigenous aquatic vegetation from a natural aquatic ecosystem (Lembi, 2003).

2.4.2 Negative impacts of excessive aquatic vegetation and phytoplankton growth:

Aquatic vegetation can become a nuisance when it interferes with the beneficial uses of a water body. Invasive aquatic plants are generally defined as non-native (from another geographical region) plant species that cause ecological and/or economic harm to a natural or managed aquatic ecosystem (Gettys et al., 2014). Non-native aquatic plants affect aesthetics, drainage, fishing, water quality, fish and wildlife habitat, flood control, human and animal health, hydropower generation, irrigation, navigation, recreation, and ultimately land values (Pimental et al., 2000; Rockwell, 2003; Madsen and Wersal, 2017).

Excessive aquatic plant proliferation is usually due to the fact that water bodies are shallow and experience sunlight penetration to the bottom, which allows for photosynthesis and hence aquatic plant growth in the littoral zones. Eutrophication enhances the growth of aquatic vegetation. In some cases, exotic plant species are extremely competitive and can take over large areas of aquatic habitats (Lembi, 2003). In other cases, native aquatic vegetation can impact negatively on the beneficial use of a water body or water conveyance system.

Some of the problems caused by excessive aquatic plant growth are as follows:

- **Interference with recreation**

Recreational activities such as swimming, fishing, boating can be impaired and even prevented by excessive macrophyte growth (Newroth, 1985; Madsen et al., 1991; Lembi, 2003; Envirokonsult, 2010). The presence of high concentrations of cyanobacteria and algae may lead to foul tastes and odours and the development of microtoxins that can affect the recreational user (Graham et al., 2012).

- **Potable water treatment**

Certain algal species can cause foul tastes and odours in drinking water (Lembi, 2003; Helfrich et al., 2009) or block filters (Envirokonsult, 2000). Some cyanobacteria produce cyanotoxins that are difficult to remove during potable water treatment and cause consumer complaints (Bruwer, 1979).

- **Aesthetical problems**

The visual appearance of an aquatic weed infested water body is unsightly and gives the impression of a neglected and unhealthy resource that should be avoided (Bruwer, 1979).

- **Flooding**

The overabundant proliferation of some aquatic plant species clog water flow and increase the risk of flooding in neglected streams in metropolitan areas (Inaba et al., 2022).

- **Effect on land values**

Excessive aquatic weed growth can lower property values and decrease the aesthetic appeal of a water body (Bruwer, 1979; Lembi, 2003; Horst and Lewis, 2009).

- **Health effects**

The aquatic stages of most mosquitos' lifecycle are not adapted to subsist in moving waters (Getty et al., 2014). Aquatic vegetation growth provides quiet water areas for mosquitos to breed (Lembi, 2003), as well as substrates for vectors of waterborne diseases, such as schistosomiasis (Bruwer, 1979). Many mosquito species are associated with human diseases, such as malaria, dengue fever, some types of encephalitis and yellow fever. Neurotoxins and hepatotoxins, produced by cyanobacteria, can have significant health effects on animals and humans consuming the affected water (Melaram et al., 2022).

- **Fish kills**

Aquatic plant and algae growth can cause fish kills as a result of DO depletion during the processes of respiration and microbial decomposition (Wilcove et al., 1998, Simon and Townsend, 2003). If aquatic vegetation growth is excessive, plants can utilise most of the DO in the water column in the littoral zone during the night. This may result in fish kills in shallow isolated areas that normally occur just before dawn when the DO concentration is at its lowest (Wetzel, 1983; Lembi, 2003). Continuous exposure to low DO concentrations can result in the loss of biodiversity, as sensitive species with higher oxygen needs are lost in favour of unwanted, less sensitive species that can tolerate low oxygen concentrations and become dominant.

- **Fish stunting and overpopulation**

Excessive macrophyte growth can also lead to fish stunting and overpopulation, as a result of the production of too much habitat protection for smaller fish which prevents effective predation by larger piscivores (Lembi, 2003; Helfrich et al., 2009).

- **Encroachment of native aquatic plant populations**

Exotic aquatic plant species can invade and completely replace native vegetation (Lembi, 2003). This may lead to the settlement of monoculture stands of exotic species which reduces the diversity of native vegetation.

- **Siltation of water bodies**

Deposition and sedimentation of aquatic vegetation and debris can lead to the gradual filling of water bodies (Lembi, 2003) and eventual loss of capacity. The snowball effect between increased aquatic vegetation growth and sedimentation may have a significant effect on loss of capacity and increased water loss due to higher evapotranspiration rates (Envirokonsult, 2012; Du Plessis, 2020).

- **Interference with irrigation**

SAV, such as *Stuckenia pectinata* and filamentous algae, such as *Cladophora glomerata*, cause operational problems, with significant economic implications, in South African irrigation canal systems. Aquatic vegetation reduces the capacity of the canals, which results in spillage, blockages, shortage on delivery and other related problems (Du Plessis and Davidson, 1995). Drainage ditches can also be blocked by many species of aquatic vegetation, ranging from macroscopic algae to reeds.

- **Interference with bulk water delivery**

The overabundant proliferation of aquatic vegetation may lead to operational problems in inter-basin water transfer schemes by interfering with the capacity of balancing dams and the blockage of water transfer pump cooling systems and open water conveyance structures (Envirokonsult, 2010).

Although the aim is never to eliminate all aquatic vegetation from a natural aquatic ecosystem, total eradication may be necessary in water conveyance systems where aquatic vegetation interferes with the operation of the system (e.g., irrigation canals, drainage ditches, balancing dams, retention dams, pump station forebays and others). Aquatic vegetation management plans often define the criteria for determining if a plant is considered a weed, native or invasive plant. In many cases, when aquatic plants affect human activities negatively (e.g., swimming boating, fishing, irrigation and others), they are considered to be a “weed” and management

may be pursued to reduce the impact on the local economy, or to protect the ecological benefits of the affected water resource (Stallings et al., 2015).

2.5 MANAGEMENT OPTIONS FOR THE CONTROL OF SUBMERSED AQUATIC VEGETATION

The purpose of this section is to give an overview of some of the different methods available to control nuisance aquatic vegetation in water bodies. Internationally, a variety of methods are available for controlling nuisance aquatic plants (AERF, 2014). In South Africa there are limitations, especially regarding the selection of herbicides, as only two active ingredients are registered for SAV on the local market. The choice of which control option(s) should be incorporated in an IAVMP will be dependent on the following factors:

- Site specific conditions,
- Specific nuisance plant species,
- Intensity of problem,
- The availability of funds,
- The availability of manpower,
- Legislation,
- The availability of tools or specific methodology in South Africa, and
- The availability of local expertise in the field of aquatic vegetation management.

The goal of aquatic vegetation management depends on the use of the specific water body. The selection of the best treatment, or combination of treatment options, depends on the species of plant, the extent of the problem, economic considerations, local environmental conditions, and water resource uses. In a natural aquatic ecosystem, native aquatic plants are highly desirable as key components in the aquatic food chain. On the other hand, in a concrete water conveyance system or a balancing dam, the presence of any vegetation, exotic or native, is undesirable and impacts negatively on the operation of the system. Between these two extremes, the water resource manager has to select the appropriate control option or integrate a few options into a management plan in order to reach his goals.

Aquatic vegetation control alternatives are categorised in the following groups: (1) preventative control approach, (2) physical control methods; (3) mechanical control methods; (4) biological control methods and (5) herbicidal control methods. Where more than one method is combined into an aquatic vegetation management plan, it is referred to as an (6) *integrated* approach (Getty et al., 2014).

2.5.1 Preventative control approach:

The primary cause of action for aquatic vegetation management is prevention of the problem of overabundant aquatic weed proliferation. Prevention of weed growth is more cost-effective and often requires less effort than reactive remediation actions (Helfrich et al., 2009). Preventative measures refer to good catchment management practices to reduce nutrient loading to reservoirs and lakes. By regulating nutrient inputs from point sources as well as non-point sources in the catchment area of a water body, the nutrient load can be regulated. In such an attempt, the South African government addressed the problem of phosphate loading from point sources by introducing a 1 mg/l phosphate standard in sensitive South African catchments in the mid-1980's (Grobler and Silberbauer, 1985). By the end of 2010 South African detergent manufacturing companies removed all phosphates from their products and have effectively switched to zero-phosphate detergents.

The management of non-point sources is however, more complex than point-sources as it is difficult to monitor. Best management practices in agriculture can reduce nutrient runoff reaching streams and rivers in an impoundment's catchment. Strip cropping and contour farming will prevent high fertiliser runoff and excessive soil erosion (Juventia, et al., 2022). The introduction of effective microorganisms (EM technology), as part of crop land chemical fertilization programmes, can reduce the amount of fertiliser used significantly by increasing the availability of plant nutrients absorption, thereby restricting the nutrient concentrations in drainage waters which will eventually end up in the receiving lake (Higa, 2001).

Many aquatic plants or their seeds are carried into a body of water by wind, birds, fish introduction, boat trailers, fishermen, etc. (Lembi, 2003). The transfer of plant fragments to uninfected or less infected water bodies can be restricted by introducing washing stations at boat launching areas. Introducing buffer zones, by

diverting nutrient enriched runoff through artificial wetlands or retention ponds, can also be valuable to prevent proliferation of nuisance weeds. Rivers and streams should be fenced off in livestock grazing areas to restrict nutrient loading from manure (Lembi, 2003). Runoff from chicken coops and animal feedlots should be treated as point sources and treated before entering a waterway.

Education is a key component of prevention. Educating lake users and the general public about the threat of invasive aquatic vegetation is necessary to prevent new infestations and to sustain effective aquatic plant management programs (Gettys et al., 2014). Where resources are limited, this can be done by involving volunteers trained to participate in lake and weed monitoring programmes.

2.5.2 Physical control options:

The physical management of SAV is distinguished from mechanical techniques in that mechanical control uses machinery acting directly on the target vegetation, whilst with physical techniques, the environment of the plants is manipulated which, in turn, has an impact on the plants (Madsen, 2000).

2.5.2.1 Aeration or artificial circulation

The purpose of aeration in lake management is to increase the DO content of the water. Aeration of reservoirs and lakes has been used for many years as a method of improving water quality. Lake aeration was first described by Scott and Foley (1919). Aeration, or artificial circulation, uses electrical or solar powered mixers, fountains, or compressed air diffuser systems, to circulate and add oxygen to the water column (Getty et al., 2014). An increase in the DO concentration has the potential to reduce phosphorus concentrations (Stallings et al., 2015) and enhance ammonium nitrogen removal (Jamieson et al., 2003) from the waterbody.

Artificial circulation of the epilimnion, resulting in destratification, may also be used to disrupt phytoplankton blooms. Mechanical mixing has been used successfully to destroy thermal stratification and suppress algal blooms (Ridley, 1972; Gebhart and Clady, 1977). Benefits of aeration have been clearly documented in all types of water bodies, ranging from small ponds to large thermally stratified lakes in which hypolimnetic aeration systems were applied (AERF, 2014). Although this technique

may disturb the growth of smaller floating macrophytes, such as duckweed or watermeal, it will not be effective for the management of larger macrophyte growth or that of macroscopic, sessile algae in the littoral zone of an impoundment.

2.5.2.2 Benthic barriers or bottom weed covers

Benthic barriers, or bottom weed covers, are used for localised control of aquatic vegetation through compression and by blocking sunlight to inhibit photosynthesis (AERF, 2014). Woven and non-woven synthetic materials can be spread over the pond bottom to block out sunlight, preventing photosynthesis thereby eliminating aquatic vegetation growth.

Barriers, specifically manufactured for aquatic vegetation control, are usually made of materials heavier than water. There are two general types of benthic barriers: (a) textile or plastic and (b) silt. These materials are expensive, but they may be useful in controlling submersed vegetation around relatively small access areas and water intakes where other management procedures cannot be used. The problem with benthic barriers is that they are largely ineffective for floating species (for example, duckweeds) and emergent species (such as cattails). Where sediments are used new plants can establish on top of the added layer (Engel and Nichols, 1984).

Benthic barriers are not selective and will impact all target and non-target organisms dependent on, or living in, the sediment.

2.5.2.3 Water level drawdown

Water level drawdown, used for the management of aquatic plants, involves exposing plants and root systems to dry conditions to kill the plants. Drawdowns are effective mainly on SAV and algae and are generally restricted to small volume reservoirs, ponds and canal structures (Du Plessis, 1998). Drawdown is not recommended, unless the pond is larger than one acre (0.4 hectares) and has a control structure that allows adjustment of the water level. In ponds without drains, water pumps can be used to manage water levels (Helfrich, et al., 2009).

A drawdown should be done during the winter when the combination of drying and exposure to cold temperatures will kill many aquatic weeds. Drawdowns of

impoundments during the warmer months are not recommended by some authors (Helfrich et al., 2009; Bornette and Puijalon, 2011), as they stress fish populations and may enhance the spread of marginal species (such as cattails, alligator weed, rushes, and willows). However, drawdowns are effectively used in South Africa as part of IAVMP's in irrigation canal systems during summer months where very high ambient temperatures of up to 40°C will kill exposed filamentous algae, such as *Cladophora glomerata* (Envirokonsult, 2014).

This technique is not species-selective and removal of beneficial species may occur. Large scale drawdowns are also not advisable in water scarce areas such as South Africa.

2.5.2.4 Shading (dyes and surface covers)

Pond dyes and surface covers can be used to reduce or block light penetration into the water column. Pond dyes block the wavelengths of light necessary for photosynthesis (Dawson and Haslam, 1983). Application rates depend on the volume of water to be treated. Treatments are usually effective for six months or occasionally longer, depending upon the retention time. If dense growths of algae or other weeds are present, mechanical removal or an herbicide treatment may be needed prior to applying a pond dye.

Recent studies have shown that this control method can be effective to control aquatic plants that do not produce seeds or other reproductive propagules, but is usually limited to small, highly controlled areas (Gettys et al., 2014). Dyes have little use in larger water bodies and are more suitable for small water bodies on golf courses or ornamental ponds.

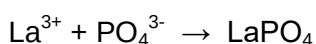
2.5.2.5 Nutrient inactivation

The chemical treatment of phosphorus, to reduce internal phosphate loading, is frequently a component of lake restoration plans. The use of chemical precipitation, to remove phosphorus from water, has a long history. The first chemical precipitation treatment of lakes was performed in Sweden during the late 1960s and early 1970s (Charboneau, 1999). Aluminium, iron, and calcium salts have been

used for centuries to treat drinking water (Cooke et al., 1993). These same salts are the primary chemicals to precipitate phosphorus in in-lake treatments.

Nutrient inactivation involves the application of aluminium or iron salts or calcium compounds (lime) to remove phosphorus from the water column and to inactivate phosphorus in the sediment (Gettys et al., 2014). Chemical reactions work in two ways to lower a lake's phosphorus content (Cooke et al., 1993). First, precipitation removes phosphorus from the water column by forming insoluble compounds that settle to the lake bottom. The phosphorus is then inactivated by further chemical reactions that prevent its release from the sediment.

The use of lanthanum chloride salt in water treatment was already suggested years ago (Melnik et al., 1974), but was only used actively in recent years to inactivate phosphorus in in-lake nutrient management strategies. Lanthanum can effectively precipitate a number of different types of phosphorus. The phosphorus removal mechanism of lanthanum (commercially available as Phoslock™) is straight forward, as shown in Equation 1. It involves the reaction of phosphate anions with lanthanum with the molar ratio of 1:1 and leads to the formation of lanthanum phosphate or rhabdophane, that is highly insoluble.



The inactivation of phosphorus can effectively suppress the development of algal blooms. The growth of most vascular plants is, however, usually limited by nitrogen and there are no readily available compounds that bind with nitrogen in the sediment (Madsen, 2000). Nutrient inactivation remains best suited for algal control and water quality improvement and is not recommended for SAV control as a reduction in dissolved phosphorus concentration and improved water clarity may encourage denser SAV infestations and allow weeds to grow in deeper areas (Gettys et al., 2014).

2.5.3 Mechanical control options:

The term “mechanical control” refers to control by methods that utilise manual labour or large power-driven equipment (Gettys et al., 2014). Madsen (2000) describes a

few mechanical control options, with their advantages and disadvantages, in Table 2.1.

2.5.3.1 Hand cutting/pulling/digging

Hand digging and removal of rooted, submersed plants is an intensive treatment option. This method involves digging out the entire plant (stem and roots) and disposing residue onshore (Stallings et al., 2015). After removal, plant material may be used as fertiliser or mulch in gardens (Lembi, 2003). This is one of the simplest and most widely used methods to clear water from nuisance SAV (Madsen, 2000). McComas (1993) listed a large number of hand devices for physical and mechanical control. In shallow water, less than a meter deep, no specialised gear is required. In deeper waters, hand removal can best be accomplished by divers using scuba or snorkelling equipment and carrying collection bags for disposal of plants.

Efficacy of plant removal depends on sediment type, visibility, and thoroughness in removing the entire plant, particularly the roots. A high degree of control over more than one season is advisable after complete removal has been achieved. The technique is time consuming and costly, especially if contract divers are used.

2.5.3.2 Mechanical harvesting

Mechanical harvesting is considered a short-term technique to temporarily remove aquatic vegetation of an impoundment. In mechanical harvesting, cutting operations are combined with plant biomass removal. Harvesting involves cutting of the aquatic plants below the water surface with the collection of the cut plant fragments for offshore disposal. Occasionally, there are separate cutting and harvesting boats, but the majority of harvesters have both a sickle-bar cutting blade with a conveyor belt that loads the cut material on a boat (Madsen, 2000).

The disposal of harvested plant material poses a challenge, as submersed aquatic plants generally consist of more than 90% water and cannot be used as feed or for other useful applications (AERF, 2014).

According to a few case studies by Peterson et al. (1974), Wile (1975), Carpenter and Adams (1978), Coyners and Cooke (1983) and Carroll and Curtis (2021) the

harvesting of aquatic vegetation is not an effective tool for reducing in-lake nutrient concentrations, as the reduction of phosphorus and nitrogen concentrations are insignificant in relation to the internal nutrient load of the impoundment and the external nutrient loading to the water body.

Since harvesting involves the physical removal and disposal of vegetation from the water, the immediate effectiveness in creating open water areas is quite apparent. The duration of control is variable, depending on a few factors. The removal of large amounts of submersed aquatic plants can improve the diel oxygen balance in littoral zones and rivers, particularly in shallower water (Carpenter and Gasith, 1978; Madsen et al., 1988). However, harvesting creates plant fragments which may contribute to secondary vegetative growth by species dispersing by fragmentation. Harvesting can also be detrimental to non-target plants and animals such as fish, macroinvertebrates, semi-aquatic vertebrates, forage fish and others (Engel, 1990).

TABLE 2.1: CHARACTERISTICS OF MECHANICAL MANAGEMENT TECHNIQUES (From Madsen, 2000).

MANAGEMENT METHOD	DESCRIPTION	ADVANTAGES	DISADVANTAGES	SYSTEMS WHERE USED EFFECTIVELY	PLANT SPECIES RESPONSE
Hand cutting/pulling	Direct hand pulling or hand tools	Low-technology, affordable, can be selective	Labour-intensive, cost is labour-based	Most of the undeveloped world, volunteer labour pools	Very effective in very localised areas
Cutting	Cut weeds with mechanical device (typically boat-mounted sickle bar) without collection	More rapid than harvesting	Large mats of cut weeds may become a health and environmental problem, may spread infestation	Heavily infested systems	Non-selective, short-term
Harvesting (cut and remove)	Mechanical cutting with plant removal	Removes plant biomass	Slower and more expensive than cutting; resuspension of sediments	Widespread use with chronic plant problems	Like cutting, it is cosmetic, nonselective short-term
Cut and grind	Mechanical cutting with grinding of plant material and in-lake disposal	Immediate relief of plant nuisance, no disposal	Resuspension of sediments, decomposition of plants in lake, floating plant material	Useful for chronic plant problems where disposal of plants is problematic	Like cutting and harvesting it is cosmetic, non selective short-term
Diver-operated suction harvester	Vacuum lift used to remove plant stems, roots, leaves, sediment left in place	Moderate selective (based on visibility and operator), longer term	Slow and cost-intensive	Useful for smaller nuisance plant populations in which plant density is moderate	Typically have minimal regrowth for Eurasian watermilfoil; not effective for tuber-setting hydrilla
Rotovating	Cultivator on long arm for tilling aquatic sediments	Disrupts Eurasian watermilfoil stem bases, intermediate-term results	May spread large numbers of fragments; resuspension of sediments	USA, mixed results	Effective in disrupting Eurasian watermilfoil dense stands; not selective and only intermediate-term

2.5.3.3 Rotovating (Bottom derooting)

Mechanical rotovating is a bottom tillage method that removes aquatic plant root systems. This results in reduced stem development and impairs growth of rooted aquatic plants. Derothing methods involve tilling the sediment to a depth of 10 to 15cm, which dislodges plants, including roots. Rotovator heads on submersible arms are used (Madsen, 2000).

A high percentage of entire plants (roots and shoots) can be removed by bottom tillage methods. Depending on plant density, carryover effectiveness of rototilling can persist for up to 2 to 3 years without retreatment. Unlike harvesting, which is conducted during summertime when plant growth is maximal, rototilling treatments for root removal can be performed during “off season” months of winter and spring. This results in no interference with peak summer-time recreational activities.

Rototilling does create a short-term turbidity increase in the area of operation, but increases are usually temporary with a rapid return to baseline conditions. Since bottom sediments are disturbed, short-term impacts on water quality and the benthic invertebrate community can occur. Rotovation is not species selective, and can result in unintentional removal of non-target plants (Du Plessis, 1998).

2.5.3.4 Hydraulic dredging

Dredging is usually not applied to manage SAV as it is an expensive operation with significant impacts on the receiving aquatic environment. Dredging is rather considered a management option to restore lakes filled with sediments, lakes having excess nutrients, inadequate pelagic and hypolimnetic zones, need deepening, or require the removal of toxic substances in the bottom sediments (Peterson, 1982).

Where dams are silting up with sediments, an increase in SAV growth can be expected. Weed control can be a secondary benefit of dredging that is done for other reasons, as dredging may increase the depth of a water body to levels unsuitable for the survival of some aquatic plant species.

2.5.3.5 Diver-operated suction harvesting

The technique utilises a small barge or boat carrying portable dredges with suction heads that are operated by scuba divers to remove individual rooted plants (including roots) from the sediment (Du Plessis, 1998; Madsen, 2000). Divers physically dislodge plants with sharp tools. The cut plant fragments are then suctioned up and carried back to the barge through hoses operated by the diver.

This methodology of aquatic plant removal is excellent for small beds of submersed vegetation with moderate density (Madsen, 2000). The process is however, time

consuming as one diver can remove approximately 100 m²/day (Eichler et al., 1993).

The success of any harvesting operation depends on the prompt and complete removal of all cut vegetation. Haphazard or partial removal of the cut vegetation can increase the problem, because each unremoved plant fragment has the potential to develop in a new individual (Helfrich et al., 2009).

2.5.4 Biological control options:

2.5.4.1 Definition and scope of biological control

Biological weed control contains the use of natural enemies to reduce the vigour or reproductive potential of an invasive alien plant. Plants often become invasive when they are introduced to a new region without any of their natural enemies. The alien plants therefore gain a competitive advantage over the indigenous vegetation, because all indigenous plants have natural enemies that feed on them or cause diseases. Biological control (or biocontrol) is an attempt to introduce the alien plant's natural enemies to its new habitat, with the assumption that these natural enemies will remove the plant's competitive advantage until its vigour is reduced to a level comparable to that of the natural vegetation (SAPIA, 2011).

Gettys et al (2014) defined biocontrol as the planned use of one organism (for example an insect, mite or microbial pathogen) to control or suppress the growth of another organism such as a weedy plant species. Biocontrol of weeds is primarily the search for, and introduction of, species-specific organisms that selectively attack a single target species such as an exotic weed.

Three different approaches are currently used in the biocontrol of aquatic weeds: classical biocontrol (importation), non-classical biocontrol (augmentation, conservation) and conservation (habitat manipulation) (Julien and White, 1997; McFadyen, 1998; Goeden and Andres, 1999; Madsen, 2000; Cuda et al., 2008). Classical biocontrol is the most common biological control method and can be defined as the planned introduction of non-native, target-specific organisms (usually arthropods, nematodes or plant pathogens) from the weed's native range to reduce the vigour, reproductive capacity or density of the target weeds in its adventive (new

or introduced) range (Gettys et al., 2014). Classical biocontrol is relatively inexpensive to develop and implement, compared to other methods of weed control. This approach provides selective, long-term control of the target weed and because the biocontrol agents reproduce, they will usually spread on their own throughout the infested area (Gettys et al., 2014).

Non-classical biocontrol involves the mass rearing and periodic release of resident or naturalised non-native aquatic weed biocontrol agents (Cuba et al., 2008). This approach is used primarily with pathogens, but can be extended to insects (Grodowitz, 1998; Jester et al., 2000; Hairston and Johnson, 2001), and fish (Sutton and Vandiver, 1986; Cassani, 1996). The “new association biocontrol” is a variation of classical biocontrol, but differs from classical biocontrol in that the natural enemies have not played a major role in the evolutionary history of the host plant and are therefore considered new associates (Hokkanen and Pimental, 1984; Lockwood, 1993; AERF, 2014). The non-classical approach requires infrastructure for mass rearing and regular distribution which entail a more expensive program.

Madsen (2000) describes “native plant restoration” as a biological management technique where the restoration of the native plant community is the end goal of the aquatic plant management program (Nichols, 1991; Smart and Doyle, 1995). Native plant restoration can be accelerated by reintroduction after a successful maintenance management program has been instituted on a water body.

The first biological control program on aquatic weeds in South Africa was initiated in 1974 with the release of the weevil, *Neochetina eichhorniae* Warner, on water hyacinth, *Eichhornia crassipes* (Mart.) Solms. Since then, *Salvinia molesta* Mitch. *Pistia stratiotes* L., *Myriophyllum aquaticum* (Vell.) Verdc., *Azolla filiculoides* Lam. and *E. crassipes* itself, have been brought under various degrees of control in South Africa by releasing natural enemies (Coetzee et al., 2011).

Although quite a few biocontrol agents were introduced on mainly floating aquatic plants in South Africa over recent years, there was no classical biological control option available for SAV until the late 1970's when grass carp were introduced into the country (Pike, 1990). The first insects were introduced on submersed aquatic plants three decades later, after the first infestation of *Hydrilla verticillata* Royle in South Africa was recorded in the Jozini Dam in the Northern region of KwaZulu-

Natal Province in 2006 (ARC, 2018). The leaf-mining flies *Hydrellia purcelli* Deeming and *H. pakistanae* Deonier were brought into the country with the stem-mining weevil, *Bagous hydrillae* O'Brien to be evaluated on hydrilla. This was the first classical biocontrol action undertaken on SAV in South Africa. However, in 2008 it was found that the Asian hydrilla moth, *Parapoynx diminutalis* Snellen, which was presumed an accidental introduction, was very effective on hydrilla in Jozini Dam (Bownes, 2018). All three classical biocontrol agents have been shelved, but research has proved them safe to be released, should hydrilla expand its range (ARC, 2018).

Although a number of organisms, including plant pathogens, insects and grass carp, have been studied as potential biocontrol agents, the most successful control agents in aquatic systems have proved to be insects and grass carp (Gettys et al., 2014). As sterile grass carp is the only available biocontrol agent in South Africa which can be utilised for the management of the three target submersed aquatic plants in this study (*Stuckenia pectinata*, *Potamogeton schweinfurthii* and *Lagarosiphon muscoides*), only this biocontrol agent is described in more detail.

2.5.4.2 Sterile grass carp

- **Background**

Fish used for aquatic vegetation control include several species of tilapia (*Tilapia* spp.), silver dollars (*Metynnis roosevelti* Eig. and *Mylossoma argenteum* E. Ahl.), common carp (*Cyprinus carpio* L.), silver carp (*Hypophthalmichthys molitrix* Val.) and grass carp (*Ctenopharyngodon idella* Val.) (Shell 1962; Yeo 1967; NAS, 1976). Of these fish, only grass carp is capable of consuming large quantities of aquatic macrophytes (Van der Zwerde, 1990).

The Chinese grass carp (*Ctenopharyngodon idella*) is a voracious aquatic plant consumer and therefore highly acclaimed as a non-classical tool for aquatic weed control. For this reason grass carp were imported into South Africa (KwaZulu-Natal Province) from Malaysia in 1967 by the Natal Parks Board (Pike, 1990). Since 1974, grass carp was bred in the Umgeni Fish Hatchery in KwaZulu-Natal. Progeny of these fish, that were later bred at the Umtata Fish Hatchery in the former Republic of Transkei (Schoonbee and Prinsloo, 1984), have been stocked into many farm dams in KwaZulu-Natal for controlling the growth of aquatic plants (Pike, 1990).

Grass carp are the most efficient phytophagous freshwater fish in the world with a versatile application as it has a wide tolerance range for temperature (Sutton, 1977). It is adapted for riverine conditions, although it is mainly utilised as biocontrol agent in lentic ecosystems (Swingle, 1957; Sutton, 1977).

- **Legal aspects**

In 1989 the Nature Conservation authorities in South Africa placed restrictions on the use of diploid (fertile) grass carp to control aquatic vegetation (Du Plessis, 2003). This decision was in line with the approach of other conservation authorities world-wide, as it is recognised that grass carp could have a serious destructive effect on aquatic ecosystems if population sizes cannot be regulated. Criticism towards the uncontrolled spreading of grass carp was based on the following issues:

- Destruction of the natural biological filter which maintains water quality;
- benthic erosion and consequently an increase in turbidity, and
- the destruction of breeding habitats and shelter of indigenous aquatic species.

Concern regarding reproduction of grass carp (Stanley, 1976; Webb et al., 1994) has been addressed largely through the use of sterile, triploid grass carp (Durocher, 1994). Only sterilised (triploid) grass carp are now allowed in South Africa and strict regulations are to be adhered to before a permit is issued by environmental authorities for stocking in any waterbody (Du Plessis, 2003).

- **History of grass carp as biocontrol agent in South Africa**

The first larger than pond size application of Chinese grass carp, as biocontrol agent for the control of aquatic vegetation in South Africa, was implemented in Germiston Lake during 1982 (Schoonbee, 1991). The biological control of *Stuckenia pectinata* (L.) Börner in Germiston Lake was first attempted with the redbreast tilapia (*Tilapia rendalli* Boulenger), the only indigenous, freshwater fish in South Africa that feeds on aquatic macrophytes. *T. rendalli* was introduced into a series of experimental enclosures in the lake at a density of 1 fish/m² during 1973. At this density, *T. rendalli* reduced the infestation of *S. pectinata* and maintained the plant at acceptable levels during summer. However, the programme failed because *T. rendalli* (native to tropical and sub-tropical Africa) did not survive through the winter, when temperatures in the lake dropped below 10 °C (Schoonbee, 1991).

Following the failure with *T. rendalli*, *Ctenopharyngodon idella* was selected for further attempts for biological control of *S. pectinata*. Although grass carp is a warm water species, this fish tolerates cold temperatures and has been successfully used to control submerged aquatic macrophytes throughout the world (Vinogradov and Zolotova, 1974; Krzywosz et al., 1980). Germiston Lake has a full surface area of 59ha (146 acres) and was successfully controlled at a stocking density of 85 grass carp/ha (Schoonbee et al., 1985). Based on above observations, 10,000 individuals of *T. rendalli* (170/ha) were necessary to achieve similar control results and their use is restricted to summer months which necessitates restocking each year.

Over the years, sterile grass carp was stocked in smaller ponds, irrigation dams and urban impoundments in South Africa. Du Plessis (2003) experimented with sterile grass carp as a biocontrol agent for the control of SAV in concrete-lined irrigation canals. This study on Heyshope Dam was however, the first large scale application of sterile grass carp as a biological control component of an IAVMP in South Africa.

- **Feeding preferences**

Grass carp are general herbivores and will consume almost any plant material. Grass carp can be considered “selective generalists” in their foraging behaviour as they eliminate species in order of decreasing palatability (Colle et al., 1978; Van Dyke et al., 1984; Leslie et al., 1987). The species has strong preferences for some plants, including *Najas guadalupensis* (Southern naiad), hydrilla and duckweed. *Myriophyllum* spp. on the other hand is very low on the grass carp food preference list (Table 2.2). Gettys et al. (2014) stated that grass carp is not an effective biocontrol agent against *Myriophyllum* spp. According to Silva et al. (2014) the more fibrous emerging macrophytes and plants with toxic compounds are rejected by grass carp.

In Table 2.2, *Ceratophyllum demersum*, *Egeria densa* and *Myriophyllum* spp. are listed in some USA states as “preferred plants” and in other states as “non-preferred plants” for grass carp consumption. Silva et al. (2014) evaluated the feeding preferences of *C. demersum*, *E. densa* and *E. najas* under artificial mesocosm conditions and found that all three species were consumed in the preference order of *C. demersum* > *E. najas* > *E. densa*. Grass carp are regarded as poor biocontrol agents of filamentous algae, spatterdock, fragrant water lily, saw grass, cattail and other larger macrophytes (Gettys et al., 2014).

TABLE 2.2: FEEDING PREFERENCE LIST, IN APPROXIMATE ORDER OF PREFERENCE, FOR TRIPLOID GRASS CARP IN FLORIDA, ILLINOIS AND OREGON-WASHINGTON (USA) (compiled from Hestand and Carter, 1978; Osborne, 1978; Nall and Schardt, 1980; Miller and Decell, 1984; Van Dyke et al., 1984; Sutton and Vandiver, 1986; Bowers et al., 1987 and Leslie et al., 1987).

FLORIDA	ILLINOIS	OREGON – WASHINGTON
PREFERRED PLANTS		
<i>Hydrilla verticillata</i> <i>Potamogeton illinoiensis</i> <i>Potamogeton</i> spp. <i>Najas guadalupensis</i> <i>Egeria densa</i> ** <i>Elodia canadensis</i> <i>Chara</i> spp. <i>Lemna</i> spp. <i>Nitella</i> spp. <i>Ceratophyllum demersum</i> ** <i>Eleocharis acicularis</i> <i>Pontederia lanceolata</i> <i>Wolffia</i> spp. <i>Wolffiella</i> sp. <i>Typha</i> spp. <i>Azolla</i> sp. <i>Spirodela</i> sp.	<i>Najas flexilis</i> <i>Najas minor</i> <i>Chara</i> <i>Potamogeton foliosus</i> <i>Elodea canadensis</i> <i>Potamogeton pectinatus</i> *	<i>Potamogeton crispus</i> <i>Potamogeton pectinatus</i> * <i>Potamogeton zosteriformis</i> <i>Elodia canadensis</i> <i>Vallisneria</i> sp.
VARIABLE PREFERENCE (May eat)		
<i>Myriophyllum spicatum</i> <i>Bacopa</i> sp. <i>Polygonum</i> spp. <i>Utricularia</i> spp. <i>Cabomba</i> spp. <i>Fuirena</i> spp. <i>Nymphaea</i> spp. <i>Brasenia schreberi</i> <i>Hydrocotyl</i> spp. <i>Panicum repens</i> <i>Stratiotes aloides</i>	<i>Potamogeton crispus</i>	<i>Myriophyllum spicatum</i> <i>Ceratophyllum demersum</i> ** <i>Utricularia vulgaris</i> <i>Polygonum amphibium</i>
NON-PREFERRED (Does not eat)		
<i>Nuphar luteum</i> <i>Vallisneria americana</i> <i>Myriophyllum brasiliense</i> <i>Eichhornia crassipes</i> <i>Alternanthera philoxeroides</i> <i>Pistia stratiotes</i> <i>Nymphoides</i> spp. <i>Phragmites</i> spp. <i>Carex</i> spp. <i>Scirpus</i> spp. <i>Ludwigia octovalis</i> <i>Colocasia asculentum</i>	<i>Ceratophyllum demersum</i> ** <i>Myriophyllum</i> spp.	<i>Potamogeton natans</i> <i>Brasenia schreberi</i> <i>Egeria densa</i>
NOTE: * <i>Potamogeton pectinatus</i> was renamed to <i>Stuckenia pectinata</i> . ** <i>Ceratophyllum demersum</i> and <i>Egeria densa</i> are listed in some states as “preferable” and in other as “non preferred”.		

- **Stocking density**

Worldwide, a considerable amount of research has been undertaken to determine the optimum number of fish required to bring different aquatic weed species under control (e.g. Kilgen and Smitherman, 1971; Edwards and Moore, 1975; Beach et al., 1976; Gasaway and Drda, 1977; Osborne and Sassic, 1979; Krzywosz et al., 1980; Mitchell, 1980; Shireman and Maceina, 1981). These investigations clearly show that each situation is unique and no generalities can apply. Their feeding activity and impact on vegetation is affected by water temperature, length of the warm-water season, type of plants, size of fish stocked and pre-stocking plant control activities. It is easy to over stock when the dominant plant species are highly palatable (AERF, 2014; Hanlon et al., 2000). When unpalatable plants dominate, stocking rates have to be higher and palatable plants will be removed first (Dibble and Kovalenko, 2009).

Stocking densities should thus be carefully considered before introductions of *C. idella* are made into water bodies (Schoonbee, 1991). A comparison of Germiston Lake and Potchefstroom Dam (South Africa) is a good example of this. The two lakes are almost the same size (± 60 ha), are situated ± 100 km from each other, the target species in both water bodies were *S. pectinata* and the magnitude of the weed infestation was similar. Yet, Germiston Lake was successfully controlled with a stocking density of 85 fish/ha as opposed to Potchefstroom Dam with a stocking density of only 35 fish/ha. The duration of efficient biological control in Germiston Lake lasted for 15 years after which restocking had to be done (Du Plessis, 2003).

Specific stocking densities, which would result in complete eradication of a specific target plant, cannot accurately be predicted across a range of different plants and environmental conditions (Dibble and Kovalenko, 2009). Partial control of vegetation is rarely achieved with grass carp (Petr, 2000; Bonar et al., 2002).

- **Production of triploid (sterile) grass carp**

Because of concerns about grass carp's potential for natural reproduction and possible negative impacts on non-target aquatic fauna and flora, early research focused on developing a non-reproductive fish (Purdom, 1972; Cassani and Caton, 1986; Sutton and Vandiver, 1986; Cassani, 1996; Dibble and Kovalenko, 2009; Gettys et al., 2014).

Sterile grass carp were developed to solve the problem of unwanted reproduction. Stanley (1976) focused on producing all female populations through gynogenesis and hormone implants followed by mating XX males to normal females (Bonar et al., 1984). Studies then focused on creating triploid hybrids through grass carp intergenetic crossing with bighead carp (*Hypophthalmichthys nobilis*) but these animals had lower feeding efficiencies and fertile diploids could occur (Marian and Krasznai, 1978; Buck, 1979). A solution to the problem involved the current production of pure (unhybridised) triploid grass carp. Hydrostatic pressure or high temperature techniques are used to produce nearly 100% triploids (Cassani and Caton, 1985; Allen and Wattendorf, 1987; Du Plessis, 2003).

There is currently only one certified facility producing triploid grass carp in South Africa.

- **Movement patterns**

The movement patterns of triploid grass carp have many possible implications in the quality of vegetation control they can provide and strongly influenced by many factors (Cassani et al., 2008). In their native habitat juvenile grass carp undergo a period of relative inactivity and growth until sexual maturity at which point they begin a slow northward migration until they arrive at their spawning grounds (Gorbach and Krykhtin, 1988). It was suggested that because of this natural tendency grass carp will not migrate downstream of their point of release, but several studies has demonstrated that this is not the case (Bain et al., 1990; Chilton and Poarch, 1997; Kirk et al., 2001).

Several studies have observed that mature grass carp move extensively (range 0.7-71.1km) (Bain et al., 1990; Cassani and Maloni, 1991; Chilton and Poarch, 1997; Maceina et al., 1999; Kirk et al., 2001), are not seasonally affected, lack directional tendency and due to high level of dispersion will occasionally move beyond preferred plant communities (Bain et al., 1990; Cassani and Maloney, 1991; Clapp et al., 1993; Chilton and Poarch, 1997).

Bain et al. (1990), Cassani and Maloney (1991) and Chilton and Poarch (1997) found that movement characteristics of grass carp include an initial period of heightened activity for 1-12 weeks after release where after dispersion occurs at all

age groups. Cassani and Maloney (1991) also observed that the fish avoided shallow, narrow areas of reservoirs.

- **Salinity tolerance**

Cassani et al. (2008) cited Paplov and Nelovkin (1963) and Kilambi (1980) documented the migration of grass carp from the Volga to the Ural River through the brackish Caspian Sea in Russia, suggesting a relative high tolerance for salinity. In Texas, USA, smooth cordgrass has disappeared in all but fenced in enclosures in parts of Galveston Bay, an area downstream of a documented population of grass carp (Leslie et al., 1996). Webb et al. (1994) investigated the possible links between grass carp populations and the loss in estuarine habitat in Galveston Bay, Texas, USA.

Cross (1969) documented maximum survival times ranging from 24 days in 10.5 ppt salinity (30% seawater) to 5 hours in 17.5 ppt salinity (50% seawater) in ≥ 2 year old grass carp. Maceina et al. (1980) suggests that signs of physiological stress may be induced between 3.1-6.6 ppt. Kilambi and Zdinak (1980) recorded the LC_{50} value of grass carp held in 3-7 ppt for 15 days to be 14.0-14.2, whereas the 24 hour LC_{50} of grass carp acclimated at 9 ppt for 15 days was 16.0. Von Zon (1977), Maceina and Shireman (1979), Kilambi (1980) found variable decreases in food consumption by grass carp in higher salinity waters.

- **Mortality**

The expected lifespan of grass carp can greatly influence the degree of aquatic plant control achieved. Knowledge of longevity and mortality rates is essential to determine the stocking density to achieve desired management goals (Cassani, et al., 2008). Many factors influence the mortality of grass carp – most notably stocking size, water temperature at stocking, hauling distance, density and predation (Gasaway, 1977; Carmichael et al., 1984; Kirk, 1992; Clapp et al., 1994).

Clapp et al. (1994) found that winter survival of larger fish (mean TL=371mm) was more than 4 times better than smaller fish (mean TL=298mm) from the same stocking centre and that hauling time did not significantly affect mortality in the winter, but did during the spring. Gasaway (1977) and Hatton (1977) both found that largemouth bass (*Micropterus salmoides*) displayed selectivity for stocked grass carp over other typically available forage when stocked at vulnerable sizes.

Shireman et al. (1977) determined that the maximum size grass carp a bass could consume is approximately 450mm in length. If stocked at this size the grass carp could theoretically avoid largemouth bass predation, but to rear the fish to this size has specific cost implications. Furthermore, Kirk and Socha (2003) found that over a period of three years the oldest of 477 fish collected from the Santee Cooper reservoirs (USA) were age 11 and total annual mortality rates of 22-39% suggest a population persistence (period where 10% of a cohort would still survive) of 5 to 9 years.

- **Removal**

Grass carp are difficult to remove from a water body after they have been introduced. Consequently, barriers capable of confining the fish while maintaining unrestricted movement of water are usually installed to prevent grass carp from escaping the target area. Santha et al. (1991) devised a model that involves the alternate stocking and harvesting of grass carp in order to achieve 40% of aquatic plant cover in 1.5 years with respect to the initial carrying capacity of the aquatic environment. This model was found to be unviable due to the cost involved and general ineffectiveness of grass carp removal techniques. Schramm and Jirka (1986) conducted tests of 11 methods of grass carp capture in agricultural canals and found most of them unsuccessful. The most successful method for grass carp removal was to bait an unobstructed area and after the fish were attracted containment by placement of a barrier and collection with rotenone as described by Colle et al. (1978). Other removal techniques included herding, angling, rotenone collection, using sound to attract the fish and the use of biodegradable capsules containing fish toxicant implanted in the fish to euthanise fish after a given period of time (Bonar et al., 1993; Duncan, 2002; Willis et al., 2002; Thomas, 2004).

2.5.5 Herbicidal control options

- **Background**

Chemical control of aquatic vegetation involves the use of registered aquatic herbicides and algaecides (Table 2.3). Herbicides are relatively easy to apply and may in some cases be the only practical method of aquatic plant control (Helfrich et al., 2009). Herbicide treatments can be costly, and may provide only short-term relief from the real problem, usually eutrophied waters (Helfrich et al., 2009). Treatments can range in size from smaller backpack spray applications for small

clusters of plants up to large-scale treatments from boats or helicopters that may target an invasive weed throughout an entire lake. The objective of some treatments may be broad spectrum control while most treatments target a specific invasive plant or algal species (Gettys et al., 2014).

The treatment of natural waters with herbicides must always be executed with caution. When aquatic vegetation is killed by chemicals, it biodegrades and releases its bonded nutrients which may stimulate secondary algal growth and/or macrophyte regrowth. Other disadvantages may include toxicity, fish kills, cost, water-use restrictions, retreatment necessary, taste and odour problems (Helfrich et al., 2009). When properly applied, certain herbicides can control aquatic vegetation without harming fish or other wildlife (Lembi, 2003).

- **Legal aspects**

In South Africa, pesticides are registered at the office of the Registrar of Agricultural Remedies of the Department of Agriculture, Forestry and Fisheries (DAFF), and regulated by the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, Act No. 36 of 1947. In the USA, no product can be labelled for use in the aquatic environment if it poses more than a one in a million chance of causing significant damage to human health, the environment, or wildlife resources. In addition, it may not show evidence of biomagnifications, bioavailability, or persistence in the environment (Joyce, 1990).

- **Limited registrations on SAV available in South Africa**

Registration of herbicides for the control of SAV is limited to diquat, acrolein, fluridone, copper sulphate and copper chelates. The copper formulations are labelled as algaecides, and although fluridone is registered in South Africa, it is not freely available. Fluridone is also much more expensive than the other herbicides registered on SAV. Fluridone also requires a longer exposure time which makes it unattractive in areas with a low retention time.

Acrolein is registered for use on SAV and algae in artificial structures such as irrigation canal systems and related structures and cannot be used in natural waterways. This leaves only diquat as chemical control formulation to be applied on SAV in natural water bodies in South Africa at this stage.

- **Types of herbicides**

Herbicides can be classified in several ways, including by their chemical family, their mode of action and their time of application in relation to growth of the weed (Gettys et al., 2014). Herbicides used for aquatic vegetation control are generally classified as either “contact” or “systemic” herbicides (Madsen, 2000).

Contact herbicides act immediately on the plant tissues contacted, typically causing extensive cellular damage at the point of uptake but not affecting areas untouched by the herbicide (Madsen, 2000). Typically these herbicides are fast acting, but they do not have a sustained effect, in many cases not killing root crowns, roots, or rhizomes (Madsen, 2000). Contact herbicides can be used for “spot” treatments; that is treatments of selected patches of vegetation. These chemicals include copper algicides and diquat (Lembi, 2003).

TABLE 2.3: USE SUGGESTIONS FOR AQUATIC HERBICIDES (adapted from Madsen, 2000).

COMPOUND	EXPOSURE TIME (WATER)	ADVANTAGES	DISADVANTAGES	SYSTEM WHERE USED EFFECTIVELY	PLANT SPECIES RESPONSE
Complexed copper	Intermediate (18-72h)	Inexpensive, rapid action, approved for drinking water	Does not biodegrade, but biologically inactive in sediments	Lakes as algicide, herbicide in higher exchange areas	Broad-spectrum, acts in 7-10 days or up to 4-6 weeks
2,4-D	Intermediate (18-72h)	Inexpensive, systemic	Public perception	Water hyacinth and Eurasian watermilfoil control, lakes and slow-flow areas, purple loosestrife	Selective to broad-leaves, act in 5-7 days up to 2 weeks
Diquat	Short (12-36h)	Rapid action, limited drift	Does not affect underground portions	Shoreline, localised treatments, higher exchange rate areas	Broad spectrum, acts in 7 days
Endothall	Short (12-36h)	Rapid action, limited drift	Does not affect underground portions	Shoreline, localised treatments, higher exchange rate areas	Broad spectrum, acts in 7-14 days
Fluridone	Very long (30-60 days)	Very low dosage required, few label restrictions, systemic	Very long contact period	Small lakes, slow flowing systems	Broad spectrum, acts in 30-90 days
Glyphosate	Not applicable	Widely used, few label restrictions, systemic	Very slow action, no submersed control	Nature preserves and refuges; emergent and floating leaved plants only	Broad spectrum, acts in 7-10 days, up to 4 weeks

NOTE:

* Endothall is not currently registered in South Africa.

** Fluridone is registered in South Africa, but not freely available.

*** Glyphosate cannot be used on submersed species

In contrast to contact herbicides, systemic herbicides are translocated through the plant. They are slower acting but often result in the mortality of the entire plant (Madsen, 2000). Systemic herbicides include fluridone, 2,4-D and glyphosate. Fluridone cannot be used for spot treatment as it may move away from the treated area before it can have an effect (Lembi, 2003). Glyphosate is a non-selective foliar-applied herbicide (Senseman, 2007) and not effective on submersed species (Madsen, 2000; Lembi, 2003).

2.6 THE IMPACT OF CONTROL METHODOLOGIES ON THE RECEIVING ENVIRONMENT WITH SPECIFIC REFERENCE TO GRASS CARP

2.6.1 Effect of SAV control on the receiving environment:

Dibble and Kovalenko (2009) found in a review of the available data on the ecological impact of grass carp that most research focused on the eradication of aquatic vegetation rather than on the ecological mechanisms responsible for the impacts. The removal of aquatic vegetation by any control method may have direct or indirect impacts on the receiving environment (Pípalová, 2006).

2.6.2 Effect of SAV control on aquatic plant abundance:

Shireman et al. (1985) concluded that while changes in the aquatic populations did occur the method of vegetation control was not the important factor and that the removal of aquatic weeds by any method will have the same effect on the receiving environment. Changes in plant abundance and community composition occur due to immediate foraging by grass carp as well as alteration of water transparency, disturbance of sediment and the deposition of faecal matter (Dibble and Kovalenko, 2009).

Grass carp can be considered as “selective generalists” in their foraging behaviour as they eliminate species in order of decreasing palatability (Colle et al., 1978; Van Dyke et al., 1984; Leslie et al., 1987; Madsen, 2000; Gettys et al., 2014). The introduction of grass carp may thus have an unexpected and undesirable impact on the SAV community as Hanlon et al. (2000) reported several cases of *H. verticillata*

overgrowth after grass carp introduction. Due to the importance of macrophytes for aquatic communities, the complete removal of SAV is an unacceptable outcome of stocking grass carp in natural aquatic ecosystems (Cassani et al., 2008).

2.6.3 Effect of SAV control on habitat heterogeneity:

The effects of grass carp on aquatic plant diversity are dependent on many factors including the density and size of fish stocked and presence or absence of preferred and/or non-preferred plant species (Cassani et al., 2008). Aquatic plants provide habitat heterogeneity important at both system and micro scales.

2.6.4 Effect of SAV control on water quality and eutrophication:

Although many nutrients are involved in plant growth, carbon, nitrogen and phosphorus are the key elements required for aquatic plant life, and their availability therefore governs primary production in freshwater ecosystems (Wetzel, 1983; Bornette and Puijalon, 2011). Aquatic plants decrease sediment resuspension and play an important role in nutrient cycling (Carpenter and Lodge, 1986; Barko and James, 1997; Wetzel, 2001). SAV create microclimates in the littoral zone and promote retention of nutrients in the vegetative state, which is important under conditions of eutrophication (Scheffer and Jeppesen, 1997; Van Donk, 1997).

Approximately 50% of the nutrients in ingested plant material are metabolised by grass carp whilst the remainder passes through the gut as partly digested and partly fragmented material (Hickling, 1966; Lembi et al., 1978; Stanley, 1974a; Stanley, 1974b). While it is assumed that this nutrient release could accelerate eutrophic conditions of waters (Hansson et al., 1987), it is not clearly demonstrated in field studies (Dibble and Kovalenko, 2009). Venter and Schoonbee (1991) did not record significant changes in water chemistry in the Germiston Lake, even though biomass was reduced by 82% during a twelve-e.g.,month study.

Increases in nutrient concentrations can also be expected after treatment of SAV with herbicides as decaying vegetation is mineralised by bacterial activity. In submerged substrates, the mineralisation of organic matter requires oxygen (Moore et al., 1992) which leads to a decrease in the DO concentration with direct impacts on aerobic biota. Changes in water quality are often followed by algal blooms

(Vinogradov and Zolotova, 1974; Canfield et al., 1983; Shireman and Smith, 1983; Klussman et al., 1988) as released nutrients are fixed in the phytoplankton community.

Phytoplankton and SAV not only release oxygen but also consume CO₂ during photosynthesis, which results in an increase in water pH (Pípalová, 2006). The increase in pH can be significant in especially irrigation canals (Du Plessis and Davidson, 1995).

Shallow lakes can experience a dramatic shift from a sudden change from a low turbidity vegetated state to a high turbidity and unvegetated stable state (Scheffer et al., 2001). Canfield et al. (1983) and Maceina et al. (1992) observed an initial large increase in concentrations of total alkalinity, calcium, magnesium, potassium, total phosphorus and chlorophyll a in conjunction with a sharp reduction in Secchi disk transparency, which coincided with declines in the macrophyte community. However, one year after complete vegetation control was achieved all chemical changes, with the exception of increased potassium, began declining back to pre-introduction levels and Secchi disk transparency increased, a phenomenon also noted by Lembi et al. (1978).

Increased rates of nutrient release after resuspension of sediments lead to decreased aquatic ecosystem stability (Wetzel, 2001) and these water quality changes are often irreversible on relatively long time scales (Scheffer et al., 2001). Anticipated changes in water quality must be considered when weighing the advantages and consequences of complete macrophyte eradication.

2.6.5 Effect of SAV control on sediment chemistry:

As cited by Pípalová (2006), Terrell (1975) studied water and sediment chemistry, and suggest that nutrients from macrophytes were trapped in the sediment (precipitated either by or with organic acids) and thus were not available to phytoplankton. In ponds stocked with grass carp, a significant increase in iron, magnesium and orthophosphate concentrations were reported in the sediment (Terrell, 1975).

Several studies have shown that a clogged substrate and a stable water level could induce increased eutrophic conditions through nutrient release (e.g., through PO_4^{3-} mobilisation from Fe-PO_4^{3-} complexes), thus favouring the dominance of floating species (Boedeltje et al., 2005), and oxygen depletion (Caraco et al., 2006).

2.6.6 Effect of SAV control on phytoplankton community:

The removal of SAV by any means will have an impact on the phytoplankton community. Wetzel (2001) suggests that primary production in a water body depends on nutrient and light availability and that the inhibition of phytoplankton growth between dense macrophyte stands is related to competition for these variables.

Grass carp stocking density and the area of SAV controlled effects the extent of phytoplankton production (Pípalová, 2006). Richard et al. (1984) observed that in four Florida (USA) lakes, the mean phytoplankton abundance increased in all cases with macrophyte reduction and most sharply with complete elimination. Pípalová (2006) found that if SAV control by grass carp is slow and some macrophytes are left in a water body, the indirect consequences of grass carp stocking on phytoplankton is not significant. At a low stocking density of 30kg/ha, changes in the chlorophyll *a* concentration were non-significant (Pípalová, 2002). Both Pípalová (2002) and Bonar et al. (2002) noted that changes in chlorophyll *a* concentrations were not significant with intermediate control. Cassani et al. (1995) also found that annual mean chlorophyll *a* concentrations remained stable in lakes where macrophyte growth was only suppressed. These observations of little change in phytoplankton communities with intermediate control of macrophytes is also supported by (Terrell, 1975; Von Zon et al., 1976; Hestand and Carter, 1978; Lembi et al., 1978; Terrell, 1982; Leslie et al., 1983; Bonar et al., 2002).

However, a high stocking density (55kg/ha) of grass carp can eliminate all aquatic vegetation and the subsequent nutrient release can significantly increase phytoplankton concentrations (Small et al., 1985). As a result of the shading effect of higher phytoplankton biomass, remaining aquatic macrophyte growth is further suppressed. In this case wind action and low substrate coverage can increase water turbidity due to sediment movement, especially in shallow water bodies (Bonar et al., 2002).

Both Crisman and Kooijman (1980) and Holdren and Porter (1986) noted shifts from diatoms, cryptophyta and chlorophyta to cyanophyta (BGB's) which dominated the phytoplankton community all year during a high grass carp stocking rate. Maceina et al. (1992) and Richard et al. (1984) also observed that the elimination of aquatic macrophytes in lakes in the south-eastern USA caused large increases in BGB's. A lower density and gradual introduction of grass carp is therefore the more sensitive approach to biological control of SAV.

2.6.7 Effect of SAV control on macroinvertebrates (zoobenthos and zooplankton):

As SAV plays an important role in benthic-pelagic coupling by subsidising pelagic fish populations and affecting nutrient loading (Schindler and Scheuerell, 2002), it can be expected that the impact of grass carp will propagate beyond the littoral zone and change the role of benthic subsidies to the pelagic habitat of lakes (Dibble and Kovalenko, 2009). Aquatic plants form a base for macrophyte-periphyton-grazer complex (Carpenter and Lodge, 1986) and support macroinvertebrates by providing them with habitat, food and refuge from predation (Diehl and Kornijów, 1997).

Many authors observed an increase in abundance of zoobenthos in the presence of grass carp (Prowse, 1971; Stott et al., 1971; Greenfield, 1973; Buck, et al., 1975; Von Zon et al., 1976; Bain, 1993; Kirkagac and Demir, 2004). Kirkagac and Demir (2004) observed a threefold increase in benthos fauna abundance after total removal of SAV by grass carp, whilst Crisman and Kooijman (1981) in contrast, observed no change in the density of individuals or the number of species between pre and post stocking periods.

Direct effects of grass carp on zooplankton are minimal since stocked grass carp are of the age that they are primarily herbivorous and no longer consume significant amounts of zooplankton (Kilgen and Smitherman, 1971; Opuszynski, 1972; Cassani and Caton, 1985). Most influences on zooplankton tend to be indirect. In lakes stocked with herbivorous fish the proliferation of zooplankton and zoobenthos is increased by the consumption of SAV by grass carp and the subsequent increase in the rate of remineralisation of plankton biomass (Pípalová, 2006). Hrbáček et al. (1961) and Richard et al. (1985) found that changes in zooplankton abundance and

community structure were due to an increase in phytoplankton and shifts in planktivore predation on zooplankton by fish after SAV removal. After macrophyte removal shifts from a copepod and copepod-cladoceran dominated community to rotifer and small cladocerans was observed (Pípalová, 2006). On the other hand, studies by Terrell (1975) and Maceina et al. (1992) indicated that the zooplankton community was unaffected by the introduction of grass carp.

2.6.8 Effect of SAV control on fish communities

Aquatic macrophytes serve as a spawning substrate (especially for phytophilous fish species), food source (phytophilous fauna attached to them) and shelter for fish. The number of especially phytophilous fish species decreased when plants were completely eliminated or their biomass decreased significantly (Pípalová, 2006). Plant levels at both extremes of density levels may decrease fish growth and survival and ultimately alter population dynamics within the fish community (Adams and DeAngelis, 1987; Savino et al., 1992; Diehl, 1993). Dense macrophyte stands will deplete DO levels during respiration phases in isolated areas to put pressure on fish health.

As a general tendency, a decrease in the abundance of fish that are dependent on aquatic plants (largemouth bass, *Micropterus salmoides* and other sunfishes, *Lepomis* spp.), is expected when SAV is eliminated, while non-phytophyllic species such as gizzard shad (*Dorosoma cepedianum*) and silversides (*Labidesthes* spp.) tend to increase in abundance (Klussman et al., 1988; Maceina et al., 1991; Bettoli et al., 1992). Colle and Shirman (1994) reported that the fish harvest declined and several fish species disappeared after complete elimination of SAV, whilst Killgore et al. (1998) observed no change in the number of littoral species and an increase in the total fish catch after the control of hydrilla by grass carp.

Petr (2000) reviewed the biological control of aquatic plants using fish and its impact on other fish. The feeding activity of grass carp reduces the spawning substrate for phytophilous fish or shelters for predatory fish and their prey. It can also indirectly influence the life of some other fish that are dependent on phytophilous animals (Von Zon, 1977).

2.6.9 Effect of SAV control on amphibians and waterfowl communities

Extensive removal of aquatic macrophytes and associated habitat simplification and thus ecological degradation contributed to amphibian declines (Murphy et al., 2002). The use of grass carp to control nuisance aquatic vegetation may reduce habitat quality for waterfowl especially because the food requirements of grass carp and some waterbirds overlap (Venter and Schoonbee, 1991; McNight and Hepp, 1995; Benedict and Hepp, 2000).

To conclude, the removal of SAV by any means will have impacts on the receiving environment. Some of these impacts may be positive and some may be negative to non-target aquatic species.

CHAPTER 3

DESCRIPTION OF STUDY AREA

The aim of this chapter is firstly to describe the *study area* in order to put all the components of the Usutu-Vaal Inter-basin Water Transfer Scheme into perspective and secondly to describe the *geographic area* in which the study was conducted. This government water transfer scheme comprises a series of large dams which are interlinked with various conveyance systems, including canals, pipelines, balancing dams, coffer dams, and pump stations. Diagrams and maps in Figures 3.2 and 3.3 explain this complex water transfer system linking the Usutu River system (draining to the Indian Ocean on the east coast) with the Vaal River system (draining to the Atlantic Ocean on the west coast of the Republic of South Africa).

3.1 BROAD DESCRIPTION OF THE CLIMATOLOGY OF SOUTH AFRICA

South Africa is a water scarce country with an average annual rainfall of about 497mm, which is well below the world average of 860mm. A comparatively narrow region along the eastern and southern coastlines is moderately to well-watered, but the greater part of the interior and the western part of the country are arid or semi-arid. Sixty-five per cent of the country receives less than 500mm of rain annually and 21% receives less than 200mm (DWAF, 1988).

As South Africa is situated within the high-pressure belt of the middle latitudes of the Southern Hemisphere, warm dry descending air, associated with high pressure systems occurs over the greater part of the country most of the time, which is unfavourable for the formation of rain. This climate is modified by the influence of the warm, southward flowing Agulhas current along the east coast and the cold northward flowing Benguela current along the west coast. The warmer east coast air masses tend to be less stable than those in the western parts of the country and are more likely to give rise to precipitation.

Surface water is thus very unevenly distributed throughout the country and demand often outstrips supply in several regions. To guarantee sustainable water delivery to

various water users it is necessary to transfer water from higher yield catchments to catchments where the demand is higher than supply.

3.2 OPERATION AND DESCRIPTION OF USUTU-VAAL INTER-BASIN WATER TRANSFER SYSTEM

This study was executed in the Heyshope Dam catchment in the north-eastern part of the Republic of South Africa, near the town of Piet Retief in the Mpumalanga province (Figure 3.1). The Mpumalanga Highveld could be described as the powerhouse of South Africa with the major electricity power stations such as Tutuka, Kriel, Matla, Duvha, Hendrina, Majuba and Kendal located in the area. It also accommodates the industrial chemical giants South African Coal, Oil and Gas Corporation (Sasol) 2 and Sasol 3 with their associated industries. Although the area is endowed with abundant reserves of coal, water availability remains the issue to be addressed as demand exceeds the yield from the catchment.

To augment the demand the yield from several catchments had to be combined and developed in order to achieve a sustainable and reliable supply of water to all the coal powered power stations and Sasol plants. Storage dams were built by the Department of Water and Sanitation (DWS) at Grootdraai (Vaal River), Jericho (Mpana River), Morgenstond (Ngwempisi River), Westoe (Usutu River), Heyshope (Assegaa River), Zaaihoek (Slang River) and Witbank (Olifants River). A network of pump stations, canals and pipelines were constructed to transfer water across watersheds to the required locations (Figure 3.2).

Provision had to be made in the configuration of the network so that shortages could be augmented from other parts of the water supply system. Major pump stations are located at Morgenstond, Jericho, Camden, Geelhoutboom, Heyshope, Kuthala, Zaaihoek, Grootdraai, Grootfontein, Rietfontein and Naauwpoort. The pump stations vary in size with electrical demands from as small as 500kVA to as large as 40MVA ranging between 3 and 8 pump sets per station. The water supply system had been developed over a period of 30 years and includes various schemes, such as the Usutu River Government Water Scheme (GWS), Usutu Vaal GWS Phase I and Phase II, Central Highveld Regional Water Scheme and the Slang River GWS.

The first part of the water supply system to be developed was the Usutu River GWS, to supply water to Camden, Kriel and Matla power stations. Storage dams were constructed at Westoe in the Usutu River, Jericho in the Mpana River and Morgenstond in the Ngwempisi River. Water is pumped across the watershed with main pump stations at Morgenstond Dam and Jericho Dam and booster pump stations at Kliphoek and Camden. The Usutu-Vaal Phase I Inter-basin Water Transfer Scheme, was constructed in the early 1970's and was designed as a remote controlled scheme with the main control centre at Jericho Dam.

The next part of the system to be developed was the Usutu-Vaal GWS (Phase I), with the purpose to supply water to the Sasol 2 and 3 developments at Secunda, using water from the upper Vaal River System. The scheme further supplemented water to Kriel and Matla power stations, as well as provided an emergency supply to Witbank Dam for Duvha power station. The major storage dam was constructed at Grootdraai near Standerton (Grootdraai Dam), from where water was transferred via canals and pipelines across the watershed to the town of Trichardt (Trichardtsfontein Dam). Major pump stations were positioned at Grootdraai, Grootfontein and Rietfontein with an intermediate storage dam at Trichardt (Trichardtsfontein Dam). A pump station to supply water to Tutuka power station was subsequently added at Grootdraai Dam. This scheme was constructed in the latter part of the 1970's/early 1980's and was designed as a monitored system with manned pump stations.

In the mid-1980's, an additional scheme to supply water to Kendal power station was added as the Central Highveld Regional Water Scheme. This scheme had a pump station constructed adjacent to Matla power station and could take water from either the Usutu or Usutu-Vaal River systems. The pump station was designed as a manned station with monitoring linked to the Jericho control centre via Kriel.

Water shortages in the Vaal River System were augmented with the construction of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme. Heyshope Dam (completed in 1985) was constructed in the Assegaa River and water transferred over the watershed to the Vaal River catchment area via Heyshope and Geelhoutboom pump stations (Figure 3.3). These stations were designed as manned stations with administrative control from the DWS area office at Jericho Dam. Water is pumped from Heyshope Dam via a 20.1km canal (including a 2km pipeline) to Geelhoutboom Balancing Dam from where the

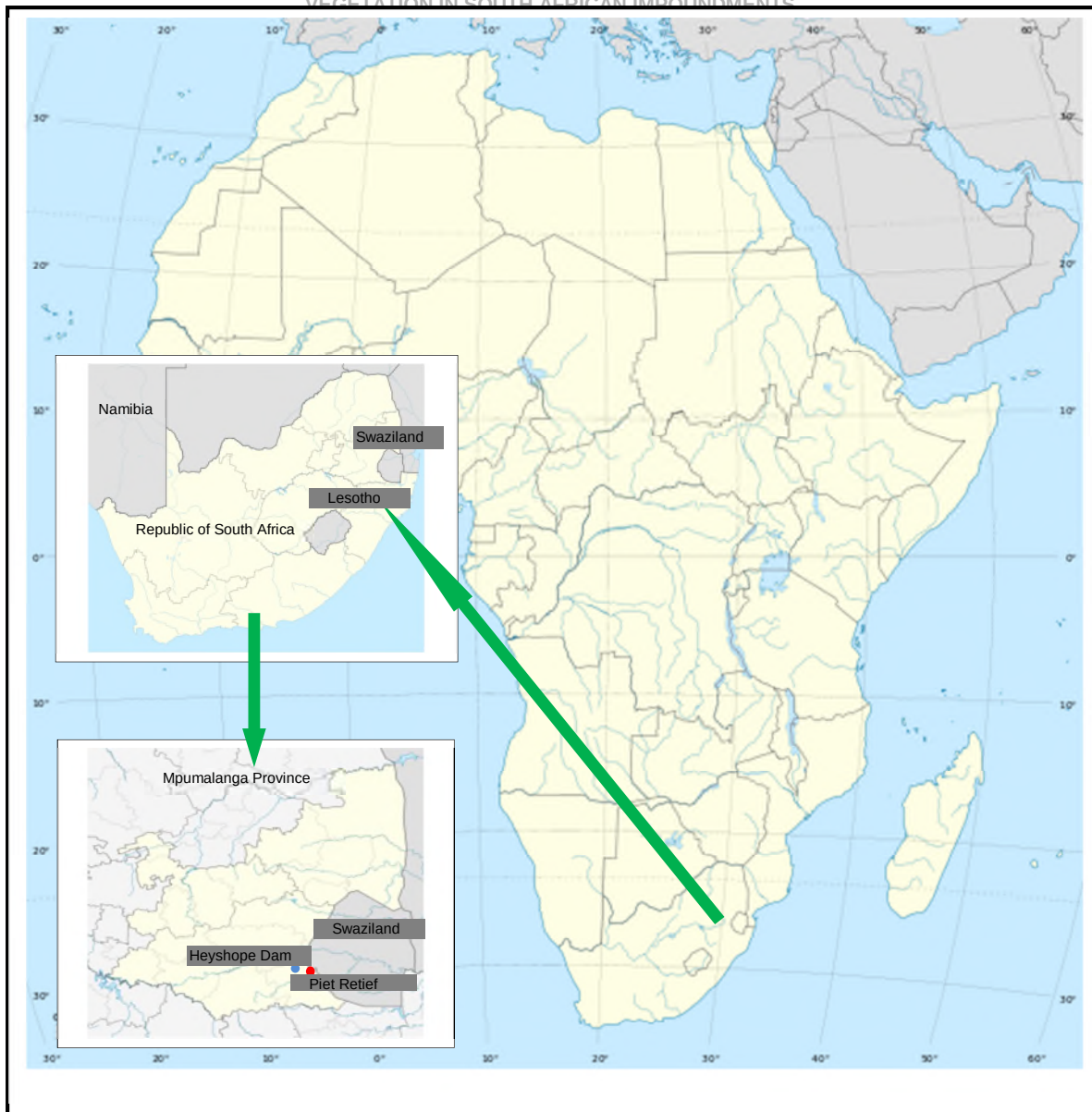


FIGURE 3.1: The location of the Heyshope Dam near the town of Piet Retief in Mpumalanga Province, Republic of South Africa.

Geelhoutboom Pump Station pumps the water over the water shed via a 4.6km pipeline to enter the Balmoral Canal.

The Balmoral Canal transports the water for a further 4.6km to the Little (Klein) Vaal River from where it flows (gravitation) to Grootdraai Dam in the Vaal River System (Figure 3.2). The Heyshope Dam, with associated conduits and pump stations, can supply the Grootdraai Dam (on demand) with at least 260 million m³ per annum. This keeps the principal Eskom power stations, as well as the Sasol refineries, operational. It is envisaged to transfer additional water to the Heyshope Dam in future with further systems.

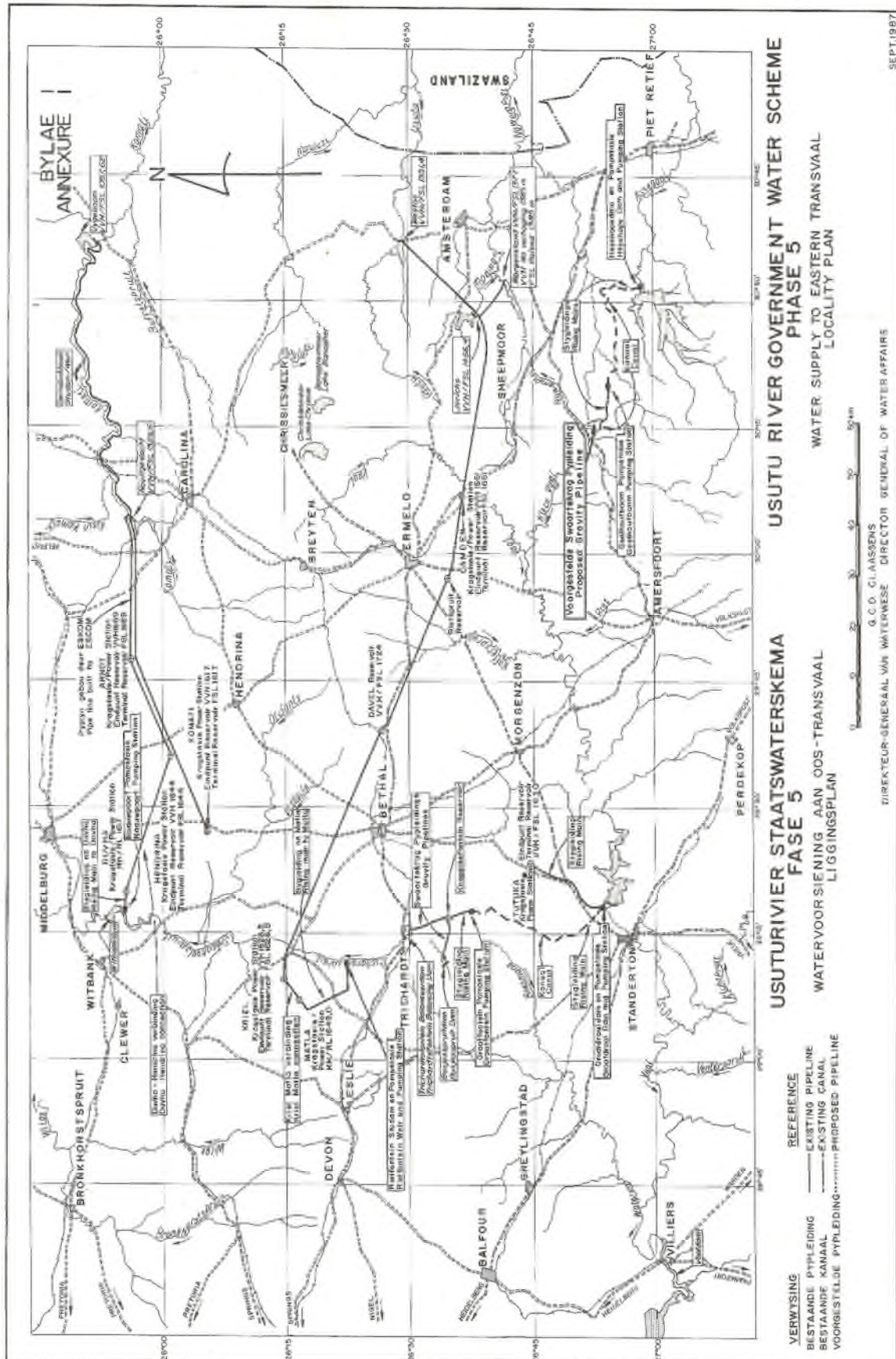
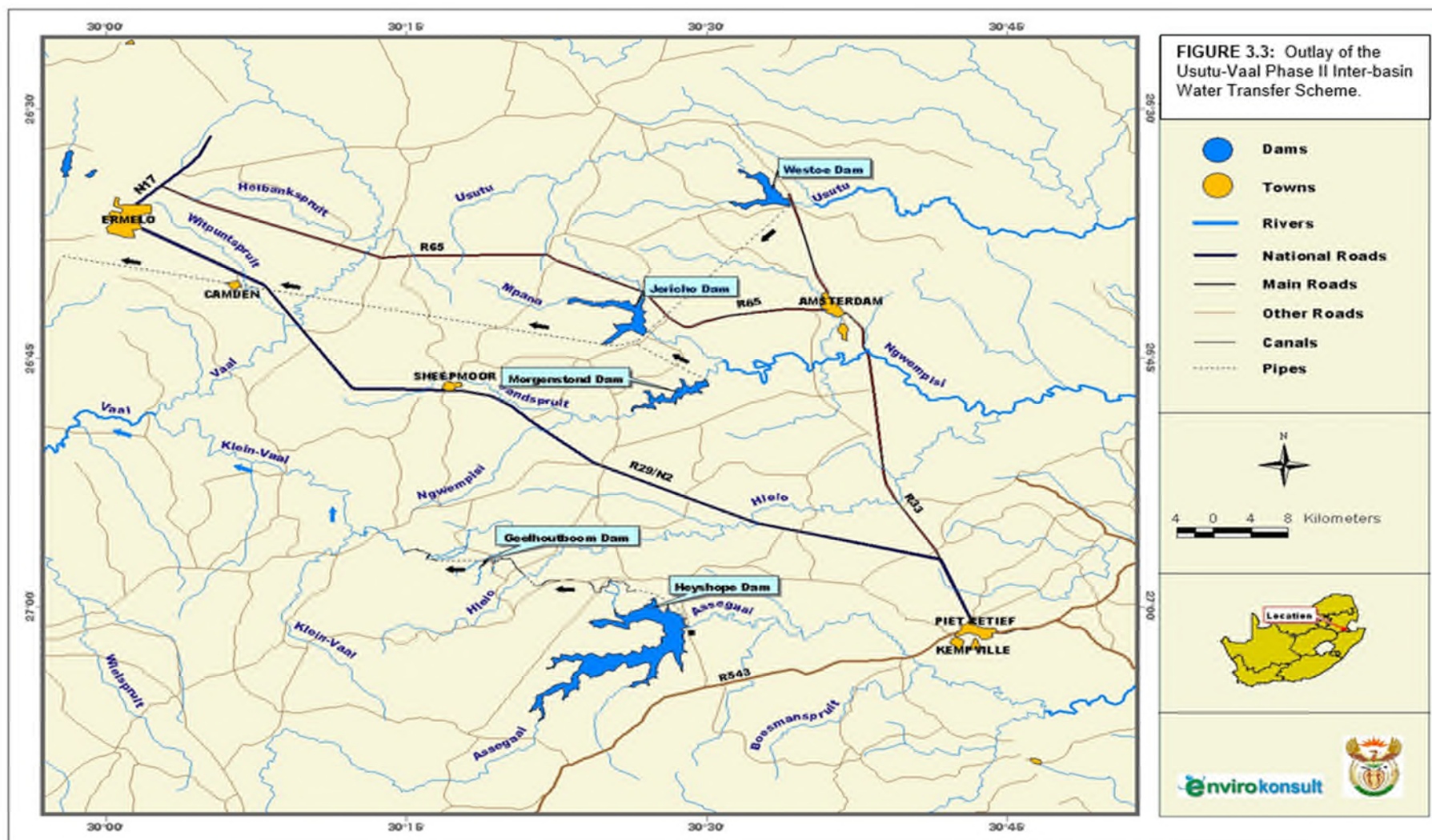


FIGURE 3.2: The Usutu-Vaal Inter-basin Water Transfer Scheme in Mpumalanga Province, Republic of South Africa.



Water originating from the Usutu River System is of a significantly higher quality than Vaal River water. Eskom (a parastatal electricity supplier) therefore prefers the use of Usutu water, whenever possible. The low levels of the Usutu reservoirs necessitated the construction of an emergency pipeline from the Balmoral Canal in 1987 to transfer water to the Morgenstond Dam (Figures 3.2 and 3.3). From this point water is transferred to the Usutu River Scheme.

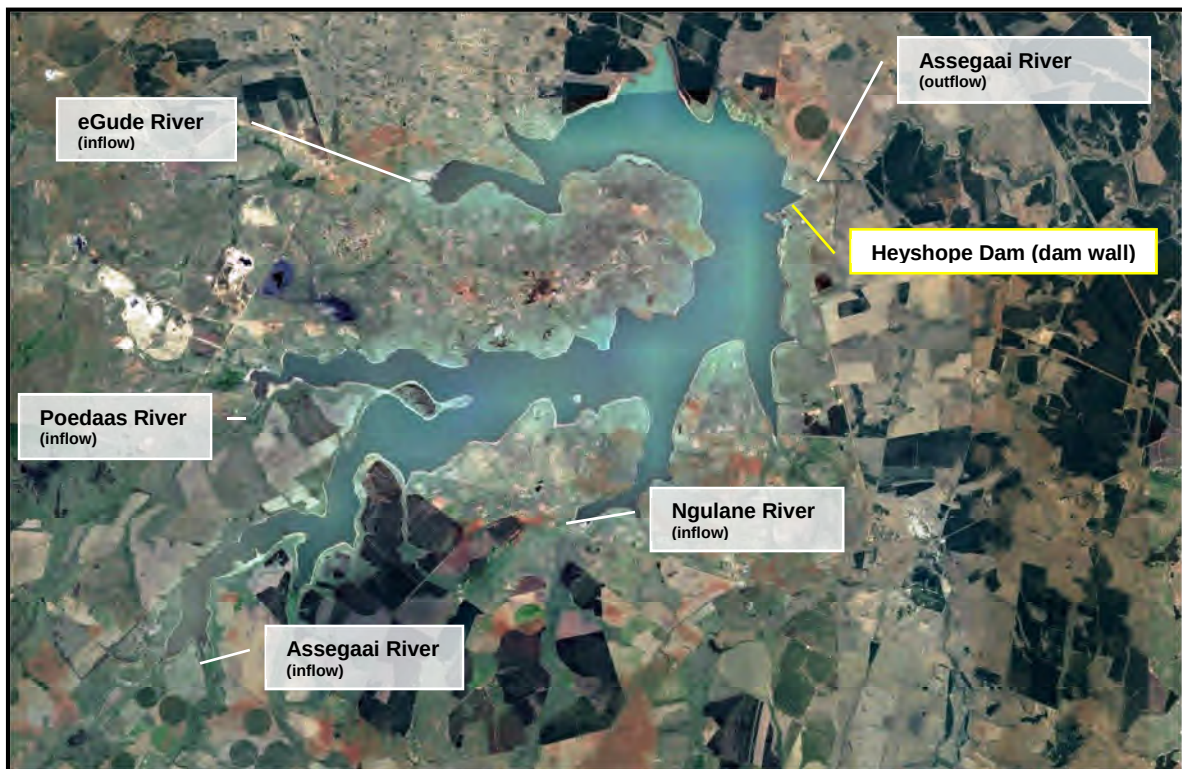


FIGURE 3.4: A satellite image of the Heyshope Dam with its tributaries.

The last scheme added to the network to supply water to Majuba power station and to augment water supply to Grootdraai Dam was the Slang River GWS. Zaaihoek Dam was erected in the Slang River to the east of the town of Volksrust with water pumped across the water shed to Majuba and the Perdewater Spruit, a tributary of the Vaal River.

3.3 DESCRIPTION OF THE PHYSICAL ATTRIBUTES OF THE HEYSHOPE DAM CATCHMENT AREA

This study focuses on the Heyshope Dam and Geelhoutboom Balancing Dam with their interlinked conduits (Table 3.1 provides a physical description of each). The

Heyshope Dam (26°59'55"S; 30°31'25"E) is situated on the Assegaaai River, 27km west of the town of Piet Retief on the Mpumalanga (Eastern Transvaal) Highveld (Figures 3.3 and 3.4). The Assegaaai River rises north-east of the village of Wakkerstroom on the eastern slope of the Langeberg – a limb of the Drakensberg mountain range. The river flows in a north-easterly direction south of Piet Retief and crosses the Swaziland international border where it joins the Great Usutu River System, south of the rural village of Manzini.

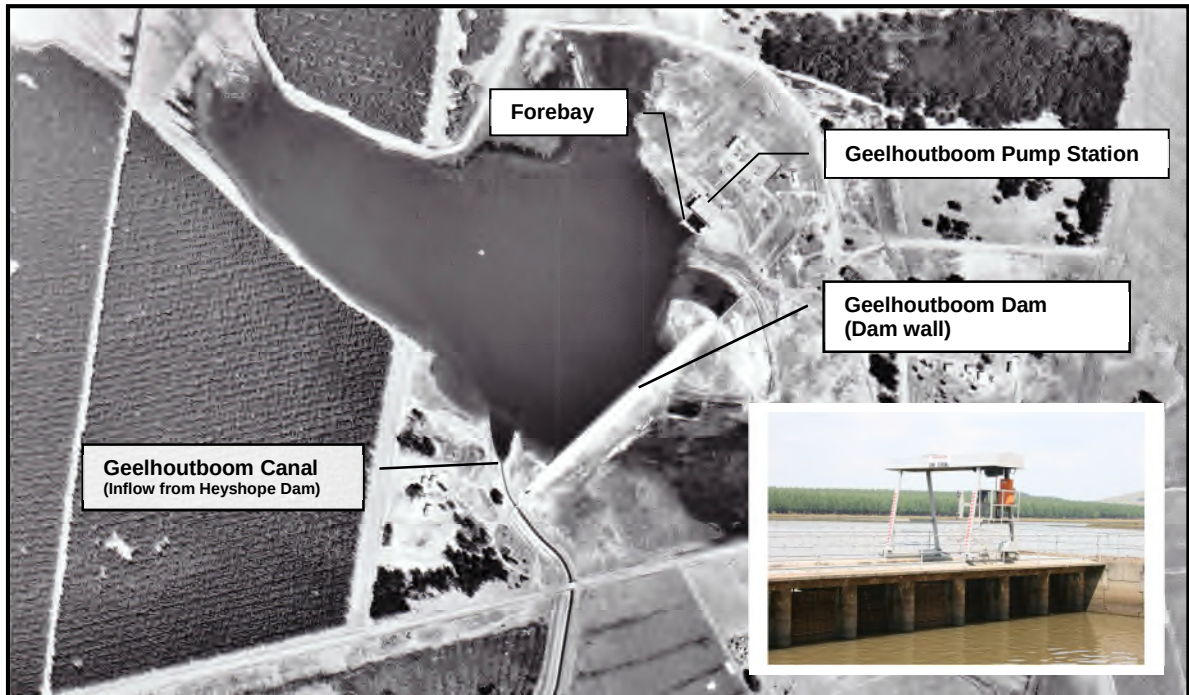


FIGURE 3.5: An aerial photograph of Geelhoutboom Balancing Dam, with a photograph inset of the forebay to the pumping station.

The mean annual temperature for the region is 16-18°C (Schulze, 1997). For the purpose of controlling aquatic vegetation by either biological or herbicidal means, the daily mean temperature is important as this influences both the feeding behaviour of sterile grass carp (the biological control agent selected for this integrated aquatic vegetation management programme) and the temperature regime for optimal herbicidal effectivity (Figure 3.6).

Rainfall in the catchment area is mainly in summer and the mean annual rainfall over the catchment is approximately 960mm. Rainfall varies from about 1,000mm at the upper reaches (almost double the average rainfall for South Africa) to 820mm at Heyshope, rising again to 1,000mm where the Assegaaai River enters Swaziland and dropping again to 900mm at the confluence with the Usutu River (DWAF, 1988).

The catchment area of the Assegaaai River upstream of the Heyshope site is 1,118km². The mean annual run-off at the Heyshope site is approximately 147.5 million/m³ (DWAF, 1988). The median rainfall is represented in Figure 3.7 and it designates a statistically expected value and is less influenced by extreme events than a mean value would be.

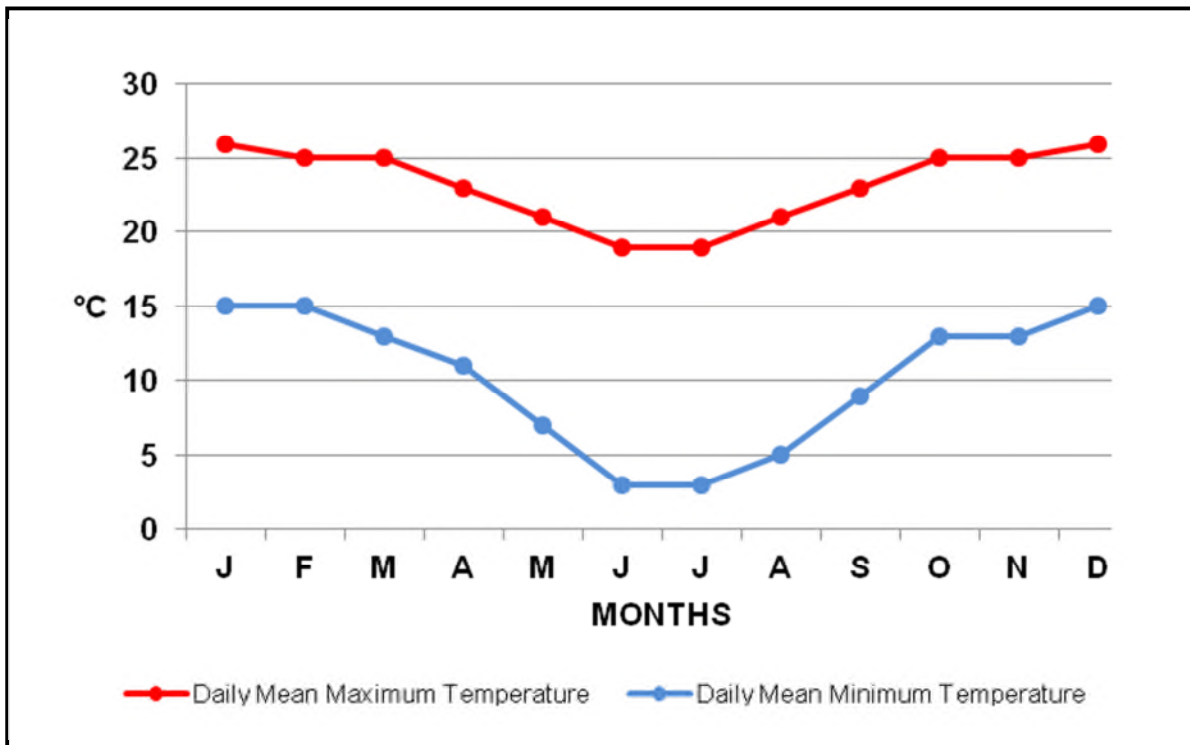


FIGURE 3.6: Daily Mean Temperature (°C) for the Heyshope Dam area (Schulze, 1997).

There are four major tributaries to Heyshope Dam, of which the Assegaaai River contributes the majority of flow (Figure 3.4). The other three rivers, the Poendaas, eGude and Ngulane Rivers, are much smaller with more variation in flow. The Mabola and Magandlandwane Rivers join the Assegaaai River before it enters the impoundment. Unfortunately, there are no flow gauging structures in any of the tributaries upstream of the reservoir, making the calculation of a hydrological balance impossible.

Heyshope Dam is situated in the Grassland Biome (Rutherford and Westfall, 1994) with the dominant vegetation units according to Mucina and Rutherford (2006) being:

- Gm 12 Eastern Highveld Grassland (Direct environs of Heyshope Dam).
- Gm 15 Paulpietersburg Moist Grassland (Transitional zone to Gm 14).
- Gm 14 Wakkerstroom Montane Grassland (Upper reaches of the Assegai River and other tributaries).

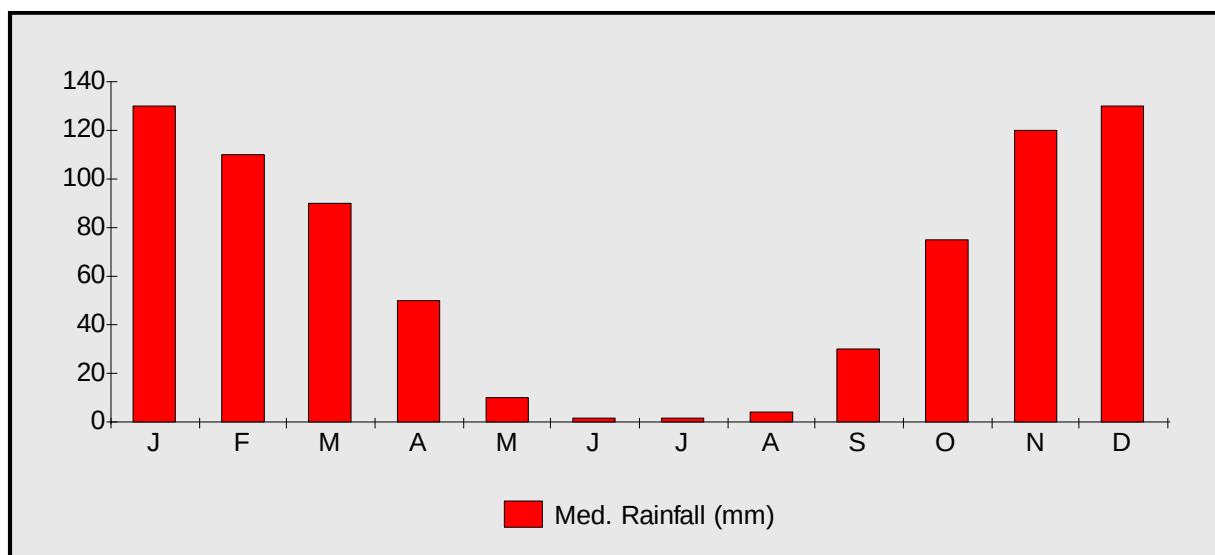


FIGURE 3.7: Monthly median rainfall (mm) for the Heyshope Dam area (Schulze, 1997).

Acocks (1988) characterised the surrounding grassveld as Veld Type 63 – Piet Retief Sourveld. Soil erosion can be found in the upper reaches, often being completely stabilized by a stoloniferous fern, *Dicranopteris linearis*.

Plant nutrient enrichment (mainly with phosphate and nitrogen species) plays a specific role in aquatic vegetation proliferation in water bodies (Du Plessis et al., 1990). In the case of the Heyshope Dam, nutrients could occur from sources such as:

- Driefontein Township and other rural settlements (storm water, sewerage, drainage from waste disposal and landfill sites, etc.). The township of Driefontein uses French drains.
- Illegal coal mining operations
- Sylviculture (*Eucalyptus* spp. and *Acacia mearnsii* plantations)
- Soil erosion and silt enrichment
- Fertilizer drainage from crop lands (minimal)
- Manure from grazing livestock (normal stocking densities)

- Excreta (guano) from water birds, and other amphibious animals (high contribution of water-soluble phosphates)
- Microbial action based upon the decay of aquatic plants and the remains of other organisms and their excreta
- Humic and fuvic acids from decaying terrestrial plants
- Recreational activities (limited impact)
- Nutrient release from bottom sediments during anoxic conditions

There are no defined registered point sources upstream of the Heyshope Dam. It can therefore be concluded that the contribution of nutrients to Heyshope Dam are from diffuse sources which are summarized in the above list.



FIGURE 3.8: Heyshope Dam: Demarcation of the catchment basin (Mucina and Rutherford, 2006).

TABLE 3.1: BASIC INFORMATION ON THE TWO IMPOUNDMENTS AND THEIR CONDUITS WHICH IS PART OF THE USUTU-VAAL PHASE II INTER-BASIN WATER TRANSFER SCHEME.

IMPOUNDMENT NAME	HEYSHOPE DAM	GEEHOUTBOOM BALANCING DAM
DAM NUMBER	W5R004	GHB-01
DATE COMPLETED	1984	1984
LATITUDE	26°59'55"	26°55'16"
LONGITUDE	30°31'25"	30°19'55"
MAIN TRIBUTARY	Assegaa River	Geelhoutboom Canal (inlet from Heyshope Dam)
TRIBUTARIES (Secondary)	(a) Poendaas River (b) eGude River (c) Ngulane River	None
DRAINAGE REGION NUMBER	2151	2151
CATCHMENT AREA (km ²)	1,122	Artificial fed via concrete canal
DEPTH _{max} AT FSL (m)	20.63	3.8
HEIGHT ABOVE SEA LEVEL (m)	1,303	1,408
SURFACE AREA (ha)	5,023.83	36
NETT CAPACITY (m ³)	463,125 x 10 ⁶	N/A
GROSS CAPACITY (m ³)	456,266 x 10 ⁶	N/A
CANAL NAME	GEELHOUTBOOM CANAL	BALMORAL CANAL
TYPE OF LINING	Concrete	Concrete
CANAL LENGHT (km)	21.1	4.6
CAPACITY (m ³ /s)	5	5

N/A: Not available

CHAPTER 4

METHODOLOGY AND APPROACH

4.1 ENVIRONMENTAL IMPACT ASSESSMENT ON HEYSHOPE DAM AND ITS TRIBUTARIES

4.1.1 Monitoring programme:

A monitoring programme was designed to evaluate the impact of the Integrated Aquatic Vegetation Management Plan on Heyshope Dam. The main tributaries of Heyshope Dam were also monitored to establish their contribution to the status of the impoundment and to determine whether the biocontrol agent (sterile grass carp) could successfully be restricted to the target areas. Furthermore, the balancing dam, Geelhoutboom Dam, was monitored at a lower frequency.

4.1.2 Location of monitoring points:

4.1.2.1 In-lake water quality monitoring sites (Heyshope Dam)

Five localities for water quality sampling were selected in the Heyshope Dam basin (Table 4.1 and Figure 4.1).

TABLE 4.1: DESCRIPTION, LATITUDE AND LONGITUDE OF MONITORING SITES IN THE HEYSHOPE DAM BASIN.

SITE NAME	ABBREVIATED NAME	SHORT DESCRIPTION OF SITE	LATITUDE	LONGITUDE
Near dam wall	HEY-Q01	50m In-lake from dam wall. [see Plate 4.1]	S 26° 59.777'	E 30° 31.339'
eGude River inflow	HEY-Q02	Bay and open water on western side of dam in area of the Driefontein settlement.	S 26° 59.351'	E 30° 28.206'
Ngulane River inflow	HEY-Q03	Bay and open water on southern side of dam in area of Ngulane River inflow.	S 27° 03.699'	E 30° 29.297'
Assegaai River inflow	HEY-Q04	Bay and open water on southern side of dam in area of Assegaai River inflow.	S 27° 04.228'	E 30° 24.097'
Poendaas River inflow	HEY-Q05	Bay and open water on western side of dam in area of coal mine.	S 27° 03.699'	E 30° 29.279'

4.1.2.2 Water quality monitoring sites in tributaries

All the main tributaries were sampled at areas where the full supply level of the dam did not influence the location. In other words samples and *in situ* measurements were taken in flowing water upstream or downstream of the impoundment. The sampling sites in the tributaries are listed in Table 4.2. The most important tributary is the Assegaai River which contributes the majority of flow to the impoundment.

TABLE 4.2: DESCRIPTION, LATITUDE AND LONGITUDE OF MONITORING SITES IN TRIBUTARIES.

SITE NAME	ABBREVIATED NAME	SHORT DESCRIPTION OF SITE	LATITUDE	LONGITUDE
Assegaai River (upstream of Heyshope Dam)	ASR-A	Assegaai River near bridge at Platjiesfontein. (± 12km upstream of HHD). [Plate 4.8]	S 27° 11.002'	E 30° 17.733'
Assegaai River (downstream of Heyshope Dam)	ASR-B	Assegaai River near bridge at Platjiesfontein. (± 12km upstream of HHD). [Plate 4.6]	S 26° 59.728'	E 30° 32.039'
Ngulane River	NGR	Upstream of gravel road bridge at inflow to HHD. [Plate 4.7]	S 27° 08.685'	E 30° 26.776'
Mabola River	MAR	Mabola River at road bridge near Dirkiesdorp. [Plate 4.5]	S 27° 10.995'	E 30° 21.698'
Mawandlane River	MER	Mawandlane River at road bridge (± 3km west from Mabola River sampling point). [Plate 4.9]	S 27° 10.995'	E 30° 21.698'
Poendaas River	POR	Poendaas River near road bridge at Maquasa. [Plate 4.10]	S 27° 03.660'	E 30° 22.129'
eGude River	EGR	eGude River at Driefontein settlement on the farm Roodekraal 21HT. [No plate]	S 26° 59.464'	E 30° 25.020'

4.1.2.3 Water quality monitoring sites in the Geelhoutboom Canal

Water is pumped from the Heyshope Dam (near the dam wall) via a short pipeline to an open canal, the Geelhoutboom Canal, from where the water gravitates over a distance of

20.1km to Geelhoutboom Dam. Two sampling sites, monitored at a low frequency, were selected in this canal - one at the starting point of the canal (GHB-IN; Plate: 4.3 and Table 4.3), and the second at the outlet of the canal to Geelhoutboom Dam (GHB-OUT; Plate: 4.4 and Table 4.3).

TABLE 4.3: DESCRIPTION, LATITUDE AND LONGITUDE OF MONITORING SITES IN THE GEELHOUTBOOM CANAL.

SITE NAME	ABBREVIATED NAME	SHORT DESCRIPTION OF SITE	LATITUDE	LONGITUDE
Geelhoutboom Canal Intake	GHB-IN	Lined canal at start of GHB Canal [Plate 4.3].	S 26°57.455'	E 30°28.502'
Geelhoutboom Canal Outlet	GHB-OUT	Lined canal, just before entering Geelhoutboom Dam [Plate 4.4].	S 26°55.270'	E 30°20.107'

4.1.2.4 Water quality monitoring site in Geelhoutboom Dam

Only one monitoring site was selected for Geelhoutboom Dam. This balancing dam has a full supply area of 36ha (89 acres) and a maximum depth of 4m. The depth at the fore bay of the Geelhoutboom pump station is 2.8m. The dam is equipped with a side flank overflow, as well as a manually operated valve pipe outlet to a small wetland.

TABLE 4.4: DESCRIPTION, LATITUDE AND LONGITUDE OF MONITORING SITE IN GEELHOUTBOOM DAM.

SITE NAME	ABBREVIATED NAME	SHORT DESCRIPTION OF SITE	LATITUDE	LONGITUDE
Geelhoutboom Dam Wall	GHB	Monitoring site at the grids of the forebay to the GHB pumping station. Water $\pm$ 2.8m deep. [Plate 4.2]	S 26°55.303'	E 30°19.724'

Geelhoutboom Dam is a constructed water conveyance structure, situated in a restricted area and is therefore not considered part of the natural aquatic ecosystem with no conservation value (Plate 4.2).



PLATE 4.1: Monitoring site HEY-Q01 – 50 m in-lake from the Heyshope Dam wall.



PLATE 4.2: Monitoring site GHB-Q01 at the pipe outlet at Geelhoutboom Dam.



PLATE 4.3: Monitoring site GHB-IN – intake of the Geelhoutboom Canal.



PLATE 4.4: Monitoring site GHB-OUT – outlet of the Geelhoutboom Canal into the Geelhoutboom balancing dam.

4.1.3 Water quality evaluation:

4.1.3.1 Biota-specific water quality variables

The following surface water quality variables were measured *in situ* at the selected sites in the Heyshope Dam and its major tributaries at locations where macro-invertebrate and fish monitoring were done: pH (325 Microprocessor WTW 100748), ambient and water temperature, dissolved oxygen and oxygen saturation (WTW Microprocessor Oxi-meter 200212), and electrical conductivity (WTW microprocessor LF 95). Variables were measured on a bi-monthly basis.



PLATE 4.5: Monitoring site MAR in Mabola River (upstream of Heyshope Dam).



PLATE 4.6: Monitoring site ASR-B in Assegaai River (downstream of Heyshope Dam)



PLATE 4.7: Monitoring site NGR in Ngulane River (upstream of Heyshope Dam).



PLATE 4.8: Monitoring site ASR-A in Assegaai River (upstream of Heyshope Dam).



PLATE 4.9: Monitoring site MER in Mawandlane River (upstream of Heyshope Dam).



PLATE 4.10: Monitoring site POR in Poendaas River (upstream of Heyshope Dam).

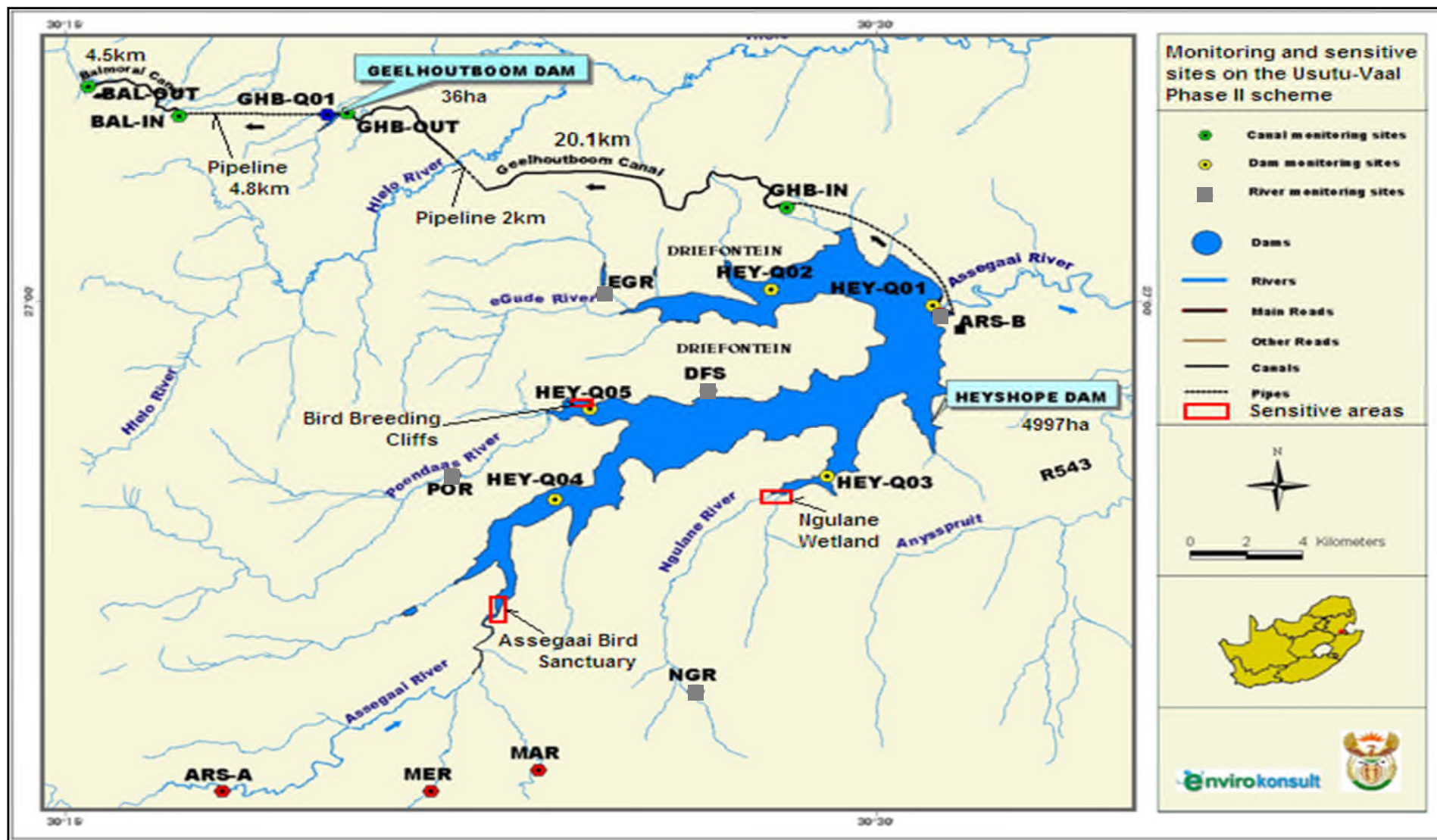


FIGURE 4.1: Location of monitoring and ecologically sensitive sites in the Heyshope Dam catchment area.

4.1.3.2 Water quality analysis

4.1.3.2.1 Historical data:

A large number of sites are sampled routinely by the DWS at varying intervals, ranging from daily to monthly, for a variety of water quality variables, throughout the Republic of South Africa. Some sampling sites are situated in reservoirs, at weirs, or in rivers, while others such as precipitation gauges, boreholes, canals, pipelines and water treatment works are also sampled.

Unfortunately, there are no routine DWS monitoring stations upstream of the Heyshope Dam, in any of its tributaries, or in the impoundment itself. Available data on the upper reaches of the Assegaa River is scarce and the availability of historically water quality data infrequent prior to the completion of the dam wall in 1986. Against this background, no historical data could be considered for the purpose of this study.

4.1.3.2.2 Current water quality status:

The current water quality status of the Heyshope Dam was assessed during monthly field trips from 2006 to 2008 to the study area.

Analysis of chemical constituents:

Grab and integrated samples were taken and analysed for macro-constituents, trace metals and suspended solids in a South African National Accreditation System (SANAS) accredited laboratory. These samples were collected at seven sites in the tributaries of Heyshope Dam, in the Heyshope Dam itself (5 sampling sites) and Geelhoutboom Dam (one sampling site) (Tables 4.3 and 4.4).

- *Macro-elements:*

Grab and integrated samples for the analysis of macro-elements were collected at all the monitoring sites in the study area. These samples were preserved with HgCl_2 and stored at 4°C.

- *Trace elements:*

Grab and integrated samples for the analysis of trace elements were collected at all the monitoring sites in the study area. These samples were not preserved, but stored at 4°C.

Analysis of biological variables:

Chlorophyll a concentrations were analysed in water samples from Heyshope Dam and Geelhoutboom Dam. Phytoplankton identification was performed on preserved (Lugol's solution) water samples from all the monitoring sites on Heyshope Dam. Analysis / identification were done by Envirokonsult Scientific Services (Pty) Ltd.

4.1.4 Characterisation of Phytoplankton community:

Phytoplankton was identified to genus level according to guidelines presented in AlgaeBase (Guiry and Guiry, 2022). Phytoplankton is classified into fifteen divisions (phyla) and 54 classes (Guiry, 2012) of which representatives of six phyla were identified in the Heyshope Dam catchment. Due to their short life cycles, phytoplankton responds rapidly to environmental changes, and therefore the species composition may be a good indicator of the quality of water in which they are found.

4.1.5 Determination of the Trophic Status:

The trophic status of an impoundment can be defined as the degree of eutrophication (enrichment of a water body with plant nutrients) and the concomitant symptoms experienced by the water body (Du Plessis et al., 1990). The classification of Du Plessis et al. (1990) was used to assess the trophic status of Heyshope Dam. This classification method, adapted from the trophic status classification by Walmsley (1984) and Walmsley and Butty (1980), is based on the (1) mean annual chlorophyll a concentration and the (2) mean annual total phosphate concentration) with the addition of (3) the mean annual transparency, determined by Secchi disk depth to distinguish between turbid and less turbid systems, as high turbidity values can suppress symptoms of eutrophication in enriched waterbodies by suppressing phytoplankton growth.

4.1.6 Aquatic vegetation surveys:

The aquatic flora was identified during several field visits to the study area. Visual observations were made by aerial reconnaissance from a helicopter, followed by a thorough boat survey to identify the aquatic macrophytes in the two impoundments. The Geelhoutboom and Balmoral canals were observed by driving/walking alongside the canal from its start to tail-end. For the purpose of this study, attention was focused on the aquatic vegetation in the Heyshope Dam, Geelhoutboom Canal, Geelhoutboom Dam and the Balmoral Canal.

As part of the aquatic vegetation surveys, all aquatic vegetation, including riparian / littoral species visible from the boat, were identified and plotted on a map for future reference. During all surveys, the dam level did not deviate more than 5% from full supply level (FSL). The methodologies used to calculate the areas of SAV infestations are described in paragraph 4.2.3.

4.1.7 Aquatic macro-invertebrate assessments:

4.1.7.1 In-lake benthic invertebrate sampling of Heyshope Dam

The sampling of benthic invertebrates from soft (mud and silt) bottom substrata was performed by employing a Birge-Ekman grab sampler (grab area = 225cm²). This apparatus proves most effective for the quantitative sampling of macroinvertebrates in soft bottom substrata.

The samples were transferred into 1ℓ plastic bottles. Rose Bengal (10 mℓ) (C.I. 45440-BDH Chemicals Ltd., Poole, England) was added to each sample. Rose Bengal is a biological colouring agent, that stains chitin containing organisms pink, enabling detection of benthic organisms within the sample. After approximately 30 minutes the samples were preserved with 20 mℓ concentrated formalin.

At the laboratory each sample was poured through a close mesh net and rinsed with running tap water, to clear the sample of excess Rose Bengal and formalin. Each sample was placed in a flat, calibrated Perspex holder and all the macroinvertebrates were then systematically removed with the aid of a travelling microscope. The macroinvertebrates from each sample were identified according to Pennak (1978) and then counted. The number of species sampled at the soft bottom substrata was multiplied by a factor of 48.7 (Van Eeden and Schoonbee, 1990). Multiplications of values were conducted in order to present the total number of macroinvertebrates per square meter at each locality.

4.1.7.2 In-lake macro-invertebrate composition of Heyshope Dam

4.1.7.2.1 *Location of in-lake macro-invertebrate sampling sites:*

Four sampling localities were selected as macro-invertebrate sampling sites in the impounded water of Heyshope Dam (Table 4.5). These sites were selected to represent all possible available biotopes for aquatic biota in the impoundment and to be in proximity to the two major tributaries of the dam.

TABLE 4.5: DESCRIPTION, LATITUDE AND LONGITUDE OF MACRO-INVERTEBRATE AND FISH MONITORING SITES IN THE HEYSHOPE DAM.

SITE NAME	ABBREVIATED NAME	SHORT DESCRIPTION OF SITE	LATITUDE	LONGITUDE
Near dam wall	HHD-1	Bay and open water on NE side of dam wall. Small bay with submerged aquatic vegetation, reeds and other emergent and SAV on the flooded portions of the banks. A few rocky areas, consisting primarily of boulders and a few cobbles, were also present on the banks (especially as a result of dam wall construction). This site also included an area of deep open water, where fewer aquatic weeds were observed.	S 26° 59.777'	E 30° 31.339'
Near Assegai River inflow	HHD-2	Bay and open lentic water on SW side of dam in area of Assegai River inflow. The habitats present were colonised primarily by SAV in the deep water, and other emergent and submerged aquatic vegetation on the flooded banks.	S 27° 04.984'	E 30° 24.442'
Near Driefontein settlement area	HHD-3	Bay and open water bordering Driefontein settlement and a plantation. It consisted primarily of deep open water next to a steep clay and mud bank and a small bay with aquatic weeds and vegetation as well as a rocky area.	S 26° 58.750'	E 30° 28.705'
Near Roodekraal area (Poendaas River inflow)	HHD-4	Bay and open water in Roodekraal area. It included a bay with a steep rock cliff on one side, and vegetated fringed banks on the other. Biotopes at this site also included deep open waters and vegetated fringes opposite of the bay.	S 27° 02.320'	E 30° 24.316'

4.1.7.2.2 Site-specific in situ water quality assessment:

Site-specific water quality variables were measured with an YSI Multimeter at the selected locations in the impoundments (Table 4.5), which include:

- Electrical Conductivity (accuracy $\pm 1\%$);
- pH (accuracy ± 0.1 pH);
- Dissolved oxygen concentration;
- % Oxygen saturation, and
- Water temperature.

4.1.7.2.3 Aquatic macro-invertebrate sampling:

Macro-invertebrate communities of shoreline sites in the dam were investigated according to the South African Scoring System, version 5 (SASS5) approach. The SASS5-method is based on the British Biological Monitoring Working Party (BMWP) method and has been adapted to South African conditions (Thirion et al., 1995). An invertebrate net (30cm x 30cm square with 0.5mm mesh netting) was used for the collection of the organisms. The available biotope types at each site were identified on arrival on each sampling site. Each of the biotopes was then sampled separately using different methods. Sampling of the biotopes was done as follows:

Stones:	All movable cobbles and boulders in shallow water. Collection of macroinvertebrates on these substrates was done by kick sampling (kicking the stones) and the invertebrate net was swiped across the disturbed area to sample the dislodged biota.
Sand:	This biotope was sampled by stirring the substrate, shuffling or scraping of the sampler's feet is done whilst the invertebrate net was continuously swept over the disturbed area.
Gravel:	Gravel typically consists of smaller stones (2 - 3 mm up to 3cm). The sampling process was similar to that of a sand substrate.
Mud:	It consists of very fine particles. Sampling process was similar to that of a sand substrate.
Marginal vegetation:	Overhanging grasses, bushes, twigs and reeds from the bank. Sampling was done by holding the net perpendicular to the vegetation (half in and half out of the water) and sweeping back and forth in the vegetation to sample dislodged invertebrates.
Aquatic vegetation:	Rooted, submersed or floating aquatic vegetation such as <i>Potamogeton</i> , <i>Stuckenia</i> , <i>Lagarosiphon</i> and <i>Nymphaea</i> . Aquatic vegetation was sampled by pushing the net (under the water) against and amongst the vegetation.

The organisms sampled in each biotope were identified *in situ* and their relative abundance to the specific macro-invertebrate community was also noted. One sample of each taxon identified was preserved for laboratory identification for quality control.

4.1.7.3 Aquatic macro-invertebrate sampling in the tributaries of Heyshope Dam

4.1.7.3.1 Location of macro-invertebrate sampling sites in the tributaries:

During the 2005 baseline, four suitable control and potentially impacted sites were selected in the streams both upstream and downstream of Heyshope Dam (Figure 4.2) to evaluate and adequately describe the impact (positive or negative) (Table 4.6). Fish and macro-invertebrate surveys were conducted and compared to available data to set baseline conditions after the introduction of sterile grass carp. The general approach used for this study was a rapid appraisal technique based on the guidelines set by the Resource Directed Measures for Protection of Water Resources (DWAF, 1999).

TABLE 4.6: DESCRIPTION, LATITUDE AND LONGITUDE OF MACRO-INVERTEBRATE AND FISH MONITORING SITES IN THE TRIBUTARIES OF HEYSHOPE DAM.

SITE NAME	ABBREVIATED NAME	SHORT DESCRIPTION OF SITE	LATITUDE	LONGITUDE
Assegaai River upstream of Heyshope Dam	SITE-1	Well-developed riffles and runs with smaller pools and backwaters.	S 27° 11.010'	E 30° 17.720'
Assegaai River downstream of Heyshope Dam	SITE-2	Well-developed riffles and runs with smaller pools and backwaters with eroded banks.	S 26° 59.734'	E 30° 32.105'
Poendaas River upstream of Heyshope Dam	SITE-3	Channeled wetland with bank erosion, loss of riparian zone and exotic vegetation encroachment.	S 27° 03.657'	E 30° 22.134'
Ngulani River upstream of Heyshope Dam	SITE-4 and 4a	Slow shallow and slow deep habitats	S 27° 04.179'	E 30° 28.174'

4.1.7.3.2 Site-specific in situ water quality assessment:

EUTHECH portable microprocessor-based testers were used during sampling at each sampling site for the following water quality measurements. The same water quality variables were measured in the tributaries as measured in the impoundment (see paragraph 4.1.7.2.2). Sampling were done once a year.

4.1.7.3.3 Aquatic macro-invertebrate sampling:

Aquatic macroinvertebrates have been used to assess the biological integrity of stream ecosystems with relatively good success throughout the world (Rosenberg and Resh,

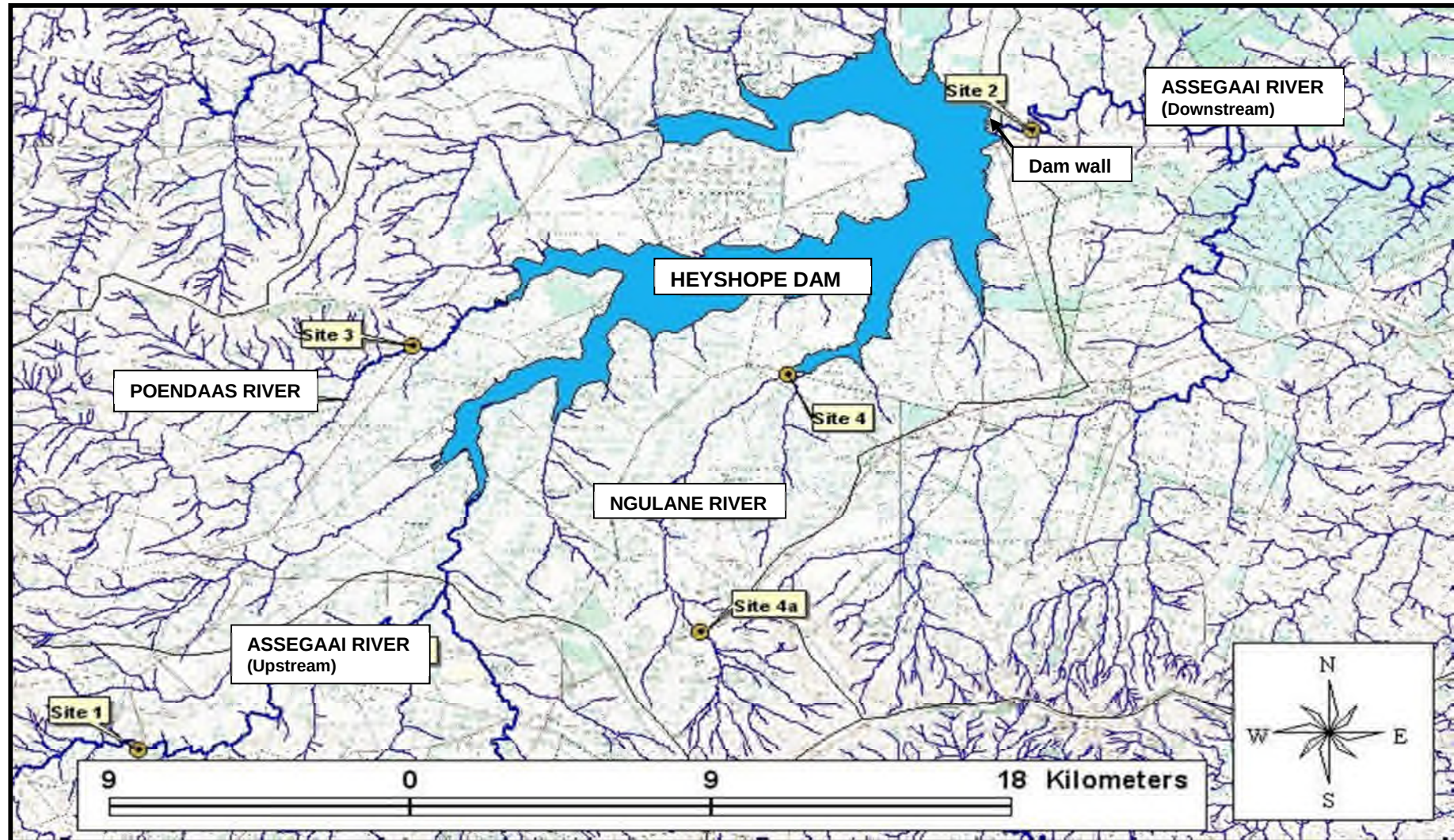


FIGURE 4.2: Location of macro-invertebrate and fish monitoring sites in the tributaries of Heyshope Dam.

1993; Barbour et al., 1996). Aquatic macroinvertebrates are more commonly used for this purpose than any other biological group (O'Keefe and Dickens, 2000) and aquatic macro-invertebrate communities offer a good reflection of the prevailing flow regime and water quality in a river.

The four major components of a stream system that determine productivity for aquatic organisms are the flow regime, physical habitat structure (e.g., channel form and substrate distribution), water quality (e.g., temperature, dissolved oxygen), and energy inputs from the watershed (e.g., nutrients and organic matter) (Milhous and Bartholow, 2004). Distribution of an aquatic macro-invertebrate population is ultimately set by the physical-chemical tolerance of the individuals in the population to an array of environmental factors. The distribution pattern, resulting from habitat selection by a given aquatic macro-invertebrate species, reflects the optimal overlap between habit (mode of existence) and physical environmental conditions comprising the habitat.

Aquatic macroinvertebrates were collected annually in the tributaries of Heyshope Dam using an invertebrate net (30cm x 30cm square with 0.5mm mesh netting). Taxa were identified to at least family level according to the SASS5 sampling technique (Dickens and Graham, 2001). Taxa collected from streams were analysed according to the standard SASS technique. Chutter (1998) developed the SASS protocol as an indicator of water quality. It has since become clear that SASS gives an indication of more than mere water quality, but rather a general indication of the present state of the invertebrate community. The SASS results can be classified into one of six classes, ranging from unimpaired (Class A), to very severely impaired (Class F) (Table 4.7). These values are only broad guidelines and conditions upstream and downstream are often a good indication of what to expect. The average score per recorded macro-invertebrate taxon (ASPT) was also determined.

Because SASS was developed for application in the broad synoptic assessment required for the River Health Programme, it does not have a particularly strong cause-effect basis. The Macro-invertebrate Assessment Index (MIRAI) was therefore used to determine the ecological condition of macroinvertebrates for the sites. The MIRAI is a rule-based model developed by DWS in conjunction with others (Thirion, 1998). It integrates with the ecological requirements of the invertebrate taxa in a community or assemblage to their response to modified habitat conditions. Although the MIRAI can be determined using information collected during a standard SASS survey, it can also be determined using more detailed information. The aim of the MIRAI is also to provide a habitat-based cause-

and-effect foundation to interpret the deviation of the aquatic invertebrate community from the reference condition.

TABLE 4.7: BROAD GUIDELINE TO PRESENT RIVERINE ECOLOGICAL STATE CLASSES IN TERMS OF INVERTEBRATE COMPOSITION AND SASS5 BIO-MONITORING RESULTS.

ECOLOGICAL CLASS	DESCRIPTION	SASS SCORE	ASPT
A	Unimpaired. High diversity of taxa with numerous sensitive taxa.	> 175	> 7
B	Slightly impaired. High diversity of taxa, but with fewer sensitive taxa.	140 – 175	6.2 – 7
C	Moderately impaired. Moderate diversity of taxa.	85 – 139	5.6 - 6.1
D	Considerably impaired. Mostly tolerant taxa present.	60 – 84	4.8 - 5.5
E	Largely impaired. Only tolerant taxa present.	41 – 59	4 - 4.7
F	Very severely impaired. Very few tolerant taxa present.	< 40	

4.1.8 Fish community:

4.1.8.1 Fish species composition of Heyshope Dam

Gill nets were set up for a period of 24 hours at the selected sites. The mesh size ranges of the gill net sets were as follows: 57, 63, 73, 93, 118 and 150mm. Another method applied, by means of a boat, was electro-narcosis. This was done by mounting the electrodes on the front of a small boat and then electro-shocking in selected areas, especially where gill netting could not be applied. Each fish was identified to species level and the standard length and mass of each specimen noted. Monitoring was done annually.

4.1.8.2 Relative abundance of fish in Heyshope Dam

Catch-Per-Unit-Effort (CPUE), also called the catch rate, is frequently the single most useful index for long term monitoring of a fishery. Declines in the CPUE may indicate that the fish population cannot support the level of harvesting or a decline in habitat integrity. An increase in CPUE on the other hand indicates favourable conditions for the fish population. The CPUE of Heyshope Dam was determined in an attempt to investigate the abundance of each species at different sites in the dam. The CPUE was determined as follows:

- Standard electro-narcosis by boat: 1 effort = adjusted to 1 minute per site.
- Standard gillnetting: 1 effort = adjusted to 1 net/1 hour per site.

4.1.8.3 General health and condition factors of fish in Heyshope Dam

The general external health was also investigated for each individual fish sampled. This was done by noting any external anomalies, such as necrosis, cysts, damage to eyes, etc. Care was taken not to include damage caused by the sampling techniques used.

Condition factors were only determined when more than twenty individuals of a species were collected at a sampling site in the dam, to ensure statistical integrity. Consequently, the length-weight relationship was applied to formulae as those used by Le Cren (1951), Du Toit (1971), Schutte (1973) and Van der Bank (1984) to determine the condition factor as follows:

$$M = c L^n$$

$$\therefore \log M = \log c + n \log L$$

$$\log c = \frac{\sum \log M \sum (\log L)^2 - \sum \log L \sum (\log L \log M)}{N \sum (\log L)^2 - (\sum \log L)^2}$$

$$\text{and } n = \frac{\sum \log M - N \log c}{\sum \log L}$$

Where: M = mass
L = length
N = amount of fish

$$K = \frac{(\text{average mass})}{c (\text{average length})^n}$$

4.1.8.4 Site selection for fish in the tributaries of Heyshope Dam

During the 2005 baseline, four suitable control and potentially impacted sites were selected in the streams both upstream and downstream of Heyshope Dam to evaluate and adequately describe the possible impact of the sterile grass carp, should they escape the target area (Table 4.6). Fish and macro-invertebrate surveys were conducted and compared to available data to set baseline conditions after the introduction of grass carp. The general approach used for this study was a rapid appraisal technique based on the guidelines set by the Resource Directed Measures for Protection of Water Resources (DWAF, 1999).

During the 2006 follow-up survey, fish and macro-invertebrate surveys conducted were at the same sites and compared to 2005 baseline conditions to detect possible aquatic health trends. Due to the high level of the water in the Heyshope Dam during 2006, the Ngulane River site (Site 4) was flooded and an alternative upstream site (Site 4a) was sampled.

4.1.8.5 Fish species composition in the tributaries of Heyshope Dam

An assessment of the biological integrity of a river is often based on indices that use attributes of fish assemblages, such as species diversity and abundance. This kind of assessment, in combination with the assessment of other groups of biota, contributes to an understanding of the current ecological state of the river.

The reference and modified reference condition of the freshwater fish assemblage in the Assegaai, Ngulani and Poendaas Rivers was mainly based on available background information (Gaigher and Pott, 1973; Jubb, 1967; Kleynhans, 1983, 1984 and Skelton, 1993), as well as the Mpumalanga Parks Board fish data base.

Fish were collected during a site visit at the selected sites with a Smith-Root electro-narcosis (AC shocking apparatus) and a small seine net (fine mesh). No suitable sites were available in the tributaries for the use of larger net types. All the collected specimens were identified. The presence, absence or abundance of species was compared to the expected reference condition based on available data. Using a rule based model developed by DWS (Fish Response Assessment Index (FRAI))(Kleynhans, 2007), changes from the reference condition were evaluated against the known response of the fish assemblage to changes in available habitat categories within parameters such as flow depth, water quality, flow conditions and available cover.

4.1.9 Waterfowl surveys on Heyshope Dam:

The first avian survey for this study was undertaken during October 2005 (summer) to establish background information regarding the waterfowl and wetland birds of the Heyshope Dam and adjacent areas. Two follow-up surveys, one in October 2006 and the last one in May 2007 (winter), were done to establish any major changes regarding waterfowl distribution and numbers on the impoundment.

The relevant wetland habitat types were surveyed by navigating the periphery (112km shoreline at FSL) of the dam by motorboat. Representative habitat types were established and associated birds frequenting these biotopes were identified per habitat.

Tarboton (1995) started avian surveys on Heyshope Dam and surrounding wetlands during May 1992, and counted birds in pre-selected bays due to the fact that these bays were accessible, most of the birds concentrated in the bays, and the surveys were regarded as accurate. Tarboton (1995) could not survey the entire shoreline as certain areas were inaccessible at that stage, and not all bays were surveyed with each visit. The counts made thus fall short of the total number of water birds on the entire dam, but they provided some basis for assessing the importance of the impoundment for birds.

Subsequent surveys by a Mpumalanga Parks Board team as part of the Coordinated Water Bird Counts (CWAC: July 2006, January and August 2007) and this study: October 2005, October 2006 and May 2007 was done with a boat and most of the impoundment's perimeter were observed from the motorboat at medium and low speeds.

However, when analysing the data, it became clear that in the case of certain bird species, the Tarboton surveys constantly recorded more individuals than counted in this study. This situation can be explained by the Tarboton counts which were done from the shore at a low speed, and thus the bays with its denser aquatic and marginal vegetation would have been covered better. In contrast, the counts from the noisy petrol driven motorboat might have sent a number of the retiring birds in hiding and these remained unaccounted for.

During the 1992 and 1994 monitoring, Tarboton counted the birds in 5 bays during every survey. During 1993 he only counted two bays on three occasions. It is therefore difficult to compare the different surveys due to these discrepancies, hence only the comparable data was used in the graphs in the discussion section of this study.

4.2 METHODOLOGY BEHIND THE DEVELOPMENT OF AN INTEGRATED AQUATIC VEGETATION MANAGEMENT PLAN (IAVMP) FOR THE USUTU- VAAL PHASE II INTER-BASIN WATER TRANSFER SCHEME

4.2.1 Develop problem statement:

The first step in the developing of an IAVMP is to develop a realistic problem statement describing the reasoning behind the necessity to implement an IAVMP in a specific water system. In other words, the problem statement should describe the limitations on beneficial uses of the target water bodies and conveyance structures and quantify the impact on the operation of the system and water users.

The primary water users of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme are industries in the industrial heartland of South Africa, as well as many power stations in the Eastern Transvaal-Mpumalanga area. These industries rely on the continuous supply of water and cannot afford downtime due to water supply interruptions. The inter-basin water transfer scheme was constructed to augment the water supply to satisfy the high demand of these industries as the flow in the upper Vaal River System was insufficient, especially during the winter months.

The problem in sustainable water delivery to water users was that SAV interferes with water supply by blocking high-capacity water transfer pumps at Heyshope Dam and Geelhoutboom Dam which reduces the capacity of the associated conduits.

4.2.2 Set management objectives:

This step identifies reasonable management goals that maximise beneficial uses, yet are compatible with water bodies' capacity to sustain those uses. These goals must address specific uses and be attainable. The goals must also be prioritised and scheduled into a time-frame.

The resident engineer of the Usutu-Vaal Phase II Inter-basin Transfer Scheme required a SAV management plan which would ensure that the high-capacity (5m³/s) pumps at the Heyshope Dam wall and the Geelhoutboom pump station will be managed clear of vegetation fragments at all times, especially during winter months when the demand in the Vaal River System was on its highest (personal com., Van Heerden, 2006). To reach this goal, the two conduits, Geelhoutboom Canal and Balmoral Canal, need to be operated as

far as possible free of vegetation at all times. The 36ha Geelhoutboom Dam (Geelhoutboom pump station) should also be free of SAV to ensure optimal functioning of the water transfer pumps and limiting blocking of grids at the pump station inlet and the water cooling system of the pumps. Furthermore, the upstream Heyshope Dam should not experience problems with SAV in the area of the abstraction point near the dam wall, whilst the impact of the aquatic vegetation control measures on the ecological sensitive areas in the impoundment should be kept to a minimum as far as possible.

4.2.3 Identification of target vegetation species and calculation of target areas:

The target SAV species were identified, quantified and their impact on all components of the inter-basin water transfer scheme was established. The Heyshope Dam was thoroughly surveyed by boat. Each and every patch of SAV were surveyed. The total area of Geelhoutboom Dam was infested as this is a shallow balancing dam. Target SAV species and areas to be treated were identified, mapped and the surface area of each area calculated. The two conduits, Geelhoutboom Canal and the Balmoral Canal were surveyed by vehicle and by foot. As these concrete-lined canals are civil structures that need to be free of all vegetation to ensure maximum (design) capacity for optimum operation, all macrophytes and algae in these structures were regarded as target species.

It is important to quantify and document areas of nuisance infestation to evaluate management success (Madsen and Wersal, 2017). To establish a baseline and evaluate the success of the IAVMP, four detailed aquatic vegetation surveys were performed to quantify the area covered by the target SAV in Heyshope Dam. As this was the first large scale SAV management project in the history of South Africa, the surveys to quantify the areas infested by submersed vegetation were done in as much detail as possible. No standard methods for quantifying SAV under local conditions were available at the time of this project. The quantitative assessments were done on Heyshope Dam during the peak winter months, with a specially equipped survey boat. The total visible surface area (hectares) of the aquatic weed infestation was calculated during each survey. The first aquatic vegetation survey was done in May 2000 (Envirokonsult, 2000), prior to the implementation of the initial IAVMP in 2001 (and five years prior to the initiation of this study), repeated in May 2006, May 2008 and May 2010 (peak winter in the southern hemisphere). The area quantified during 2000 was used as baseline to this study and the success of the SAV management programme was evaluated in the subsequent assessments.

All areas of aquatic vegetation were systematically surveyed from the boat with a Navisound ecosounder (Model: Navisound 110) and DGPS-Differential (Model: Omnistar) consisting of a GPS receiver that interfaced with a data recorder (laptop computer or data logger). Transducers (190-210 kHz) were used with a 3° cone as it gives the most precise depth under the boat and it will usually not penetrate silt. In the data acquisition phase, the boat skipper was responsible for the navigation, positioning and depth determination with the software and hardware on the boat. The information was logged and interfaced with Hypack (Software).

When SAV strips along the littoral zone were surveyed, the shoreline was extracted from existing maps of the dam. The width of the SAV strips was accurately mapped. With large SAV areas in the open water, the boat followed the perimeter of the total infested area in order to measure the surface area using the GPS equipment. The data was then presented as mapped areas with the use of Model Maker software indicating the (1) location of each patch of submersed vegetation, (2) depth at specific monitoring locations and (3) SAV species identification. Where small patches of SAV were encountered, the infested area was estimated in relation to the length of the survey vessel, which is 5.1 meters long. In all cases the area of submersed aquatic macrophytes was calculated for both species (*P. schweinfurthii* and *S. pectinata*) present in Heyshope Dam as they both occupied the same niche. No distinction was made between the species as both were regarded as target species to be managed.

4.2.4 Identification of non-target areas as conservation areas:

During the initial survey of an impoundment, it is necessary to establish the location of ecological sensitive areas and to evaluate their conservation status. If it is anticipated that the proposed aquatic vegetation management plan may have a negative impact on these areas, such areas should be avoided or appropriate mitigation actions should be addressed in an Environmental Management Plan (EMP). In the case of Heyshope Dam, the Assegaa River inflow was regarded as a sensitive aquatic ecosystem in terms of the presence of large numbers of various species of waterbirds, as well as specific aquatic plant species (*Persicaria amphibia*, *Marsilea macrocarpa*). The Ngulane Wetland at the Ngulane River inflow was also regarded as sensitive for the same reasons. A well designed IAVMP will consider these areas and preserve their ecological integrity.

The Heyshope Dam and its catchment were surveyed initially (2000) by helicopter and then in detail by boat and all areas with conservation value were identified and mapped.

All aquatic vegetation in the littoral zone of the 112km periphery of the impoundment was identified and recorded.

4.2.5 Selection of appropriate control measures:

The choice of site-specific SAV control measures involves the selection of the combination of control methodologies that best meets the needs of the programme with the least impact on the receiving (non-target) environment. The approach involves examining the alternatives with regard to factors such as: the extent of the problem; scale of the infestation; intensity and timing of treatment; effectiveness against target vegetation; duration of control (short-term vs. long-term); availability of control methodologies (herbicides, biocontrol-agents, mechanical equipment, etc.), human health concerns; environmental impacts and mitigation; programme cost and permit requirements.

The IAVMP for the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme was built around herbicidal and biological control components, where a diquat-based formulation was used for the herbicidal control and sterile (triploid) grass carp (*Ctenopharyngodon idella* Val.) as the biocontrol agent.

The biocontrol agent was used in both impoundments of the scheme. As far as the herbicidal component is concerned, only formulations which are registered with the Registrar of Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act 1947, according to the requirements of Act No. 36 of 1947, can be used in South Africa. This was challenging during the timeframe of this study as the formulations registered for SAV were limited and those that were registered were not freely available on the South African market. At the time of the project only diquat was registered on the target SAV species and available in the market, hence this formulation was used as the herbicidal component for this project.

4.2.5.1 SAV control measures in Heyshope Dam

Only partial control of SAV is required in Heyshope Dam, as the upper reaches do have a specific conservation value and impacts of the IAVMP may be negative on the receiving aquatic ecosystem, if not managed.

A diquat-based formulation, bypiridyl (200 g/l), with a concentration of 50 liters/ha/m, was used to treat the SAV. The herbicide was applied by subsurface injection from a motorboat. The herbicide contractor was provided with maps of the impoundment with demarcated areas to be treated, as well as timeframes. The aim was to reduce SAV in the Heyshope Dam from 700ha to 70ha, a 90% reduction in total cover by SAV.

Over a period of nine years a total of 36,000 sterile grass carp fingerlings were stocked into the impoundment. The first stocking started in 2001 (prior to this study) and the last in 2009. It was anticipated that piscivores such as the exotic *Micropterus salmoides* (largemouth bass) would have a significant impact on the grass carp numbers stocked.

Hence, a stocking rate of 50 fingerling sized (maximum fork length of 10cm) per hectare infested area was selected based on the original SAV infestation of 700ha. Herbicide SAV control in Heyshope Dam was undertaken at the area in front of the abstraction points at the dam wall to prevent interference from plant biomass at the high-capacity pumps at the pump station.

4.2.5.2 SAV control measures in Geelhoutboom balancing dam

It was decided to over-stock sterile grass carp in Geelhoutboom Dam where total control was required in this 36 hectare civil structure with no conservation value. A total of 1,400 fingerling sized sterile grass carp were stocked into this impoundment prior to the time-frame of this study (2002–2004). This resulted in a stocking density of 39 fish/ha (FSA=36ha). It was important to control the submersed aquatic vegetation in this balancing dam in the shortest possible time as the pumps experienced problems on almost a continuous basis. Divers were also used to clear the fore bay grids of the pump station on a regular basis at high cost. Herbicidal control was not considered by the managers of the scheme at that stage.

To ensure that the sterile grass carp did not escape the Geelhoutboom balancing dam, an outlet structure was designed and constructed at the Geelhoutboom Canal outlet into the Geelhoutboom Dam (Plate 5.24 and Plate 5.25). A metal grid was incorporated into the design as part of the outlet structure to contain grass carp in the balancing dam and eliminate upstream migration from the target area.

4.2.5.3 SAV control measures in the Geelhoutboom Canal

The application of triploid grass carp for the biocontrol component of the IAVMP may be an appropriate tool in vegetation control in Heyshope Dam and Geelhoutboom Dam, but will be an impractical approach in the two concrete-lined canals. Acrolein (95% 2-propenal) was recommended to manage the vegetation in the Geelhoutboom Canal while in full operation. When the canal is not operational, spot treatment of SAV with a diquat-based formulation, and the algae with a copper-based formulation, was recommended. The two active ingredients can also be applied in a mixed application. The selection of the acrolein treatment locations was important to avoid fish kills (grass carp) in the receiving Geelhoutboom Dam.

4.2.5.4 SAV control measures in the Balmoral Canal

Spot treatments with a diquat-based herbicide in the Balmoral Canal were recommended as the latter consists of a very short (4.6 km long) concrete-lined structure that spills directly in the natural aquatic ecosystem of the Klein-Vaal River from where the water gravitates to the Vaal River System. This canal section is too short to use acrolein, because the herbicide would reach the natural aquatic ecosystem downstream and will have a negative impact on the receiving non-target fauna and flora.

4.2.6 Specify control intensity:

This step links control intensity to the operational function of the system. For optimal functioning of the water conveyance system of the Usutu-Vaal Phase II Inter-basin Water Scheme, it must be functional and able to operate at optimal operational conditions at all times. Thus a high level of SAV control is necessary in the conveyance structures, but a lower level or partial control may be sufficient in the source (Heyshope Dam), where the conservation of the aquatic ecosystem is also a priority. The SAV in the area near the abstraction point at the Heyshope Dam must, however, be controlled to a higher level.

4.2.7 Method of application of herbicides and biocontrol agents:

It is important that specific methodologies of application of herbicides, biocontrol-agents and other selected control measures are clearly thought through and understood by the contractors who will do the applications. Especially where an integrated approach is followed, the different control measures should be integrated to ensure optimal synergism

between all components of the IAVMP. Different legislation needs to be considered and adhered to.

4.2.8 Formulation of integrated treatment scenario:

This step identifies critical factors for choosing the combination of control methodologies that best meets the goals of long-term management, with the least impact on the non-target, receiving environment. In the case of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme, different approaches were necessary for different components of the system, as discussed in the paragraphs above. The approach was to establish a 90% reduction of SAV in the 700 hectares of Heyshope Dam using a diquat-based herbicide and introducing sterile grass carp to manage the SAV on a cost-effective long-term basis.

4.2.9 Timing and sequence of control application:

The introduction of all facets of the IAVMP should be strategically scheduled to ensure optimum efficacy on the target plants. The following factors play a role: Suitable environmental conditions; water delivery schedule of system and availability of control agents. A monitoring programme is essential for the optimisation of all facets of the IAVMP.

4.2.10 Project team:

A project team, consisting of the project manager and contractors, must be appointed before the implementation of an IAVMP. The project manager should be a qualified professional aquatic vegetation management scientist, licensed as a professional Pest Control Operator (PCO) with the Registrar of Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act 1947, according to the requirements of Act No. 36 of 1947. The DWS may also appoint a management committee to ensure adherence to legislation and interaction with other departmental and inter-departmental structures.

4.2.11 Develop a long term management strategy:

Depending on the severity of the aquatic vegetation problem, it can take years to achieve specific management goals. Therefore, a dynamic long term management strategy is essential for the integrity of the Usutu-Vaal Inter-basin Water Transfer Scheme. If the manager of a water delivery system chooses not to address the management of nuisance

aquatic vegetation, it is critical to consider the possible consequences, e.g., will there be impacts on delivery, human safety, recreational uses, aquatic life and habitat if the problem conditions in the impoundment or water conveyance structures are allowed to continue or not? What will the financial implications be? In the case of this system, there are significant consequences, not only for the operation of the system, but also for the economy of the country.

4.2.12 Develop a monitoring programme:

A lake or impoundment is an active dynamic living ecosystem. Conditions in the target system may change over time. As a result an IAVMP must include a monitoring element to regularly evaluate treatment effectiveness and recommend adjustments as and when needed. The effectiveness of the overall programme should be evaluated at least on an annual basis. Important water delivery structures, such as the Usutu-Vaal System, need to have a long-term monitoring programme with specific goals to maintain the system in optimal state of operation at all times.

4.2.13 Budget:

From the experience gained on Heyshope Dam, it will be possible to compute costs and a budget to implement an IAVMP on other impoundments with similar problems. A budget may include planning costs, contracted treatment costs, capital costs (equipment and materials), operation and maintenance costs, equipment replacement costs, programme monitoring and evaluation costs, non-target area mitigation costs, permit costs and auditing costs. The cost to manage SAV can be expressed as cost/hectare of infested area.

The managers of the Usutu-Vaal System requested a methodology to enable them to calculate the possible worst-case scenario of SAV infestations at various water supply levels. The question was how to calculate the maximum area in the dam that would support SAV growth. To accommodate this, a "Submersed Aquatic Vegetation Potential Growth Area" (SAVPGA) tool was presented. The SAVPGA was based on the observations during the study that the two target species in Heyshope Dam, *Stuckenia pectinata* (L.) Böerner and *Potamogeton schweinfurthii* (Benn.) could grow down to a depth of 2.5 and 3m respectively. These observations were supported by Coetzer (1987) and Kantrud (1990) for *S. pectinata* and Van Ginkel and Cilliers (2017) for *P. schweinfurthii*.

To calculate the SAVPGA, the topographic contour lines from a bathymetric map of the impoundment were used. The full supply level (FSL) with gauge plate reading of 20.63m is calculated at contour line 1,303.00 meters above sea level (MSL). The two target SAV species in Heyshope Dam are able to grow up to 3m deep (*Potamogeton schweinfurthii* grows up to 3m and *Stuckenia pectinata* up to 2,5m), thus down to contour line 1,300.00 MSL (1,303.00 – 1,300.00 = 3m), when the dam is 100% full. To calculate the SAVPGA at 100% dam level (SAVPGA₁₀₀), the surveyed geographic area in hectares at the 1,300.00 MSL is subtracted from the area surveyed at the FSL (1,303 MSL). The following formula is used:

$$\text{SAVPGA}_{\text{DL}} = \text{GA}_{\text{DL}} - \text{GA}_{\text{DL-3m}}$$

Where:

SAVPGA _{DL}	=	SAV potential growth area at a specific dam level (DL)
GA _{DL}	=	Geographic area (ha) calculated at topographic contour line at DL
GA _{DL-3m}	=	Geographic area (ha) calculated at topographic contour line 3m lower than DL

Example: The SAVPGA for Heyshope Dam at 100% DL can be calculated as follows:

$$\text{SAVPGA}_{\text{DL}} = \text{GA}_{\text{DL}} - \text{GA}_{\text{DL-3m}}$$

$$\begin{aligned} \text{SAVPGA}_{100} &= \text{GA}_{100} - \text{GA}_{100-3\text{m}} \\ &= 5,023.83 \text{ ha} - 3,950.00 \text{ ha} \\ &= \underline{1,074 \text{ ha}} \end{aligned}$$

A table is produced from which the SAVPGA can be read at different dam levels, from 100% (FSL or full dam capacity) to 0.3%, to calculate maximum cost to manage SAV at a specific dam level. This approach is used as a first round calculation assuming that the target SAV will be able to proliferate in all areas of the impoundment up to 3m deeper than the dam level at that specific stage. The accuracy of this first round formula can be improved by the site-specific evaluation of biotic and abiotic factors that will influence the abundance and distribution of SAV in a specific lake, as variations in environmental factors affect the distribution and abundance of aquatic vegetation (Lacoul and Freedman, 2006). Sediment composition for example, influences submersed plant colonisation and distribution (Doyle, 1999; Madsen et al., 2001; Case and Madsen, 2004; Madsen and Wersal, 2017).

CHAPTER 5

RESULTS AND DISCUSSION

In this chapter, the results of the study are presented and discussed in two sections:

- *Section 5.1:* Covers the environmental impact assessment to establish the impact of the Integrated Aquatic Vegetation Management Plan (IAVMP) on the receiving environment. This section focuses on the Heyshope Dam as this waterbody is the only component of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme with a conservation value. The other three components, the Geelhoutboom Canal (transferring water from Heyshope Dam to Geelhoutboom Dam), Geelhoutboom balancing dam and the Balmoral Canal (transferring water from the Geelhoutboom Dam to the Klein-Vaal River (Vaal River catchment)) are civil water transfer structures without any conservation value.
- *Section 5.2:* Discusses the components of the IAVMP on the Usutu-Vaal Phase II Water Transfer Scheme and the successes achieved after initiation of the SAV control programme from 2002 to 2008, with a final SAV survey in 2010.

5.1 ENVIRONMENTAL IMPACT ASSESSMENT ON HEYSHOPE DAM

5.1.1 Monitoring programme:

The monitoring programme included water quality analysis, evaluation of the phytoplankton community, determination of the trophic status of the two impoundments, aquatic vegetation surveys, macro-invertebrate surveys, fish surveys, waterbird surveys and SAV surveys on the Heyshope Dam, Geelhoutboom Dam and the tributaries of Heyshope Dam. Where possible, the information gathered from 2006 to 2008 was evaluated against a once-off monitoring in 2000 (Envirokonsult, 2000). This data was used to describe the conditions in the study area prior to the initiation of the SAV control efforts which kicked-off in 2001 and was formalised into a more structured IAVMP in 2006 to 2008. A final SAV survey was done in 2010.

5.1.2 Water quality:

The water quality status of the different components of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme was established over a three-year period from 2006 to 2008.

Water samples collected at the various sampling locations (Figure 5.1) was sent to the Resource Quality Services division (RQS) of the DWS for analysis. Unfortunately the RQS decided at a very late stage that their laboratories did not have the capacity to handle the samples of this project. A private SANAS accredited laboratory was contracted to assist in the analysis of the water samples but many of the samples were already old and data of the plant nutrients appeared to be unreliable. All samples for nutrient analysis were preserved with HgCl_2 , but the integrity of these preserved samples can only be guaranteed for three months after sampling. An effort was made to collect and use once-off data with of a higher integrity where necessary.

There are no point sources upstream of the Heyshope Dam. Therefore all nutrient contributions to the water system are from diffuse sources. The Driefontein rural settlement next to the Heyshope Dam is not equipped with a sewerage system as they made use of French drains and pit latrines. The possibility exist that nutrient loading occurs from Driefontein settlement to the impoundment. Furthermore, there is limited centre-pivot irrigation in the Assegaai River area upstream of the impoundment which may contribute to the nutrient loading to Heyshope Dam. Other possible, but unquantified source of pollution may be the illegal mining of coal in the basin of the Heyshope Dam. Efforts to stop this action seem to be unsuccessful as this practice is still continuing.

5.1.2.1 Current water quality status of Heyshope Dam

5.1.2.1.1 In situ water quality variables monitored:

During the various site visits, physico-chemical measurements were taken at five selected monitoring sites (Figure 5.1) to establish the physical water quality of Heyshope Dam. For the purpose of this study only the data of the monitoring point at the dam wall (monitoring location HEY-Q01) is discussed (Table 5.1).

The surface water of the impoundment was found to be near saturation or over saturated with oxygen ($DO=9.83\text{mg}/\ell$ / %SAT=108) for most of the season. The surface water temperature fluctuated between a minimum of almost 12°C up to a relatively high water temperature of 28°C in peak summer months, and the electrical conductivity (EC) was found to be in the region of $100\mu\text{S}/\text{cm}$. An average pH of 8.11 was measured over the monitoring period and water transparency in terms of Secchi disk measurements, was found to be less than 0.8m, which classifies the Heyshope Dam as a turbid system according to the classification of Du Plessis et al. (1990). All this fell well within the boundaries of good surface water quality.

When evaluating the average Secchi disk depth record for each year of the programme (not tabulated), the following become evident: In 2006, the average Secchi disk measurement was 0.9m ($\pm$ SD 0.378), in 2007 it was Secchi = 0.6m ($\pm$ SD 0.122), in 2008 it was Secchi = 0.73m ($\pm$ SD 0.07) and in 2009 it was 0.8m. Thus, the turbidity of the water column in Heyshope Dam decreased by 30% from 2006 to 2007, and then an increase was observed from 2008 to 2009. It is unclear if the biocontrol-agent was responsible for this phenomenon as this catchment is characterised by intermittent high flows contributing to constant variation in turbidity. As no flow gauging stations are available in the tributaries upstream of the impoundment it is difficult to characterise the hydrological dynamics of the system.

TABLE 5.1: *IN SITU* WATER QUALITY AS MEASURED AT THE MONITORING LOCATION AT HEYSHOPE DAM AT DAM WALL (HEY-Q01) 2006 - 2008.

Variables	n	Minimum	Maximum	Median	Average $\pm$ SD
Water temperature ($T_w^{\circ}\text{C}$)	18	11.98	28.24	20.11	19.64 ± 4.88
Dissolved Oxygen Concentration (DO mg/ℓ)	18	7.36	14.4	10.88	9.83 ± 1.78
Oxygen Saturation (% DO)	18	68.5	161	114.75	108 ± 20.9
Electrical Conductivity (EC mS/cm)	18	75	116	95.5	103 ± 11.19
pH	18	7.5	8.7	8.1	8.11 ± 0.4
Total Dissolved Substances (g/ℓ)	18	0.065	0.077	0.071	0.07 ± 0.004
Turbidity as Secchi measurement (m)	18	0.5	1.0	0.75	0.78 ± 0.14

High oxygen levels, above water saturation level, are an indication of active photosynthesis activity in the water column. The median chlorophyll a concentration was

found to be $3.5\mu\text{g}/\ell$. Phytoplankton identification was done to determine the algal species present (Section 5.1.3).

5.1.2.1.2 Chemical and biological analysis of water samples:

Results of the chemical analysis of integrated water samples, taken with a 100mm diameter hosepipe from the water surface to a depth of 5m (0-5m integrated water sample), were analysed in a SANAS accredited chemical laboratory. Selected results of this analysis are represented in Table 5.2.

TABLE 5.2: WATER QUALITY LABORATORY ANALYSIS - MONITORING LOCATION AT HEYSHOPE DAM AT DAM WALL (HEY-Q01) 2006-2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
pH	6.77	8.48	7.62	7.79 ± 0.2942
Electrical Conductivity (EC mS/cm)	10.9	15.4	13.15	13.161 ± 1.004
Total Phosphate Concentration ($\mu\text{g}/\ell$)	3.0	54.0	13.5	13.10 ± 2.90
Nitrogen Concentration (Kjeldahl) ($\text{NH}_4\text{-N mg}/\ell$)	0.02	0.19	0.105	0.0874 ± 0.0447
Nitrate-Nitrite Concentration ($\text{NO}_3 + \text{NO}_2\text{-N mg}/\ell$)	0.02	0.15	0.85	0.065 ± 0.042
Chlorophyll a Concentration ($\mu\text{g}/\ell$)	1.5	6.4	3.5	5.5 ± 0.057

(a) pH:

The pH ranged from pH6.77 to a maximum of pH8.48 with an average and median pH of pH7.63 (Table 5.2) which is lower than that of the typical nutrient enriched water bodies. pH values (not showed) from the water surface to the bottom of the impoundment varied very little throughout the season which is also an indication of a waterbody with a relative low productivity.

(b) Electrical Conductivity:

Electrical conductivity (EC) is a measure of the total amount of inorganic salts dissolved in water. The EC concentration is directly proportional to the total dissolved salt concentration (TDS) of water. EC is a measure of the ability to conduct an electrical current. This ability is a result of the presence of ions in the water, all of which carry an electrical charge. The average EC value of 13mS/cm for the surface water of the Heyshope Dam is moderate in terms of South African surface water quality (Table 5.2).

(c) Nutrients:

Plant nutrients are elements required by plants, algae and blue-green bacteria for normal growth and reproduction, as far as aquatic flora is concerned. Plant nutrients include carbon, nitrogen, phosphorus, potassium, calcium, magnesium, sulphate and silica as well as micro-nutrients (required in lesser quantities) (Wetzel, 1983). Of the major nutrients listed, nitrogen and phosphorus are the most important in increasing the general productivity of an impoundment, in other words, increasing plant growth and the abundance of aquatic fauna and flora.

In the normal process of “lake aging”, impoundments become more enriched with nutrients and progress from a relative unproductive (oligotrophic) to a better-nourished, more highly productive (meso- or eutrophic) status, which will ultimately fill the waterbody with organic material up to the point where it became obliterated (Wetzel, 1983). The system is normally in equilibrium, but man-induced enrichment (cultural eutrophication) leads to a shift in this equilibrium. Cultural eutrophication accelerates the lake aging process. This may lead to significant impacts on the structure and functioning of biotic communities, and ultimately to nuisance conditions such as the overabundant growth of aquatic macrophytes and algae, with associated economic implications.

In the case of Heyshope Dam the measured phosphate concentrations varied between a minimum of 3.0µg/ℓ to a maximum of 54.0µg/ℓ (Table 5.2). It is anticipated that the higher concentration may be attributed to a laboratory fault as the integrity of the nutrient analysis is questioned. The median phosphate concentration was calculated at 13.5µg/ℓ. The Kjeldahl Nitrogen (KN) concentration in Heyshope Dam was analysed to a minimum value of 20µg/ℓ and a maximum of 105µg/ℓ, and the average nitrate-nitrite (NO₃-NO₂-N) concentration 65µg/ℓ (Table 5.2).

5.1.2.2 Water quality status of Geelhoutboom Dam

The surface water of the Geelhoutboom Dam was found to be generally saturated with oxygen (average DO=12.63mg/ℓ / %SAT=98) (Table 5.3). Over the study period the minimum dissolved oxygen concentrations (DO) were never lower than 74% saturation. The water temperature fluctuated between a minimum of 10°C and a maximum of 28°C, and the electrical conductivity (EC) was found to be in the region of 100µS/cm (similar to the monitoring location at Heyshope Dam wall). An average pH7.9 was monitored. Water transparency in terms of Secchi disk measurements, was never lower than 0.5m

and reached a high at 1.2m during the study period. It must be emphasised that the water level of this balancing dam was periodically very low (less than 1.5m) and in the majority of these cases, sunlight penetration was down to the bottom of the balancing dam with a maximum depth of 3.8m at FSL. All this fell well within the boundaries of good surface water quality.

TABLE 5.3: *IN SITU* WATER QUALITY AS MEASURED AT THE MONITORING LOCATION AT GEELHOUTBOOM DAM AT DAM WALL (GHB-Q01) 2006-2008.

Variables (n=14)	Minimum	Maximum	Median	Average $\pm$ SD
Water temperature (T_w °C)	10.36	27.7	18.53	17.69 $\pm$ 4.96
Dissolved Oxygen Concentration (DO mg/l)	7.8	18.6	17.1	12.63 $\pm$ 2.69
Oxygen Saturation (%DO)	73.7	148.6	111.15	97.6 $\pm$ 18.7
Electrical Conductivity (EC mS/cm)	55	131	93	98 $\pm$ 5.89
pH	7.2	8.62	7.91	7.9 $\pm$ 0.67
Total Dissolved Substances (g/l)	0.04	0.096	0.068	0.063 $\pm$ 0.035
Turbidity as Secchi measurement (m)	0.5	1.2	0.8	0.75

TABLE 5.4: WATER QUALITY LABORATORY ANALYSIS - MONITORING LOCATION AT GEELHOUTBOOM DAM AT DAM WALL (GHB-Q01) 2006 - 2008.

Variables (n=14)	Minimum	Maximum	Median	Average
pH	7.68	7.68	7.68	N/A
Electrical Conductivity (EC mS/cm)	12.8	12.8	12.8	N/A
Total Phosphate Concentration (μ g/l)	3.2	17.0	4.6	6.6
NH ₄ – Nitrogen Concentration (Kjeldahl) (NH ₄ -N mg/l)	0.012	0.012	0.012.	N/A
NO ₃ + NO ₂ – Nitrogen (NO ₃ + NO ₂ -N mg/l)	0.207	0.207	207	N/A
Chlorophyll a Concentration (CHL a μ g/l)	3.0	4.6	-	3.5

The lowest water temperature measured in Geelhoutboom balancing dam from 2006 to 2008 was just higher than 10°C (Table 5.3); temperatures of 8°C were measured for very short periods during winter months prior to this monitoring period (2001 to 2003) (Envirokonsult, 2000). This suggests that the average minimum temperature has risen slightly over the past few years and that the water temperature (Heyshope Dam: minimum: 11.98°C; maximum 28.24°C and Geelhoutboom Dam: minimum: 10.36°C; maximum: 27.7°C) will sustain grass carp foraging in these impoundments throughout

the year. Krupauer (1989) reported an optimum water temperature range for grass carp food consumption of 20 to 28°C in South Bohemian ponds, whilst Stroganov (1963) and Opuszyński (1972) reported comparable ranges of 21 to 26°C and 25 to 28°C, respectively. According to observations by Stroganov (1963), Amádek and Sanh (1981) and Krupauer (1989) plant consumption is initiated at 10 to 16°C and intensive feeding occurs when water temperatures reach 20°C or higher. The upper temperature limit of plant consumption is about 35°C (Opuszyński, 1972). Although feeding and growth of grass carp is strongly influenced by fish size and water temperature (Osborne and Riddle, 1999), food consumption does not only depend on absolute water temperature but also on sudden variations in temperature (Stroganov, 1963; Krupauer, 1989 and Pípalová, 2006).

While the total phosphate concentrations (median = 4.6µg/ℓ) in the dam are high enough to sustain a healthy phytoplankton community, no phytoplankton blooms were experienced in the period of monitoring (2006-2008). Chlorophyll a concentrations were also low (3.5µg/ℓ) indicating oligotrophic conditions in Geelhoutboom Dam (Table 5.4).

5.1.2.3 Water quality status of tributaries of Heyshope Dam

(a) Dissolved oxygen (DO):

The DO content of the tributaries of Heyshope Dam was measured at seven river monitoring locations (Figure 4.1). Relatively high oxygen concentrations were measured throughout the monitoring programme. Super saturation with oxygen was found in all the rivers throughout the season. High oxygen concentrations are generally indicative of good water quality with a low decomposing organic component. The average percentage of oxygen saturation varied from 69% to 163% both measured at the Assegaa River (ASR-B) downstream of the Heyshope Dam. The super saturation levels can be attributed to active photosynthesis by aquatic vegetation and phytoplankton in the tributaries of Heyshope Dam as well as efficient mixing of oxygen into active flowing rivers.

(b) Water Temperature:

Natural thermal characteristics of running water are dependent on hydrological, climatologically and structural features of the region and catchment area. Hydrological, factors such as the source of water, the relative contribution of groundwater, and the rate of flow, will influence the temperature regime. Climatological factors such as air temperature, cloud cover, wind speed, vapour pressure and precipitation events, all

influence thermal conditions of rivers. Average *in situ* temperatures in the tributaries measured during the study ranged from 8.0°C at the Assegaaai River upstream of the Heyshope Dam (ASR-A) to a very 29.0°C for lotic waters at the same monitoring location during peak summer months.

(c) pH:

In situ pH values fluctuated between pH7.03 and pH8.72, with the lowest pH value measured at the Assegaaai River downstream of the impoundment (ARS-B) and the highest at the Ngulane River, upstream of the impoundment. The Ngulane River monitoring location is not far downstream of the Driefontein settlement. Women of the local rural community use the river for washing clothes, which contributed to the higher pH.

(d) Electrical conductivity (EC):

The *in situ* EC varied greatly, from a minimum of 66.0mS/cm at Poendaas and eGude rivers to 240mS/cm in the Assegaaai River upstream of the Heyshope Dam. The lower values were 50% higher than measured in 2000 (Envirokonsult, 2000), whilst the maximum value in the Assegaaai River corresponds with the values measured in 2000.

(e) Nutrients:

The nutrient analysis on water samples monitored from 2006 to 2008 at all monitoring points was found to be unreliable. As mentioned earlier, this is due to the long time lapse between collection and analysis of these samples. If the 2000 figures are however considered, the highest Kjeldahl nitrogen concentration was measured as 0.50mg/ℓ in the Ngulane River, and between 0.15-0.20mg/ℓ in the other tributaries. This corresponded well with the 0.46mg/ℓ measured in Heyshope Dam and 0.52mg/ℓ in Geelhoutboom Dam in 2000. The Total Phosphorus concentration (2000 figures) in the tributaries varied from 17µg/ℓ in the Poendaas River to 21µg/ℓ in the Assegaaai River and 41µg/ℓ in the Ngulane River (Envirokonsult, 2000). In terms of nutrient loading, the Assegaaai River was be the highest contributor to the Heyshope Dam, as most of the incoming flow is from the Assegaaai River catchment.

TABLE 5.5: *IN SITU* WATER QUALITY AS MEASURED AT MONITORING LOCATION IN THE ASSEGAAI RIVER UPSTREAM OF HEYSHOPE DAM (ASR-A) 2006 - 2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
Water temperature (T_w °C)	8.0	29.0	18.5	16.43 $\pm$ 6.19
Dissolved Oxygen Concentration (DO mg/l)	7.0	19.0	13.0	10.875 $\pm$ 4.665
Oxygen Saturation (%DO)	79.0	162.0	120.5	90 $\pm$ 32.57
Electrical Conductivity (EC mS/cm)	90.0	240.0	165.0	170 $\pm$ 52.14
pH	7.79	8.25	8.025	8.025 $\pm$ 0.26
Total Dissolved Substances (g/l)	0.045	0.120	0.082	0.093 $\pm$ 0.07

TABLE 5.6: WATER QUALITY LABORATORY ANALYSIS - MONITORING LOCATION IN THE ASSEGAAI RIVER UPSTREAM OF HEYSHOPE DAM (ASR-A) 2006 - 2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
pH	7.79	8.26	8.02	8.145 $\pm$ 0.19
Electrical Conductivity (EC mS/cm)	9.98	26.0	17.99	19.375 $\pm$ 11.5
Total Phosphate Concentration (μ g/l)	0.04	0.04	0.02	0.04 $\pm$ 0.0
Nitrogen Concentration (Kjeldahl) ($\text{NH}_4\text{-N}$ mg/l)	0.02	0.02	0.01	0.02 $\pm$ 0.0
Nitrate-Nitrite Concentration ($\text{NO}_3\text{+NO}_2\text{-N}$ mg/l)	0.6	0.6	0.3	0.06 $\pm$ 0.06

TABLE 5.7: *IN SITU* WATER QUALITY AS MEASURED AT MONITORING LOCATION IN THE ASSEGAAI RIVER DOWNSTREAM OF HEYSHOPE DAM (ASR-B) 2006 - 2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
Water temperature (T_w °C)	8.0	25.5	16.75	19.10 $\pm$ 5.42
Dissolved Oxygen Concentration (DO mg/l)	6.0	16.6	11.3	10.11 $\pm$ 2.73
Oxygen Saturation (%DO)	69.0	163.0	116.0	111.79 $\pm$ 26.28
Electrical Conductivity (EC mS/cm)	87.0	140.0	113.5	113.69 $\pm$ 14.24
pH	7.03	8.61	7.82	7.79 $\pm$ 0.55
Total Dissolved Substances (g/l)	0.08	0.08	0.04	0.08 $\pm$ 0.0

TABLE 5.8: WATER QUALITY LABORATORY ANALYSIS - MONITORING LOCATION IN THE ASSEGAAI RIVER DOWNSTREAM OF HEYSHOPE DAM (ASR-B) 2006 - 2008).

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
pH	7.26	8.69	7.97	7.94 $\pm$ 0.12
Electrical Conductivity (EC mS/cm)	8.53	20.4	14.46	13.35 $\pm$ 4.36
Total Phosphate Concentration (μ g/l)	<0.04	<0.04	<0.02	0.04 $\pm$ 0.0
Nitrogen Concentration (Kjeldahl) ($\text{NH}_4\text{-N}$ mg/l)	<0.02	<0.02	<0.01	0.02 $\pm$ 0.0
Nitrate-Nitrite Concentration ($\text{NO}_3\text{+NO}_2\text{-N}$ mg/l)	<0.6	<0.6	<0.03	0.06 $\pm$ 0.06

TABLE 5.9: *IN SITU* WATER QUALITY AS MEASURED AT MONITORING LOCATION IN THE NGULANE RIVER UPSTREAM OF HEYSHOPE DAM (NGR) 2006 - 2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
Water temperature (T_w °C)	10.4	26.5	18.45	20.23 $\pm$ 6.19
Dissolved Oxygen Concentration (DO mg/l)	7.85	11.38	9.61	9.4 $\pm$ 4.68
Oxygen Saturation (%DO)	96.2	100.0	98.1	98.18 $\pm$ 4.64
Electrical Conductivity (EC mS/cm)	96.2	162.0	129.1	99.175 $\pm$ 32.57
pH	7.35	8.72	8.03	7.728 $\pm$ 0.26
Total Dissolved Substances (g/l)	45.0	120.0	82.5	0.07 $\pm$ 0.004

TABLE 5.10: WATER QUALITY LABORATORY ANALYSIS - MONITORING LOCATION IN THE NGULANE RIVER UPSTREAM OF HEYSHOPE DAM (NGR) 2006 - 2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
pH	7.91	8.08	7.99	8.01 $\pm$ 0.17
Electrical Conductivity (EC mS/cm)	10.5	19.4	14.95	14.875 $\pm$ 6.39
Total Phosphate Concentration (μ g/l)	<0.04	<0.04	<0.02	0.04 $\pm$ 0.0
Nitrogen Concentration (Kjeldahl) ($\text{NH}_4\text{-N}$ mg/l)	<0.02	<0.02	<0.01	0.02 $\pm$ 0.0
Nitrate-Nitrite Concentration ($\text{NO}_3\text{+NO}_2\text{-N}$ mg/l)	<0.6	<0.6	<0.3	0.06 $\pm$ 0.06

TABLE 5.11: *IN SITU* WATER QUALITY AS MEASURED AT MONITORING LOCATION IN THE POENDAAS RIVER UPSTREAM OF HEYSHOPE DAM (POR) 2006 - 2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
Water temperature (T_w °C)	10.3	21.0	15.65	15.8 $\pm$ 4.37
Dissolved Oxygen Concentration (DO mg/l)	7.5	10.88	9.19	8.876 $\pm$ 1.262
Oxygen Saturation (%DO)	80.0	97.4	88.7	87.13 $\pm$ 7.44
Electrical Conductivity (EC mS/cm)	66.0	118.0	92.0	98.0 $\pm$ 22.86
pH	7.79	8.08	7.93	7.84 $\pm$ 0.34
Total Dissolved Substances (g/l)	0.108	0.129	0.118	0.114 $\pm$ 0.006

TABLE 5.12: WATER QUALITY LABORATORY ANALYSIS - MONITORING LOCATION IN THE POENDAAS RIVER UPSTREAM OF HEYSHOPE DAM (POR) 2006 - 2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
pH	7.26	8.69	7.97	7.94 $\pm$ 0.12
Electrical Conductivity (EC mS/cm)	8.53	20.4	14.46	13.37 $\pm$ 4.06
Total Phosphate Concentration (μ g/l)	<0.04	<0.04	<0.02	0.04 $\pm$ 0.0
Nitrogen Concentration (Kjeldahl) ($\text{NH}_4\text{-N}$ mg/l)	<0.02	<0.02	<0.01	0.02 $\pm$ 0.0
Nitrate-Nitrite Concentration ($\text{NO}_3\text{+NO}_2\text{-N}$ mg/l)	<0.6	<0.6	<0.3	0.06 $\pm$ 0.06

TABLE 5.13: *IN SITU* WATER QUALITY AS MEASURED AT MONITORING LOCATION IN THE eGUDE RIVER UPSTREAM OF HEYSHOPE DAM (EGR) 2006 - 2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
Water temperature (T_w °C)	10.3	21.0	15.65	15.8 $\pm$ 4.37
Dissolved Oxygen Concentration (DO mg/ℓ)	7.5	10.88	9.19	8.876 $\pm$ 1.262
Oxygen Saturation (%DO)	80.0	97.4	88.7	87.13 $\pm$ 7.44
Electrical Conductivity (EC mS/cm)	66.0	118.0	92.0	98.0 $\pm$ 22.86
pH	7.79	8.08	7.935	7.84 $\pm$ 0.34
Total Dissolved Substances (g/ℓ)	0.108	0.129	0.1185	0.114 $\pm$ 0.006

TABLE 5.14: WATER QUALITY LABORATORY ANALYSIS - MONITORING LOCATION IN THE eGUDE RIVER UPSTREAM OF HEYSHOPE (EGR) 2006 - 2008.

Variables (n=18)	Minimum	Maximum	Median	Average $\pm$ SD
pH	7.26	8.69	7.975	7.94 $\pm$ 0.12
Electrical Conductivity (EC mS/cm)	8.53	20.4	14.465	13.37 $\pm$ 3.89
Total Phosphate Concentration (μ g/ℓ)	<0.04	<0.04	<0.02	0.04 $\pm$ 0.0
Nitrogen Concentration (Kjeldahl) ($\text{NH}_4\text{-N}$ mg/ℓ)	<0.02	<0.02	<0.01	0.02 $\pm$ 0.0
Nitrate-Nitrite Concentration ($\text{NO}_3\text{+NO}_2\text{-N}$ mg/ℓ)	<0.6	<0.6	<0.3	0.06 $\pm$ 0.00

5.1.3 Phytoplankton community and trophic status of the waterbodies:

5.1.3.1 In-lake phytoplankton composition of Heyshope Dam

AlgaeBase (Guiry and Guiry, 2022) classifies phytoplankton into 15 Divisions (Phyla) (Guiry and Guiry, 2022), and representatives of six of these were identified in the Heyshope Dam catchment – Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, Euglenophyta and Pyrrophyta. Due to their short life cycles, phytoplankton respond rapidly to environmental changes, and therefore the species composition is a good indicator of the water quality in which they are found (Bellinger and Sigee, 2015).

At the in-lake monitoring location near the Heyshope Dam wall (HEY-Q01) (Figure 4.1), the number of species and individuals were particularly low during the winter months, although there was a clear dominance of the phytoplankton community by *Aulacoseira granulata* and *Ceratium hirundinella*. During the summer months *A. granulata* also dominated the phytoplankton population, but significant numbers of the potential

problematic cyanobacterium, *Microcystis aeruginosa*, were also found. During winter no cyanobacteria were encountered.

At the inflow of the eGude River next to the Driefontein settlement (HEY-Q02), cyanophyta were present in small numbers during winter months, when the phytoplankton population was dominated by *A. granulata* and *C. hirundinella*. Although these two species dominated the phytoplankton community, the concentration and diversity were relatively low. During the summer months more species were observed, as well as a fairly large increase in the number of individuals compared to the winter monitoring period. The number of *C. hirundinella* individuals was found to be lower during summer compared to winter, with *A. granulata* the dominant species throughout the season at this sampling site.

At the Ngulane River inflow (HEY-Q03), the Assegai River inflow (HEY-Q04) and Poendaas River inflow (HEY-Q05), a few individuals from all six phytoplankton phyla were present during the winter months, and the phytoplankton community was again dominated by *A. granulata* and *C. hirundinella*. Similar to HEY-Q02, the *C. hirundinella* concentration was lower during summer compared to winter, and *A. granulata* was dominant throughout the season.

At all the monitoring sites in Heyshope Dam, the chain-forming diatom species, *A. granulata*, was dominant during the summer months, while *C. hirundinella*, a member of the Pyrrophyta (dinoflagellates), dominated the phytoplankton community during winter months.

The dominant species encountered in Heyshope Dam are known to be problematic. *Microcystis aeruginosa*, although not a problem in Heyshope Dam at this stage, can secrete the potent hepatotoxin microcystin, as well as volatile organic substances (geosmin and methylisoborneol) responsible for taste and odours in drinking water. It can also cause dermatitis and skin irritations when the skin of humans comes into contact with the water during recreational activities. Blooms of *A. granulata* produce fishy, rancid, oily, grassy, or cucumber odours (AWWA, 2010; Watson and Jüttner, 2019). *A. granulata* is also problematic regarding coagulation, flocculation, and filtration in the water treatment process (Joh et al., 2011). Water treatment processes do not efficiently remove this species due to its long cylindrical shape, high surface to volume ratio, extensive superficial area, and higher surface contact with the surrounding media, which are all related to physical buoyancy or difficulties in settling

(Padisáket et al., 2003; Brasil and Huszar, 2011; Joh et al., 2011). Furthermore, this species also clogs sand filters, leading to a need for repeated backwashing, thus limiting the production of clean water (Joh et al., 2011). *C. hirundinella* is known to produce a variety of organic substances responsible for odours.

Ewerts et al. (2018) identified five fatty acids (primarily palmitic and oleic acids) and two dicarboxylic acids (succinic and sebacic acids) secreted by *C. hirundinella* from South Africa. This species, together with all the other flagellated cells mentioned above, also have the potential to disrupt floc formation during water purification processes (Ewerts et al., 2016). If these cells penetrate through the unit processes of water purification and chlorine is dosed, trihalomethanes (THM) may be formed (Abdullah et al., 2009; Van der Walt et al., 2009; Lui et al., 2011; Zamyadi et al., 2012). The formation of THM poses a health risk to drinking water consumers, because THM are mutagenic, carcinogenic and toxic (Abdullah et al., 2009; Hebert et al., 2010).

Phytoplankton concentrations were found not to be a concern over the study period from 2006 to 2008.

5.1.3.2 In-lake phytoplankton composition of Geelhoutboom Dam

The Geelhoutboom Dam was under total biological control by the winter of 2009. Macrophytes were scarce because the biocontrol-agent removed all visible vegetation in the balancing dam. Since competition for food was extremely high amongst the sterile grass carp (1,400 units were stocked between 2002 and 2004 to a stocking density of 38/ha), evidence exists (personal observations) that the fish was foraging on the edges of the shoreline by burrowing into the roots of sedges (*Schoenoplectus brachyceras* and *Cyperus denudatus*) in the upper littoral zone.

During the summer months, as many as 25 phytoplankton species were found in Geelhoutboom Dam. A relatively large number of individuals of *Coelastrum*, *Oocystis*, *Aulacoseira*, and *Ceratium* were sampled, indicating dominance of these algae throughout the year. The overall species count was higher during summer periods, with most individuals belonging to the genera *Coelastrum*, *Oocystis* and *Tetraedron*. No algal blooms were noted in Geelhoutboom Dam over the study period.

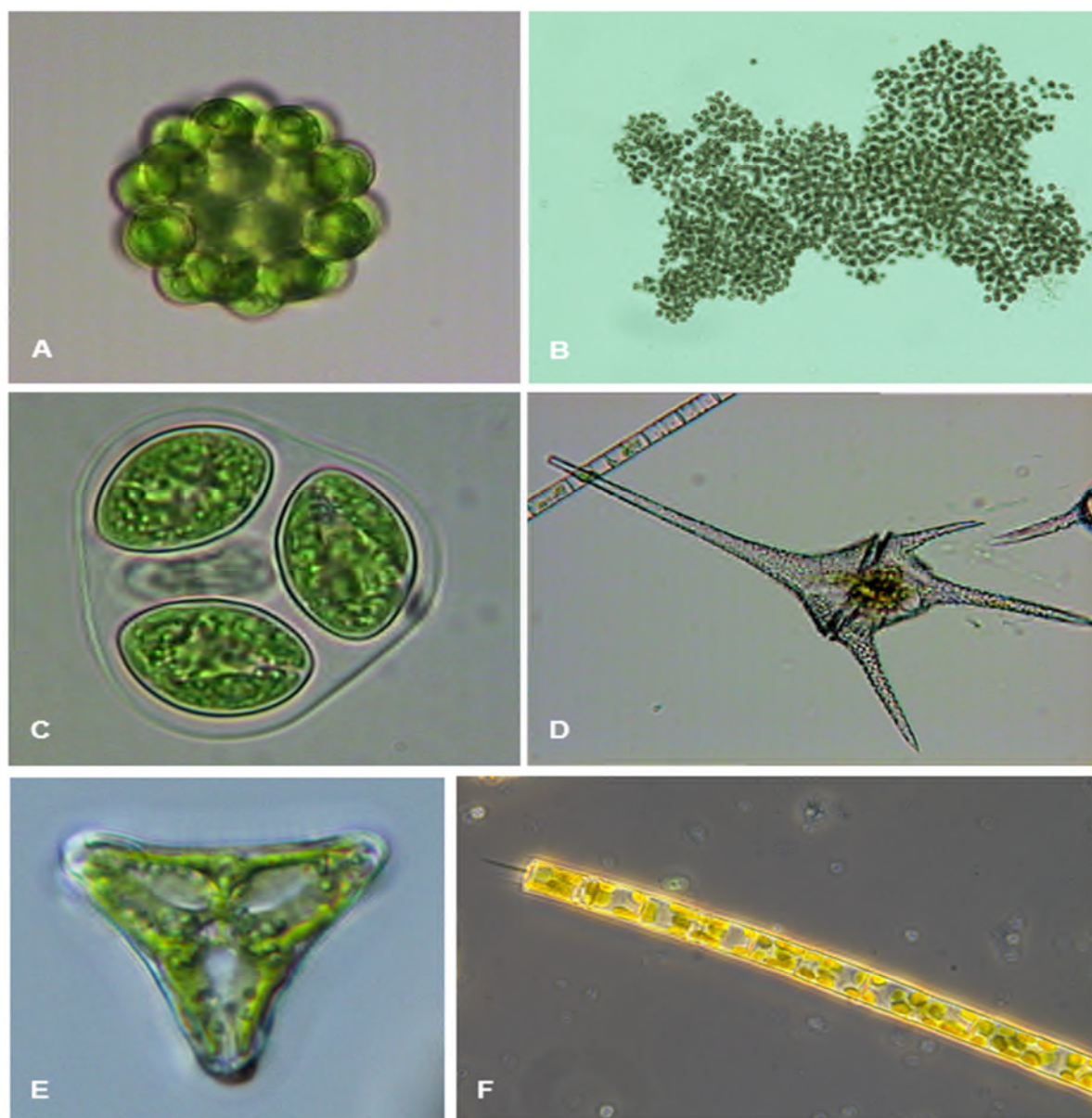


PLATE 5.1: A collage of phytoplankton species present in the Heyshope and Geelhoutboom dams (photo credits: Sanet Janse van Vuuren and Jonathan Taylor). **A:** *Coelastrum pseudomicroporum*, **B:** *Microcystis aeruginosa*, **C:** *Oocystis lacustris*, **D:** *Ceratum hirundinella*, **E:** *Tetradron mediocris* and **F:** *Aulacoseira granulata*.

5.1.3.3 Trophic Status of Heyshope Dam

The trophic status of an impoundment can be defined as the degree of enrichment of a waterbody with plant nutrients, and the concomitant symptoms associated with this enrichment (Du Plessis et al., 1990). The degree of eutrophication experienced by an impoundment is termed the “trophic status” of the waterbody. An impoundment can be classified as *oligotrophic* (low nutrient concentrations and productivity, but high species diversity), *mesotrophic* (characteristics intermediate between oligo- and eutrophic),

eutrophic (high nutrient concentrations and excessive productivity with lower species diversity), and *hypertrophic* (extremely high nutrient concentrations associated with excessive phytoplankton blooms and very low species diversity) (Wetzel, 1983; Yang, et al., 2008).

The trophic status classification of Du Plessis et al. (1990) was used to assess the trophic status of Heyshope Dam. This trophic status classification methodology is based on a combination of three variables:

- Mean annual Chlorophyll a value;
- Mean annual Total Phosphate value, and
- Mean annual Transparency value (Secchi disk measurement).

This classification method was based on the earlier classification of Walmsley (1984) and Walmsley and Butty (1980) which applies the mean annual Chlorophyll a and total phosphate concentrations (Table 5.15 and 5.16), adapted by a transparency component (Table 5.17) to distinguish between nutrient enriched waterbodies which express the general symptoms of eutrophication and enriched, turbid systems where the symptoms of eutrophication are suppressed due to high concentrations of abiotic (soil/mud) particles, which is characteristic of many South African waterways.

TABLE 5.15: TROPHIC STATUS CLASSIFICATION BASED ON THE MEAN ANNUAL CHLOROPHYLL a CONCENTRATION (FROM WALMSLEY, 1984).

CLASSIFICATION	MEAN CHLOROPHYLL a CONCENTRATION
Oligotrophic	Instantaneous Chlorophyll a concentration never exceeds 10µg/ℓ.
Mesotrophic	Concentration exceeds 10 µg/ℓ at times, but never 30µg/ℓ.
Eutrophic	Concentration exceeds 30µg/ℓ for at least 8% of the annual cycle.

TABLE 5.16: TROPHIC STATUS CLASSIFICATION BASED ON THE MEAN TOTAL PHOSPHATE CONCENTRATION (FROM WALMSLEY AND BUTTY, 1980).

CLASSIFICATION	MEAN TOTAL PHOSPHATE CONCENTRATION (µg/ℓ)
Oligotrophic	< 15
Mesotrophic	15 - 47
Eutrophic	> 47

TABLE 5.17: TRANSPARENCY CATEGORIES AS A TOOL FOR TROPHIC STATUS CLASSIFICATION (FROM DU PLESSIS et al., 1990).

MEAN ANNUAL TRANSPARENCY	HIGHLY TURBID	TURBID	CLEAR
Secchi disc depth (meters)	< 0.2	0.2 – 0.8	>0.8

According to this trophic status classification model Heyshope Dam, with a mean annual chlorophyll a concentration of $3.5\mu\text{g}/\ell$, a mean annual total phosphate concentration of $13.1\mu\text{g}/\ell$ and a mean annual Secchi disk value of 0.78m, was classified as an *oligotrophic, turbid aquatic system*.

5.1.3.4 Algal bloom potential in Heyshope Dam

With the removal of target species, such as macrophytes or higher plants, the now freely available plant nutrients (mainly phosphorus and nitrogen) may be utilised by the phytoplankton community (algae and cyanobacteria), which in turn may give rise to phytoplankton blooms during favourable environmental conditions. The problems associated with algal blooms may be more severe than those experienced with the nuisance plants before removal. Factors like these need to be considered carefully before an IAVMP is implemented in a waterbody.

The literature refers to several case studies (Stroganov, 1963; Hickling, 1966; Small et al., 1985; Hajra, 1987) where an increase in nutrient concentration values was experienced after the introduction of grass carp. While it is assumed that this nutrient release would accelerate eutrophication (Hansson et al., 1987) and initiate a shift from macrophytic to phytoplankton dominated lakes, this has not been clearly demonstrated as Venter and Schoonbee (1991) did not record any significant changes in water chemistry under field conditions, even though the aquatic plants decreased with 82% from $193\text{g}/\text{m}^2$ to $34\text{g}/\text{m}^2$ during a one year study in South Africa. Li (1998) upheld the opinion that the released nutrients may be bounded into the fish to such extent that the eutrophication potential is decreased, whilst Lembi et al., (1978) reported that as much as 42% of the nitrogen and 54% of the phosphorus in the plants were translocated to fish tissue and were therefore not available to the phytoplankton community.

Heyshope Dam is a relative turbid waterbody (Secchi disk ~ 0.8m) and the turbidity (and relative low nutrient concentrations) suppressed algal proliferation by inhibiting

light penetration into the water column. As Heyshope Dam is classified as an oligotrophic, turbid system, with average annual total phosphate concentration of 13.1µg/ℓ, algal blooms were unlikely at this stage. The maximum total phosphate concentration did, however, reach 54µg/ℓ on occasion, which put the waterbody in the eutrophic category for a short period of time. This situation could increase the algal bloom potential of the impoundment if the turbidity of the impoundment should decrease during a period of low flow (drought period).

When utilising grass carp to manage or control aquatic vegetation, a conservative approach is important to avoid overstocking. Overstocking may result in the excessive removal of macrophytes, associated with an increase in nutrient concentration, with the consequent possibility of algal bloom development. It must be realised that if only partial control of nuisance vegetation is required (as in the case of Heyshope Dam), a herbicidal component will still be part of the IAVMP in order to “tone” the excess biomass to acceptable levels and to keep fish away from water-abstraction points.

5.1.4 Aquatic vegetation survey:

5.1.4.1 Aquatic vegetation assemblage in Heyshope Dam

All the aquatic vegetation species noted in the littoral zone of the impoundment were identified and listed in Table 5.18. The areas where they were located are indicated on maps of the impoundment with grid references of their locations (Figures 5.2 – 5.7).

5.1.4.2 Submersed aquatic plants

Four submersed aquatic plant species were identified in Heyshope Dam. The two target species in the IAVMP, *Potamogeton schweinfurthii* Bennett (Broad-leaved pondweed) and *Stuckenia pectinata* (L.) Börner (Fennel-leaved pondweed) as well as *Najas marina* (L.) (Prickley waternymph) (only patches were found) and *Potamogeton nodosus* Poir. (Floating pondweed) (also scarcely represented). In Geelhoutboom Dam, both *P. schweinfurthii* and *S. pectinata*, as well as *Lagarosiphon muscoides* Harv. (Fine oxygen weed) were identified prior to total biological control by *Ctenopharyngodon idella*.



PLATE 5.2: The two target nuisance submersed aquatic vegetation species in Heyshope Dam, *Potamogeton schweinfurthii* on the left and *Stuckenia pectinata* (formerly: *Potamogeton pectinatus*) on the right.

All the SAV species found in the study area are preferred food sources for grass carp (Table 2.2). Prior to the first control efforts on Heyshope Dam in 2001, *P. schweinfurthii* comprised 80% of the SAV population and *S. pectinata* 18% of the total SAV coverage of 700ha (1,730 acres) of the impoundment. By 2006 grass carp removed *S. pectinata* by preference before *P. schweinfurthii*, and it is assumed that the fish prefers the softer structured *S. pectinata* to the harder, weedy structured and broad-leaved *P. schweinfurthii*. *S. pectinata* is therefore higher on the feeding preference list of grass carp than *P. schweinfurthii*.

5.1.4.3 Floating-leaved, attached to substrate aquatic plants

Four species of floating-leaved, attached aquatic plants were identified in Heyshope Dam. These species were *Marsilia macrocarpa* C. Presl. (Water clover), *Nymphoides thunbergiana* (Grisebach) O. Kuntze (Floating heart), *Nymphaea nouchali* var. *ovalifolia* (Conard) Verdcourt (Water lily) and *Persicaria amphibia* (L) Gray (Water smartweed).

These aquatic plant species are on the grass carp's variable preference list (Table 2.2), and it is suggested that grass carp may start feeding on them once the more palatable species are consumed.

5.1.4.4 Emergent, broad-leaved aquatic plants

Persicaria decipiens (R. Brown) K.L. Wilson (Slender knotweed), *Persicaria lapathifolia* (L) Gray (Curley-top knotweed), *Ludwigia adscendens* (L) Hara (Water primrose) and *Typha capensis* (Rohrbach) Brown (Bulrush) were identified in Heyshope Dam.

Table 2.2 lists *Polygonum* spp. as a food source of variable preference, thus indicating that grass carp “may feed” on this more hardy species. As *P. decipiens* and *P. lapathifolia* were formerly classified as *Polygonum* spp., they should, therefore, also be on the variable preference list. *Typha* spp. were, however, listed in Florida (USA) as preferred plants for grass carps (Miller and Wilke, 1986).

5.1.4.5 Emergent, narrow-leaved aquatic plants

Four emergent, narrow-leaved aquatic plants were identified on the periphery of Heyshope Dam. The universal and robust *Phragmites australis* (Cav.) Steud. (Common reed) is distributed throughout southern Africa, *Cyperus denudatus* L.f. var. *denudatus* (Winged sedge), *Cyperus sextangularis* (Nees) and *Schoenoplectus brachyceras* (Hochst. Ex A. Rich.) were found dispersed around the impoundment. No strong monoculture reed beds were present. *Phragmites* is on the non-preferred grass carp feeding list (Table 2.2). Both *Cyperus* spp. and *S. brachyceras* were not consumed by the grass carp in Geelhoutboom Dam after all SAV were removed from the balancing dam and the fish started to die-off, as their food source was exhausted. It is, therefore, concluded that none of the four emergent, broad-leaved aquatic plants are on the grass carp feeding list.

5.1.4.6 Sensitive indigenous flora in Heyshope Dam

During May 2008, a distinct reduction of two aquatic floral species was noticed. A small population of *Persicaria amphibia* in the sensitive Assegaa River inflow area, and a relatively large population of *Marsilea macrocarpa* at the Ngulane River inflow were considerably reduced (Plate 5.2). During an inspection in October 2008, both species were found to be absent from the waterbody. As these areas were not treated with herbicides, it is concluded that the grass carp established in 2008 throughout the impoundment and were feeding on these non-target species as well.

TABLE 5.18: AQUATIC VEGETATION SURVEY HEYSHOPE DAM RESULTS OF MAY 2006 SURVEY.

No.	SPECIES	FIGURE	GRID	TARGET OR NON-TARGET VEGETATION	TYPE
1.	<i>Potamogeton schweinfurthii</i>	5.2	I5, I4, H5, F5, C7, B7, B8, C8, C7, D7, E8, F8, F7, G7, H7, I7, J7, J8,	Target	Submersed
		5.3	A5, B5, C5, E6, E7, F7		
		5.4	B3, B8, B9, C6, D3, D1, F3, F5, F6, F7		
		5.5	B4, C3, C4, D3, D4, E4, F4, H3, I2, K1, K2, I6, I7, H7, f5, H5, E5, B6		
		5.6	C6, D4, D5, D6, E4, E5, E6, E7, F3, G3, H3, H4, I1		
		5.7	E6, E7, F6, H6, H8, E9, I1, I6		
2.	<i>Stuckenia pectinata</i>		None visible from 2006 onwards. Was ~18% of SAV area in 2000.	Target	Submersed
3.	<i>Phragmites australis</i>	5.2	I5	Non-target	Emergent, narrow-leaved
		5.4	F6		
		5.5	C3, B6		
		5.6	D6, E3, E4, E5, E6, E7, E8, F4, G3, H3, J1		
		5.7	E6, E7, F6, H6, H8, E9, I1, I6		
4.	<i>Schoenoplectus brachyceras</i>	5.2	I5, I4, H5, C7, B7, I7,	Non-target	Emergent, narrow-leaved
		5.3	B4, E9		
		5.4	B3, B8, B9, C6, D3, D1, F1, F3, F5, F6, F7		
		5.5	B4, C3, C4, D3, D4, E4, F4, H3, I2, K1, K2, I6, I7, H7, f5, H5, E5, B6		
		5.6	C6, D4, D5, D6, E4, E5, E6, E7, F3, G3, H1, H3, H4, I1		
		5.7	E6, E7, F6, H6, H8, E9, I1, I6		
5.	<i>Najas cf. marina</i>	5.2	I4, B4	Non-target	Submersed
		5.4	F3		
6.	<i>Potamogeton nodosus</i>	5.2	I4	Non-target	Submersed
		5.3	B4		
7.	<i>Persicaria decipiens</i> and <i>Persicaria lapathifolia</i>	5.2	I4	Non-target	Emergent, broad-leaved
		5.4	B8		
		5.5	B3, G7		
8.	<i>Typha capensis</i>	5.2	I3, I4	Non-Target	Emergent, broad-leaved
		5.3	B3, B4, E7		
		5.4	B7, C7, F6		
		5.5	C5, D5, I5, J5		
		5.7	E6, E7, F6, H6, H8, E9, I1, I6		
9.	<i>Nymphoides thunbergiana</i>	5.2	I3, B7	Non-Target	Floating- leaved, attached
		5.3	B3		
		5.5	F5		
10.	<i>Persicaria amphibia</i>	5.2	D5, B7	Non-Target	Floating- leaved, attached
		5.3	B3		
		5.4	B7, F7, H8		
11.	<i>Ludwigia adscendens</i>	5.3	C5	Non-Target	Emergent, broad-leaved
12.	<i>Nymphaea nouchali</i>	5.2	D5	Non-Target	Floating- leaved, attached
		5.5	H8		
13.	<i>Cyperus denudatus and Cyperus sextangularis</i>	5.2	B7,	Non-Target	Emergent, narrow-leaved
		5.3	B3, B4, D5		
		5.6	D6, E6, E7, E8, F4, I3		
		5.7	E6, E7, F6, H6, H8, E9, I1, I6		
14.	<i>Marsilea macrocarpa</i>	5.3	B4	Non-Target	Floating- leaved, attached
		5.5	G8		



PLATE 5.3: Two indicator aquatic plant (non-target) species in Heyshope Dam. *Persicaria amphibia* on the left and *Marsilea macrocarpa* on the right.

Grass carp is not a target specific biocontrol-agent and will feed on any palatable plant material available. However, grass carp has a preference of certain plant species above others, as they tend to feed firstly on softer species and younger plant material before moving to harder species (Table 2.2). It is unavoidable that grass carp will feed on non-target species if their food source becomes limited. A conservative approach in stocking density is, therefore, very important when utilising grass carp as a biocontrol-agent in an IAVMP.

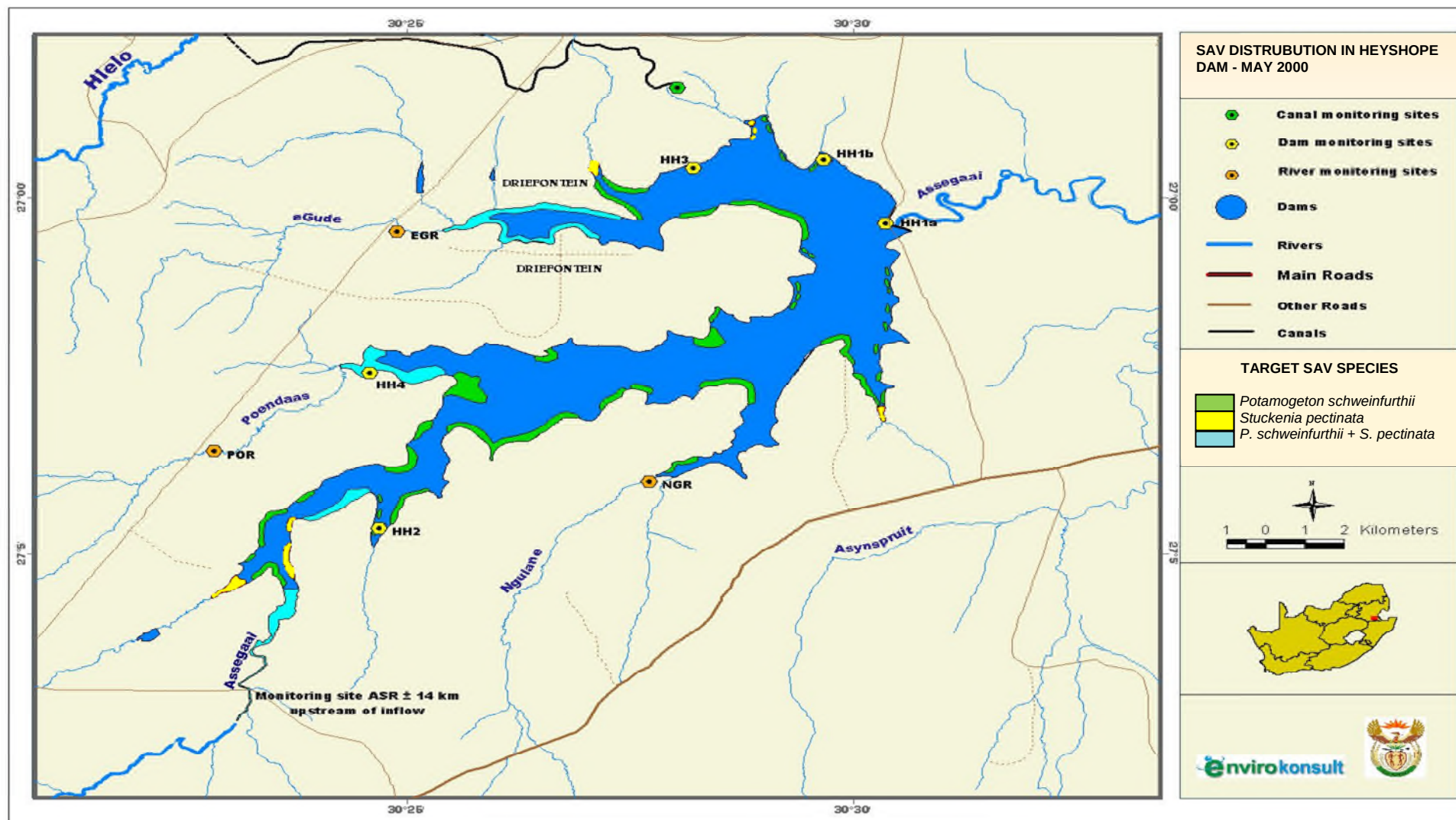


FIGURE 5.1: Heyshope Dam SAV survey performed in May 2000, prior to the implementation of the IAVMP, indicating the target SAV species, *Potamogeton schweinfurthii* and *Stuckenia pectinata* as monocultures and mixed areas (Adapted from Envirokonsult, 2000).

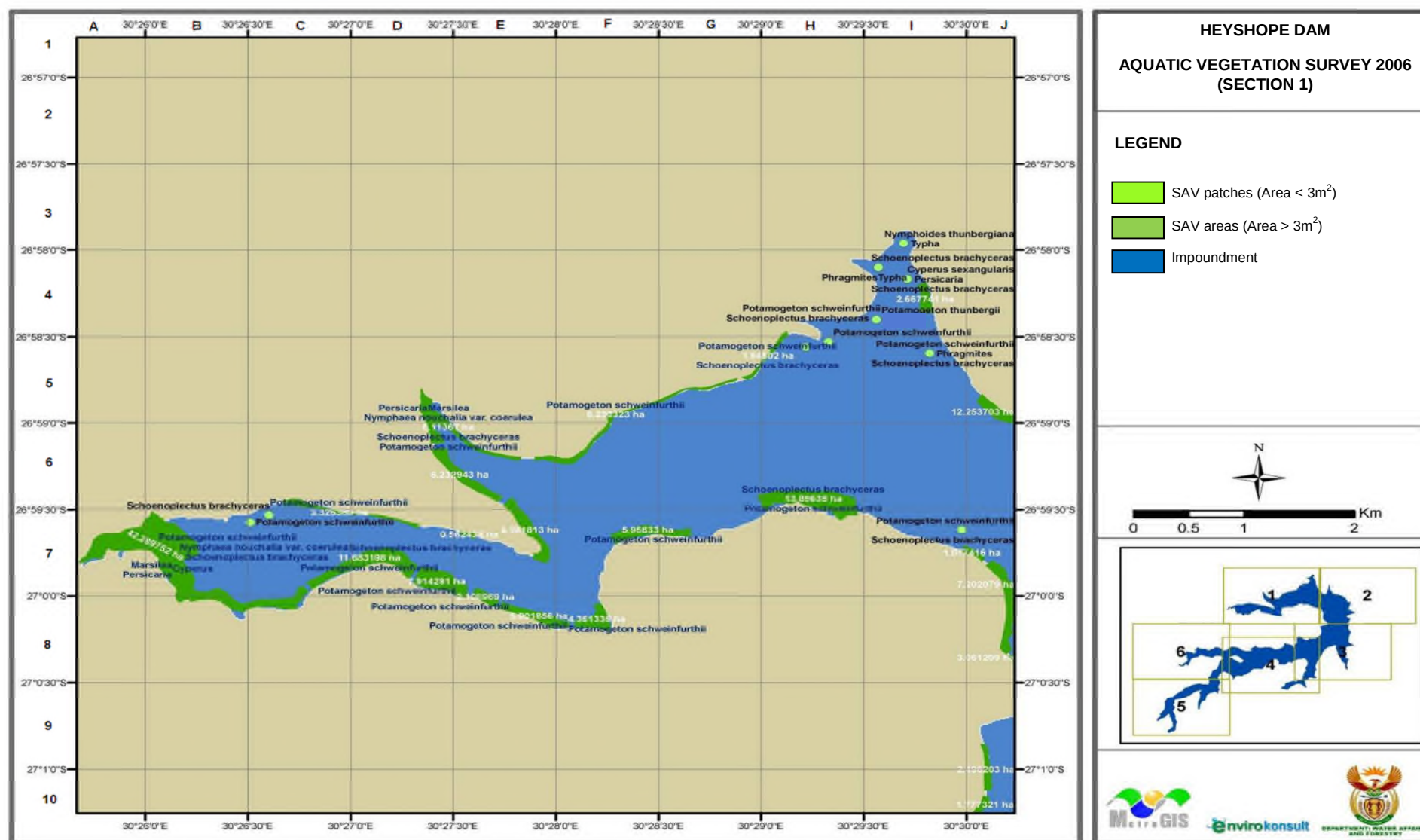


FIGURE 5.2: Heyshope Dam aquatic vegetation survey performed in May 2006 (Section 1 of 6 of dam surface). SAV areas indicated in green and growth areas indicated in hectares.

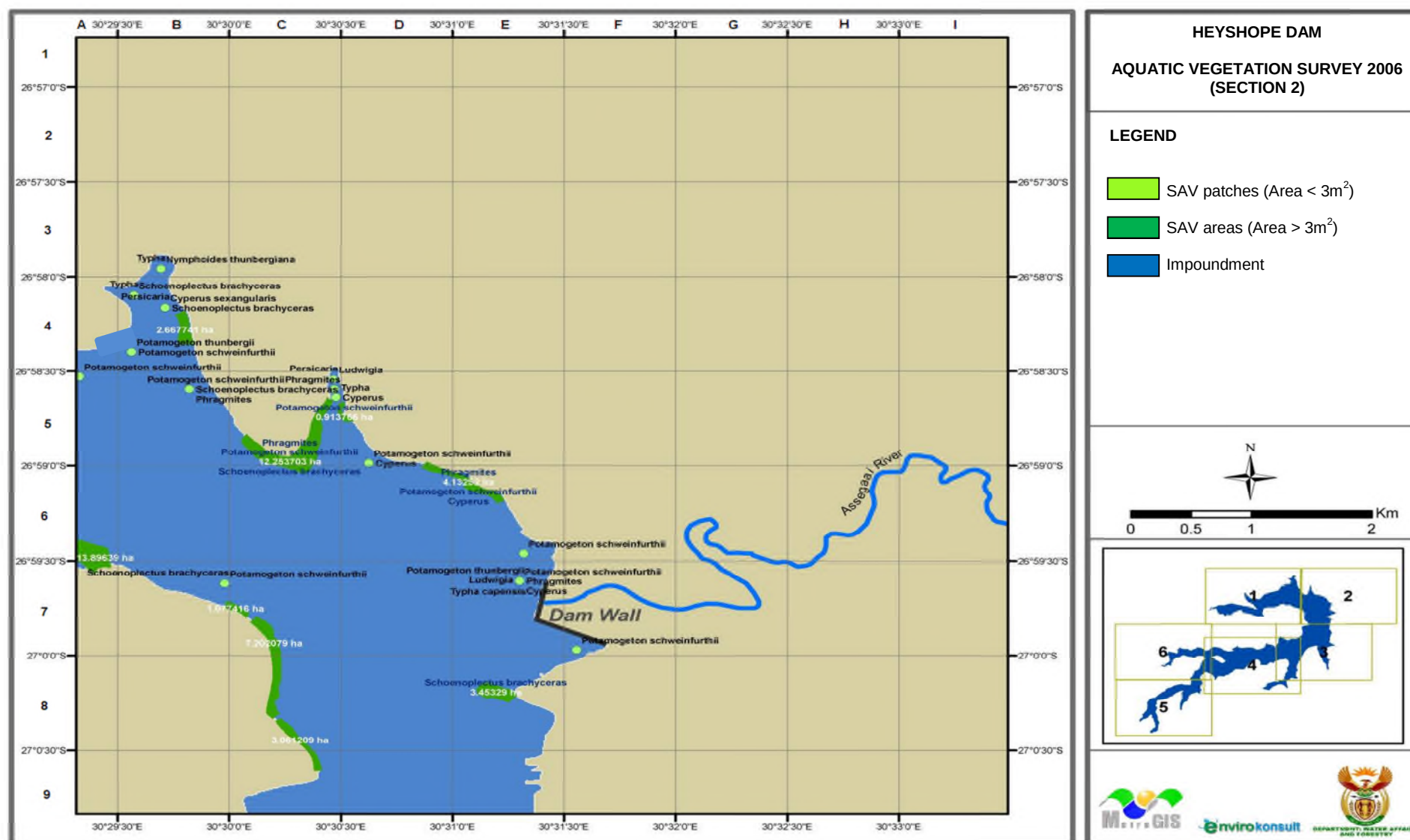


FIGURE 5.3: Heyshope Dam aquatic vegetation survey performed in May 2006 (Section 2 of 6 of dam surface). SAV areas indicated in green and growth areas indicated in hectares.

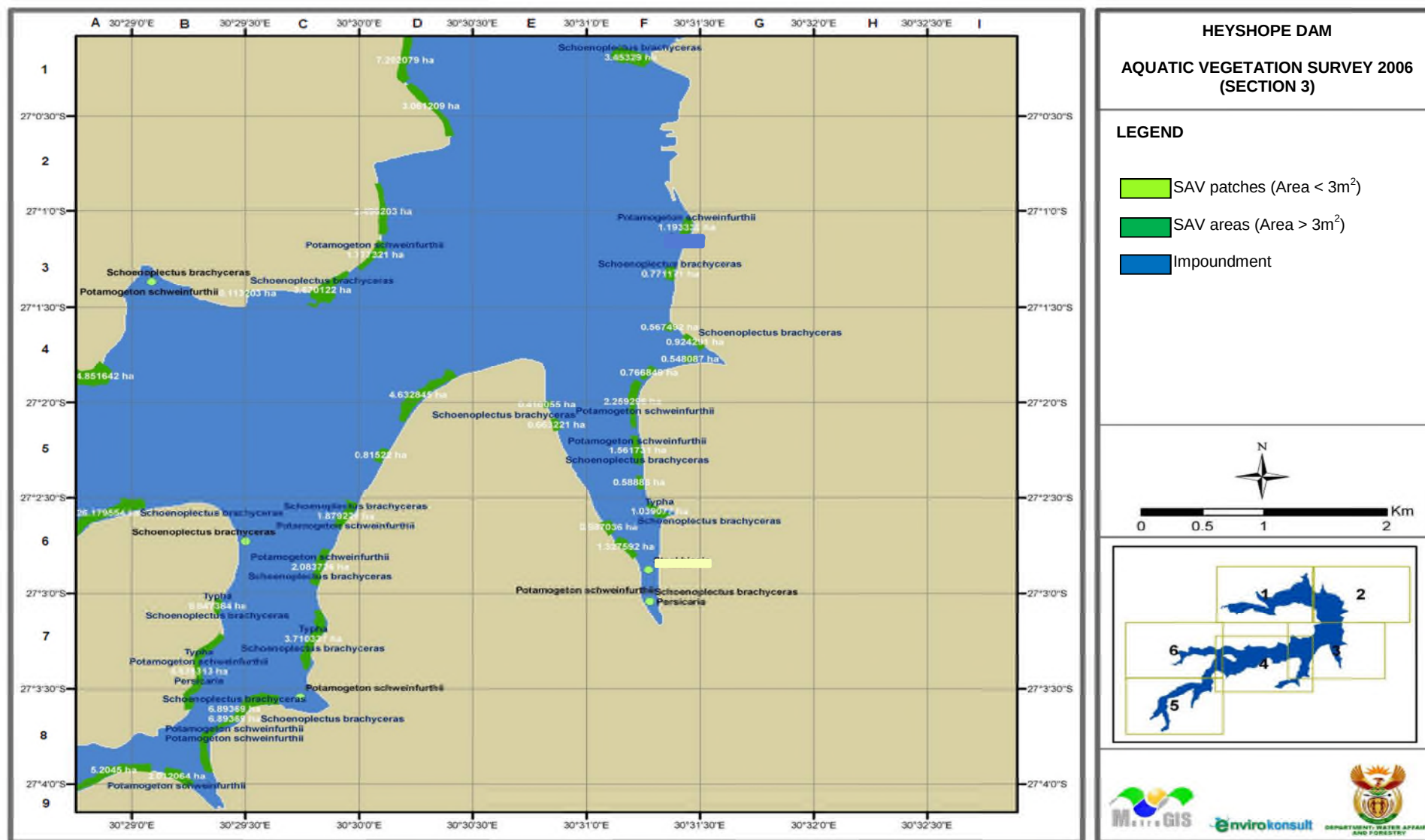


FIGURE 5.4: Heyshope Dam aquatic vegetation survey performed in May 2006 (Section 3 of 6 of dam surface). SAV areas indicated in green and growth areas indicated in hectares.

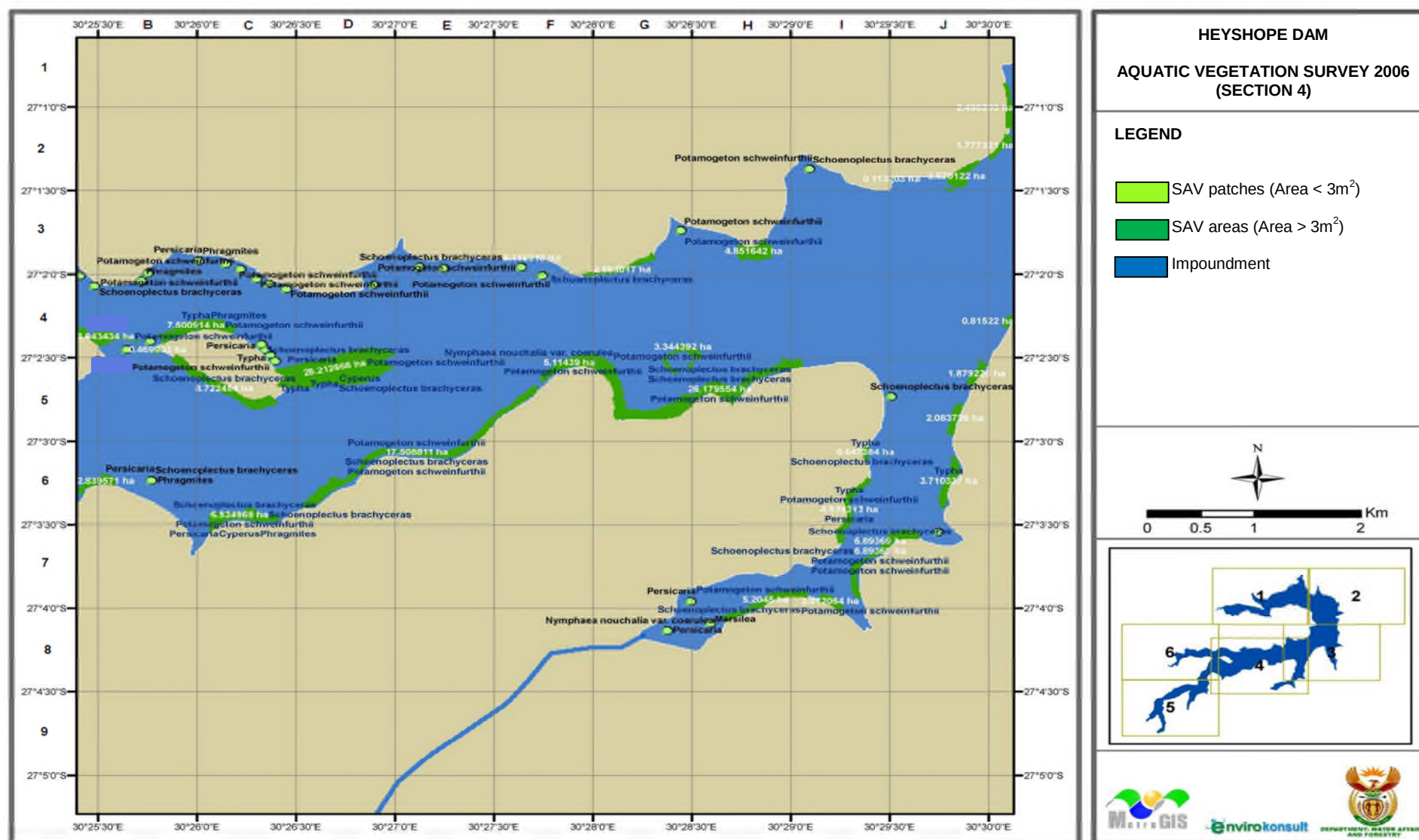


FIGURE 5.5: Heyshope Dam aquatic vegetation survey performed in May 2006 (Section 4 of 6 of dam surface). SAV areas indicated in green and growth areas indicated in hectares.

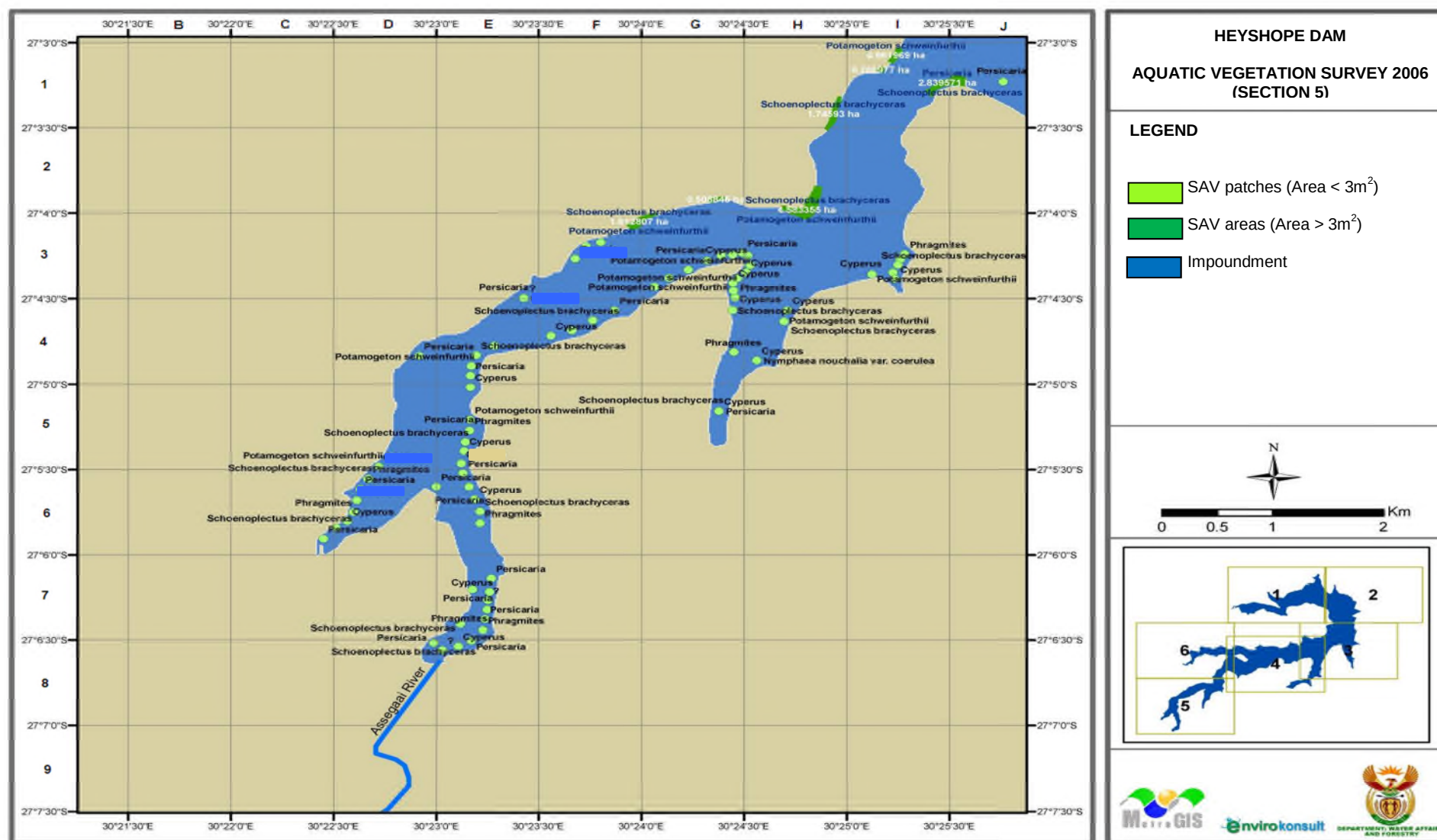


FIGURE 5.6: Heyshope Dam aquatic vegetation survey performed in May 2006 (Section 5 of 6 of dam surface). SAV areas indicated in green and growth areas indicated in hectares.

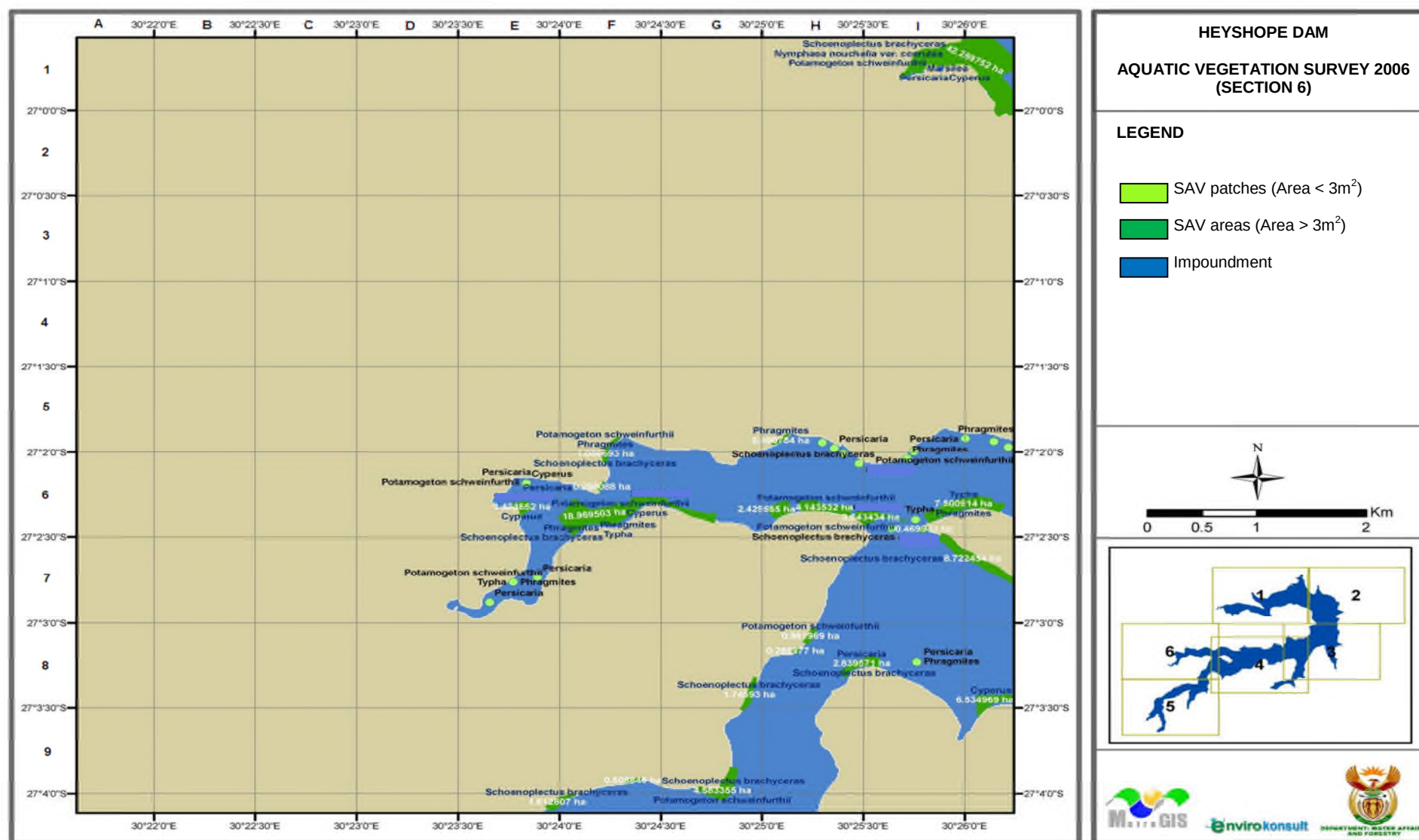


FIGURE 5.7: Heyshope Dam aquatic vegetation survey performed in May 2006 (Section 6 of 6 of dam surface). SAV areas indicated in green and growth areas indicated in hectares.

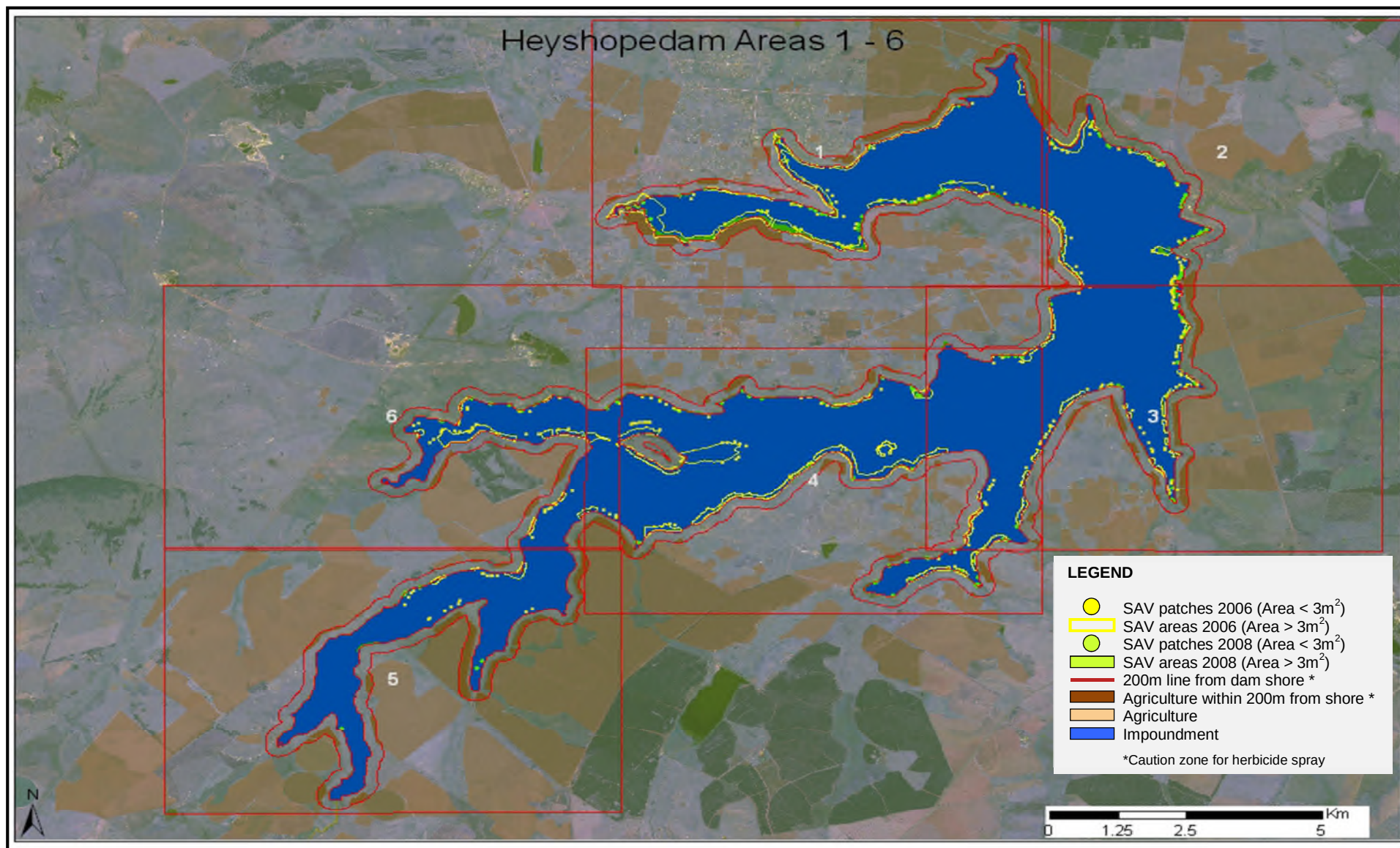


FIGURE 5.8: Heyshope Dam aquatic vegetation survey – comparison between 2006 and 2008 surveys. Both surveys conducted in May months (the end of growing season).

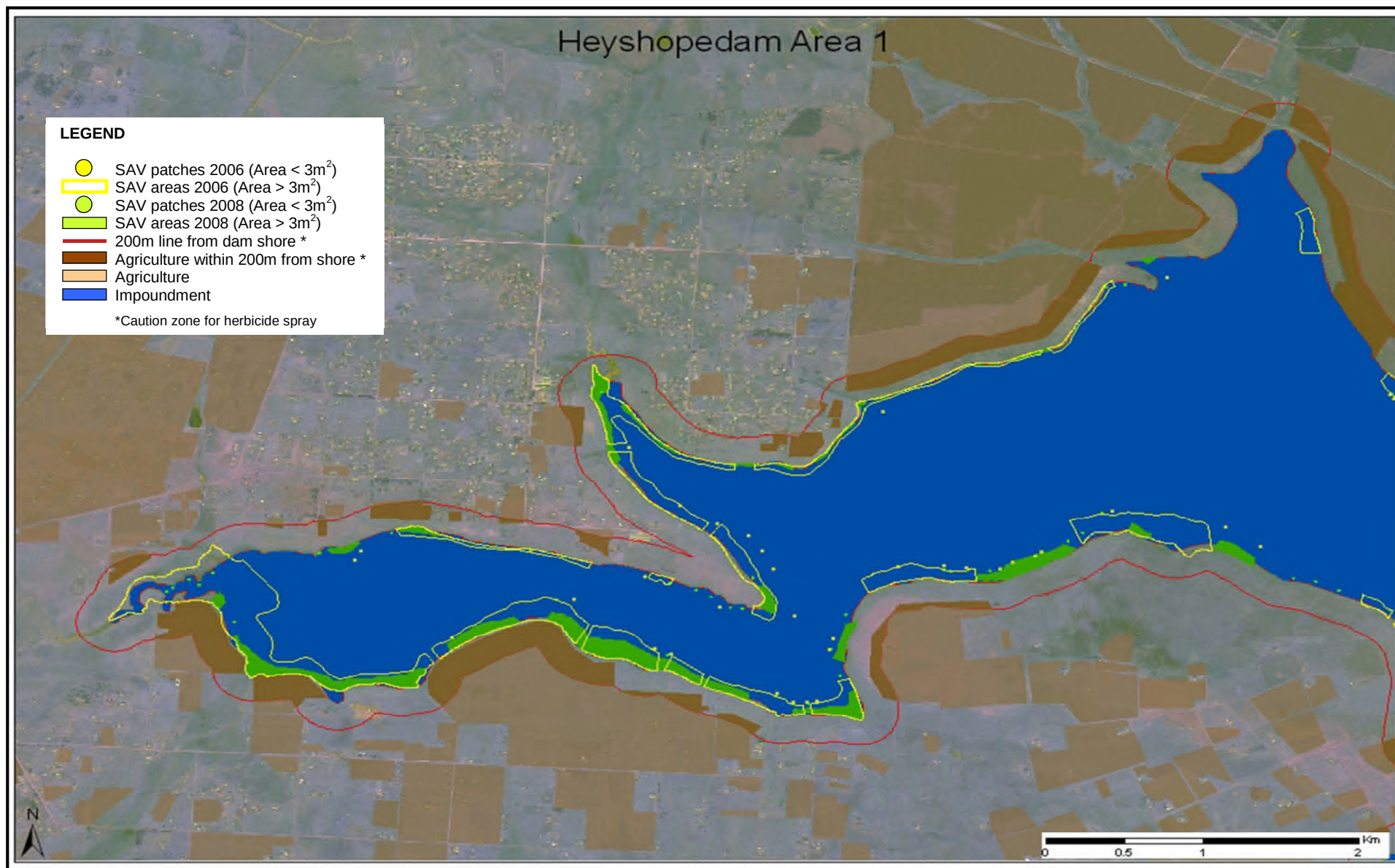


FIGURE 5.9: Comparison between the aquatic vegetation surveyed in Heyshope Dam in May 2006, with area surveyed in May 2008 (Area 1).

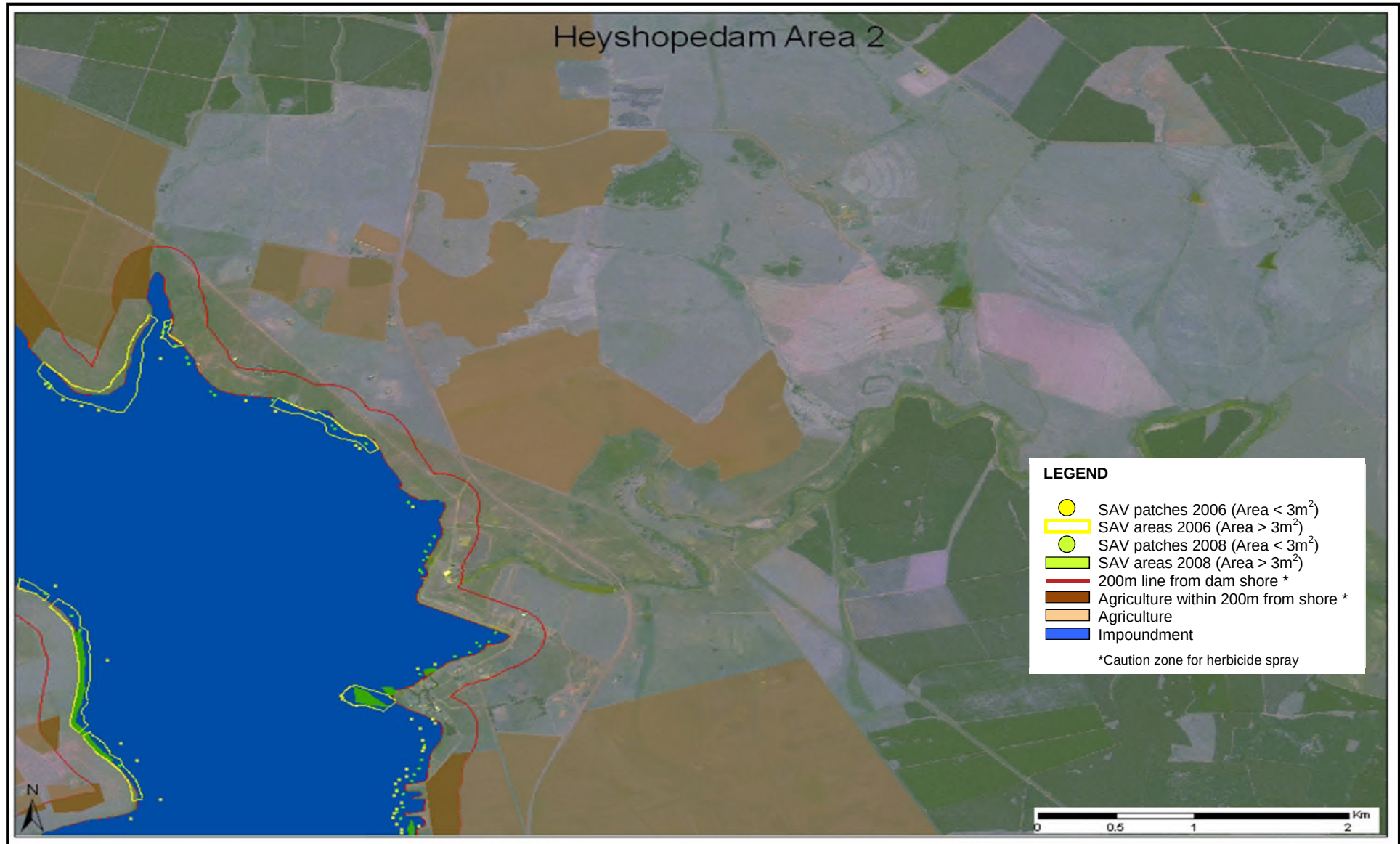


FIGURE 5.10: Comparison between the aquatic vegetation surveyed in Heyshope Dam in May 2006, with area surveyed in May 2008 (Area 2).

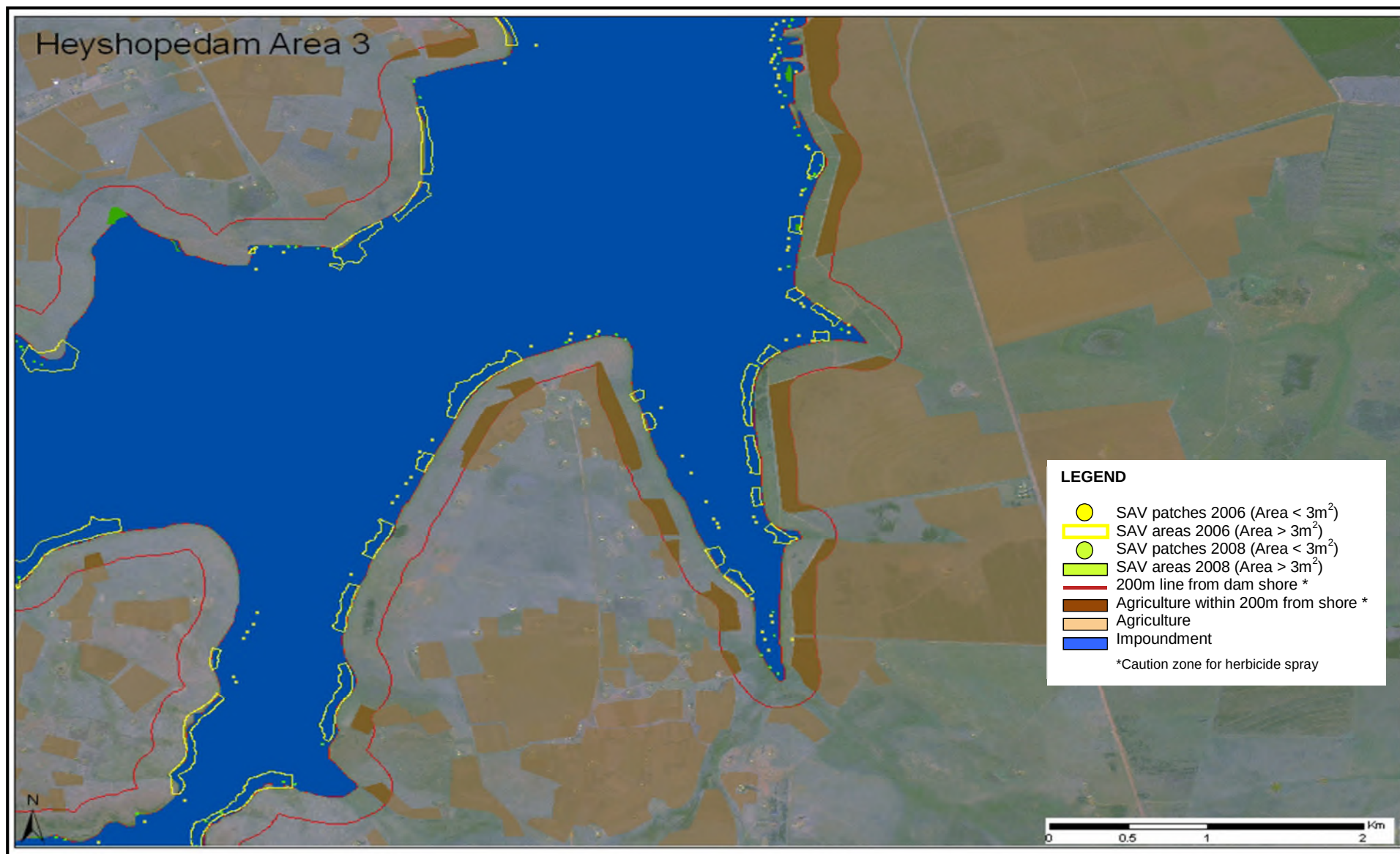


FIGURE 5.11: Comparison between the aquatic vegetation surveyed in Heyshope Dam in May 2006, with area surveyed in May 2008 (Area 3).

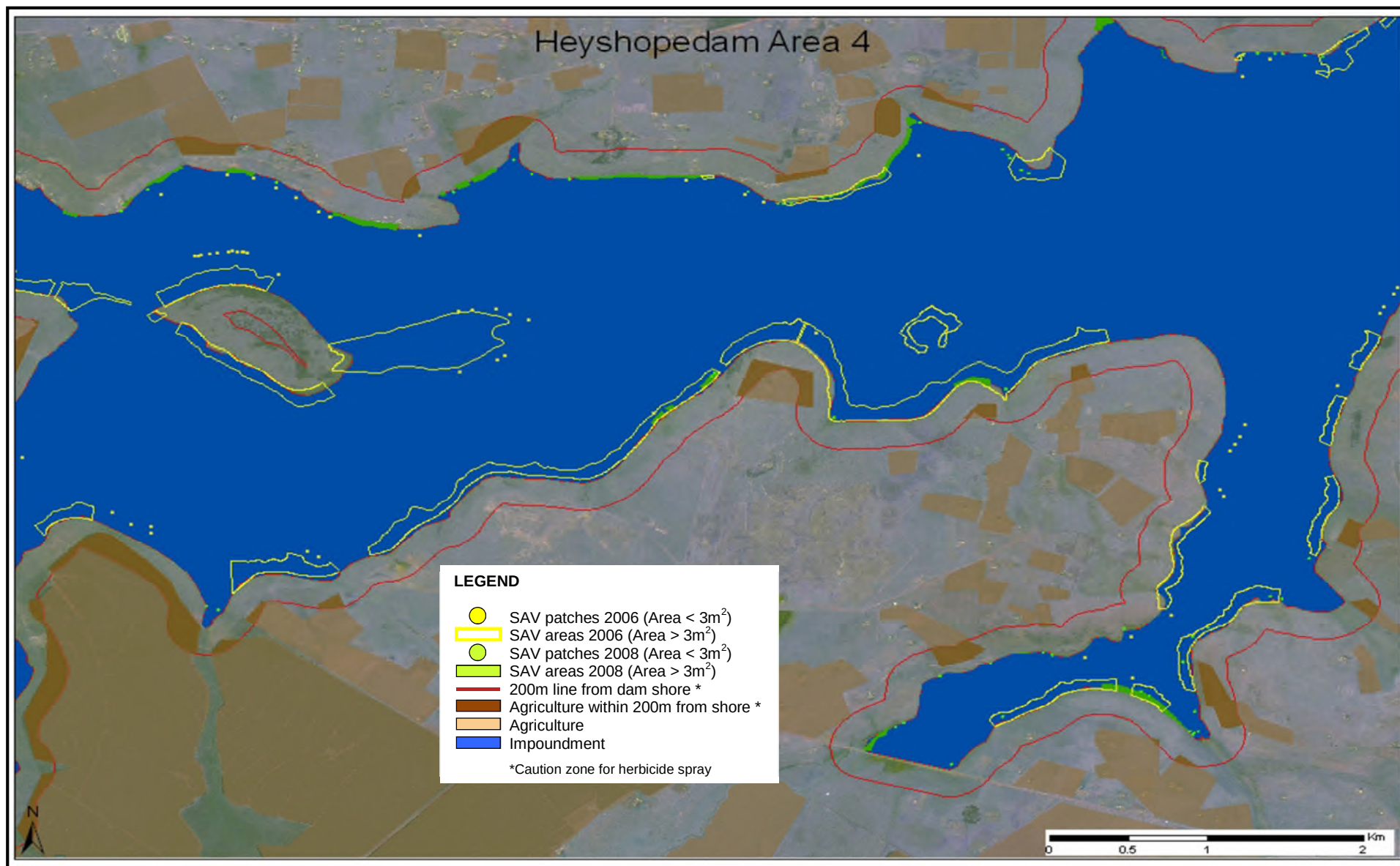


FIGURE 5.12: Comparison between the aquatic vegetation surveyed in Heyshope Dam in May 2006, with area surveyed in May 2008 (Area 4).

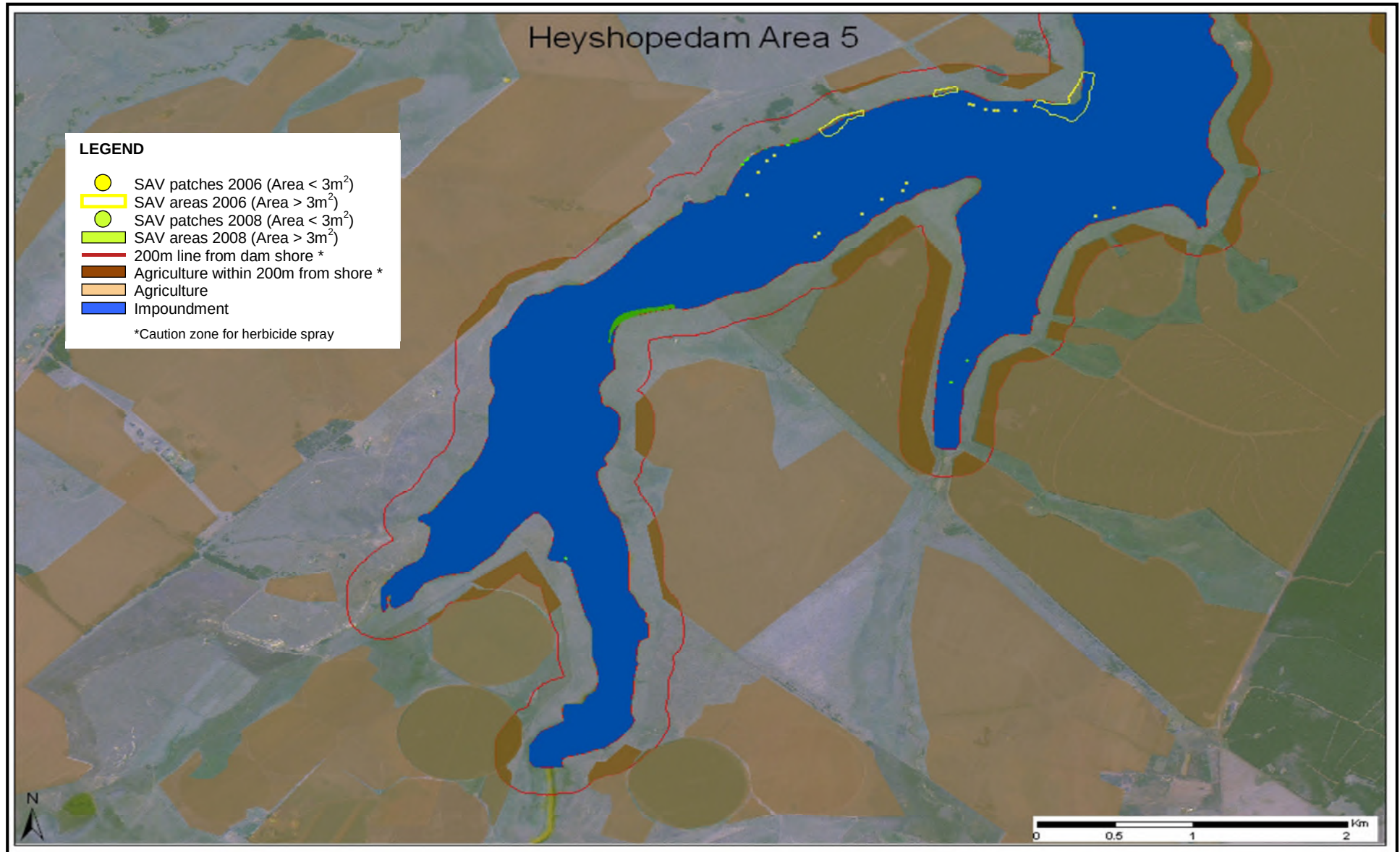


FIGURE 5.13: Comparison between the aquatic vegetation surveyed in Heyshope Dam in May 2006, with area surveyed in May 2008 (Area 5).

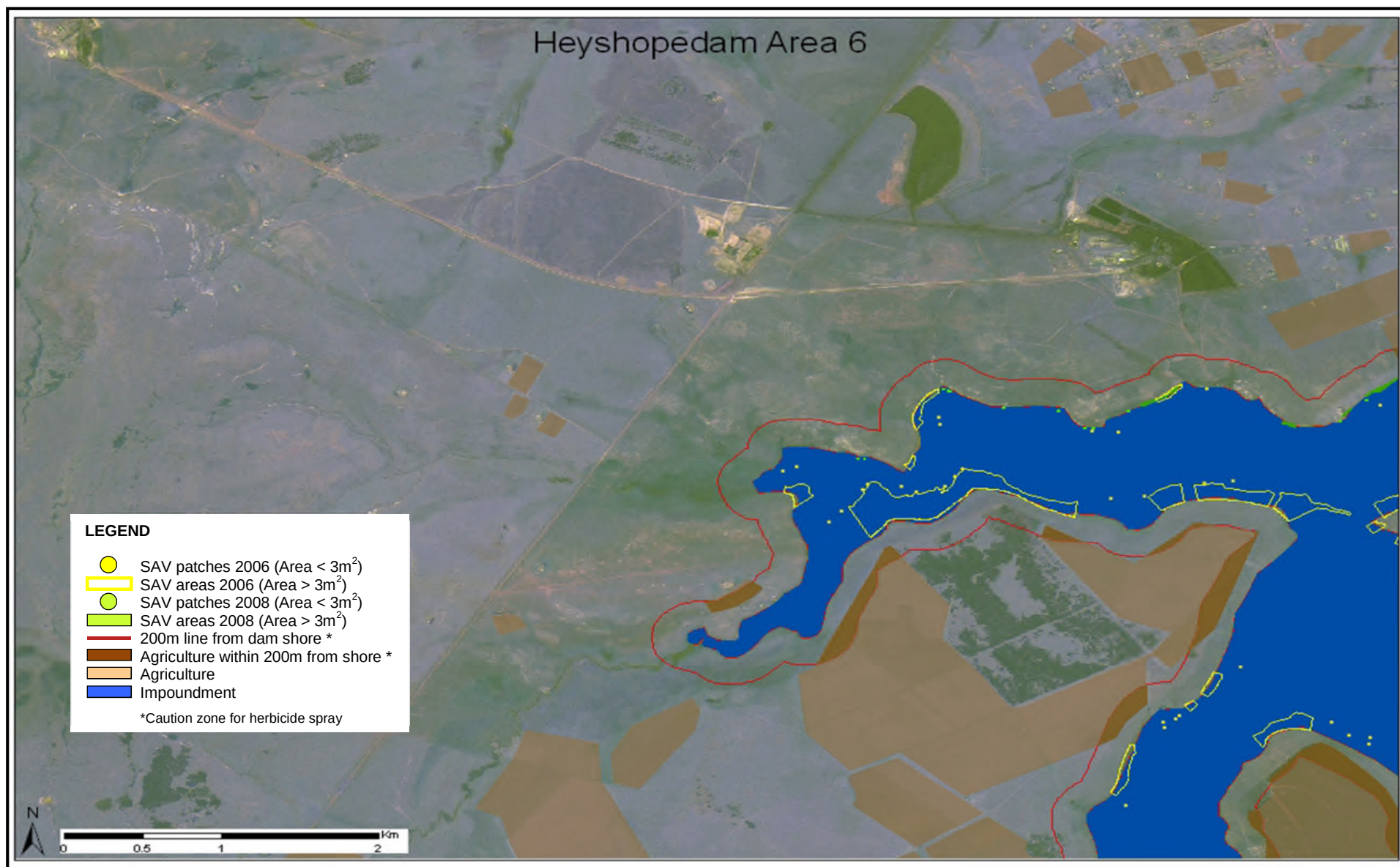


FIGURE 5.14: Comparison between the aquatic vegetation surveyed in Heyshope Dam in May 2006, with area surveyed in May 2008 (Area 6)

5.1.5 Aquatic macroinvertebrates:

5.1.5.1 In-lake macro-invertebrate composition of Heyshope Dam

5.1.5.1.1 In situ water quality assessment:

Changes in water quality can be expected as a result of the introduction of an IAVMP into the system. The primary changes would be associated with decreases in aquatic vegetation. A previous study conducted in Lake Marion, South Carolina (Foltz and Kirk, 1994) indicated that the reduction of aquatic macrophytes by grass carp would improve water quality, thereby increasing the capability to support more complex fish communities. The *in situ* water quality variables measured at the macroinvertebrate sampling locations indicated a substantial change in pH during the October 2006 survey (Table 5.19).

TABLE 5.19: TEMPORAL VARIATION IN SELECTED WATER QUALITY VARIABLES MEASURED IN APRIL 2000, OCTOBER 2005 AND OCTOBER 2006 AT SELECTED LOCATIONS IN HEYSHOPE DAM.

MONITORING LOCATION	CONDUCTIVITY (µS/cm)			pH			DISSOLVED O ₂ (mg/ℓ)			WATER TEMPERATURE (°C)		
	04/2000	10/2005	10/2006	04/2000	10/2005	10/2006	04/2000	10/2005	10/2006	04/2000	10/2005	10/2006
HH1	92.0	104.0	98.0	7.41	8.16	6.18	6.84	11.07	7.48	21.8	20.8	18.2
HH2	93.3	109.0	121.0	6.9	7.84	6.35	N/A	11.87	7.06	17	20.4	24.3
HH3	92.5	93.0	95.0	6.9	7.8	6.18	N/A	11	6.2	18.5	20.3	20.3
HH4	86.8	110.0	104.0	6.7	7.96	5.91	6.5	11.51	6.25	21.2	21.1	22.7

N/A = Not Available

During this survey the pH decreased over time, changing from neutral/alkaline to acidic conditions. The cause of this change is uncertain. The water quality variables were measured specifically to assist the interpretation of the biological information gathered during the macro-invertebrate survey.

5.1.5.1.2 Aquatic macroinvertebrate assemblage:

A total of 19 macro-invertebrate taxa were sampled in the Heyshope Dam during April 2007, with the application of the SASS5 sampling protocol (Table 5.22). The highest diversity of aquatic macro-invertebrates was observed at site HH1, where 13 taxa were observed in 2007 and 16 in 2000 (Envirokonsult, 2000). Site HH2 had a

total of 10 taxa sampled in 2007 and 16 in 2000. Only 5 and 7 taxa were sampled at sites HH3 and HH4 respectively in 2007, while 12 and 8 taxa were sampled during 2000 respectively at HH3 and HH4, before the introduction of grass carp.

To examine temporal trends, the two April surveys (2000 and 2007) were compared (Figure 5.15). This was done to compare similar seasonal data.

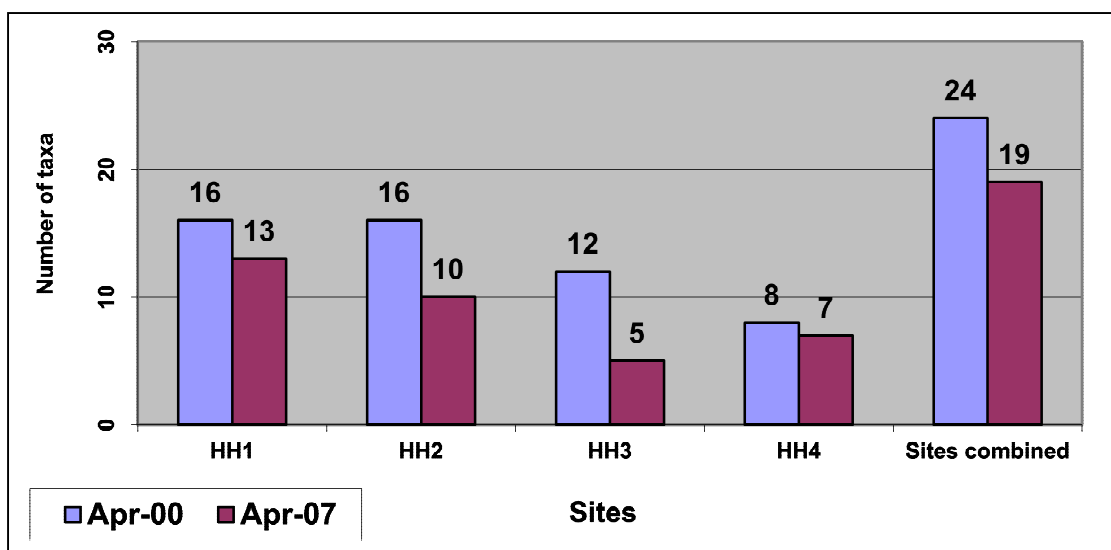


Figure 5.15: Number of macro-invertebrate taxa sampled at the different monitoring sites during April surveys (2000 and 2007).

The difference in taxa richness and abundance between the different sites can primarily be attributed to differences in biotope diversity and habitat conditions. Differences in water quality between the sites can, however, also be responsible for the observed differences in invertebrate communities. Anthropogenic impacts (diffuse sources) around the dam, and in the catchments of the rivers draining into the dam, contribute to pollution in the Heyshope Dam. During April 2007, the waterbody was dominated by taxa classified as pollution tolerant. Four taxa indicative of moderate tolerance to pollution (Athyridae, Hydracarina, Aeshnidae and Gomphidae) were also sampled.

During April 2000 24 invertebrate taxa were sampled (Envirokonsult, 2000), in comparison to 19 taxa observed during April 2007 (Table 5.19 to 5.23; Figure 5.15). Furthermore, fewer taxa were encountered at all sites during April 2007 than April 2000 (Figure 5.15). It is therefore evident that there has been a change in the overall aquatic macro-invertebrate taxa of the biotopes sampled in the dam, being

lower after introduction of the grass carp (this coincides with a previous study conducted in lakes in Florida by Colle and Shireman, 1994).

The following factors or a combination thereof could attribute to this observation:

- There was less SAV present in the dam during April 2007 than April 2000 survey. These differences can be attributed to the aquatic vegetation control programme in the impoundment. The change in amount of aquatic vegetation may have been responsible for an overall decrease in the number of aquatic macro-invertebrate taxa. These changes may have resulted in a decrease in the food source of the fish and waterfowl feeding on the macroinvertebrates. It must however, be kept in mind that this, being a manmade reservoir, is an unnatural system, and the purpose of the dam is not for the protection of biodiversity, but rather for the storage and supply of water. The higher diversity observed prior to the stocking of grass carp can, therefore, also be seen as unnatural and related to the high abundance of SAV.
- The water quality changes observed since April 2000 (Envirokonsult, 2000) possibly further contributed to the change in the number of macroinvertebrates.

5.1.5.1.3 Conclusions:

The following conclusions were drawn from in-lake biomonitoring surveys conducted on the Heyshope Dam during 2000, 2005, 2006 and 2007:

- During April 2007, 19 macro-invertebrate taxa were sampled in the Heyshope Dam with the application of the SASS5 sampling protocol. The impoundment was dominated by taxa classified as pollution tolerant. Four taxa of moderate tolerance to pollution (Athyidae, Hydracarina, Aeshnidae and Gomphidae) were also sampled.
- During April 2000, 24 invertebrate taxa were sampled (Envirokonsult, 2000).
- All the sites showed a decrease in the number of taxa from 2000 to 2007.
- It is therefore evident that there has been a change in the number of the overall aquatic macro-invertebrate taxa of the biotopes sampled in the dam, being lower after introduction of the IAVMP compared to before the intervention.

TABLE 5.20: MACRO-INVERTEBRATE TAXA ASSEMBLAGES OF THE BIOMONITORING LOCATIONS BEFORE THE INTRODUCTION OF GRASS CARP IN THE HEYSHOPE DAM (APRIL 2000).

MACRO-INVERTEBRATE TAXON	MONITORING LOCATIONS											
	HH1			HH2			HH3			HH4		
	Vegetation	GSM	Total	Vegetation	GSM	Total	Vegetation	GSM	Total	Vegetation	GSM	Total
TURBELLARIA	-	A	A	-	-	-	A	-	A	-	-	-
Oligochaeta	-	A	A	A	A	A	-	-	-	-	-	-
Leeches	A	A	A	D	C	D	-	-	-	-	-	-
Atyidae	B	-	B	B	-	B	B	-	B	B	-	B
HYDRACARINA	-	-	-	B	B	B	-	-	-	-	-	-
Baetidae	B	A	B	A	-	A	B	A	B	B	A	B
Caenidae	A	A	B	-	-	-	A	-	A	-	-	-
Coenagrionidae	-	A	A	A	-	A	-	-	-	A	-	A
Aeshnidae	A	-	A	-	-	-	-	-	-	-	-	-
Corduliidae	-	A	A	-	-	-	-	-	-	-	-	-
Gomphidae	-	A	A	-	-	-	-	-	-	-	-	-
Belostomatidae*	A	-	A	B	-	B	A	-	A	A	-	A
Corixidae*	B	A	B	A	-	A	B	B	B	A	-	A
Naucoridae*	A	A	B	A	-	A	A	A	B	-	-	-
Nepidae*	A	-	A	-	-	-	-	-	-	-	-	-
Notonectidae*	A	-	A	A	-	A	-	A	A	-	-	-
Pleidae*	A	-	A	B	-	B	A	-	A	-	-	-
Veliidae*	A	-	A	B	-	B	A	A	A	B	-	B
Leptoceridae	C	B	C	B	-	B	B	-	B	A	-	A
Dytiscidae (adults*)	-	A	A	-	-	-	-	-	-	-	-	-
Chironomidae	B	B	B	A	B	B	A	A	A	B	A	B
Lymnaeidae*	A	-	A	A	-	A	-	-	-	-	-	-
Physidae*	A	-	A	-	-	-	-	-	-	-	-	-
Planorbinae*	A	A	A	-	-	-	-	-	-	-	-	-

KEY:

Highly tolerant to pollution

Moderately tolerant to pollution

Very low tolerance to pollution

A = 1-10 individuals; B = 11-100 individuals; C = 101-1000 individuals

GSM = Gravel / Sand / Mud biotopes

Veg = Vegetation

* = Adults

- = Absent

TABLE 5.21: MACRO-INVERTEBRATE TAXA ASSEMBLAGES OF THE BIOMONITORING LOCATIONS IN THE HEYSHOPE DAM (OCTOBER 2005).

MACRO-INVERTEBRATE TAXON	MONITORING LOCATIONS													
	HH1			HH2			HH3				HH4			
	Stones	Veg	Total	Veg	GSM	Total	Stones	Veg	GSM	Total	Stones	Veg	GSM	Total
TURBELLARIA	B	B	B	-	-	-	B	-	A	B	-	-	-	-
Oligochaeta	-	-	-	-	A	A	-	-	A	A	A	-	-	A
Atyidae	-	A	A	-	-	-	-	A	-	A	-	A	-	A
HYDRACARINA	-	-	-	-	-	-	-	-	-	-	-	A	-	A
Baetidae	A	B	B	B	B	B	B	-	B	B	A	B	-	B
Coenagrionidae	A	B	B	B	-	B	A	B	-	B	A	B	-	B
Gomphidae	-	-	-	-	-	-	-	-	A	A	-	-	-	-
Belostomatidae*	-	B	B	-	-	-	-	-	-	-	-	-	-	-
Corixidae*	-	A	A	A	B	B	A	-	A	A	C	B	B	C
Gerridae	-	-	-	-	-	-	-	-	-	-	-	A	-	A
Notonectidae*	-	-	-	A	A	A	-	-	-	-	A	A	-	A
Veliidae*	-	A	A	-	-	-	-	A	-	A	-	-	-	-
Gyrinidae (adults*)	-	A	A	-	-	-	-	-	-	-	-	-	-	-
Ceratopogonidae	-	A	A	A	-	A	A	A	A	A	A	A	A	A
Chironomidae	-	-	-	A	A	B	A	-	A	A	-	-	A	A
Culicidae*	-	-	-	-	-	-	-	-	A	A	-	-	-	-
Lymnaeidae*	-	B	B	A	-	A	-	A	-	A	-	A	-	A
Physidae*	-	B	B	-	-	-	-	-	-	-	-	-	-	-
Planorbinae*	-	A	A	-	-	-	-	-	-	-	-	-	-	-
Nr. of families	3	12	12	7	5	8	6	5	8	12	6	9	3	11

KEY:

Highly tolerant to pollution

Moderately tolerant to pollution

Very low tolerance to pollution

A = 1-10 individuals; B = 11-100 individuals; C = 101-1000 individuals

GSM = Gravel / Sand / Mud biotopes

Veg = Vegetation

* = Adults

- = Absent

TABLE 5.22: MACRO-INVERTEBRATE TAXA ASSEMBLAGES OF THE BIOMONITORING LOCATIONS IN THE HEYSHOPE DAM (OCTOBER 2006).

MACRO-INVERTEBRATE TAXON	MONITORING LOCATIONS															
	HH1				HH2				HH3				HH4			
	Stones	Veg	GSM	Total	Stones	Veg	Mud	Total	Stones	Veg	GSM	Total	Stones	Veg	GSM	Total
TURBELLARIA	A	A	-	A	-	-	-	-	-	A	-	A	-		-	-
Oligochaeta	A	-	-	A	-	-	A	A	-	-	-	-	A		-	A
Leeches	-	-	-	-	-	A	A	A	-	-	-	-	-		-	-
Potamonautide*	A	-	-	A	-	-	-	-	-	-	-	-	-		-	-
Atyidae	-	A	-	A	-	A	-	A	-	A	-	A	-	A	-	A
HYDRACARINA	-	A	-	A	-	B	A	B	-	-	-	-	-		-	-
Baetidae	-	B	-	B	-	A	A	B	B	B	-	B	B	B	-	B
Coenagrionidae	-	-	-	-	-	-	-	-	-	A	-	A	-	B	-	B
Belostomatidae*	-	-	-	-	-	A	-	A	-	B	-	B	-	A	-	A
Corixidae*	-	-	-	-	-	B	A	B	-		-	-	-	-	-	-
Gerridae	-	-	-	-	-	A	-	A	-		-	-	-	-	-	-
Notonectidae*	-	-	-	-	-	A	A	A	-		-	-	-	-	-	-
Veliidae*	-	A	-	A	-	A	-	A	-		-	-	-	-	-	-
Leptoceridae	-	-	-	-	-	A	-	A	-		-	-	-	-	-	-
Dytisidae*	-	-	-	-	-	-	-	-	-		-	-	-	A	-	A
Ceratopogonidae	-	A	-	A	-	A	-	A	-		-	-	A	B	-	B
Chironomidae	A	-	-	A	-	A	-	A	A	B	-	B	-	B	-	B
Lymnaeidae*	-	A	-	A	-	-	-	-	-	A	-	A	-	-	-	-
Nr. of families	4	7	0	10	0	12	6	13	2	7	0	7	3	7	0	8

KEY:

Highly tolerant to pollution

Moderately tolerant to pollution

Very low tolerance to pollution

A = 1-10 individuals; B = 11-100 individuals; C = 101-1000 individuals

GSM = Gravel / Sand / Mud biotopes

Veg = Vegetation

* = Adults

- = Absent

TABLE 5.23: MACRO-INVERTEBRATE TAXA ASSEMBLAGES OF THE BIOMONITORING LOCATIONS IN THE HEYSHOPE DAM (APRIL 2007).

MACRO-INVERTEBRATE TAXON	MONITORING LOCATIONS											
	HH1			HH2			HH3			HH4		
	Stones	Veg	Total	Veg	GSM	Total	Veg	GSM	Total	Veg	GSM	Total
TURBELLARIA	A	-	A	A	-	A	-	-	-	-	-	-
Oligochaeta	A	-	A	-	-	-	-	-	-	-	B	B
Leeches	-	-	-	A	A	A	-	-	-	-	-	-
Atyidae	A	B	B	B	-	B	A	-	A	B	-	B
HYDRACARINA	-	-	-	-	A	A	-	-	-	-	-	-
Baetidae	A	A	B	-	-	-	A	-	A	A	-	A
Coenagrionidae	-	A	A	A	-	A	A	-	A	-	-	-
Aeshnidae	-	A	A	-	-	-	-	-	-	-	-	-
Gomphidae	-	-	-	-	-	-	-	-	-	-	A	A
Belostomatidae*	-	A	A	-	-	-	-	-	-	-	-	-
Corixidae*	-	-	-	A	A	A	-	-	-	-	-	-
Nepidae*	-	-	-	-	-	-	-	-	-	A	-	A
Notonectidae*	-	A	A	B	-	B	-	-	-	-	-	-
Pleidae*	-	A	A	-	-	-	-	-	-	-	-	-
Veliidae*	-	A	A	-	-	-	-	-	-	A	-	A
Ceratopogonidae	-	-	-	A	-	A	-	-	-	-	A	A
Chironomidae	A	A	A	A	-	A	A	-	A	-	-	-
Lymnaeidae*	-	B	B	A	-	A	-	-	-	-	-	-
Physidae*	-	B	B	-	-	-	B	-	B	-	-	-
Nr. of families	5	11	13	9	3	10	5	0	5	4	3	7

KEY:

Highly tolerant to pollution

Moderately tolerant to pollution

Very low tolerance to pollution

A = 1-10 individuals; B = 11-100 individuals; C = 101-1000 individuals

GSM = Gravel / Sand / Mud biotopes

Veg = Vegetation

* = Adults

- = Absent

TABLE 5.24: MACRO-INVERTEBRATE TAXA ASSEMBLAGES OF THE BIOMONITORING LOCATIONS IN THE HEYSHOPE DAM PRESENT DURING APRIL 2000, OCTOBER 2005, OCTOBER 2006 AND APRIL 2007.

MACRO-INVERTEBRATE TAXON	MONITORING LOCATIONS															
	HH1				HH2				HH3				HH4			
	APRIL 2000	OCT 2005	OCT 2006	APR 2007	APRIL 2000	OCT 2005	OCT 2006	APR 2007	APRIL 2000	OCT 2005	OCT 2006	APR 2007	APRIL 2000	OCT 2005	OCT 2006	APR 2007
TURBELLARIA	-	B	A	A	-	-	-	A	A	B	A	-	-	-	-	-
Oligochaeta	-	-	A	A	A	A	A	-	-	A	-	-	-	A	-	A
Leeches	A	-	-	-	B	-	A	A	-	-	-	-	-	-	-	-
Potamonautide*	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-
Atyidae	B	A	A	B	B	-	A	B	B	A	A	A	B	A	A	B
HYDRACARINA	-	-	A	-	B	-	B	-	-	-	-	-	-	A	-	-
Baetidae	B	B	B	B	A	B	B	-	B	B	B	A	B	B	B	A
Ceanidae	B	-	-	-	-	-	-	-	A	-	-	-	-	-	-	-
Coenagrionidae	-	B	-	A	A	B	-	A	-	B	A	A	A	B	B	-
Aeshnidae	-	-	-	A	-	-	-	-	-	-	-	-	-	-	-	-
Corduliidae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gomphidae	-	B	-	-	-	-	-	-	-	-	-	-	-	-	-	A
Nepidae	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A
Belostomatidae*	A	B	-	A	B	-	A	-	A	-	A	-	A	-	A	-
Corixidae*	B	A	-	-	A	B	B	A	B	A	-	-	A	C	-	-
Naucoridae	A	-	-	-	A	-	-	-	B	-	-	-	-	-	-	-
Gerridae	-	-	-	-	-	-	A	-	-	-	-	-	-	A	-	-
Notonectidae*	A	-	-	A	A	A	A	B	A	-	-	-	-	A	-	-
Pleidae	A	-	-	A	B	-	-	-	A	-	-	-	-	-	-	-
Veliidae*	A	A	A	A	B	-	A	-	A	A	-	-	B	-	-	A
Leptoceridae	C	-	-	-	B	-	A	-	B	-	-	-	A	-	-	-
Gyrinidae	-	A	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dytisidae*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	A	-
Ceratopogonidae	-	A	A	-	-	A	A	A	-	A	-	-	-	A	B	-
Chironomidae	B	-	A	A	B	B	A	A	A	A	B	A	B	A	B	A
Culicidae	-	-	-	-	-	-	-	-	-	A	-	-	-	-	-	-
Lymnaeidae*	A	B	A	B	A	A	-	A	-	A	A	-	-	A	-	-
Physidae	A	B	-	B	-	-	-	-	-	-	-	B	-	-	-	-
Planorbidae	A	A	-	-	A	-	-	-	-	-	-	-	-	-	-	-
Nr. of families	16	13	10	13	16	8	13	10	12	11	7	5	8	11	7	7
Nr. of tolerant taxa	14	11	8	11	13	8	10	8	10	10	6	4	6	9	6	5
Nr. of moderately tolerant taxa	2	2	2	2	3	0	3	2	2	1	1	1	2	2	1	2

KEY:

Highly tolerant to pollution

Moderately tolerant to pollution

Very low tolerance to pollution

A = 1-10 individuals; B = 11-100 individuals; C = 101-1000 individuals

GSM = Gravel / Sand / Mud biotopes

Veg = Vegetation

* = Adults

- = Absent

5.1.5.2 Aquatic macro-invertebrate composition in the tributaries of Heyshope Dam

5.1.5.2.1 Monitoring location – Site 1:

(a) Site description for Monitoring Site 1

Monitoring site 1 was located in the Assegaa River, just upstream of Heyshope Dam (Figure 4.2). The riffles and runs were relatively well developed and it also contained some smaller pools and backwaters that provided a good habitat for fish and macro-invertebrate sampling (Plate 5.4). However, marginal vegetation at the site was almost absent and provided very little cover for fish and macroinvertebrates. The riparian zone was notably trampled, overgrazed by free roaming cattle and the river channel was noticeably deeply cut down with eroded banks.

(b) *In situ* water quality

Measurements of water quality variables at Monitoring Site 1 were very similar and close to expected conditions, except for conductivity that was slightly higher than expected for this system (Kempster et al., 1980; Alabaster and Lloyd, 1982; Davies and Day, 1998; Dallas, 2000) (Table 5.25).

TABLE 5.25: SELECTED WATER QUALITY VARIABLES MEASURED IN THE ASSEGAAI RIVER (MONITORING SITE 1) DURING OCTOBER 2005, OCTOBER 2006 AND APRIL 2007.

VARIABLES	2005	2006	2007
pH	8.3	8.6	8.6
CONDUCTIVITY ($\mu\text{S}/\text{cm}$)	220	210	230
WATER TEMPERATURE ($^{\circ}\text{C}$)	23	17	24
TURBIDITY (visual)	Cloudy	Slightly cloudy	Slightly cloudy
COLOUR (visual)	Grey	Grey	Grey

(c) Aquatic macro-invertebrate assemblages

A reasonable diversity of invertebrate fauna, dominated by Trichoptera (Caddis flies), Diptera (flies), Ephemeroptera (mayflies), Coleoptera (beetles) and Hemiptera (bugs), was present at this site (Table 5.26). The abundance of the filter feeding Simuliidae (Diptera) and Hydropsychidae (Trichoptera) at this site can be related to the influence of increasing the surface of Heyshope Dam on the availability of abundant plankton (food source). This could also be indicative of the grass carp activity recycling the nutrients by feeding on the macrophytes, thereby increasing the abundance of plankton. The low abundance of the Heptageniidae and absence of Psephenidae, highly likely to occur in the rivers in this Ecoregion (Dallas, 2007), suggest that the diversity of sensitive

invertebrates in this river was slightly lower than expected. This assumption is also supported by the lower-than-expected SASS scores for the Stones In and Out of Current biotope (S) (Table 5.25). The present ecological state of this site for the review period, according to the rule-based Macro-invertebrate Response Assessment Index (MIRAI), can be classified as Class C (moderately impaired with moderate diversity and fewer sensitive invertebrate taxa). This is largely supported by the delineation of the SASS and Average Score Per Taxon (ASPT) values according to Table 4.7.



PLATE 5.4: Monitoring Site 1, indicating well developed riffles and runs with some backwaters and pools.

Monitoring location – Site 2:

(a) Site description for Monitoring Site 2

This site was in the Assegaa River, just downstream of Heyshope Dam (Figure 4.2). The riffles and runs were relatively well developed at the site, and it also contained some smaller pools and backwaters that provided a habitat that could be sampled for macroinvertebrates and fish (Plate 5.5). The marginal vegetation at the site was sparse and provided a limited habitat for fish and macroinvertebrates. The river channel was noticeably cut-down and the banks were eroded. Flow regulation has a major impact at this site and different flow levels were encountered during the surveys. During the 2007 survey virtually no flow was observed at this site, and various habitat types were isolated and dry.

TABLE 5.26: SASS5 TAXA WITH A HIGH EXPECTANCY OF OCCURRENCE IN THE CENTRAL HIGHLANDS ECOREGION AND TAXA COLLECTED AT SITE 1 DURING THE REVIEW PERIOD

FAMILY	TAXON	Sc	2005				2006				2007			
			S	V	G	TOT	S	V	G	TOT	S	V	G	TOT
TURBELLARIA	Planarians	3						A		A				
ANNELIDA	Oligochaeta	1			A	A	A			A				
CRUSTACEA	Potamonautidae*	3	A			A	A	A		A	A			A
	Atyidae	8						A		A		A		A
HYDRACARINA	Water mites	8		A		A		A		A			A	A
PLECOPTERA	Perlidae	12												
EPHEMEROPTERA	Baetidae 1sp	4												
	Baetidae 2 sp	6												
	Baetidae > 2 sp	12	B	B	A	C	A			A	B	B	A	C
	Caenidae	6	A		A	B	A	C	B	C	A	A	A	B
	Heptageniidae	13										A		A
	Leptophlebiidae	9	A			A					A			A
	Tricorythidae	9	A			A	B	1	A	B	B		A	B
ODONATA	Chlorocyphidae	10												
	Chlorolestidae	8												
	Coenagrionidae	4		A		A		A		A		B	A	B
	Lestidae	8												
	Aeshnidae	8					A	A		A	A		A	B
	Corduliidae	8												
	Gomphidae	6	A		A	A	A		B	B	A	A	B	B
	Libellulidae	4	A			A			A	A	A	A		B
HEMIPTERA	Belostomatidae*	3		A		A		A		A		A		A
	Corixidae*	3	A	A		B		C	B	C	A		B	B
	Gerridae*	5		A		A		A		A		A		A
	Naucoridae*	7		A		A						A		A
	Nepidae*	3		B		B								
	Notonectidae*	3	A	B		B		A		A		A	A	A
	Pleidae*	4		A	A	B								
	Veliidae/M...veliidae*	5		A	A	B		A	A	B		A		A
TRICHOPTERA	Hydropsychidae 1 sp	4												
	Hydropsychidae 2 sp	6												
	Hydropsychidae 2 sp	12					B			B	B		B	C
	Philopotamidae	10	A			A								
Cased caddis:	Leptoceridae	6		A		A	A			A				
COLEOPTERA	Dytiscidae*	5		A		A		C	C	C		A		A
	Elmidae/Dryopidae*	8	B			B						A	A	A
	Gyrinidae*	5		A		A	A	A		B		A	A	A
	Hydrophilidae*	5		A		A		A	A	A		A	A	A
	Psephenidae	10												
DIPTERA	Athericidae	10												
	Ceratopogonidae	5					A	A		B				
	Chironomidae	2	A			A	A	A		B	A	A		A
	Culicidae*	1	A			A								
	Dixidae*	10							A	A				
	Muscidae	1												
	Simuliidae	5					C		A	C	A	A	A	A
	Tabanidae	5	A			A								
	Tipulidae	5	A		A	B	A			A	A			A
GASTROPODA	Ancylidae	6	A			A	A			A	A			A
	Bulininae*	3												
	Lymnaeidae*	3												
	Physidae*	3												
	Planorbinae*	3												
	Corbiculidae	5												
PELECYPODA	Sphaeriidae	3												
	Unionidae	6												
	SASS SCORE		92	78	39	153	91	90	58	157	90	106	94	169
	NO. OF TAXA		16	15	7	29	15	18	10	28	14	18	14	27
	ASPT		5.8	5.2	5.6	5.3	6.1	5.0	5.8	5.6	6.4	5.9	6.7	6.3

KEY: Sc = Score
S = Stones in and out of current
V = Marginal vegetation
G = Gravel, sand and mud
TOT = Total



PLATE 5.5: Monitoring Site 2, indicating well developed riffles and runs with some backwaters and pools.

(b) *In situ* water quality

Measurements of water quality variables at Site 2 were close to the expected, except for pH that was slightly higher than the expected reference condition (Kempster et al., 1980; Alabaster and Lloyd, 1982; Davies and Day, 1998; Dallas, 2000) (Table 5.27). The increase in pH values can be contributed to the increase in rates of photosynthesis in the dam and the consumption of CO₂ during the process. However, in the absence of sunlight, the biotic processes of respiration and decomposition release CO₂ that can decrease the pH.

TABLE 5.27: SELECTED WATER QUALITY VARIABLES MEASURED IN THE ASSEGAAI RIVER AT MONITORING SITE 2 DURING OCTOBER 2005, OCTOBER 2006 AND APRIL 2007.

VARIABLES	2005	2006	2007
pH	8.3	8.6	8
CONDUCTIVITY (µS/cm)	120	160	210
WATER TEMPERATURE (°C)	23	17	24
TURBIDITY (visual)	Cloudy	Slightly cloudy	Slightly cloudy
COLOUR (visual)	Grey	Grey	Grey

(c) Aquatic macro-invertebrate assemblages

A reasonable diversity of invertebrate fauna, dominated by Trichoptera (Caddis flies), Diptera (flies), Ephemeroptera (mayflies), Coleoptera (beetles) and Hemiptera (bugs),

was present at this site (Table 5.28). The abundance of the filter feeding Simuliidae (Diptera) and Hydropsychidae (Trichoptera) at this site can be related to the influence of increasing the surface of Heyshope Dam on the availability of abundant plankton as a food source. This could also be indicative of the grass carp activity recycling the nutrients by feeding on the macrophytes, increasing the abundance of plankton.

The low abundance of the Heptageniidae and absence of Psephenidae, highly likely to occur in the rivers in this Ecoregion (Dallas, 2007), suggest that the diversity of sensitive invertebrates in this river is slightly lower than expected. This assumption is also supported by the lower SASS value than expected for the Stones In and Out of Current biotope (S) (Table 5.28). The Present Ecological State of this site for the review period, according to the rule based MIRAI, can be classified as a Class C (moderately impaired with moderate diversity and fewer sensitive invertebrate taxa). This is largely supported by the delineation of the SASS and ASPT values according to Table 4.7.

5.1.5.2.3 Monitoring location – Site 3:

(a) Site description for Monitoring Site 3

This site was in the Poendaas River just upstream of Heyshope Dam (Figure 4.2) and could be described as a channelled wetland with some actively eroding and slumping banks (Plate 5.6). Bank erosion, loss of riparian zone and encroachment by exotic vegetation, such as poplar and black wattle, were the main factors affecting the availability of habitat for fish and invertebrates. From the 2005 survey until the survey of 2007 a drastic decline in habitat quality was observed.

This stream consisted of slack runs and small pools with sandy and/or clay substrate and well-developed marginal vegetation providing good habitats for fish and macroinvertebrates. Riffles and rocky habitat were largely absent in this stream (Plate 5.6).

(b) *In situ* water quality

Although the measurements of water quality variables at Site 3 were close to that expected (Kempster et al., 1980; Alabaster and Lloyd, 1982; Davies and Day, 1998; Dallas, 2000) (Table 5.29), the notable increase in the conductivity and pH may be indicative of increased nutrient inputs in the catchment.

TABLE 5.28: SASS5 TAXA WITH A HIGH EXPECTANCY OF OCCURRENCE IN THE CENTRAL HIGHLANDS ECOREGION AND TAXA COLLECTED AT SITE 2 DURING THE REVIEW PERIOD.

FAMILY	TAXON	2005					2006				2007			
		Sc	S	V	G	TOT	S	V	G	TOT	S	V	G	TOT
TURBELLARIA	Planarians	3					A			A	A			A
ANNELIDA	Oligochaeta	1			A	A	A		1	A				
CRUSTACEA	Potamonautidae*	3	A		A	A	A			A	A			A
	Atyidae	8		B		B		1		1	A	B	A	B
HYDRACARINA	Water mites	8		A		A								
PLECOPTERA	Perlidae	12												
EPHEMEROPTERA	Baetidae 1sp	4												
	Baetidae 2 sp	6												
	Baetidae > 2 sp	12	C	A	A	C	B	B	A	C	A	B	A	B
	Caenidae	6	C	A	A	C	A		A	B	A			A
	Heptageniidae	13	1			1					A	A	A	B
	Leptophlebiidae	9									A		A	A
	Tricorythidae	9					A			A	A		A	A
ODONATA	Chlorocyphidae	10												
	Chlorolestidae	8												
	Coenagrionidae	4		A	A	B						A		A
	Lestidae	8										A		A
	Aeshnidae	8									A	A	A	B
	Corduliidae	8												
	Gomphidae	6							A	A	A	A	A	B
	Libellulidae	4		A	A	B					A		A	A
HEMIPTERA	Belostomatidae*	3						A	A	B				
	Corixidae*	3		A	A	B							A	A
	Gerridae*	5		B		B						A		A
	Naucoridae*	7		A	A	A							A	A
	Nepidae*	3												
	Notonectidae*	3		A		A							A	A
	Pleidae*	4												
	Veliidae/M...veliidae*	5		B		B		A	A	B	A	A		A
TRICHOPTERA	Hydropsychidae 1 sp	4												
	Hydropsychidae 2 sp	6						A	A					
	Hydropsychidae 2 sp	12	C		A	C	C			C	C		B	C
	Philopotamidae	10												
Cased caddis:	Leptoceridae	6		B	A	B	A			A		A		A
COLEOPTERA	Dytiscidae*	5		A	A	B			A	A		A	A	A
	Elmidae/Dryopidae*	8		B	B	B		A		A	A	A		A
	Gyrinidae*	5		B		B	A	A	A	B		B		B
	Hydrophilidae*	5		1		1			A	A		A		A
	Psephenidae	10												
DIPTERA	Athericidae	10												
	Ceratopogonidae	5												
	Chironomidae	2		A	A	B	B	A	A	B	A	A	A	A
	Culicidae*	1										A		A
	Dixidae*	10												
	Muscidae	1			1	1	A		A	B	A	A		A
	Simuliidae	5	D	D	C	D	C	C	B	C	B		B	C
	Tabanidae	5	A		A	B	A			A	A			A
	Tipulidae	5	A			A	A			A				
GASTROPODA	Ancylidae	6	A	A		B	A			A	A			A
	Bulininae*	3												
	Lymnaeidae*	3												
	Physidae*	3												
	Planorbinae*	3												
	Corbiculidae	5	B		A	B	A			A	A		A	B
PELECYPODA	Sphaeriidae	3												
	Unionidae	6					1			1				
	SASS SCORE		72	107	89	152	92	54	62	132	130	102	114	182
	NO. OF TAXA		10	19	17	27	17	9	13	24	20	17	17	31
	ASPT		7.2	5.6	5.2	5.6	5.4	6.0	4.8	5.5	6.5	6.0	6.7	5.9

KEY:
 Sc = Score
 S = Stones in and out of current
 V = Marginal vegetation
 G = Gravel, sand and mud
 TOT = Total



PLATE 5.6: Monitoring Site 3, indicating well developed riffles and runs with some backwaters and pools.

TABLE 5.29: SELECTED WATER QUALITY VARIABLES MEASURED IN THE ASSEGAAI RIVER AT MONITORING SITE 3 DURING OCTOBER 2005, OCTOBER 2006 AND APRIL 2007.

VARIABLES	2005	2006	2007
pH	8	8.7	8
CONDUCTIVITY ($\mu\text{S}/\text{cm}$)	120	200	200
WATER TEMPERATURE ($^{\circ}\text{C}$)	20	19	19
TURBIDITY (visual)	Slightly cloudy	Cloudy	Clear to Slightly cloudy
COLOUR (visual)	Grey	Grey	Grey

(c) Aquatic macro-invertebrate assemblages

Monitoring Site 3 contained a reasonable diversity of macroinvertebrates during both the 2005 and 2006 surveys, despite the absence of the Stones In and Out of Current biotope (Table 5.30). As expected, the invertebrates were dominated by fewer flow-dependent taxa, such as the Diptera (flies), Hemiptera (bugs) and Coleoptera (beetles). The number of taxa recorded at this site for the 2005 and 2006 surveys were slightly lower than expected to occur in habitats characteristic of these types of rivers (Dallas, 2000). Table 5.29 suggests that there may be a loss of more sensitive taxa and an increase in the abundance of more tolerant taxa. This may be an indication of reasonably good water quality, with a deterioration of the habitat as a result of poor catchment management.

The Present Ecological State of this site for the 2005 and 2006 surveys, according to the rule based MIRAI, can be classified as low Class C (moderately impaired with moderate

diversity and fewer sensitive invertebrate taxa). This is largely supported by the delineation of the SASS and ASPT values presented in Table 4.7.

5.1.5.2.4 Monitoring location – Site 4:

(a) Site description for monitoring Site 4

The site just upstream of Heyshope Dam (Monitoring Site 4), used during the 2005 survey, was completely inundated during the 2006 survey and an upstream site (Site 4a) in the Ngulene River was selected as an alternative. As this site proved to be more suitable, it was re-used during the 2007 survey. The site consisted predominantly of slow-shallow and slow-deep habitats (Plate 5.7) with fast-shallow habitats connecting the slow habitat types.



PLATE 5.7: Monitoring Site 4, indicating well developed riffles and runs with some backwaters and pools.

(b) *In situ* water quality

Measurements of water quality variables were still close to expected for this ecoregion, except for pH, which may be indicative of increased photosynthesis in the stream (Kempster et al., 1980; Alabaster and Lloyd, 1982; Davies and Day, 1998; Dallas, 2000) (Table 5.31).

TABLE 5.30: SASS5 TAXA WITH A HIGH EXPECTANCY OF OCCURRENCE IN THE CENTRAL HIGHLANDS ECOREGION AND TAXA COLLECTED AT SITE 3 DURING THE REVIEW PERIOD.

FAMILY	TAXON	2005					2006				2007			
		Sc	S	V	G	TOT	S	V	G	TOT	S	V	G	TOT
TURBELLARIA	Planarians	3						A		A				
ANNELIDA	Oligochaeta	1												
CRUSTACEA	Potamonautidae*	3	A			A		A		A	A	A	A	A
	Atyidae	8					A	A		A	A	A	A	A
HYDRACARINA	Water mites	8		B		B		A		A		A		A
PLECOPTERA	Perlidae	12												
EPHEMEROPTERA	Baetidae 1sp	4												
	Baetidae 2 sp	6												
	Baetidae > 2 sp	12	B	A	A	B	B	B	A	C	B	B	A	C
	Caenidae	6	A				A	A	A	B	A			A
	Heptageniidae	13		A			A			A				
	Leptophlebiidae	9	1			1								
	Tricorythidae	9					A	A		B				
ODONATA	Chlorocyphidae	10												
	Chlorolestidae	8												
	Coenagrionidae	4		A		A	A	B		B		B		B
	Lestidae	8												
	Aeshnidae	8												
	Corduliidae	8												
	Gomphidae	6	A		A	A	B		B	B	A			A
	Libellulidae	4		A		A		1		1	B	B	A	B
HEMIPTERA	Belostomatidae*	3		A		A		A		A		A		
	Corixidae*	3		A	B	B		A		A		A		
	Gerridae*	5		A		A		A		A		A		
	Naucoridae*	7		A		A								
	Nepidae*	3		A		A						A		
	Notonectidae*	3		A		A		A		A		A		
	Pleidae*	4		A		A						A		
	Veliidae	5		B		B	A	A		B		A		
TRICHOPTERA	Hydropsychidae 1 sp	4					A	A		A				
	Hydropsychidae 2 sp	6	A			A					A	A	A	B
	Hydropsychidae 2 sp	12												
	Philopotamidae	10												
Cased caddis:	Leptoceridae	6										A		A
COLEOPTERA	Dytiscidae*	5		A		A		A		A		A		A
	Elmidae/Dryopidae*	8		A		A					A	A		A
	Gyrinidae*	5		B		B	A	B		B				
	Hydrophilidae*	5						A		A		B		B
	Psephenidae	10												
DIPTERA	Athericidae	10												
	Ceratopogonidae	5		A		A		A		A				
	Chironomidae	2		A		A	A	A		A				
	Culicidae*	1		1		1						A		A
	Dixidae*	10										A		A
	Muscidae	1												
	Simuliidae	5	C	A	A	C	A			A				
	Tabanidae	5												
	Tipulidae	5												
GASTROPODA	Ancylidae	6									A			A
	Bulininae*	3												
	Lymnaeidae*	3												
	Physidae*	3												
	Planorbinae*	3		B		B								
	Corbiculidae	5												
PELECYPODA	Sphaeriidae	3												
	Unionidae	6												
	SASS SCORE		47	108	26	119	79	102	24	126	59	106	33	98
	NO. OF TAXA		7	21	4	24	12	20	3	23	9	20	5	16
	ASPT		6.7	5.1	6.5	5.0	6.6	5.1	8.0	5.5	6.6	5.3	6.6	6.1

KEY: Sc = Score
S = Stones in and out of current
V = Marginal vegetation
G = Gravel, sand and mud
TOT = Total

TABLE 5.31: SELECTED WATER QUALITY VARIABLES MEASURED IN THE ASSEGAAI RIVER AT MONITORING SITE 4 IN OCTOBER 2005, OCTOBER 2006 AND APRIL 2007.

VARIABLES	2005 Site 4	2006 Site 4a	2007 Site 4a
pH	8.3	8.9	8
CONDUCTIVITY ($\mu\text{S}/\text{cm}$)	300	140	130
WATER TEMPERATURE ($^{\circ}\text{C}$)	22	19	20
TURBIDITY (visual)	Cloudy	Cloudy	Cloudy
COLOUR (visual)	Grey	Grey	Grey

(c) Aquatic macro-invertebrate assemblages

A high to very high diversity of invertebrate fauna was present at this site, ranging from 23 (in 2005) to 32 taxa (2007; Table 5.32) and several sensitive taxa, such the Ephemeroptera (Mayflies) and Odonata (Damselflies), were present. The Present Ecological State for the total SASS score of this site can be classified as Class B (slightly modified for invertebrates) according to the expected and observed values indicated by Dallas (2000, 2007) for the Central Highlands Ecoregion.

5.1.5.2.5 Monitoring location – Site 5:

(a) Site description for monitoring Site 5

This site is directly below the Heyshope Dam wall and extends to the gauging weir approximately 500m downstream (Figure 4.2). The site consisted predominantly of a slow, deep habitat with lentic characteristics and a well-vegetated bank (Plate 5.8).



PLATE 5.8: Monitoring Site 5, indicating slow-moving, deep waters upstream of weir.

TABLE 5.32: SASS TAXA WITH A HIGH EXPECTANCY OF OCCURRENCE IN THE CENTRAL HIGHLANDS ECOREGION AND TAXA COLLECTED AT SITE 4 DURING THE REVIEW PERIOD.

FAMILY	TAXON	2005					2006				2007			
		Sc	S	V	G	TOT	S	V	G	TOT	S	V	G	TOT
TURBELLARIA	Planarians	3		A		A	A			A				
ANNELIDA	Oligochaeta	1												
CRUSTACEA	Potamonautidae*	3		A		A	A			A	A	A		A
	Atyidae	8	A	A		A		A		A		A		A
HYDRACARINA	Water mites	8		A		A						A		A
PLECOPTERA	Perlidae	12												
EPHEMEROPTERA	Baetidae 1sp	4						A						
	Baetidae 2 sp	6												
	Baetidae > 2 sp	12	B	B	A	C	A			B	B	B	A	C
	Caenidae	6	A	A	A	B	B	A	B	B	B		A	B
	Heptageniidae	13	A			A	A			A				
	Leptophlebiidae	9					B	A	B	C	B			B
	Tricorythidae	9	A	A		B	A			A	A			A
ODONATA	Chlorocyphidae	10												
	Chlorolestidae	8									A			A
	Coenagrionidae	4	A	B		B		A		A		A		A
	Lestidae	8						A		A		A		A
	Aeshnidae	8					A	A	A	B	B	B		B
	Corduliidae	8												
	Gomphidae	6	B		B	B	A	A	A	B	A		A	A
	Libellulidae	4		1		1		A		A	A	A	A	B
HEMIPTERA	Belostomatidae*	3		A		A		A				A		A
	Corixidae*	3		A		A	A	B	B	C	A	A	A	B
	Gerridae*	5		A		A		A		A		A		A
	Naucoridae*	7											B	B
	Nepidae*	3										A		A
	Notonectidae*	3		A		A		A	A	B		A	A	A
	Pleidae*	4										A	A	A
	Veliidae*	5	A	A		B	A	B	B	C		A	A	A
TRICHOPTERA	Hydropsychidae 1 sp	4	A	A		A	A	A		B			A	
	Hydropsychidae 2 sp	6												
	Hydropsychidae 2 sp	12									B			B
	Philopotamidae	10												
Cased caddis:	Leptoceridae	6										A		A
COLEOPTERA	Dytiscidae*	5		A		A	A	A		A	A	A	A	B
	Elmidae/Dryopidae*	8												
	Gyrinidae*	5	A	B		B	A	A		B	A	B		B
	Hydrophilidae*	5		A		A					A	A	A	B
	Psephenidae	10												
DIPTERA	Athericidae	10												
	Ceratopogonidae	5		A		A	B	A		B				
	Chironomidae	2	A	A		A	A			A	A	A	A	B
	Culicidae*	1						B		B	A			A
	Dixidae*	10						A		A				
	Muscidae	1									A			A
	Simuliidae	5	A			A	B	A		B	A			A
	Tabanidae	5												
	Tipulidae	5					A			A	A		A	A
GASTROPODA	Ancylidae	6									A			A
	Bulininae*	3												
	Lymnaeidae*	3												
	Physidae*	3												
	Planorbinae*	3												
	Corbiculidae	5												
PELECYPODA	Sphaeriidae	3												
	Unionidae	6												
	SASS SCORE		82	127	26	145	113	130	50	162	133	121	78	203
	NO. OF TAXA		12	20	3	23	18	21	7	26	20	20	14	32
	ASPT		6.8	6.4	8.7	6.3	6.3	6.2	7.1	6.2	6.7	6.1	5.6	6.3

KEY: Sc = Score
S = Stones in and out of current
V = Marginal vegetation
G = Gravel, sand and mud
TOT = Total

(b) *In situ* water quality

Measured water quality variables are listed in Table 5.33. The water quality of this monitoring site is representative of the in-lake water quality of the impoundment as it was only a few meters downstream of the Heyshope Dam dam wall. Thus higher EC values were recorded downstream of the dam than was recorded at the upstream macro-invertebrate and fish monitoring sites. Although the water column was slow-moving the water temperature did not differ significantly from the upstream monitoring locations.

TABLE 5.33: SELECTED WATER QUALITY VARIABLES MEASURED IN THE ASSEGAAI RIVER AT MONITORING SITE 5 IN OCTOBER 2005, OCTOBER 2006 AND APRIL 2007

VARIABLES	2005	2006	2007
pH	8.5	8.9	8.6
CONDUCTIVITY ($\mu\text{S}/\text{cm}$)	325	280	240
WATER TEMPERATURE ($^{\circ}\text{C}$)	23	21	20
TURBIDITY (visual)	Cloudy	Cloudy	Slightly cloudy
COLOUR (visual)	Grey	Grey	Grey

(c) Aquatic macro-invertebrate assemblages

Due to the lentic characteristics of this monitoring location, only fish monitoring was done at Site 5. A high concentration of filter feeding macro-invertebrate taxa was however, observed at this site which is an indication of abundant phytoplankton in the upstream impoundment.

5.1.5.2.6 Conclusions:

Conclusions from the macro-invertebrate surveys conducted in the tributaries of Heyshope Dam during October 2005, October 2006 and April 2007:

- Lower SASS scores than expected for this ecoregion were calculated in the tributaries of Heyshope Dam.
- The Present Ecological State of the tributaries for the review period, according to the rule based MIRAI, can be classified as Class C (moderately impaired with a moderate diversity and few sensitive invertebrate taxa) to Class B (slightly modified for invertebrates).
- The diversity of sensitive and flow-dependent invertebrate taxa, collected during the review period at all sites, was slightly below the expected. Although the marginal vegetation was in a poor state, a high diversity, but low abundance of taxa dependent on this biotope, was still present in most of the sites.

- The extreme abundance of filter feeding taxa downstream from the Heyshope Dam is an indication of abundant plankton in the water flowing out of the dam. This may be an indication that the reduction in macrophytes by grass carp may be increasing the abundance of phytoplankton in the impoundment. However, reservoirs are known to increase the compensation depth (depth of water where photosynthesis can occur), thereby increasing the abundance of algae.

5.1.6 Fish community:

5.1.6.1 Fish species composition in Heyshope Dam

5.1.6.1.1 Fish assemblage prior to grass carp stocking in 2000:

(a) Fish assemblage:

Three indigenous fish species, Bushveld Smallscale Yellowfish (*Labeobarbus polylepis* Boul.), Southern Mouthbrooder (*Pseudocrenilabrus philander* Weber) and Banded Tilapia (*Tilapia sparrmanii* Smith), and two exotic fish species, Carp (*Cyprinus carpio* L.) and Largemouth Bass (*Micropterus salmoides* Lac.), were sampled at the selected sites in the Heyshope Dam during the 2000 survey, prior to the implementation of the grass carp stocking programme. A total of 256 individuals were collected using selected sampling techniques (Table 5.34).

A total of 146 *Labeobarbus polylepis* were sampled, occurring at all sampling sites in the impoundment. A total of 14 *Tilapia sparrmanii* were sampled, being present only at sites HH1 and HH2. Only four *Pseudocrenilabrus philander* individuals were sampled, occurring only at site HH1. This more sensitive species is distributed from the Orange River and southern KwaZulu-Natal northwards throughout the area. It occurs in a wide range of habitats, from flowing water to lakes and isolated potholes. They usually prefer vegetated areas. *P. philander* feeds on insects, shrimps and even small fish. They breed from early spring to late summer (Skelton, 1993).

Cyprinus carpio were relatively common, amounting to 55 individuals at all the sites surveyed. It is a hardy species, tolerating a wide range of conditions and it usually prefers large water areas with slow-flowing or stagnant water and a soft, muddy bottom. They are omnivorous, breeding in spring and summer (Skelton, 1993).

TABLE 5.34: NUMBER OF INDIVIDUALS OF DIFFERENT FISH SPECIES SAMPLED PRIOR TO THE INTRODUCTION OF GRASS CARP (2000) AT DIFFERENT LOCALITIES IN HEYSHOPE DAM.

SPECIES	COMMON NAME	LOCALITY				TOTAL
		HH 1 (Dam wall)	HH 2 (Assegaa)	HH 3 (Driefontein)	HH 4 (Roodekraal)	
<i>Labeobarbus polylepis</i>	Smallscale yellowfish	56	14	49	27	146
<i>Tilapia sparrmanii</i>	Banded tilapia	10	4	-	3	17
<i>Pseudocrenilabrus philander</i>	Southern mouthbrooder	4	-	-	3	7
<i>Cyprinus carpio</i>	Common carp	4	28	3	20	55
<i>Micropterus salmoides</i>	Largemouth bass	10	16	3	2	31
TOTAL		84	62	55	55	256

Thirty-one *Micropterus salmoides* individuals, which were present at all the sites investigated, were sampled. This species is widely distributed throughout the Eastern and Western Cape coastal drainages, KwaZulu-Natal midlands and Transvaal-Mpumalanga areas. This species favours clear, standing or slow-flowing waters with submerged or floating vegetation and does well in farm dams. *M. salmoides* can tolerate temperatures from below 10°C to as high as 32°C. It is primarily piscivorous, but will take virtually any food encountered. Young largemouth bass feed mostly on insects and fish from 50mm size. They breed in spring once water temperatures reach about 18°C (Skelton, 1993).

The observed fish species diversity of the Heyshope Dam was very low, as only three indigenous species were observed. According to the Heyshope Dam angling club and local residents, two eel species are also often encountered by anglers. It is expected that it may be the Longvin eel (*Anguilla mossambica*) and the African mottle eel (*Anguilla bengalensis labiata*). No eels were captured during this survey, probably as a result of the sampling techniques used. They are usually caught by anglers using bait, not in nets and very rarely by electro-fishing. No small barbs (ghieliemientjies) were observed during the survey. This is a matter of concern and can be attributed to the impact of the predatory largemouth bass in the dam. Their presence is also responsible for the low number of southern mouthbrooders and Banded tilapia observed.

It was expected that eradication of SAV by the implementation of an IAVMP would cause changes in the fish community of a system. This is primarily attributed to reduced cover, as well as feeding and breeding habitats. Colle and Shireman (1994) observed a decline in populations of some fish species and an increase in others, after the elimination of submersed vegetation by grass carp in two Florida Lakes in United States of America. In most cases, such as with largemouth bass, the effect of dense vegetation is generally more negative than

with scarce aquatic vegetation. Dense growth of aquatic vegetation reduces foraging efficiency, can result in lower standing crop and even reduces the condition of fish. High levels of aquatic vegetation generally result in higher recruitment of largemouth bass (Mallison et al., 1994). Largemouth bass biomass and numbers collected by electro-fishing in Lake Yale, declined with decrease in aquatic vegetation coverage (Mallison et al., 1994). In some cases, the introduction of grass carp into systems had minimal effects on the fish populations (Wrenn et al, 1994).

(b) Relative abundance:

Labeobarbus polylepis was the most abundant fish species captured in the impoundment (Table 5.35). This species was only sampled with gillnetting, probably due to it frequenting deeper water (where this technique was applied). The scarcest species sampled in the lentic waters of the Heyshope Dam was *Pseudocrenilabrus philander*. As previously mentioned, it can be expected that the composition of the fish community will change due to the introduction of an IAVMP, especially with grass carp as the biological control component. These baseline values (Table 5.34), calculated for the present conditions, will be of cardinal importance to detect any changes in the relative abundance of the fish species in future.

(c) Condition factors and general health:

Condition factors calculated were all above the value of 1 (Table 5.36). It can therefore be deduced that the fish were in a healthy condition. In a previous study, it was noted that dense growth of aquatic vegetation reduces foraging efficiency in some fish species, which resulted in reduced condition of the fish (Mallison et al., 1994). The condition factors calculated were used to monitor any changes in fish condition after the introduction of grass carp into the system.

TABLE 5.35: CATCH PER UNIT EFFORT (CPUE) VALUES CALCULATED FOR THE DIFFERENT SAMPLING TECHNIQUES USED DURING THE 2000 FISH SURVEY.

SPECIES	LOCALITY									
	HH1		HH2		HH3		HH4		DAM	
	BS	GN	BS	GN	BS	GN	BS	GN	BS	GN
<i>Labeobarbus polylepis</i>	0	1.87	0	0.58	0	2.04	0	1.13	0	1.40
<i>Tilapia sparrmanii</i>	0.33	0	0	0.2	0	0	0.1	0	0.08	0.05
<i>Pseudocrenilabrus philander</i>	0.13	0	0	0	0	0	0.1	0	0.05	0
<i>Cyprinus carpio</i>	0	0.16	0.05	0.95	0.13	0.04	1	0.83	0.06	0.5
<i>Micropterus salmoides</i>	0.33	0	0.3	0.2	0.13	0.04	0.8	0.08	0.37	0.08

KEY: BS – Electro-narcosis by boat (number of individuals per minute)
GN – Gillnetting (number of individuals per hour)

Based on external examination of all individuals caught, the fish were observed to be generally healthy. Even in a fish population living under unperturbed conditions, a small percentage of

individuals can be expected to be infested with parasites or to exhibit some anomalies (Kleynhans, 1997). Under such conditions, the expected percentage individuals with anomalies are assumed to be less than 2%. The only species found with any external anomalies was *L. polylepis* (Table 5.36). The high percentage of external anomalies observed can be of concern. Anomalies included skin necrosis and very commonly a blind or damaged eye. These anomalies can most probably be attributed to damage by angling hooks or by the predatory largemouth bass.

(d) Sensitive species in catchment:

No Red Data fish species were recorded during the field survey. However, according to Engelbrecht (personal comm., 2000), there are three fish species of concern in the Assegai River catchment. These are *Chiloglanis emarginatus* (Phongolo suckermouth), which is considered as rare, *C. anoterus* (pennant-tailed suckermouth), which is endemic, and *Varicorhinus nelspruitensis* (Inkomati chiselmouth), also endemic. Of the above-mentioned three species, *Chiloglanis emarginatus* is listed as a rare species (Group 3) in the South African Red Data Book – Fishes (Skelton, 1987). The conservation categories used in the classification of the importance of species, are listed in Table 5.37.

TABLE 5.36: CONDITION FACTORS AND PERCENTAGE OF INDIVIDUALS WITH EXTERNAL ANOMALIES CALCULATED FOR THE DIFFERENT SPECIES SAMPLED IN THE HEYSHOPE DAM (VALUES IN PARENTHESIS WERE CALCULATED FOR BETWEEN 10 AND 20 INDIVIDUALS, AND CAN THEREFORE BE EXPECTED TO BE LESS ACCURATE, THE REST ARE ALL BASED ON SAMPLES OF MORE THAN 20 INDIVIDUALS).

SPECIES	LOCALITY							
	HH1		HH2		HH3		HH4	
	CF	% Ext. Anom.	CF	% Ext. Anom.	CF	% Ext. Anom.	CF	% Ext. Anom.
<i>Labeobarbus polylepis</i>	1.14	11	(1.03)	7	1.13	2	1.09	7
<i>Cyprinus carpio</i>	(1.01)	0	1.68	0	-	0	1.23	0
<i>Micropterus salmoides</i>	-	0	(1.83)	0	-	0	1.3	0

KEY: CF – Condition factor
% Ext. Anom. - % individuals with external anomalies.

According to the Red Data List, *C. emarginatus* is known in South Africa from the Komati tributary of the Incomati River System and tributaries of the Pongola River System. Beyond the borders of South Africa, *C. emarginatus* occurs in Swaziland (Pongola and Umbeluzi River Systems), and Zimbabwe in the Pungwe and Zambezi River Systems.

Skelton (1993) described the preferred habitat of *C. emarginatus* as shallow, rocky river stretches (flats, stickles and runs) of clear rivers. It feeds on invertebrates, such as mayfly nymphs and caddis fly, black fly or midge larvae grazed from rocks. As *Ctenopharyngodon idella* is an herbivorous fish, it will not directly compete with *C. emarginatus* for survival, but may disturb substrate, which sustain its food source. The tributaries of Heyshope Dam were not monitored in 2000 and therefore none of the above-mentioned species were sampled.

TABLE 5.37: DESCRIPTION OF THREATENED CATEGORIES FOR FISH SPECIES IN SOUTH AFRICA (SKELTON, 1987).

NR	CONSERVATION CATEGORY	DESCRIPTION
I	ENDANGERED	Species in danger of extinction and whose survival is unlikely if the causal factors continue operating.
II	VULNERABLE	Species believed likely to move into the endangered category in the near future if causal factors continue operating.
III	RARE	Species with small or restricted populations, which are not, at present endangered or vulnerable, but which are at risk.
IV	SAFE	Species formerly included in one of the threatened categories and which are now considered to be relatively secure because effective conservation measures have been taken, or the previous threat to their survival has been removed, or new information is available to show that the species is not threatened.
V	INTERMEDIATE	Species that are suspected of being threatened but for which insufficient information is currently available.

5.1.6.1.2 Fish assemblage after grass carp stocking in year 2007:

Three indigenous fish species (*Labeobarbus polylepis*, *Clarias gariepinus*, and *Tilapia sparrmanii*), and three exotic species (*Cyprinus carpio*, *Micropterus salmoides* and *Gambusia affinis*) were sampled at the selected sites in the Heyshope Dam during the 2007 survey.

The only notable change in the fish community since the inception of the study was the disappearance of *Pseudocrenilabrus philander*. The fact that none were sampled during the last survey does not imply that this species disappeared completely from the Heyshope Dam, but certainly suggests that it is not doing well within the impoundment at the time of the survey. The following factors (or combination thereof) could be responsible for this phenomenon:

- Reduced habitat was available for this species due to eradication of aquatic vegetation. The Heyshope Dam is, however, not the only habitat of choice for *Pseudocrenilabrus philander* and this factor is therefore unlikely.
- The more likely cause is thought to be predation and competition by exotic piscivore species. Largemouth bass are possibly the main reason for the absence of *P. philander* as it is an aggressive predator which could easily prey on a species such as *P. philander*, which is not adapted to co-exist with predators. In addition, *Gambusia affinis* is known to occur within similar biotopes and may well be out-competing *P. philander*. A third exotic species, namely *Cyprinus carpio*, could possibly be contributing to habitat destruction of this indigenous species.

5.1.6.1.3 Relative abundance of fish species in Heyshope Dam:

The smallscale yellowfish (*Labeobarbus polylepis*) was found to be the most abundant fish species throughout the study period (2000-2007). Based on the four surveys completed up to date, it appears that the exotic species, *Gambusia affinis*, could become more abundant on a linear regression timescale.

The Heyshope Dam has limited conservation value from a biological integrity point of view. This is because it is an unnatural impounded ecosystem. However, it has the potential to be of economic value in terms of the abundance of the smallscale yellowfish (*Labeobarbus polylepis*), as this species is an important angling species and could be an important food source. For this reason, the smallscale yellowfish should be seen as the most important fish species in the Heyshope Dam. It is therefore encouraging that this species appears to become more abundant on a linear regression timescale and during 2007 there was no evidence that the introduced sterile grass carp had any negative impact on their numbers.

The study was conducted over a period of several years and indicated a slightly decreased/lowered aquatic biodiversity (macroinvertebrates and fish) over time. This is however, not of any conservation concern as the impoundment is regarded as an unnatural ecosystem. The presence of Smallscale Yellowfish should be seen as the most important biological component of the Heyshope Dam and this species has in fact done very well and actually increased in abundance since the introduction of the exotic sterile grass carp as biocontrol-agent for the control of SAV.

5.1.6.1.4 General health and condition factors of fish in Heyshope Dam:

During the study period, the condition factors for *Labeobarbus polylepis* ranged from 1.00 to 1.14, indicating a good physiological condition (above 1). There was no conclusive trend in improvement or deterioration in condition observed between the four surveys conducted and it is therefore evident that fish health was not reduced on a temporal scale. It must be kept in mind that the SAV in Heyshope Dam was reduced from 700ha in 2000, to 375ha in 2006, to 69ha in 2008 (1 year after the final fish surveys of 2007) to around 1ha in 2010. This eradication of submersed macrophytes may have had a significant impact on the fish community, which can only be established with follow-up surveys.

5.1.6.2 Fish species composition in the tributaries of Heyshope Dam

- NOTE:** (1) For a more detailed description of the habitat at each monitoring location, refer to section 5.1.6.1 where it is characterised with the discussion of the macro-invertebrate assemblages of each site.
- (2) There was no monitoring of the tributaries prior to the implementation of the IAVMP and the stocking of grass carp. Monitoring of the tributaries was therefore done after grass carp introduction into the impoundment (hence from 2006-2008).

5.1.6.2.1 Monitoring location – Site 1:

Monitoring site 1 was characterised by riffles and runs with some smaller pools and backwaters providing good habitat for fish (Plate 5.1) and it is located in the Assegaa River just upstream of Heyshope Dam (Figure 4.2).

Twelve fish species were expected to occur at this site in its natural state (reference condition) of which only five were collected during the 2007 survey (Table 5.38). Species preferring fast, shallow habitats (*Chiloglanis anoterus* and *Amphilius uranoscopus*) were abundant during these surveys, but species dependent on substrate (rocks) in fast, deep habitats (*Barbus argenteus*, *Chiloglanis emarginatus* and *Varichorhinus nelspruitensis*) were largely absent from this sampling site. During the 2006 survey, two individuals of the threatened *Chiloglanis emarginatus* were collected at this site, confirming its presence in the area, however, during the 2007 survey this species was not sampled. During the 2007 survey, *Barbus eutaenia* was collected for the first time at this site. This flow-dependent species is dependent on a habitat with permanent flow during all its life phases (rheophilic). This species' presence indicates a

large, natural flow regime at this site. This species often occurs in small tributaries which can act as refuge for this species during unfavourable habitat conditions.

The low abundance of *Barbus anoplus* and absence of *Pseudocrenilabrus philander* and *Tilapia sparrmanii* at this site could possibly be contributed towards the lack of marginal vegetated areas with undercut banks in slow flowing habitats. The presence of large impoundments, creating an obstruction to migration, in downstream areas may be responsible for the absence or low abundance of migratory species, such as the catadromous *Anguilla mossambica* (migrates to sea for breeding) and *Labeobarbus polylepis*.

TABLE 5.38 FISH SPECIES EXPECTED AND OBSERVED AT SITE 1 IN THE ASSEGAAI RIVER UPSTREAM OF HEYSHOPE DAM DURING THE REVIEW PERIOD.

FISH SPECIES	2005				2006				2007			
	Obs	Juvenile	Sub-Adults	Adults	Obs	Juvenile	Sub-Adults	Adults	Obs	Juvenile	Sub-Adults	Adults
ANGUILLIDAE												
<i>Anguilla mossambica</i>												
AMPHILIIDAE												
<i>Amphilius uranoscopus</i>	25		X	X	34		X	X	71		X	X
CYPRINIDAE												
<i>Barbus anoplus</i>	2			X	7			X	2			X
<i>Barbus argenteus</i>												
<i>Barbus cf. brevipinnis</i>												
<i>Barbus eutaenia</i>									10		X	X
<i>Labeobarbus marequensis</i>												
<i>LabeoLabeobarbus polylepis</i>	17		X		19		X	X	98		X	X
<i>Varichorhinus nelspruitensis</i>												
MOCHOKIDAE												
<i>Chiloglanis anoterus</i>	93		X	X	146		X	X	100		X	X
<i>Chiloglanis emarginatus</i>					2			X				
CICHLIDAE												
<i>Pseudocrenilabrus philander</i>												
<i>Tilapia sparrmanii</i>												
POECILIIDAE												
<i>Gambusia affinis</i> *												
Number of species	4				5				5			
Number of individuals	137				208				281			
CPU Electro-shocking	2.654				3.107				4.76			
CPU Seine net	0				12.5				19			

KEY: Obs. = Observed
CPU = Catch per Unit

The results of the three surveys during the review period suggest that there may have been a small increase in the abundance of species preferring fast, shallow habitats such as *C. anoterus* and *A. uranoscopus*. Similarly, the presence of large numbers (n=98) of sub-adults and adults of *Labeobarbus polylepis* indicates an increase in the population compared to the 2005/2006 results, reflecting recent successful breeding. This increase is also reflected in the increase in the CPUE for electro-shocking (2.7 to 3.1 to 4.7) and the increase in the CPUE for seine netting from 0 to 12.5 to 19. This indicates that, although there was still a relatively good abundance of fish in the stream, the abundance of fish in Slow Deep and Slow Shallow habitats was extremely low due to the absence of marginal vegetation. According to the rule-based Fish Response Assessment index

(FRAI) the present ecological class of this site remained a high Class B/C (moderately impaired for fish) during the review period.

5.1.6.2.2 Monitoring location – Site 2:

This site was in the Assegaai River, just downstream of Heyshope Dam (Figure 4.2). The riffles and runs were relatively well developed at the site. And it also contained some smaller pools and backwaters providing some habitat that could be sampled for fish (Plate 5.5).

Based on the available information, 11 fish species were expected to occur at this site, of which six species were collected during the 2007 survey (Table 5.39). The results of the surveys during the review period suggest that most fish fauna dependent on substrate (rock) in fast, deep and fast, shallow habitats (*Amphilius uranoscopus*, *Chiloglanis emarginatus*, *Barbus argenteus* and *Varichorhinus nelspruitensis*) were absent from this site. Although these species have not previously been collected at the site, their known distribution for the area suggests that they should naturally occur at the site.

TABLE: 5.39 FISH SPECIES EXPECTED AND OBSERVED AT SITE 2 IN THE ASSEGAAI RIVER DOWNSTREAM OF HEYSHOPE DAM DURING THE REVIEW PERIOD.

FISH SPECIES	2005				2006				2007			
	Obs	Juvenile	Sub-Adults	Adults	Obs	Juvenile	Sub-Adults	Adults	Obs	Juvenile	Sub-Adults	Adults
ANGUILLIDAE												
<i>Anguilla mossambica</i>					1		X		1			X
AMPHILIIDAE												
<i>Amphilius uranoscopus</i>												
CYPRINIDAE												
<i>Barbus anoplus</i>												
<i>Barbus argenteus</i>												
<i>Barbus cf. brevipinnis</i>												
<i>Barbus eutaenia</i>												
<i>Labeobarbus marequensis</i>												
<i>Labeobarbus polylepis</i>					3		X		2		X	
<i>Varichorhinus nelspruitensis</i>												
MOCHOKIDAE												
<i>Chiloglanis anoterus</i>	10			X	31			X	82			X
<i>Chiloglanis emarginatus</i>												
CICHLIDAE												
<i>Pseudocrenilabrus philander</i>	41		X	X	9		X	X	14		X	X
<i>Tilapia sparrmanii</i>	30			X	6		X		21		X	X
POECILIIDAE												
<i>Gambusia affinis*</i>					2			X	1			X
Number of species	3				6				6			
Number of individuals	81				52				121			
CPU Electro-shocking	0.975				0.706				3.46			
CPU Seine net	9.75				2.25				5.6			

KEY: Obs. = Observed
CPU = Catch per Unit

During the 2006 survey *Chiloglanis emarginatus* was collected at Monitoring Site 1 (upstream in the Assegaai River) and it was also collected downstream of Heyshope Dam during 2007 biomonitoring surveys. The abundance of *Chiloglanis anoterus* and *Labeobarbus polylepis* was notably lower at this site, compared to Site 1. The absence

of *Barbus anoplus* and the very low abundance of *Tilapia sparrmanii* and *Pseudocrenilabrus philander* can largely be related to the lack of suitable habitats in marginal vegetated areas with undercut banks in slow-flowing habitats, as well as the fluctuating levels due to flow regulation of the dam.

Reduced and/or regulated flow at this site may largely be responsible for the absence of at least four of the expected flow-dependent species (*Amphilius uranoscopus*, *Barbus argenteus*, *Varichorhinus nelspruitensis* and *Chiloglanis emarginatus*). This assumption is supported by apparent decreases and increases in the abundance of fish, reflected by CPUE values of 0.975 (2005), 0.706 (2006) and 3.46 (2007) for electro-shocking and 9.75 (2005), 2.25 (2006) and 5.6 (2007) for seine netting at this site.

The absence or low abundance of *Anguilla mossambica* at the site could not be attributed to any significant impoundments downstream preventing the migration or re-colonisation of this catadromous species. However, the low abundance of local migratory species, such as *Labeobarbus polylepis*, may be indicative of smaller obstructions, such as weirs, impacting on breeding and recruitment migrations. Because this site is located a short distance below the Heyshope Dam, flow regulation and scouring may be some of the contributing factors affecting the abundance and diversity of fish at this site.

The presence of the exotic species *Gambusia affinis* at this site is concerning and most likely indicates the presence of a viable population of this species in the Heyshope Dam (although it was not sampled in the impoundment itself). However, the poorly developed marginal vegetation at this site will not be conducive to the proliferation of the species. According to the rule based FRAI the Present Ecological Class of this site for the review period is Class C (moderately impaired for fish).

5.1.6.2.3 Monitoring location – Site 3:

This site was in the Poendaas River, just upstream of Heyshope Dam (Figure 4.2) and could be described as a channelled wetland with actively eroding and slumping banks (Plate 5.6). Based on the available information, at least four species were expected to occur at this site. Only three of the four expected species (Table 5.40) were collected during the review period. Only two habitat types were present that could be sampled (slow, deep and slow, shallow). Electro-shocking could not be used at this site due to

loss of suitable habitat and therefore only small seine nets were used in slow habitats (slow, deep and slow, shallow).

Most species recorded at this site (*Tilapia sparrmanii*, *Pseudocrenilabrus philander* and *Barbus anoplus*) preferred slow-flowing habitats with undercut banks, root wads and marginal vegetated habitats. Although most of the expected fish species were present at the site, their abundance had declined drastically since 2005, as a result of a loss of available habitat. The results during the review period indicate a notable decrease in abundance of species (Table 5.40). This loss of abundance is reflected in the decrease of CPUE for small seine netting from 11.2 in 2005 to 7.1 in 2006 and to 2.25 during 2007.

TABLE 5.40: FISH SPECIES EXPECTED AND OBSERVED FOR SITE 3 IN THE POENDAAS RIVER UPSTREAM OF HEYSHOPE DAM DURING THE REVIEW PERIOD

FISH SPECIES	2005				2006				2007			
	Obs	Juvenile	Sub-Adults	Adults	Obs	Juvenile	Sub-Adults	Adults	Obs	Juvenile	Sub-Adults	Adults
ANGUILLIDAE												
<i>Anguilla mossambica</i>												
AMPHILIIDAE												
<i>Amphilius uranoscopus</i>												
CYPRINIDAE												
<i>Barbus anoplus</i>	5			X	2			X	1			X
<i>Barbus argenteus</i>												
<i>Barbus cf. brevipinnis</i>												
<i>Barbus eutaenia</i>												
<i>Labeobarbus marequensis</i>												
<i>Labeobarbus polylepis</i>	2		X									
<i>Varichorhinus nelspruitensis</i>												
MOCHOKIDAE												
<i>Chiloglanis anoterus</i>												
<i>Chiloglanis emarginatus</i>												
CICHLIDAE												
<i>Pseudocrenilabrus philander</i>	58		X	X	52		X	X	4		X	X
<i>Tilapia sparrmanii</i>	2			X	3		X		6		X	X
POECILIIDAE												
<i>Gambusia affinis</i> *												
Number of species	4				3				3			
Number of individuals	67				57				11			
CPU Electro-shocking	-				-				0.064			
CPU Seine net	11.2				7.125				2.25			

KEY: Obs. = Observed
CPU = Catch per Unit

The absence of *Labeobarbus polylepis* at this site can largely be attributed to the absence of fast flowing habitats and rocky substrates preferred by the species. The influence of weirs and a large impoundment on the local migration and recruitment of *Labeobarbus polylepis* may also contribute to their low abundance or absence. According to the rule based FRAI the Present Ecological Class of this site for 2005 and

2006 was Class B/C, but for the 2007 survey this site's rating was reduced to a lower Class C (moderately impaired for fish).

5.1.6.2.4 Monitoring location – Site 4:

This monitoring location, just upstream of Heyshope Dam (Site 4) used during the 2005 survey, was completely inundated during the 2006 survey and therefore an upstream site (Site 4a) in the Ngulane River was selected as an alternative (Figure 4.2). As this site proved to be a more suitable location, it was again monitored during the 2007 survey.

Based on the available information, at least six fish species were expected to occur at this site, of which five species were recorded (Table 5.41). During the 2006 survey the flow in the river was quite low and contained only Slow Deep and Slow Shallow habitats without any fast-flowing sections. This suggested that the Ngulane River may not be suitable to permanently support populations of flow-dependent species. However, in its natural state, it could have supported flow-dependent species and served as a nursery area during high rainfall years as similar rivers have been found to support large numbers of juvenile flow-dependent species.

During the 2007 survey, higher flows were experienced at this site, creating additional fast shallow riffles that connected the slow deep habitats. Due to the presence of the impoundment, this river is isolated from any larger streams that can support permanent populations of flow-dependent species and it can therefore no longer support juvenile life stage of flow-dependent fish species. This is further supported by results obtained during this survey where only one *Barbus argenteus* was collected for the first time at this site. This flow-dependent species is dependent on a habitat with permanent flow during all its life phases (rheophilic).

During the 2006 survey, the high abundance of *Barbus anoplus* and *Barbus brevipinnis* suggests that the Slow Deep category environments provided excellent habitats for these species. This assumption is supported by a relatively high CPUE of 32.3 for the small seine and 1.9 for electro-shocking. The 2007 survey indicated a slight decrease in abundance of species, but an increase in species diversity. During the 2007 survey, the CPUE for electro-shocking was 2.33 and the CPUE value for seine netting was 6.5. According to the recent International Union for Conservation of Nature (IUCN) evaluations (IUCN, 2022), the *Barbus cf. brevipinnis* may be threatened. According to

the rule based FRAI the Present Ecological Class of this site for the present survey remains Class B (slightly impaired for fish).

TABLE 5.41: FISH SPECIES EXPECTED AND OBSERVED FOR SITE 4 AND 4A IN THE NGULENE RIVER UPSTREAM OF HEYSHOPE DAM DURING THE REVIEW PERIOD

FISH SPECIES	2005 Location: 4				2006 Location: 4a				2007 Location: 4a			
	Obs	Juvenile	Sub-Adults	Adults	Obs	Juvenile	Sub-Adults	Adults	Obs	Juvenile	Sub-Adults	Adults
ANGUILLIDAE												
<i>Anguilla mossambica</i>												
AMPHILIIDAE												
<i>Amphilius uranoscopus</i>									15		X	X
CYPRINIDAE												
<i>Barbus anoplus</i>					193		X	X	57		X	X
<i>Barbus argenteus</i>									1			X
<i>Barbus cf. brevipinnis</i>												
<i>Barbus eutaenia</i>					22		X	X	8		X	X
<i>Labeobarbus marequensis</i>												
<i>Labeobarbus polylepis</i>												
<i>Varichorhinus nelspruitensis</i>												
MOCHOKIDAE												
<i>Chiloglanis anoterus</i>												
<i>Chiloglanis emarginatus</i>												
CICHLIDAE												
<i>Pseudocrenilabrus philander</i>	120		X	X	5			X	2		X	
<i>Tilapia sparrmanii</i>	39		X	X								
POECILIIDAE												
<i>Gambusia affinis</i> *												
Number of species	2				3				5			
Number of individuals	159				220				83			
CPU Electro-shocking	-				1.895				2.33			
CPU Seine net	54.71				32.25				6.5			

KEY: Obs. = Observed
CPU = Catch per Unit

5.1.6.2.5 Monitoring location – Site 5:

Monitoring Site 5 was located directly below the Heyshope Dam wall and extended to the gauging weir approximately 500m downstream of the dam wall structure (Figure 4.2). The site consisted predominantly of a slow, deep habitat with lentic characteristics and a well-vegetated bank (Plate 5.8).

TABLE 5.42: GILLNET CATCHES AS PER MESH SIZE FOR A 13 HOUR PERIOD (OVERNIGHT) IN THE ASSEGAAI RIVER BETWEEN THE HEYSHOPE DAM WALL AND THE OUTLET GAUGING WEIR DURING THE 2007 SURVEY.

GILLNET LENGTH	STRETCH MESH SIZE	SPECIES COLLECTED	NUMBERS
30m	70mm	<i>Labeobarbus polylepis</i>	37
		<i>Clarias garipinus</i>	4
30m	90mm	<i>Labeobarbus maraquensis</i>	2
		<i>Labeobarbus polylepis</i>	63
30m	110mm	<i>Labeobarbus polylepis</i>	28
		<i>Cyprinus carpio</i>	3

This habitat was surveyed with gill nets (stretch mesh size 70mm, 90mm and 110mm), since this is the most likely habitat in the river where large fish, such as grass carp, can

occur should they escape from the impoundment. During the 2006 survey, this effort was terminated when 48 ripe and running *Labeobarbus polylepis* were caught in the nets after only 6 minutes of netting. Gill netting is non-selective and fatal with a low survival rate for fish caught. This technique was therefore not further utilised at this location, as the species was in a spawning migration and continued efforts would have resulted in extensive mortalities. This site was surveyed during 2007 prior to the spawning season to minimise the impact of gill netting on *Labeobarbus polylepis*. During this survey, gillnets were set in this stretch of water for an overnight period totalling 13 hours. In total 128 *Labeobarbus polylepis*, 4 *Clarias garipinus*, 2 *Labeobarbus marequensis* and 3 *Cyprinus carpio* were caught (Table 5.42). No grass carp were collected or observed, indicating that this species did not escape downstream from the dam.

5.1.6.2.6 Conclusions:

Conclusions from the fish surveys conducted in the tributaries of Heyshope Dam during October 2005, October 2006 and April 2007:

- During the 2007 survey the species composition of fish collected in the Assegaaai River, compared to species expected in this catchment, indicates a notable loss of species diversity. Twelve fish species were expected in the Assegaaai River of which six were collected downstream of the Heyshope Dam, compared to the three and six species, respectively for the 2005 and 2006 surveys. Five of the expected twelve species were collected upstream of the impoundment, compared to the four species collected during 2005 and five species collected during 2006. However, the comparison of the expected and observed species, both downstream and upstream, indicates an increase in the abundance of species, as well as in species diversity from 2005 to 2007.
- A comparison of the different age classes collected, disclosed that all age classes expected were present in the form of sub-adults and adults. No juveniles were collected during 2006 because the breeding season had not yet commenced, whilst the 2007 survey coincided with a post breeding season.
- The absence or low abundance of *Chiloglanis emargenatus*, *Varichorhinus nelspruitensis* and *Barbus argenteus* can be related to habitat loss, or the possibility that the sampling sites were marginal to their distributional pattern. The absence or low abundance of *Barbus marequensis* can possibly be attributed to altitude (1,300m above sea level), as *B. marequensis* occurs mostly at lower altitudes, and only utilises these areas during spawning migrations.

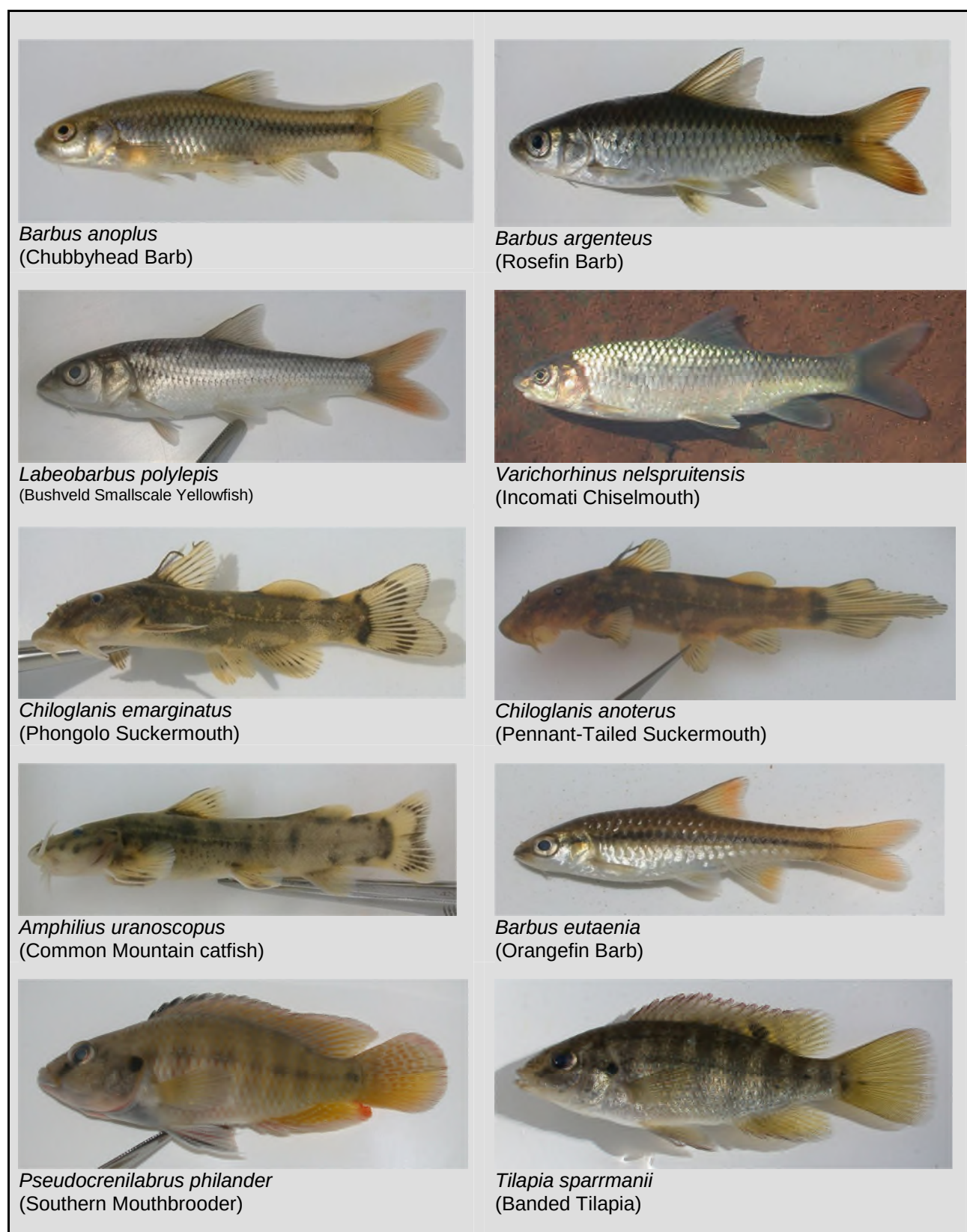


PLATE 5.9: Photographs of important fish species, from a conservation perspective, in the study area.

The low abundance of *Anguilla mossambica* is possibly related to the presence of obstructions downstream preventing re-colonisation of this catadromous (migrates to sea to breed) species.

- According to the FRAI the Present Ecological Class of both sites within the Assegaai River remained the same for the survey period (2005-2007), with the upstream site rating Class B/C and the downstream site Class C.
- During the 2005/2006 survey, the Ngulane and Poendaas rivers reflected no loss of species diversity. Results obtained from the 2007 survey, however, indicated a drastic decline in the abundance of species in the Poendaas River, whilst abundance in the Ngulane River remained stable. Further to this the different age classes in the Ngulane River were as expected, but for the Poendaas River a skewed age class representation was present.
- According to the FRAI, the Present Ecological Class for the Ngulane River remained the same for the survey period (2005-2007), with the Present Ecological Class rating of Class B. The Present Ecological Class according to the FRAI for the Poendaas River was however, reduced to a lower Class C, due to extreme degradation of the habitat type. This is further reflected in the comparison of fish species expected and observed in the Poendaas River.
- In the Assegaai River, the presence of dams or larger pools may create suitable habitat for *Ctenopharyngodon idella*. During the 2006 surveys gillnetting efforts had to be abandoned due to seasonal spawning migrations of species. Using gillnets during such breeding migrations and associated congregations of large numbers of fish can cause unnecessary mortalities in large numbers of these fish. This could have had long term effects.
- No grass carp, or evidence of their presence, were recorded in the tributaries during the survey periods (2005, 2006 and 2007). However, it cannot be concluded that they were absent in the Assegaai River and its tributaries. High flow periods in these rivers could provide the necessary stimuli and accessibility for grass carp to migrate into these rivers and obstructions to migration, such as weirs, can be negotiated in these high flow periods. Although the poor state and/or absence of marginal and in stream vegetation were notable and of some concern, the poor state can largely be attributed to poor catchment management. It is highly unlikely that significant numbers of grass carp are present in the rivers upstream and downstream of the Heyshope Dam.

5.1.7 Waterbirds:

It was anticipated that the IAVMP would influence the submersed aquatic vegetation (*Potamogeton schweinfurthii* and *Stuckenia pectinata*) in Heyshope Dam as scheduled. However, other non-target aquatic vegetation might have been affected similarly by the control methodologies, i.e., by grass carp on the longer term and to a lesser extent by herbicidal control (species-specific spot treatments with diquat) on the short term.

5.1.7.1 Description of water bird habitats in and around Heyshope Dam

In the identified habitats, the following assemblages of aquatic or wetland vegetation types were identified during the survey of 2005:

- Open, unvegetated banks
- Sedges
- Inundated sedges and hydrophilic grass
- Inundated hydrophilic grass
- Inundated rock ledges
- Inflowing streams to Heyshope Dam
- Inflowing stream to Ngulane wetland
- Ngulane wetland
- Open water areas
- Terrestrial and riparian vegetation

It was however, decided to simplify the habitat types for the 2006 and 2007 surveys to the following:

- Exposed bank with low herbaceous cover
- Marginal and inundated vegetation
 - Sedges and hydrophilic grass
 - *Persicaria-Ludwigia*
 - Reeds
- Inflowing streams to Heyshope Dam
- Ngulane wetland
- Rock ledge with tree cover
- Open water (with or without floating or submerged aquatic vegetation)

These biotopes are formed by vegetation assemblages and are important habitats for most of the aquatic birds and their food sources (frogs, fish, aquatic insects,

crustaceans, and molluscs), while the vegetation itself also serves as food for a number of birds.

It can be expected that certain waterfowl habitats formed by vegetation will be influenced by a significant decrease in SAV biomass. Due to continuous fluctuation in dam levels, the marginal habitats will recover adequately, should the control agents influence them in any way. It is the floating and inundated aquatic vegetation in the open water areas that will be influenced most by the biocontrol component control program. These are also the SAV targeted by the IAVMP to be controlled, i.e., the IAVMP target species.

During the 2007 survey, an estimation was made of the proportion of biotope covering the banks of the dam in the study area (Table 5.43). This breakdown of habitats did not include the open water habitat, which comprised more than 90% of all wetland habitats.

TABLE 5.43: WATER BIRD HABITAT TYPES ALONG THE LITTORAL ZONE OF THE HEYSHOPE DAM, EXPRESSED AS A PERCENTAGE OF COVERAGE OF THE PERIPHERY OF THE IMPOUNDMENT.

Habitat	Proportion
• Exposed bank with low herbaceous cover	55%
• Marginal and inundated vegetation	40%
➤ Sedges and hydrophilic grass	1.6%
➤ <i>Persicaria</i>	0.4%
➤ Reeds beds	
• Rock ledge with tree cover	< 0.3%

5.1.7.2 Categories of wetland vegetation

To establish the importance of the different vegetation zones in the Heyshope Dam system for utilising by wetland birds, the zoning of the dam can be described as follows (Wetzel, 1983):

The zone adjacent to the terrestrial area is called the epilittoral zone. This zone lies above the full level of the dam, created by shallow groundwater levels, and will not be directly influenced by open water activities. The supralittoral zone also lies above the water level and is influenced by spray, but not by open water activities. The eulittoral zone encompasses the shoreline region between the highest and lowest seasonal water levels. The shallower parts of the waterbody, below the lowest water level, are called

the infralittoral zone. The infralittoral zone is subdivided into 3 sub-zones in relation to the distribution of macrophytic vegetation: Upper infralittoral zone (emergent, rooted vegetation); Middle infralittoral zone (floating-leaved, rooted vegetation) and the Lower infralittoral zone (submersed, rooted vegetation). The eulittoral and the infralittoral zones collectively form the littoral zone. Plankton is found in the open water and consists of suspended phyto- and zooplankton.

5.1.7.3 Wetland biotopes utilised by birds

5.1.7.3.1 *Exposed banks with low herbaceous cover:*

This habitat is mostly open with very little marginal vegetation, apart from short grass cover on the land (Plate 5.10). This biotope covers 55% of the shoreline of the Heyshope Dam.



PLATE 5.10: Typical eroded and intact open bank biotopes of Heyshope Dam.

5.1.7.3.2 *Marginal and inundated vegetation:*

(a) Sedges and hydrophilic grass biotope

This combination biotope consists of sedges and hydrophilic grass on the banks of the impoundment and inundated sedges and hydrophilic grass in the shallow water of the waterbody's periphery (Plate 5.11). This biotope covers 40% of the 120km shoreline of the Heyshope Dam and includes species such as *Cyperus denudatus* L.f.,



PLATE 5.11: Inundated sedges and hydrophilic grass biotope in the shallow water on the periphery of Heyshope Dam.



PLATE 5.12: The *Persicaria-Ludwigia* biotope consists mainly of inundated rooted plants in shallow backwaters of Heyshope Dam.

C. sextangularis Nees and *Schoenoplectus brachyceras* (Hochst. Ex A. Rich.) Lye (Table 5.18 and Figures 5.2 – 5.7).

(b) *Persicaria-Ludwigia* biotope

The *Persicaria-Ludwigia* biotope consists mainly of inundated rooted plants in shallow backwaters of the littoral zone (Plate 5.12). About 1.6% of the 120km long shoreline of Heyshope Dam is covered by *Persicaria amphibia* (L.) Gray, *P. decipiens* (R. Brown) K.L. Wilson, *P. lapathifolia* (L.) Gray and *Ludwigia adscendens* (L.) H. Hara (Table 5.18 and Figures 5.2 – 5.7).



PLATE 5.13: The reed bed biotope of Heyshope Dam.

(c) Reed bed biotope

Reeds are not common along the shores of the Heyshope Dam. Reed beds are mostly found near river inflows into the Heyshope Dam (Plate 5.13) (Table 5.18 and Figures 5.2 – 5.7).

5.1.7.3.3 Tributaries to Heyshope Dam:

A number of rivers flow into the Heyshope Dam, the most important ones being the Assegaai (largest), Poendaas, eGude, and Ngulane rivers. Where the rivers become inundated by the dammed water, viable habitats are created for birds (Plate 5.14). Upstream in these rivers, flow creates biotopes utilised by different riparian and riverine birds.

5.1.7.3.4 Ngulane wetland:

This biotype comprises a small stream, the Ngulane River, flowing into the Ngulane wetland and a shallow, grass-inundated wetland where the impoundment extends into the floodplain of the stream (Plate 5.15). The Ngulane wetland is separated from the large impoundment by a low water bridge equipped with metal grids to prevent the grass carp from entering the wetland.



PLATE 5.14 Inundated marshlands at river inflows into the impoundment.

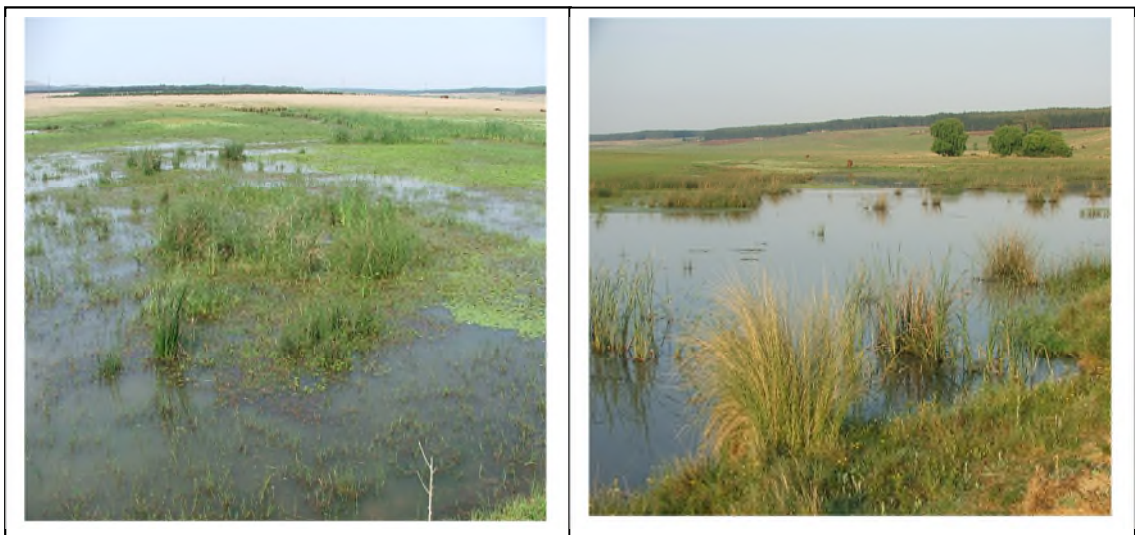


PLATE 5.15 The shallow, Ngulane wetland biotope with inundated vegetation.

5.1.7.3.5 *Rock ledges with tree cover:*

This habitat is on a limited stretch (30m) of the bank of the dam. The hollows in the bedrock render this habitat very favourable as nesting sites for birds (Plate 5.16).



PLATE 5.16 Rock ledges with tree cover biotope.



PLATE 5.17 Spur-winged geese (*Plectropterus gambensis*) on the open water biotope.

5.1.7.3.6 Open water biotope:

Birds on the open water surface or diving into deeper water, utilise this biotope mostly for feeding and resting (Plate 5.17). The SAV patches in the impoundment are utilised for food by some birds.

5.1.7.4 Birds of Heyshope Dam

The bird assemblages considered in this study are wetland birds utilising the waterbody and associated aquatic and semi-aquatic resources. Their presence is influenced by changes to the system. Changes in SAV will have an influence on the ecology of certain

birds, some more than others, and thus the reduction or increase of aquatic vegetation will affect the resident bird population.

When considering wetland birds visiting Heyshope Dam, 54 bird species were observed in the area during the different surveys. Most of these birds utilise the dam proper and associated wetland habitats (inflowing rivers, seepage sponges, shoreline, etc.) for:

- Feeding:
 - feeding on aquatic organisms (plants and animals)
 - feeding in/on:
 - open water
 - marginal, emergent vegetation
 - shoreline
 - inundated vegetation
- breeding in:
 - marginal vegetation
 - riparian zone
 - structures in open water (drowned trees, emergent vegetation)
- shelter
- perching
- refuge:
 - temporary refuge during migration
 - refuge during drought periods

The bird groups considered can be divided into the following guilds based on their feeding ecology:

- Open water:
 - Carnivores such as piscivores (fish-eating), invertivores (invertebrate-eating), and insectivores (insect-eating) species in deep or shallow open water.
 - Omnivores: Bird species eating a mixed diet of meat (fish, invertebrates), plant material (inundated and emergent macrophytes) and protists (plankton) in deep or shallow open water.
- Marginal vegetation:
 - Carnivores (piscivores, invertivores, insectivores): Species feeding in shallow marginal aquatic areas amid emergent hydrophilic vegetation (reeds and sedges).
 - Omnivores: Bird species eating a mixed diet of meat (fish, invertebrates), plant material (inundated and emergent macrophytes and protists (plankton)

in shallow marginal aquatic areas amid emergent hydrophilic vegetation (reeds and sedges).

- Terrestrial habitats (mud flats, moist soil, wetland vegetation): Bird species of any feeding guild feeding in areas on the shoreline marginal to the dam amid wetland vegetation, or on mud flats and moist soil.

When analysing Table 5.44, several aspects become apparent, such as the expected seasonal changes in bird numbers. Some, mostly migrants (intra-African and Palearctic), increase towards the warmer period (spring), while others flock to the area during the approaching winter season (autumn) – probably due to drying up of pans and other wetlands in the region. Birds move in when food sources become available as the wetted perimeter fluctuates.

5.1.7.5 Bird numbers on Heyshope Dam

The following account summarises observations made on individual bird species through the survey period, including historical surveys:

5.1.7.5.1 Open water carnivores (*piscivores*, *invertivores*, *insectivores*):

Carnivorous birds should not be influenced directly by the removal of SAV. However, fish and macroinvertebrates can utilise dense patches of SAV and thus adversely be influenced by the removal of vegetation. Great Crested Grebe, African darter, African spoonbill, African fish eagle, osprey, African marsh harrier, grey-headed gull, whiskered tern, and pied kingfisher were always present in low numbers and these numbers varied as the seasons changed and wet and dry years occurred. Their numbers were however, low, and it was not anticipated that the change in SAV densities would influence these birds. There are breeding records of Great Crested Grebe and African Darter on the dam (Mpumalanga Parks data, pers. comm.).

Black-winged stilts were always present in low numbers on the dam, but during the onset of the 1992-1993 drought these species appeared in much larger numbers on the waterbody, up to 173 individuals during May 1992 (Table 5.44). Hammerhead stork, Cape teal, Caspian tern, white-winged tern, and giant kingfishers were scarce and only a few stragglers visited the dam periodically.

Table 5.44: Total wetland bird species found at Heyshope Dam (and periphery) since the first surveys by Tarboton (1995) up to the 2005-2007 surveys, which includes the data for this study, as well as data generated by Mpumalanga Parks (pers. comm.).

SEASON	SUMMER		AUTUMN			WINTER					SPRING		
BIRDS (Common names)	2007 January Mpumalanga	1993 February (Tarboton 1995)	1994 March (Tarboton 1995)	1992 May (Tarboton 1995)	2007 May This study	1993 June (Tarboton 1995)	1994 June (Tarboton 1995)	1992 July (Tarboton 1995)	2006 July Mpumalanga	2007 August Mpumalanga	2005 October This study	2006 October This study	1993 November (Tarboton 1995)
Open water carnivores (piscivore, invertivore, insectivore)													
Dabchick	0	5	46	649	46	51	364	107	5	138	2	0	25
Great Crested Grebe	0	0	39	5	0	4	48	0	0	0	2	0	19
White-breasted cormorant	19	2	2	291	9	0	103	99	0	11	8	14	1
Reed cormorant	40	2	70	80	27	6	335	159	83	26	34	54	1
African Darter	5	0	11	17	18	0	45	13	14	31	10	16	0
African spoonbill	21	2	5	16	7	0	15	6	25	6	7	10	1
Hammerhead stork	1	0	0	1	1	0	0	0	0	2	0	2	0
Cape teal	0	0	0	1	0	0	0	0	0	6	0	0	0
Cape shoveller	2	9	31	392	17	34	76	372	31	114	27	32	45
African fish eagle	3	0	0	0	1	0	0	0	1	1	1	1	0
Osprey	1	0	0	0	0	0	0	0	0	0	0	0	0
African marsh harrier	0	0	0	1	1	0	0	0	0	0	0	0	0
Black-winged stilt	0	0	0	173	2	14	10	94	0	1	0	0	0
Grey-headed gull	68	0	28	15	11	0	44	23	2	0	15	1	0
Whiskered tern	20	0	4	24	0	0	2	8	0	0	5	0	0
Caspian tern	0	0	0	0	0	0	0	1	0	0	0	0	0
White-winged tern	0	0	0	0	0	0	0	0	0	0	0	0	1
Giant kingfisher	1	0	0	0	0	0	0	0	2	0	2	1	0
Pied kingfisher	8	0	0	0	1	0	0	0	0		2	1	0
Open water omnivores													
Greater flamingo	0	0	0	1	0	0	0	23	0	6	0	2	0
Knob-billed duck	0	0	0	0	3	0	0	0	2	0	0	0	0
African black duck	1	0	0	0	0	0	0	0	0	0	0	0	0
Yellow-billed duck	386	102	355	5727	808	722	1,956	1,446	1,230	730	225	471	100
Southern pochard	2	0	0	0	0	0	0	0	0	0	0	0	0
Pied avocet	0	0	0	3	0	0	0	0	1	0	0	0	0
Open water herbivores													
Red-knobbed coot	57	3,269	4,408	35,889	149	4,185	15,295	-	65	257	141	96	4104
Marginal vegetation carnivores (piscivore, invertivore, insectivore)													
Grey heron	8	4	12	10	3	1	17	5	14	6	3	5	0
Little egret	14	1	0	6	6	0	1	0	2	7	0	7	0
Yellow-billed egret	0	0	0	2	0	0	3	0	0	0	3	4	0
Great White Egret	6	1	14	12	0	0	8	0	8	4	6	9	1
Goliath heron	13	0	0	0	17	0	0	0	14	17	3	10	0

AN INTEGRATED AQUATIC VEGETATION MANAGEMENT PLAN FOR THE CONTROL OF SUBMERSED AQUATIC VEGETATION IN SOUTH AFRICAN IMPOUNDMENTS

Purple heron	0	0	4	0	1	0	0	1	2	1	6	4	0
Squacco heron	0	0	0	2	0	0	0	0	0	0	0	1	0
Glossy ibis	7	7	1	22	0	0	18	0	0	0	5	4	19
African Jacana	8	0	1	7	2	0	1	1	4	6	0	0	0
Malachite kingfisher	9	0	0	0	6	0	0	0	3	1	1	0	0
Marginal vegetation omnivores													
White-faced duck	6	1	30	43	0	21	85	162	0	80	0	6	1
White-backed duck	0	0	9	101	0	0	135	33	0	0	0	0	2
Red-billed teal	3	3	15	231	44	16	65	629	3	142	3	9	2
Maccoa duck	0	0	4	10	0	0	0	0	0	2	0	0	2
South African shelduck	0	0	0	17	2	0	0	0	0	0	0	0	0
Hottentot teal	0	0	0	1	0	0	0	0	0	0	0	0	0
Purple gallinule	0	0	1	0	1	0	0	0	0	2	0	0	0
Common moorhen	0	0	0	1	4	0	0	0	0	2	0	0	0
Lesser moorhen	0	0	1	0	0	0	0	0	0	0	0	0	0
Terrestrial habitats (mud flats, moist soil, wetland vegetation) – herbivores, carnivores or omnivores													
Black-headed heron	4	0	0	0	3	0	0	0	14	9	7	13	0
Cattle egret	337	0	0	0	13	0	0	0	39	35	2	44	0
Blue crane	0	0	0	0	0	0	0	0	0	0	8	0	0
Grey crowned crane	30	-	-	-	8	-	-	-	46	60	-	22	-
Bald ibis	0	0	0	0	0	0	0	0	0	0	-	18	0
Hadedda ibis	72	0	0	0	13	0	0	0	39	10	8	34	0
Sacred ibis	8	1	0	2	11	0	1	1	5	6	0	1	0
Egyptian goose	625	8	38	149	823	7	412	496	1,026	2,539	52	473	198
Spur-winged goose	10	8	18	13	1071	29	361	22	961	2,085	162	104	29
Three-banded plover	9	1	0	11	3	2	1	9	5	12	10	0	1
Common ringed plover	1	0	0	0	0	0	0	0	0	0	0	0	0
White-fronted plover	0	0	0	0	1	0	0	0	0	0	0	0	0
Kittlitz's plover	1	0	2	43	0	0	5	57	2	8	0	0	0
Blacksmith plover	225	98	96	110	84	35	34	45	119	168	76	143	12
Wattled plovers	0	0	0	1	1	0	0	0	6	13	0	18	0
Marsh sandpiper	0	3	6	0	0	0	0	0	0	0	0	0	4
Common Greenshank	0	0	0	2	0	0	0	0	0	0	2	0	0
Curlew sandpiper	0	0	0	13	0	0	0	142	0	0	0	0	10
Wood sandpiper	12	3	6	0	0	0	0	0	0	0	2	0	4
Common sandpiper	14	0	1	0	1	0	0	0	0	4	4	5	0
Ruff	3	0	0	0	3	0	0	0	0	4	2	12	37
Little stint	3	0	0	30	0	0	0	142	0	0	0	11	10
Ethiopian snipe	4	0	0	35	28	0	0	24	1	17	2	0	0
Water Dikkop	0	0	0	0	0	0	0	0	0	0	0	2	0
African pied wagtail	0	0	0	0	0	0	0	0	4	0	0	0	0
Cape Wagtail	50	0	0	0	22	0	0	0	79	229	17	24	0
Totals	2,117	3,530	5,258	44,159	3,272	5,127	19,440	4,120	3,857	6,798	865	1,684	4,629

(a) Dabchick (*Tachybaptus ruficollis*)

During the early drought period of 1992-1993, great numbers of *Tachybaptus ruficollis* (Pallas) appeared in the Heyshope Dam (649 individuals during autumn and 107 during the winter of 1992) (Table 5.44). This can mainly be ascribed to the fact that most of the large numbers of pans in the region dried up and this was the only aquatic habitat available during the period. The initial very high number of dabchicks diminished as the drought continued, probably dispersing to other more natural refuges with better food sources (Figure 5.16). The high count of 364 during June 1994 might be attributed to the fact that the newly filled pans in the area were in the process of recovery and the food items not available in quantity yet, but the birds already returned to the feeding grounds.

This concentration was reduced after 1994 when the drought had ended (Figure 5.16, Graph on the left). The drier year of 2007 (Figure 5.16, Graph on the right) also experience a smaller increase in numbers (138 individuals). It is recognised that these birds are nomadic and will come and go as circumstances change. During wetter years the dabchick numbers were lower (0-46 individuals) and it was not anticipated that the removal of SAV would have any substantial influence on this species. There are no breeding records of these birds on Heyshope Dam.

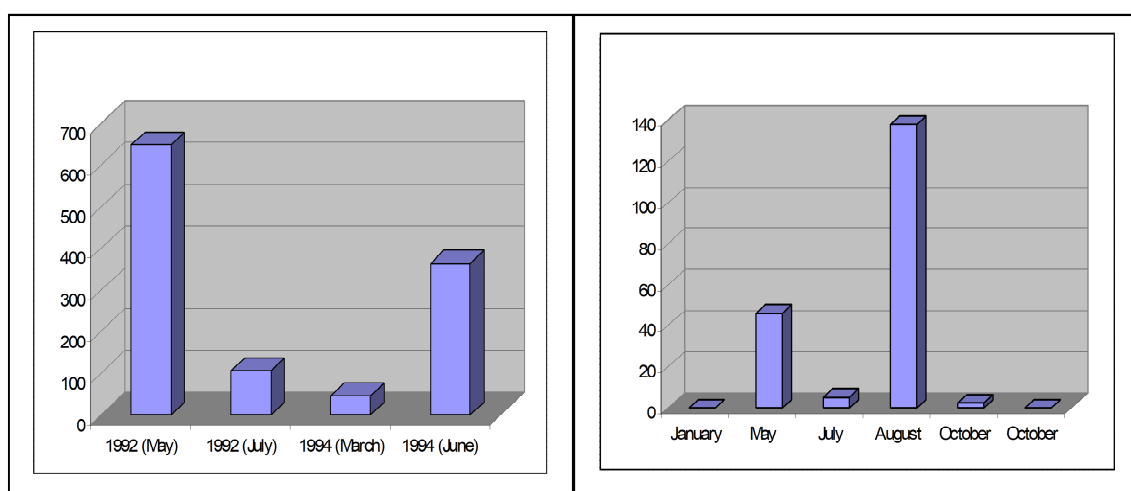


Figure 5.16: Dabchick (*Tachybaptus ruficollis*) numbers during the winter surveys of Tarboton (1995) on the left and surveys from this study on the right (2005-2007).

(b) Reed cormorant (*Microcarbo africanus*)

Microcarbo africanus (Gmelin) were regularly present on the dam, ranging from 2 to 83 individuals (Figure 5.17). During the beginning of the 1992-1993 droughts, they increased and between 80 and 159 individuals were counted. Thereafter the

concentration was reduced through 1993 as birds probably found more suitable feeding grounds and only returned in larger numbers during 1994 (Figure 5.17). The high count of 335 during June 1994 might be attributed to the fact that the newly filled pans in the area were in the process of recovery and food not available in quantity yet. Breeding records exist for these birds on the dam.

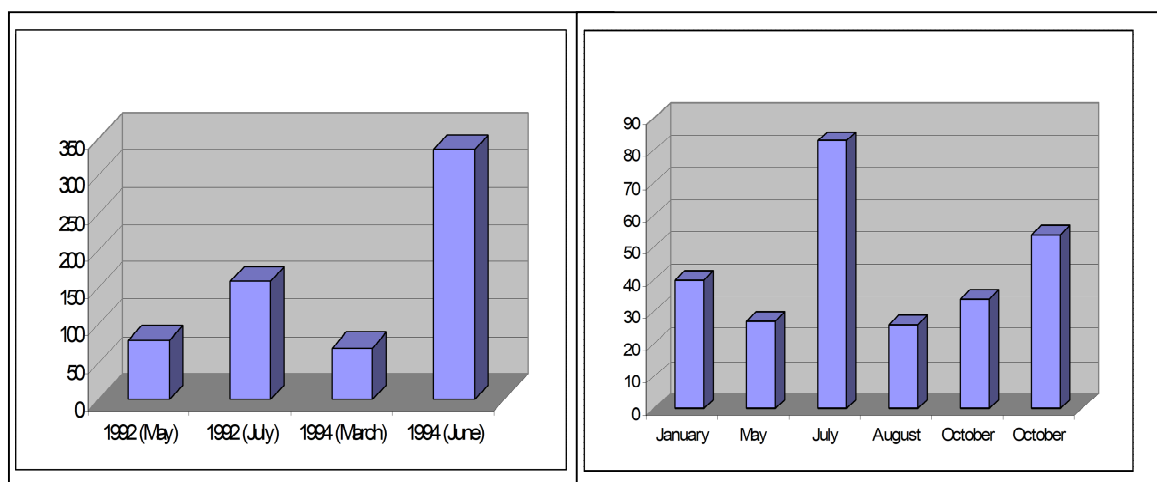


Figure 5.17: Reed cormorant (*Microcarbo africanus*) numbers during the winter surveys of Tarboton (1995) on the left and surveys from this study on the right (2005-2007).

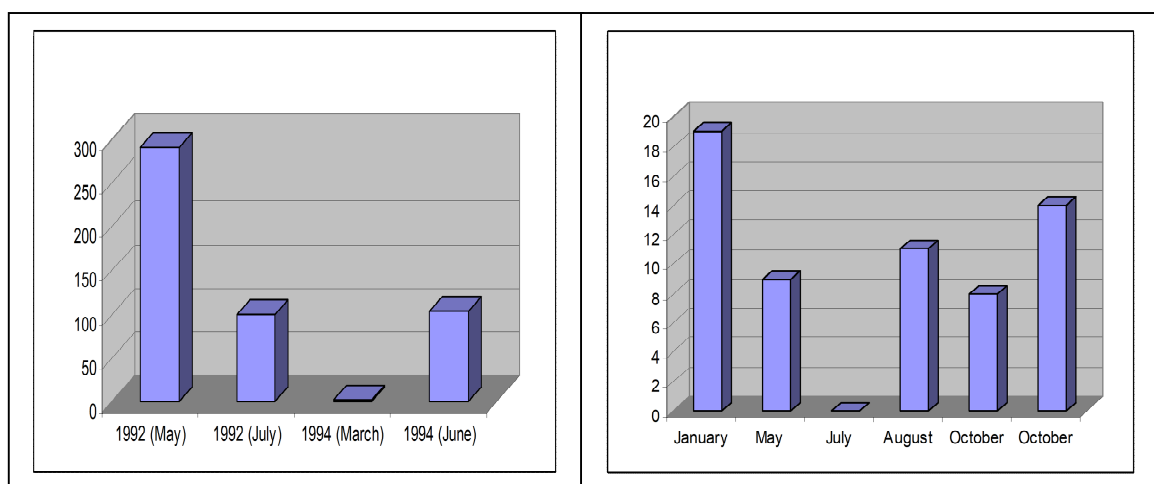


Figure 5.18: White-breasted cormorant (*Phalacrocorax carbo*) numbers during the winter surveys of Tarboton (1995) on the left and surveys from this study on the right (2005-2007).

(c) White-breasted cormorant (*Phalacrocorax carbo*)

Phalacrocorax carbo (L.) usually occurred in lower numbers on the dam (Figure 5.18), probably due to the lack of proper fish stocks. The increase in numbers during the summer can be due to breeding in the nesting sites created by inundated tree stumps

(there are breeding records for these birds on the dam). However, during the 1992-1993 droughts these birds increased and up to 291 individuals were counted during the beginning of this period when the pans dried up in the adjacent area. These numbers declined through the drought as birds found more suitable feeding grounds and only returned in larger numbers during June 1994 (Figure 5.18).

(d) Cape shoveller (*Anas smithii*)

During the onset of the 1992-1993 droughts, *Anas smithii* (Hart.) appeared in great numbers at the Heyshope Dam (May-July 1992), but the numbers dwindled as the drought continued (Figure 5.19). During the drier winter of 2007 the numbers also increased from an average of 20 birds to 114 birds. It thus appears that the Cape shoveller ducks were using the dam as an interim refuge during droughts and migrate to better areas if the drought persists. During wetter years a smaller number were present on the dam (up to 30 individuals).

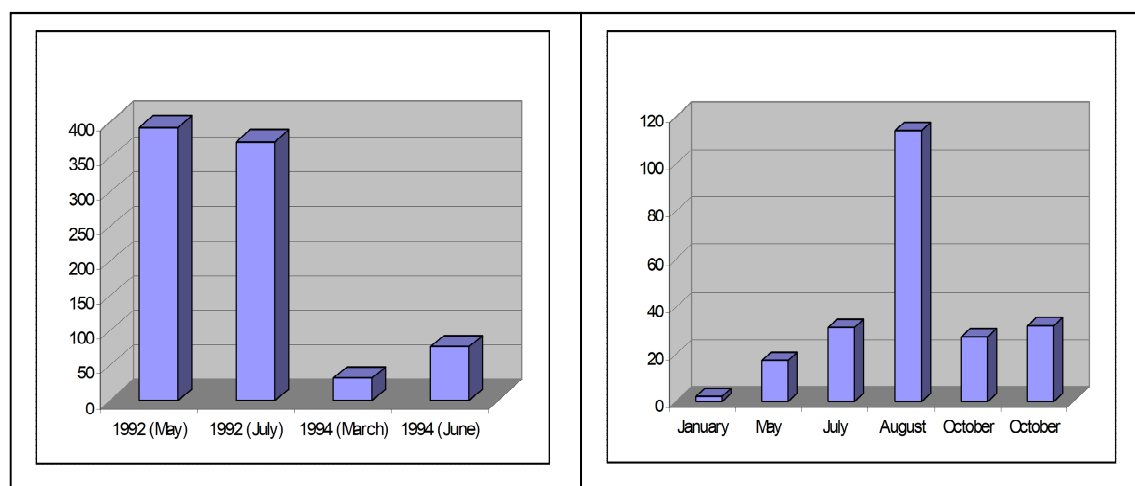


Figure 5.19: Cape shoveller (*Anas smithii*) numbers during the winter surveys of Tarboton (1995) on the left and surveys from this study on the right (2005-2007).

5.1.7.5.2 Open water omnivores:

Omnivorous birds should not be influenced extensively by the removal of aquatic vegetation, because these birds can utilise a wide variety of food sources. *Phoenicopterus roseus* Pallas (Greater flamingo), *Sarkidionis melanotos* (Penn.) Knob-billed duck, *Anas sparsa* Eyt. (African black duck), *Netta erythrophthalma* (Wied-Neuwied) (Southern pochard) and *Recurvirostra avosetta* L. (Pied avocet) were scarce on the Heyshope Dam and only a few stragglers visited the dam periodically.

(a) Yellow-billed duck (*Anas undulata*)

According to the 2005-2007 data, the *Anas undulata* (Blyth) increased in numbers on the dam during the winter months (Figure 5.20) as wetlands in the region dried up, but they migrated back again as soon as good rains replenish these resources. At the onset of the 1992-1993 drought the ducks appeared in large numbers, up to 5,727 individuals, at the Heyshope Dam (May-July 1992), but these numbers dwindled as the drought continued (Figure 5.20). The high count of 1,956 individuals during June 1994 might be attributed to the fact that the newly filled pans in the area were in the process of recovery and food was not available in quantity yet. Breeding records exist for these birds on Heyshope Dam.

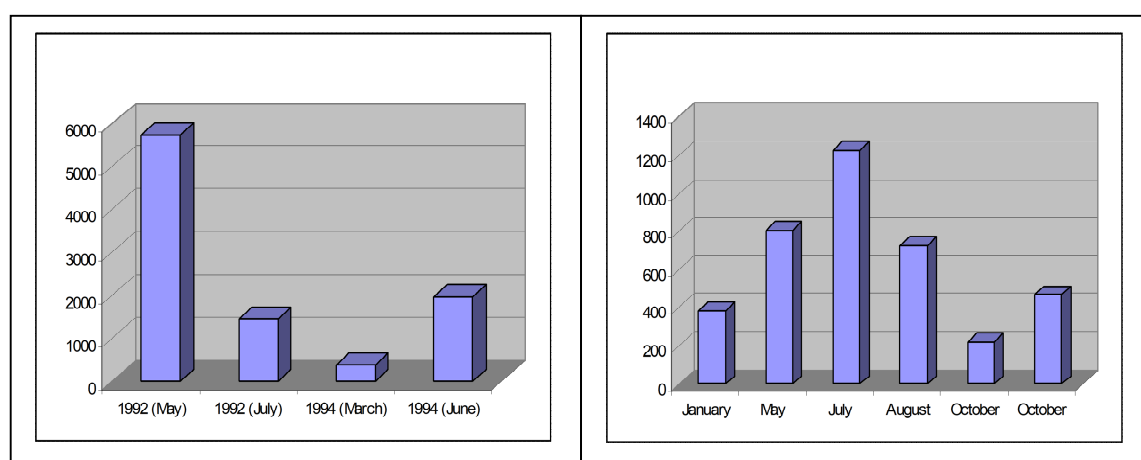


Figure 5.20: Yellow-billed duck (*Anas undulata*) numbers during the winter surveys of Tarboton (1995) on the left and surveys from this study on the right (2005-2007).

5.1.7.5.3 Open water herbivores:

Herbivorous birds include the waterfowl group that will be most severely influenced by the removal of SAV, as these birds feed predominantly on submersed vegetation and other plant material. The only true herbivores recorded at Heyshope Dam were red-knobbed coot and white-backed ducks.

(a) Red-knobbed coot (*Fulica cristata*)

Part of the *Fulica cristata* Gmelin population (Plate 5.18) on the Heyshope Dam was resident and sedentary, but the larger portion nomadic, moving in response to rainfall. Although the waterbody provides refuge during years of low rainfall, numbers fluctuate continuously, regardless of rainfall, indicating movement even in dry years.

At the onset of the 1992-1993 drought coots arrived in large numbers at the Heyshope Dam, and up to 35,889 individuals were counted during May 1992 (Tarboton, 1995). These numbers decreased as the drought continued (Figure 5.21) to 4,408 individuals in March 1994, but increased again in June 1994 to 15,295 individuals. This high count at the end of the drought might be attributed to the fact that the newly filled pans in the area were in the process of recovery and food was not available in quantity yet.

Figure 5.21 indicates that the Red-knobbed coots increased in numbers on the impoundment during the winter of 2005-2007 as wetlands in the region dried up, but they should migrate back again as soon as good rains replenish these resources. During the drier winter of 2007, the numbers increased to 257 birds, but never reached the high numbers obtained during the 1992-1993 droughts. The fact that these herbivorous birds eat a wide variety of plants (grazing short grass lawns, green cultivated crops, filamentous macroscopic algae, aquatic ferns, stems, flowers, leaves and fruit of a wide range of macrophytes, SAV, etc.), makes them less likely to be influenced by SAV reductions in the dam.

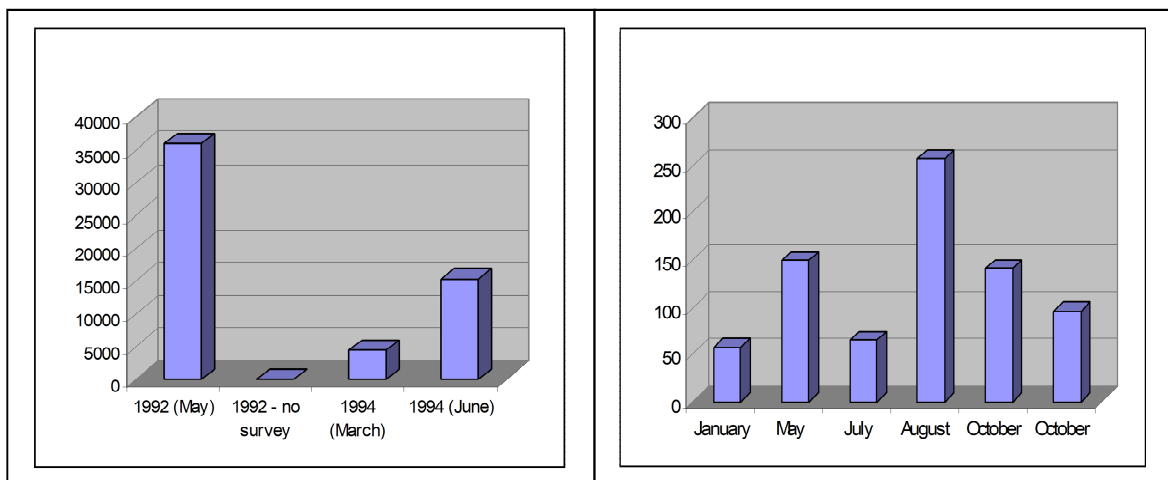


Figure 5.21: Red-knobbed coot (*Fulica cristata*) numbers during the winter surveys of Tarboton (1995) on the left and surveys from this study (2005-2007) on the right.

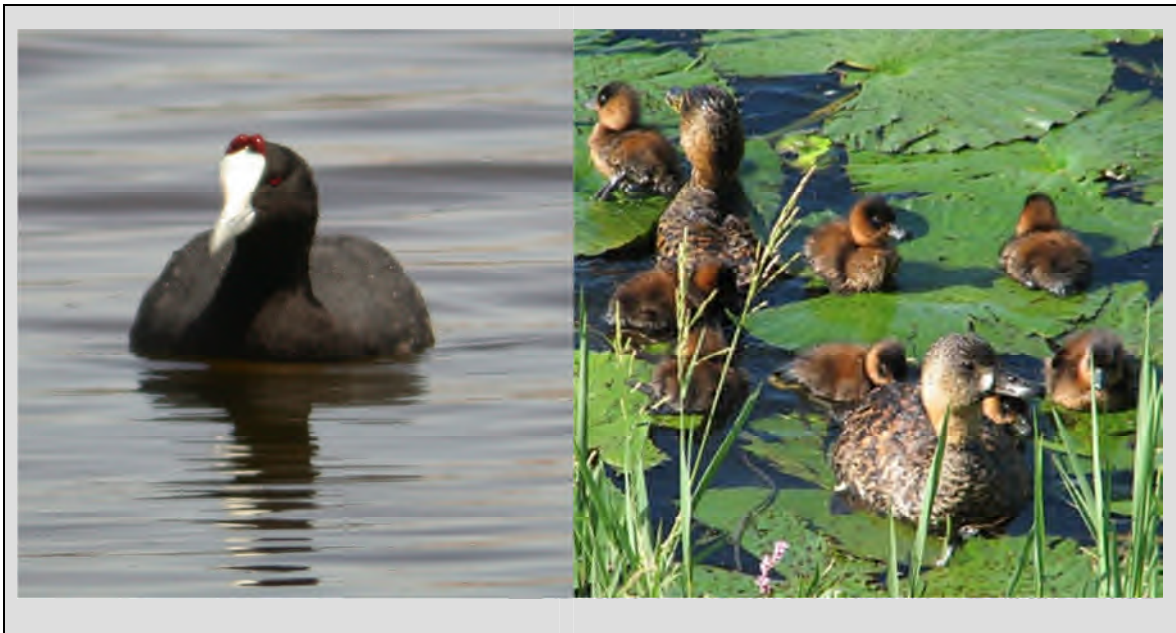


PLATE 5.18: The two true open water herbivores on the Heyshope Dam, the Red-knobbed coot (*Fulica cristata*) on the left and White-backed Duck (*Thalassornis leuconotus*) on the right.

(b) White-backed duck (*Thalassornis leuconotus*)

Thalassornis leuconotus Eyton (Plate 5.18) are common and widespread in years of good rains. These birds are largely nomadic and their occurrence and numbers in most parts were erratic. They usually arrive and breed in huge numbers on flooded pans after heavy rains. As part of their array of wetland habitats, they also visit larger dams, such as Heyshope Dam, where there are stands of emergent and floating plants. However, they prefer ephemeral pans and isolated stands of sedges, rushes or reeds, which are well-covered with aquatic grasses.

They forage mostly by diving to bottom muds in open water among aquatic herbs. They feed largely on floating and submerged macrophytes. They will be impacted by the drying-up of wetlands, rivers and natural pans. This most probably explains the large number appearing on Heyshope Dam during the 1992-1993 droughts, as well during the period of recovery in 1994.

No white-backed ducks have been observed during the 2005-2007 surveys. The fact that these ducks are usually secretive and find shelter in the marginal vegetation may be a reason why no birds have been monitored by the motorboat during these surveys.

5.1.7.5.4 *Marginal vegetation carnivores (piscivores, invertivores, insectivores):*

Marginal vegetation carnivores will make use of the stretches of emergent vegetation habitats in the eulittoral zone. These habitats harbour frogs and their tadpoles, small fish species and fry that utilise the overhanging vegetation, and numerous invertebrate groups find refuge in the shallower, vegetation covered areas. All these organisms serve as a rich food source for the marginal vegetation carnivores.

Grey herons, little egrets, great white egrets, Goliath herons, purple herons, glossy ibis, African jacana, and malachite kingfishers were always present in low numbers and these numbers varied as the seasons changed and wet and dry years occurred. Their numbers were however low, and it was not anticipated that deep water changes would influence these birds. Yellow-billed egrets and Squacco herons were scarce on the Heyshope Dam and only a few stragglers visited the dam periodically.

5.1.7.5.5 *Marginal vegetation omnivores:*

Marginal vegetation omnivores utilised stretches of emergent vegetation habitats in the eulittoral zone. These habitats harbour small animals that utilise the biotope as well as the plant material present, would it be larger algae, phytoplankton or macrophytes. All these biota serve as a rich food source for the marginal vegetation omnivores.

Maccoa ducks, South African shelducks, Hottentot teal, Purple gallinule, Common moorhen and Lesser moorhen were scarce on the dam and only a few stragglers visited the dam periodically.

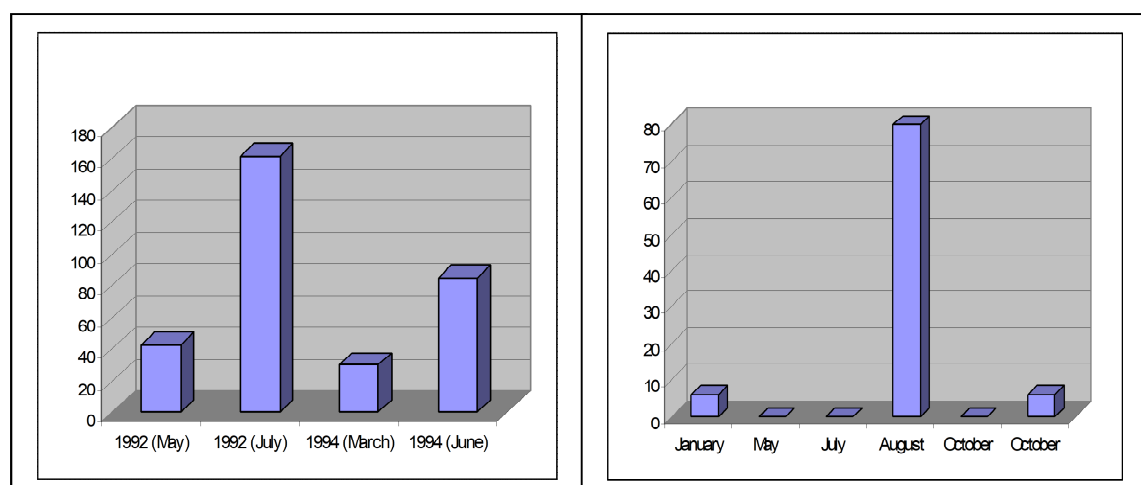


Figure 5.22: White-faced duck (*Dendrocygna viduata*) numbers during the winter surveys of Tarboton (1995) on the left and surveys from this study on the right (2005-2007).

(a) White-faced duck (*Dendrocygna viduata*)

The visits by *Dendrocygna viduata* (L.) were erratic (Figure 5.22) but it is evident that they utilised the impoundment as a refuge during the drier periods (drought of 1992-1993 and drier period during August 2007).

(b) Red-billed teal (*Anas erythrorhyncha*)

The visits by *Anas erythrorhyncha* Gmelin were erratic, but it is evident that they utilised the dam as a refuge during the drier periods (drought of 1992-1993 and the drier period during August 2007).

5.1.7.5.6 Marginal terrestrial habitats (mud flats, moist soil, and wetland vegetation) – herbivores, carnivores or omnivores:

Most of the birds utilising this biotope will not be influenced due to changes in the submerged aquatic vegetation crop of the dam, and therefore, these birds will not be discussed in detail regarding the effect of the removal. On the other hand, because Egyptian and Spur-winged geese occasionally feed on aquatic vegetation, they will be discussed with the aquatic bird assemblages of the impoundment.

The six species of plover mainly utilised the mud flats and short grass on the dam shoreline, while the five sandpiper species were confined to the mud flats. The other two waders were also found on the mudflats together with the two wagtail species. The black-headed heron and the cattle egret were found with the two crane species in the seepage zones and grassland, while the Ethiopian snipe sheltered in the shallow flooded areas with long grass. The three ibis species utilised a combination of mud flats and moist soil in marshy conditions.

(a) Egyptian goose (*Alopochen aegyptiacus*)

Interestingly, *Alopochen aegyptiacus* (L.) did not utilise Heyshope Dam to the same extent that other refuge-seeking birds flocked here during the drought of 1992-1993 (Figure 5.23). The 496 individuals present during 1992 were not more than the numbers present in the waterbody during this study.

Drying up of ephemeral water bodies causes nomadism and dispersal (increase during the 1992-1993 droughts), however, annual post-breeding moult movements were undertaken in early winter. Recently built, large dams are often chosen as new

destinations for post-breeding moult movements, and the increase in Egyptian geese from May to August (number escalated to 2,539 individuals during August 2007; Figure 5.23) can most probably be ascribed to this phenomenon.

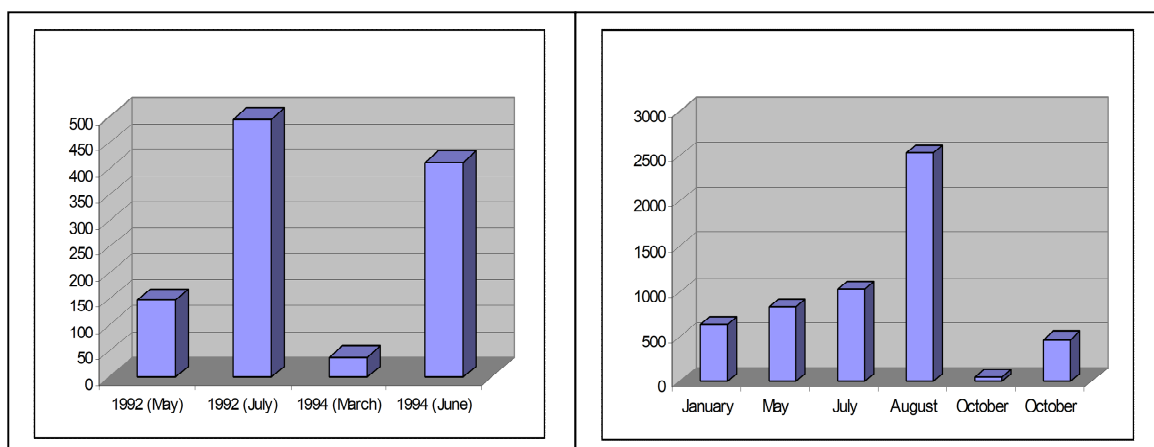


Figure 5.23: Egyptian geese (*Alopochen aegyptiacus*) numbers during the winter surveys of Tarboton (1995) on the left and surveys from this study on the right (2005-2007).

(b) Spur-winged goose (*Plectropterus gambensis*)

Plectropterus gambensis (L.) did not utilise Heyshope Dam to the same degree as other wetland birds during the drought of 1992-1993 (Table: 5.44). The 361 individuals present during June 1994 were not more than the numbers present at the dam during the winter of this study.

Spur-winged geese are nomadic birds in response to rain (increase of geese at Heyshope Dam during the 1992-1993 droughts) and cultivation of favoured food crops, but with large winter moult, they gather at permanent water bodies. As Heyshope Dam is a permanent waterbody, the increase in Spur-winged geese from May to August 2007 to 2,085 individuals, can most probably be ascribed to a combination of moult gathering and reaction to wetland availability.

5.1.7.5 Conclusions

The IAVMP reduced the SAV from the original area of 700ha in 2000, to 375ha in 2006, to 69ha in 2008 and eventually to 1 ha in 2010.

The different water bird biotopes are formed by vegetation assemblages and are important habitats for most of the aquatic birds and their food sources (frogs, fish,

aquatic insects, crustaceans and molluscs), while the vegetation itself also serves as food for a number of waterfowls.

With the near total eradication of the SAV in Heyshope Dam by 2010, habitats consisting of submersed vegetation disappeared. Because the dam levels are fluctuating, the marginal habitats will be able to recover adequately should the control agents influence them in any way. Therefore, birds influenced by the IAVMP, will be those that utilised or depended on the SAV in the open water biotope.

It is not clear how aquatic animals serving as food for birds on the Heyshope Dam will be influenced by the removal of the submersed macrophyte species. Because the deeper parts of the dam provide shelter from aerial predation, and good marginal vegetation cover provides refuge and breeding areas, most of the aquatic animals utilising this man-made habitat will find a niche to survive in, should the submersed aquatic vegetation be removed.

The only bird data available on Heyshope Dam, are data obtained by Tarboton (1995) during 1992-1994, De Wet and a Mpumalanga Parks Board team as part of the Coordinated Water Bird Counts, and this study that covered 2005 to 2007. As the 1992-1994 survey by Tarboton (1995) was performed during an intense drought period, the data obtained did not supply the typical situation at the dam, but do illustrate the value of the dam as a refuge area for wetland birds during adverse conditions. This survey, together with the surveys of De Wet (pers. comm.: Mpumalanga Parks), covers a similar time period, but fortunately these surveys were conducted during different seasons and an indication of seasonal changes in bird numbers could be obtained from the recent data.

It was evident from available data that changes in bird numbers on the Heyshope Dam are mainly regulated by rainfall in the region. During the periods that pans and wetlands dried out in the area, birds flocked to the more stable wetland habitats of Heyshope Dam. This became evident during the dry winter of 2007, and during the drought of 1992-1993, when all the pans in the region dried up, resulting in large numbers of waterfowls congregating at the dam. It also suggests that once the natural pans in the area filled up again, most of the birds would return to them, indicating the fact that Heyshope Dam acted as a temporary refuge and did not have the quantity and quality of habitat provided by the natural wetlands. Results showed that birds left the dam during

the drought period, probably moving to other traditional refuges further away, and returned to the dam as the wetlands were recovering after the drought.

Although the Heyshope Dam acts as a refuge to many birds, there are certainly some birds making the impoundment their permanent habitat. The bays where rivers flowed into the waterbody were especially diverse in wetland habitats.

Analysing the data, it became clear that there were two feeding guilds of wetland birds that included vegetation as a significant part of their diet. They were the open water omnivores, open water herbivores and marginal vegetation omnivores. The marginal vegetation omnivores utilised the marginal habitats and thus obtained a major part of their diet from plants in the shallow marginal habitats. It is not envisaged that these habitats will be influenced in any significant way by the IAVMP. The open water feeders utilised submersed aquatic vegetation in their diets and will be influence in some way by the removal of the plants. Open water omnivores possibly can survive without the submersed aquatic vegetation, as they will supplement their diet with animal matter and floating algae.

Thus, whereas most of the birds in the different feeding guilds can survive in the dam when the submerged aquatic vegetation disappears by utilising alternative food sources, it will be the open water herbivores that will potentially be influenced by the weed removal program. The only two true open water herbivores on the dam were Red-knobbed coot and White-backed ducks.

It was shown by the available data that the Red-knobbed coot utilised the Heyshope Dam to a greater extent during drier periods, but it is also possible that there were birds that resided permanently on the dam. The fact that these herbivorous birds eat a wide variety of plants (grazing short grass lawns, green cultivated crops, filamentous and macroscopic algae, aquatic ferns, stems, flowers, leaves and fruit of a wide range of macrophytes, etc.), made them less at risk to be influenced should the SAV be removed from the dam. These birds will also utilise invertebrates when they are available in abundance.

White-backed ducks are largely nomadic and their occurrence and numbers in most parts were erratic. They will be impacted by the drying-up of vleis, rivers and natural pans. This most probably explains the large number appearing on Heyshope Dam during the 1992-1993 droughts.

These ducks feed largely on floating and submersed macrophytes. They forage mostly by diving to bottom muds in open water among aquatic herbs. It is thus suggested that submersed aquatic vegetation are their main source of nutrition and that their presence on the dam will be governed by the availability of this resource. Should all the submersed aquatic vegetation disappear from the dam, it will render this dam less viable as a dry period refuge, although there might still be some less favourable marginal vegetation that could be utilised in periods of need.

It should be kept in mind that the habitat created by the impoundment is a rare biotope in the natural environment of the region. These habitats are usually man-made and wetland birds will adapt and use the new habitat, even though original habitats are still present in the area. This artificial habitat provides additional, and in this case more permanent, habitat to wetland fowl of the region. Should it fail in providing some services (such as supplying submersed aquatic vegetation as a food source), wetland birds should revert to traditional feeding grounds or succumb to a natural occurrence. Should natural wetlands, however, be reduced due to human intervention, this artificial refuge might be increasingly important as a refuge for these replaced birds.

5.2 SUCCESS OF THE IAVMP ON THE USUTU-VAAL PHASE II INTER-BASIN WATER TRANSFER SCHEME

5.2.1 Components of the IAVMP:

The IAVMP on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme was developed on the following components:

- A biological component with triploid grass carp (*Ctenopharyngodon idella* Val).
- An herbicidal component with diquat-based herbicide for submersed vegetation and glyphosate-based herbicide for terrestrial vegetation (where necessary).
- A mechanical component to prevent aquatic vegetation from damaging departmental infrastructure and to prevent the escape of the biocontrol-agent from target areas.
- A monitoring and auditing programme to evaluate the success of the IAVMP and the impact on the non-target environment.

5.2.2 Biological control component:

Sterile grass carp were stocked over a period of 9 years (2001-2009) in the Heyshope Dam to a total of 36,000 units (Table 5.45). The original SAV target area in the impoundment was 700ha (2000), calculating to a grass carp stocking density of 51 fish/ha. In the 36ha Geelhoutboom balancing dam (100% SAV cover), grass carp were stocked on two occasions, 400 units in 2002 and a further 1,000 units in 2004, calculating to a stocking density of 38 fish/ha (Plate 5.19). No biocontrol agent was stocked in the two concrete-lined canals (Geelhoutboom Canal and Balmoral Canal).



PLATE 5.19: Sterile grass carp released in Geelhoutboom Dam.

The anticipated predation of the fingerling/juvenile grass carp by *Micropterus salmoides* in Heyshope Dam was perceived to reduce the grass carp numbers significantly. Hence a stocking density of around 48 fish/ha was proposed for this impoundment. However, the unscheduled stocking of 2,000 units in early 2009 increased the stocking density to 51 fish/ha. The 48 fish/ha figure was based on experience gained from the only two grass carp stocking examples in larger than pond size South African impoundments, namely Germiston Lake and Potchefstroom Dam. These two small municipal impoundments are almost the same size (± 60 ha) and are situated approximately 100km from each other. The magnitude of the SAV infestation was similar. Yet, Germiston Lake was successfully controlled with a stocking density of 85 fish/ha, as opposed to Potchefstroom Dam which was successfully managed with a much lower stocking density of only 35 fish/ha (Du Plessis, 2003).

TABLE 5.45: NUMBERS OF STERILE GRASS CARP STOCKED IN HEYSHOPE DAM FROM 2001 TO 2009

YEAR	PROJECT PHASE	NUMBER OF GRASS CARP STOCKED	GRASS CARP STOCKED PER PHASE
2001	I	4,000	
2002		4,000	
2003		8,000	
2004		3,000	
2005		6,000	
2006	II	5,000	30,000
2007		Nil	
2008	III	4,000	4,000
2009		2,000	2,000
		36,000	

5.2.3 Herbicidal control component:

A diquat-based contact herbicide (1,1'-Ethylene-2,2'-bipyridylium dibromide) was used as the chemical control component on SAV in Heyshope Dam during this project, as this was the only herbicidal control option available for the management of SAV in South Africa at the time. Diquat at label concentrations proved highly effective on the target SAV species, allowing fish to escape readily to adjacent areas without any observed discomfort or fish kills. Areas were treated as spots or strips and were not large enough to cause oxygen depletion on organic decomposition of the treated biomass.

Diquat is a broad-spectrum liquid herbicide with a short half-life (less than 48h in the water column), with a rapid action and limited drift (if sprayed). The results become

visible within 7 days after treatment with this formulation and underground portions (roots, rhizomes, and tubers) are not affected as diquat is a contact herbicide. Diquat disrupts the plant cell membranes of exposed vegetation and inhibits photosynthesis. Contact and control time varies according to plant species and rate of regrowth. Diquat is largely neutralised on contact with soil particles and dissolved organic matter. The herbicide was applied sub-surface to label concentrations of 50 litres/ha-m although lower concentrations were successfully applied in shallow bay areas (Plate 5.20).



PLATE 5.20: Sub-surface treatment of SAV in Heyshope Dam with a diquat-based herbicide from a motorboat.

5.2.4 Mechanical adaption to target areas:

The forebay of the Geelhoutboom Pump Station was designed with metal grids to prevent SAV and debris entering the high-capacity pumps (Plate 5.22). The main problem with SAV in the Usutu-Vaal Phase II Inter-Basin Water Transfer Scheme was that these grids were blocked by SAV, which resulted in the cavitation of the pumps as the forebay was sucked empty in minutes when flow was blocked by the SAV biomass on the grids. In addition to this, the SAV fragments also ended up in the cooling systems of the pumps, leading to overheating resulting in cut-outs.

The Geelhoutboom Canal inlet structure into Geelhoutboom Dam was designed with metal grids to prevent the biocontrol agent to escape from the balancing dam upstream into the Geelhoutboom Canal (Plates 5.21 and 5.22). The operational rules at the balancing dam were also adapted to manage the water level so that it is sufficiently lower than the spillway to prevent fish from jumping over the spillway structure.

Sensitive areas such as Ngulane Wetland were blocked off from the Heyshope Dam with grids welded onto the metal pipes underneath a low water bridge.

5.2.5 Success of the IAVMP on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme:

The primary purpose of the programme to manage SAV in the Usutu-Vaal Inter-basin Water Transfer Scheme (which was initiated in 2001) was to develop and implement tools to prevent nuisance aquatic vegetation from impacting on the system's ability to sustain an uninterrupted water supply to the Vaal River System in the neighbouring catchment. It was envisaged that the results of the programme be incorporated into a generic IAVMP for extrapolation to other impoundments in South Africa experiencing similar SAV problems. From 2001 to the end of 2005 there was unfortunately no monitoring component incorporated into the programme. From mid-2006 the programme was formalised into a more structured IAVMP. The success of the IAVMP was measured in the degree in which the original aims of the programme were met after a period of seven years (2001–2008) from implementation.

5.2.5.1 Management objective for Geelhoutboom Dam

<u>Management Objective 1:</u>	Priority No 1: Maintain Geelhoutboom Dam (surface area = 36ha (89 acres)) free of all aquatic vegetation on a permanent basis. The aim of the IAVMP was therefore to maintain a condition of total control of SAV at all times in the Geelhoutboom balancing dam. Total aquatic vegetation control is a prerequisite for the optimal operation of the system at design capacity at all times.
<u>Success rate:</u>	100%
<u>Date achieved:</u>	This aim was successfully reached in 2005 with sterile grass carp as biocontrol agents. Stainless steel grids were built into the Geelhoutboom Canal inlet structure to contain the biocontrol-agent in the target area (Plates 5.24 and 5.25). A total of 1,400 sterile grass carp were stocked at fingerling to juvenile size to a stocking density of 38 units per hectare or 15 units per acre. A total of

400 units of sterile grass carp were stocked in 2002 and another 1,000 units in 2004.

Current status:

Geelhoutboom balancing dam was under 100% biological control.

Conclusion:

About 90% of the water surface of Geelhoutboom Dam was covered by *Potamogeton schweinfurthii*, *Stuckenia pectinata* and *Lagarosiphon muscoides* prior to intervention in 2001 (Plate 5.21). No herbicidal treatments were done on this impoundment preceding the stocking of 1,400 sterile grass carp to a final stocking density of 38 fish/ha. *L. muscoides* was removed before *S. pectinata* and *S. pectinata* was removed before *P. schweinfurthii*, confirming that grass carp prefers the softer structured SAV species to the harder and more fibrous species.

By 2005, all SAV were removed from the balancing dam and no problems were experienced with biomass blocking the grids in the forebay of the inlet structure (Plate 5.22) up to the 5m³/s high-capacity water transfer pumps of the Geelhoutboom Pumping station. The Geelhoutboom Dam was still found to be under biological control in 2021, 17-19 years after stocking.

5.2.5.2 Management objective for Geelhoutboom and Balmoral canals

Management Objective 2:

Priority No 2: Maintain both the **Geelhoutboom and Balmoral canals** free of terrestrial and aquatic vegetation on a permanent basis. The aim was to maintain a condition of total control of aquatic vegetation at all operational periods in these two canal systems.

Success rate:

100%

Date achieved:

This aim was successfully achieved in 2006 with an herbicidal control programme for (1) SAV with a diquat-based herbicide, as well as (2) terrestrial vegetation with a glyphosate-based herbicide.

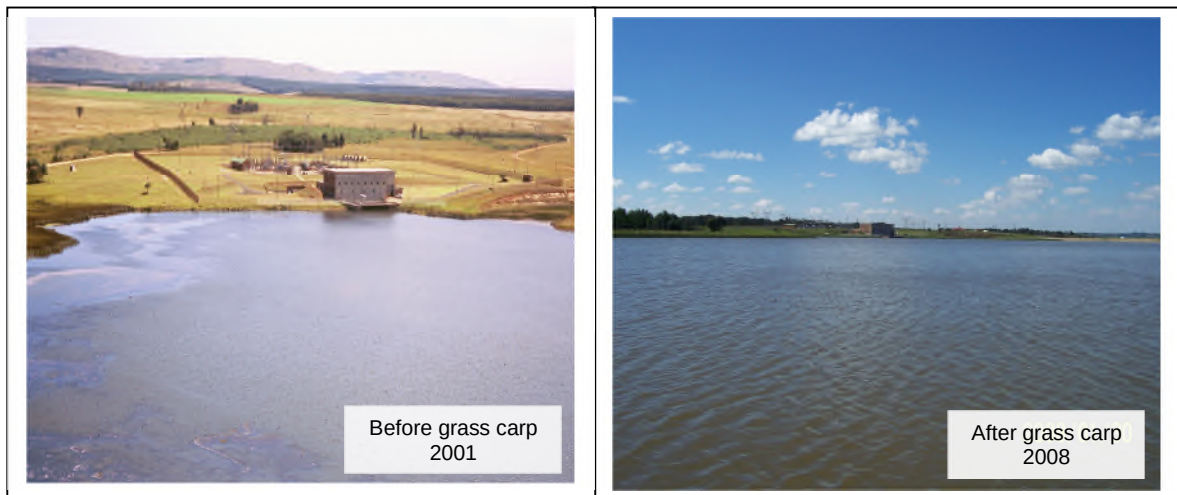


PLATE 5.21 Geelhoutboom balancing dam infested with SAV prior to the stocking of sterile grass carp on the left (2001), and a SAV free waterbody on the right (2008).



PLATE 5.22 Geelhoutboom balancing dam, dam wall with water level gauge plates on the left, and the forebay metal grids of the Geelhoutboom Pump Station on the right to prevent SAV sucked into the pumps.

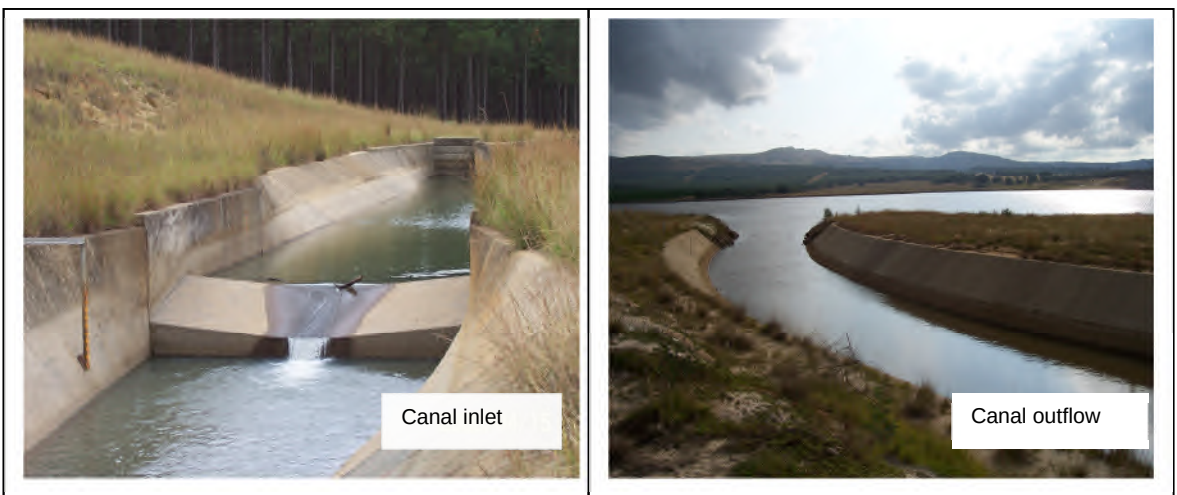


PLATE 5.23 Geelhoutboom Canal inlet at Heyshope Dam on the left and the outflow of the Geelhoutboom Canal into Geelhoutboom Dam downstream of the grid structure on the right.



PLATE 5.24 Stainless steel grids on the inflow structure Geelhoutboom balancing dam preventing grass carp from escaping from the Geelhoutboom Dam upstream into the Geelhoutboom Canal. Direction of flow is indicated by the yellow arrow.



PLATE 5.25 Stainless steel grids on the tail end structure of Geelhoutboom Canal preventing debris from entering Geelhoutboom Dam (flow direction towards the grids on the left). Direction of flow is indicated by the yellow arrow.

Status: 100% control of all SAV in operational periods in the canals by 2008. The status of the aquatic vegetation in the two canals was uncertain in 2020.

Conclusion/recommendations: The two concrete-lined conduits were treated successfully with a diquat-based and a glyphosate-based herbicide by means of spot-treatments during canal dry periods.

An acrolein-based product was registered for use in South Africa in 2010. Acrolein is recommended for use in the 21km long Geelhoutboom Canal. Caution should be taken with the location of this algaecide/herbicide dosing locations on the canal as the formulation is toxic to fish at label concentrations. The concentration of the active ingredient should be lower than the LC₅₀ value of acrolein for fish before the treated water spills into Geelhoutboom Dam to ensure the safety of the grass carp in the balancing dam. The balancing dam should also be managed at near full capacity during acrolein treatments to ensure maximum dilution of acrolein in the dam.

The 4km long concrete-lined Balmoral Canal spills into the Klein-Vaal River from where it gravity feed the Grootdraai Dam in the neighbouring Vaal River catchment. As the river system is a natural and relatively undisturbed aquatic ecosystem, care should be taken that herbicides applied in the canal do not reach the non-target ecosystem in the river downstream. Hence acrolein is not recommended for SAV management in this canal, but rather spot-treatments with a diquat-based herbicide during dry periods.

5.2.5.3 Management objective for Heyshope Dam

Management Objective 3: Priority No 3: Reduce the infestation of nuisance submersed aquatic vegetation (700ha in 2000) in the

Heyshope Dam (FSA = 5,023.8ha) to 10% (70ha) of the original covered surface area and minimise the impact on non-target fauna and flora (partial aquatic vegetation control) if possible.

Success rate:

100%

Date achieved:

The 90% reduction in SAV surface area (from 700ha in 2001 to 69ha in 2008) was successfully reached in May 2008 with a combination of herbicidal (diquat) and biological control (sterile grass carp) methodologies. The SAV surface area was further reduced to only 1 ha with the final SAV survey two years later in May 2010.

Current status:

100% control of target submerged aquatic vegetation in the impoundment.

Conclusion:

All the management objectives of the project have been met by May 2008. No pump failures due to interference by aquatic vegetation were experienced over the total period of this project. Unscheduled downtimes could not be attributed to nuisance aquatic vegetation blockages of grids or pumps.

From an ecological point of view, the potential impact of the piscivores on the stocked fingerling/juvenile grass carp was overestimated. It was anticipated that *Micropterus salmoides* (Largemouth bass) would predate heavily on the small grass carp fingerlings after stocking. However, this seemed not to be the case as almost all SAV were removed from the impoundment by May 2010.

5.2.6 Rate of achieving management objectives in Heyshope Dam:

The original surface area covered by SAV in Heyshope Dam was 700ha in 2000 (see Figure 5.1) with *Potamogeton schweinfurthii* and *Stuckenia pectinata* contributing more than 98% of the total SAV population. The aim of the IAVMP was to reduce the SAV area (from 2001) with 90%, from 700ha to 70ha over an unspecified period to achieve partial control of the submerged aquatic vegetation in Heyshope Dam. The original infestation was ~14% of the reservoir's FSA. The intention was to reduce the SAV area

to ~ 1.4% of the FSA. This objective was reached in May 2008 (after 7 years) when an infested area of 69ha was surveyed. Unfortunately, the SAV was further reduced to only 1ha in May 2010, ten years after the initiation of the project.

- **Phase A: Year 2001 to 2006** - Reduction of original SAV area from 700ha to 375ha. This is a 46% reduction of in SAV surface area over a period of 5 years. If the reduction was linear, it would have resulted in a decrease in biomass of 75 ha/annum.

- Target vegetation: *Potamogeton schweinfurthii* and *S. pectinata* (Plate 5.2)
- Herbicidal control actions = Several applications ($\pm 1,000$ ha). The author was not directly involved at this stage of the programme and the herbicidal treatments were therefore not monitored as part of this study.
- Sterile grass carp stocked 30,000 units

14% of FSA was covered by *P. schweinfurthii* (80% of SAV infestation) and *S. pectinata* (18% of SAV infestation). It was observed that the sterile grass carp removed *S. pectinata* by preference before starting to feed visibly on *P. schweinfurthii*.

- **Phase B: Year 2006 to 2008** – Reduction of SAV area from 375ha to 69ha. This is a (further) 82% reduction in SAV surface area over a period of 2 years. If this reduction was linear, it would have resulted in a decrease in biomass of ~155ha/annum.

- Target vegetation: *Potamogeton schweinfurthii*. No *S. pectinata* was observed during the 2006 aquatic vegetation survey. Grass carp removed this species from the impoundment by 2006.
- Herbicidal control actions 105ha in selected areas
- Sterile grass carp stocked 6,000 units

- **Phase C: Year 2008 to 2010** – The reduction in SAV surface area was established by a final aquatic vegetation survey in May 2010. This was also the final monitoring action in terms of the study period. A follow-up monitoring programme was proposed to DWS, but it was unfortunately not implemented.

The SAV survey in May 2010 revealed that the SAV area of 69ha surveyed in 2008 was reduced to only a few patches (about 1ha) of SAV in the waterbody. Sterile grass carp reduced the SAV to an undesirable low concentration, lower than the goal of 10% of the original infestation, which was 70ha. Although a moratorium was placed on any additional stocking of grass carp, 2,000 unscheduled grass carp were stocked into Heyshope Dam in January 2009. It was clear that the anticipated predation of the fingerling/juvenile sized grass carp by piscivores, mainly *Micropterus salmoides*, did not reduce the grass carp numbers significantly.

The potential implications of the removal of almost all the SAV were (a) loss of non-target flora, e.g., (i) *Persicaria amphibia* at the Assegaa River inlet; (ii) *Marsilea macrocarpa* at the Ngulane inlet; (b) loss of shoreline vegetation which could lead to bank erosion, and (c) an increase in lake turbidity.

- Target vegetation: *Potamogeton schweinfurthii*
- Herbicidal control actions 11ha at dam wall area
- Sterile Grass Carp stocked 2,000 units (Unscheduled stocking in January 2009)

5.2.7 First round determination of the Submersed Aquatic Vegetation Potential Growth Area (SAVPGA):

Managers of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme requested a tool to put them in a position to budget for the worst-case scenario for SAV control in the Heyshope Dam. A tool was presented to calculate the maximum area that will support SAV growth at different dam levels. From Figure 5.24, it is clear that the dam level fluctuated for the period 2000 to 2020, mainly between 80% and 100% of the FSL.

The SAVPGA was based on observations during this study that *Potamogeton schweinfurthii* could grow down to 3m and *Stuckenia pectinata* down to 2.5m from the water surface. These observations were supported by Van Ginkel and Cilliers (2017) for *P. schweinfurthii* and Coetzer (1987) and Kantrud (1990) for *S. pectinata*.

A table (Table 5.46) was presented where the SAVPGA can be deducted from, according to different dam levels. This approach is used as a first round calculation of the maximum area that could potentially be covered by SAV, assuming that SAV will be

able to grow in all areas (substrates) of the dam up to 3m deep at a specific dam level. This is of course a simplification as variation in biotic and abiotic factors influences the growth and abundance of SAV in a specific area (Doyle, 1999; Madsen et al., 2001; Lacoul and Freedman, 2006; Madsen and Wersal, 2017).

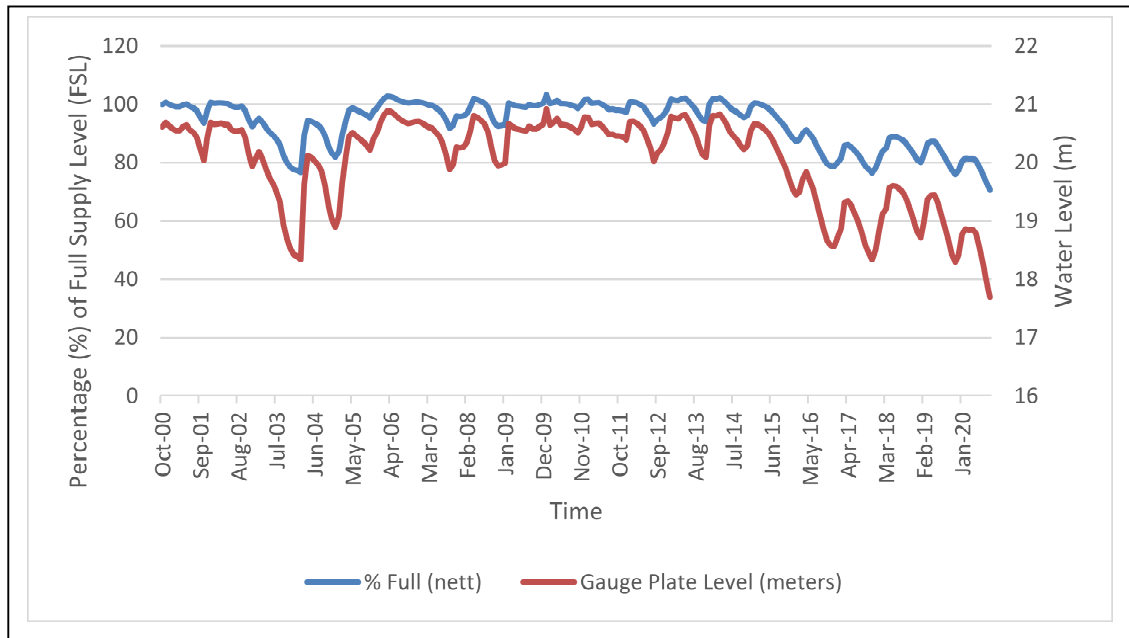


FIGURE 5.24: Heyshope Dam water levels (percentage of FSL and gauge plate level) from the start of the hydrological year (October) 2000 to April 2020.

The SAVPGA calculations can be improved over time with site-specific evaluations of biotic and abiotic conditions that will influence the abundance and distribution of SAV in a specific waterbody. Areas not suitable for SAV growth can then be deducted from the calculated maximum area for SAV growth. It can be concluded from Table 5.46 that the SAVPGA₁₀₀ at a dam level of 100% will be 1,074ha, which calculates to 21.36% of the water surface at FSL. In the case of an 80% dam level, SAVPGA₈₀ will be 1,031ha, which calculates to 23.30% of the water surface at 80% of the FSL. These areas can then be multiplied with the cost per hectare to treat the impoundment with herbicides or play a role in the calculations of grass carp stocking densities for other impoundments in the future.

The water level of Heyshope Dam was never below 80% over the study period. (Figure 5.24). The SAVPGA for this period fluctuated between 1,031 and 1,074ha. The maximum SAV coverage was 700ha in 2001, thus 65-68% of the SAVPGA for Heyshope Dam.

**TABLE 5.46: THE SUBMERSED AQUATIC VEGETATION POTENTIAL GROWTH AREA (SAVPGA)
AT DIFFERENT WATER LEVELS IN HEYSHOPE DAM**

NO	DAM LEVEL (%)	GAUGE PLATE READING (m)	CONTOUR (m) MSL***	CAPACITY (m ³ x 10 ⁶)	SURFACE AREA (ha)	SAVPGA* (ha)	SAVPGA* AS % OF SURFACE AREA
01	118	23.63	1,306.00	620.455	6,138.91	Not relevant	
02	114	22.63	1,305.00	561.034	5,752.22	Not relevant	
03	108	21.63	1,304.00	505.421	5,380.17	Not relevant	
04	100 (FSL**)	20.63	1,303.00	453.440	5,023.83	1,074	21.36
05	90	19.63	1,302.00	404.981	4,678.78	1,077	23.06
06	80	18.63	1,301.00	360.065	4,314.48	1,031	23.10
07	70	17.63	1,300.00	318.819	3,950.00	944	23.10
08	62	16.63	1,299.00	281.130	3,601.97	852	23.10
09	54	15.63	1,298.00	246.772	3,283.97	783	23.04
10	47	14.63	1,297.00	215.374	3,005.40	735	24.46
11	41	13.63	1,296.00	186.651	2,749.49	696	25.00
12	36	12.63	1,295.00	160.449	2,501.45	658	26.00
13	30	11.63	1,294.00	136.650	2,270.47	623	27.44
14	26	10.63	1,293.00	115.82	2,052.88	590	28.74
15	22	9.63	1,292.00	95.657	1,843.42	568	30.00
16	18	8.63	1,291.00	78.256	1,647.32	548	33.27
17	14	7.63	1,290.00	62.759	1,462.95	530	36.23
18	11	6.63	1,289.00	49.119	1,275.18	519	40.70
19	8	5.63	1,288.00	37.302	1,098.87	507	46.14
20	6	4.63	1,287.00	27.181	932.99	495	53.66
21	4	3.63	1,286.00	18.795	756.68	480	62.09
22	3	2.63	1,285.00	12.099	592.16	592	100
23	2	1.63	1,284.00	7.007	438.11	438	100
24	1	0.63	1,283.00	3.525	276.66	277	100
25	0.3	0	1,282.00	1.526	138.17	138	100

NOTES:

* SAVPGA = Submersed Aquatic Vegetation Potential Growth Area

** FSL = Full Supply Level

*** MSL = Meters above Sea Level

5.2.8 Discussion:

In 2000 the original infestation of the target SAV (*Potamogeton schweinfurthii* and *Stuckenia pectinata*) in the Heyshope Dam was surveyed to be 700ha. This was 14% of the 5,023.8ha FSA of the impoundment and between 65-68% of the SAVPGA. The aim of the IAVMP was to reduce this biomass (from year 2001) with 90% to 70ha over an unspecified period.

A conservative approach was proposed at that stage to limit the possible negative effect on the receiving environment by removing too much aquatic vegetation from the waterbody.

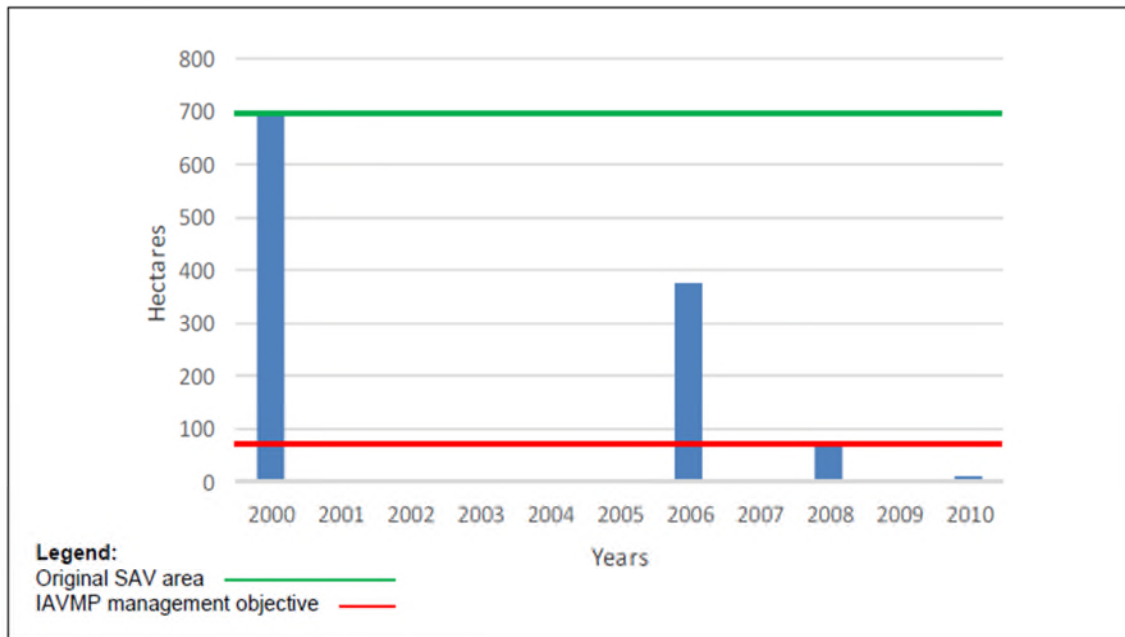


FIGURE 5.25: Decrease of SAV surface area surveyed on four occasions from April 2000 to May 2010 in Heyshope Dam.

The management objective of the IAVMP in Heyshope Dam was therefore to obtain partial control of SAV, in contrast with the other structures of the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme (Geelhoutboom Canal, Geelhoutboom Dam and Balmoral Canal), where total control of aquatic vegetation was the objective. The original SAV infestation in Heyshope Dam was reduced to 1.4% of the FSA in May 2008, 7 years after initiation of the project, when an infested area of 69ha was surveyed. As the project was terminated towards the end of 2008, no environmental monitoring was done after this date, except for a final SAV survey in May 2010 (ten years after the initiation of the project) when it was found that the 69ha surveyed in 2008 was reduced to only a few patches of SAV, totalling a mere 1ha surface area in Heyshope Dam (Figure 5.25).

As aquatic plants are important components of freshwater ecosystems and perform a wide variety of beneficial functions, the rationale to obtain only partial control of aquatic vegetation in Heyshope Dam was to:

- prevent operational problems at the water transfer pumps at Heyshope Dam's wall structure (limit aquatic vegetation to prevent interference with the high-capacity pumps at the Heyshope pump station);
- prevent distribution of the target SAV species from Heyshope Dam downstream via the conveyance structures to the rest of the system, and

- to conserve the ecological integrity of the waterbody by not removing all SAV, i.e., retain 70ha.

The extent of the target SAV in Heyshope Dam during May 2000 is presented in Figure 5.1. The aquatic vegetation species list in Table 5.18 is based upon the Heyshope Dam survey in 2006 as demonstrated in Figures 5.2 to 5.7.

A comparison of the May 2006 and May 2008 Heyshope Dam aquatic vegetation surveys is illustrated in Figures 5.8 to 5.14. No map was produced to indicate the approximately 1ha of SAV surveyed in May 2010. Although the initial target set by the IAVMP for SAV coverage (70ha) for Heyshope Dam was successfully reached in 2008, the ability of grass carp to survive the anticipated predation by piscivores was underestimated. As a result, more grass carp survived predation and hence more SAV was removed from the waterbody over a ten-year period than was the original goal of the IAVMP.

The IAVMP was highly successful and all the management objectives in all components of the Usutu-Vaal Phase II Inter-Basin Water Transfer Scheme were reached, with the exception of the goal to reserve 10% of the original SAV area to sustain the aquatic integrity of Heyshope Dam. All SAV control strategies were effective and the sustainable supply of water from the Usutu River catchment to the Vaal River System was not interrupted by SAV at any time during the programme. No downtime due to pump failures as a result of SAV blockages was experienced at the pump stations at Heyshope Dam or Geelhoutboom Dam up to date (2021).

CHAPTER 6

AN INTEGRATED AQUATIC VEGETATION MANAGEMENT PLAN FOR THE USUTU-VAAL PHASE II INTER-BASIN WATER TRANSFER SCHEME

6.1 PROBLEM STATEMENT

The primary purpose of the study was to develop and implement tools to prevent nuisance SAV from impacting on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme's ability to sustain an uninterrupted water supply from the Usutu River catchment to the neighbouring Vaal River System. Large industries, such as the strategic petroleum refineries, SASOL II and III near Secunda, and ESKOM's power stations in the Mpumalanga Highveld, play a major role in the macro economy of South Africa. These industries rely on an uninterrupted water supply from the Vaal River System which had to be augmented from the Usutu River catchment with the Usutu-Vaal Inter-basin Water Transfer Scheme to meet the increasing water demand from a growing economy in central South Africa.

Problems with nuisance SAV were experienced at the pumping stations at both Heyshope Dam and Geelhoutboom Dam when SAV biomass blocked the grids of the forebay at the Geelhoutboom Pumping station, as well as at the pump intakes at Heyshope Dam. SAV biomass also blocked the cooling systems of the high-capacity water transfer pumps at both locations. Nuisance aquatic vegetation furthermore reduced the design capacities of the two conduits, the Geelhoutboom Canal and the Balmoral Canal. As the impact of SAV on the system was severe, with significant economic implications, it had to be addressed by a preventative maintenance SAV control programme.

The aim of this chapter is to describe the IAVMP developed for the Usutu-Vaal Inter-basin Water Transfer Scheme and to make it available as a blueprint for extrapolation to other impoundments and water distribution schemes in South Africa. All IAVMP's should however, be developed site-specifically with cognisance of the unique character and circumstances of each target impoundment or scheme.

6.2 DEFINITION OF AN INTEGRATED AQUATIC VEGETATION MANAGEMENT PLAN

An Integrated Aquatic Vegetation Management Plan (IAVMP) can be defined as the coordinated synergism of ecological, herbicidal, biological, mechanical, and physical control strategies into a structured management programme for the optimal control of nuisance aquatic vegetation, whilst minimising potential adverse impacts to water use activities, water infrastructure and the receiving environment.

6.3 MANAGEMENT OBJECTIVES

6.3.1 Geelhoutboom Dam:

The first priority for the IAVMP on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme was to keep the Geelhoutboom Dam (FSA = 36ha) free of all aquatic vegetation (SAV and others) on a permanent basis. The management objective for Geelhoutboom Dam was therefore to implement a programme of total aquatic vegetation control at all periods.

Geelhoutboom Dam is the balancing structure from where water is pumped from the Usutu River System over the watershed to the Vaal River System. The Geelhoutboom Pumping Station is the most vulnerable structure to problems associated with nuisance SAV. Hence the focus of the IAVMP was on this infrastructure.

6.3.2 Geelhoutboom Canal:

The second priority of the IAVMP on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme was to maintain the Geelhoutboom Canal free of all terrestrial and aquatic vegetation. The management objective for Geelhoutboom Canal was therefore also to implement a programme of total aquatic vegetation control at all operational periods.

6.3.3 Balmoral Canal:

The third priority of the IAVMP on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme was to maintain the Balmoral Canal free of all terrestrial and aquatic vegetation. This conduit is the final component of the water transfer system before the Usutu River

water is spilled in the Vaal River System. The management objective for the Balmoral Canal was therefore also to implement a programme of total aquatic vegetation control at all operational periods.

6.3.4 Heyshope Dam:

The fourth priority of the IAVMP on the Usutu-Vaal Phase II WTS was to reduce the infestation of nuisance SAV (700ha in year 2000) in Heyshope Dam (FSA = 5,023.8 ha) to 10% (70ha) of the original infestation and to minimise the impact of the IAVMP on non-target fauna and flora of the receiving environment. The management objective for the Heyshope Dam was therefore to implement a programme of partial aquatic vegetation control in order to reduce problem SAV (1) to the extent that they do not interfere with the pumps at the Heyshope Dam Pumping Station, and (2) to a level where contamination of the rest of the water transfer system is restricted (taking into consideration that bird migration between the water bodies also contributes to aquatic plant distribution).

6.4 TARGET AQUATIC VEGETATION SPECIES:

6.4.1 Geelhoutboom Dam:

The dominant nuisance aquatic vegetation species in Geelhoutboom Dam were: *Stuckenia pectinata* (Fennel-leaved Pondweed) and *Lagarosiphon major* (Coarse Oxygen weed) with *Juncus* spp. (rushes) on the periphery of this balancing dam.

6.4.2 Geelhoutboom Canal:

The primary aquatic vegetation species were: *Lagarosiphon muscoides* (Fine Oxygen weed), *Typha capensis* (Bulrush), *Persicaria* spp., *Nymphaea nouchalia* var. *coerulea* (Blue Water lily) and *Juncus* spp.

Terrestrial grasses are problematic as they establish themselves in the joints between the concrete slabs of this 20.1km concrete-lined canal. Approximately 2km of this conduit is a closed pipeline, leaving 18.1km of open canal vulnerable to nuisance vegetation growth (Plate 6.1).



PLATE 6.1: Rushes (*Juncus* sp.) (left) and Fine oxygen weed (*Lagarosiphon muscoides*) (right) causing operational problems in the Geelhoutboom Canal system.

6.4.3 Balmoral Canal:

The primary aquatic vegetation species the Balmoral Canal were: *Lagarosiphon major* (Coarse Oxygen weed), *Typha capensis*, and *Juncus* spp.

As in the case of the Geelhoutboom Canal, terrestrial grasses cause problems as they establish themselves in the joints between the concrete slabs of this 4.5km concrete-lined conduit. The Geelhoutboom Dam is connected via a 4.8km pipeline to the Balmoral Canal inlet. The canal spills directly in the Klein-Vaal River of the neighbouring Vaal River catchment.

6.4.4 Heyshope Dam:

The target aquatic vegetation species were: *Potamogeton schweinfurthii* (Broad-leaved Pondweed) and secondarily *Stuckenia pectinata* (Fennel-leaved Pondweed).

6.5 SELECTED SAV CONTROL METHODS FOR TARGET AREAS

6.5.1 SAV control techniques applied:

6.5.1.1 Herbicidal control component

6.5.1.1.1 *Geelhoutboom Dam:*

Herbicides should be applied when SAV species are actively growing (water temperatures >13-15°C). At this stage a diquat-based herbicide, applied by sub-surface dosing at a concentration of 50liters/ha/m (label concentrations), is recommended. Only diquat and fluridone are currently registered for the control of SAV in South Africa, with the latter not freely available in the market. Chemical applications should be done from a suitable equipped motorboat or airboat. The aim of herbicide applications in Geelhoutboom Dam is to reduce the biomass in the balancing dam to generate new, more palatable growth for young sterile grass carp (*Ctenopharyngodon idella*) when the current stocking reaches the end of its lifespan and is replaced with new grass carp.

No herbicides were applied to Geelhoutboom Dam for the period 2007 to 2021 as the nuisance vegetation was 100% controlled by sterile grass carp. As the stocked grass carp were more than 18-20 years old (2021), it can be expected that the target species will return to this water body when the biocontrol agent has reached the end of its lifespan. A restocking should soon be done to keep the balancing dam clear of all aquatic vegetation. If sterile grass carp is not available it is recommended that a herbicidal management programme, consisting of four treatments per season with a diquat-based herbicide, should be implemented on the Geelhoutboom balancing dam.

6.5.1.1.2 *Geelhoutboom Canal:*

(a) **During operational periods:**

The Geelhoutboom Canal is only operational when the water transfer scheme augments water to the Vaal River System. During drought periods the canal system can be continuously in use for long periods. In this case it is recommended that an acrolein-based algaecide-herbicide is used to eliminate nuisance vegetation during the operation of the canal. Acrolein controls SAV and algae in both lined and unlined canals and enclosed waters. Acrolein should be applied at the canal inlet (Plate 5.23) according to the label directives. Acrolein is a non-selective contact herbicide which is effective on

both algae and SAV at concentrations ranging from 2 to 15 ppm. If acrolein is used as part of a preventative maintenance programme with frequent scheduled treatments, treatment concentrations of 6 to 7 ppm should be sufficient to control algae and SAV in the canal. The concentration and contact period of acrolein are dependent on the amount of biomass in the canal, flow, target species and water temperature. Acrolein is registered as a restricted-use herbicide in South Africa and may only be applied by the registration holder who will be registered as a certified applicator.

(b) During dry periods:

If the canal is treated during dry (off) periods, when the canal is not operational, the treatment of SAV and terrestrial weeds in the concrete-lined conduit can be done on an as-and-when-required basis. For this purpose, spot-treatments with a diquat-based herbicide are recommended (the canal does not totally dry out). All herbicide applications should be applied when the target plants are actively growing. SAV areas should be managed with a diquat-based herbicide at a concentration mix of 10% active ingredient. Where algae are also encountered, a diquat-copper tank mixture should be used to control both algae and SAV.

The treatment of terrestrial weeds and grasses in concrete slab joints with a glyphosate-based herbicide is recommended on an as-and-when-required basis. Direct spraying with a 4 to 6% active ingredient (glyphosate) mix with wetting agent is recommended for terrestrial plants. It is important to always keep the slab joints free of any plant material as root cavities behind the slabs erode backfill, leading to water intrusion behind the slabs and eventually slab failure.

6.5.1.1.3 Balmoral Canal:

(a) During operational periods:

It is recommended that SAV in the Balmoral Canal should only be treated during dry (off) periods as this concrete-lined canal is only 4.5km long and too short for inline treatment while in operation.

(b) During dry periods:

The treatment of SAV and terrestrial weeds on an as-and-when-required basis is recommended for the Balmoral Canal. All herbicide applications should be applied when the plants are actively growing. For aquatic weeds spot-treatment with a diquat-based herbicide, at a concentration mix of 10% active ingredient is recommended. Where algae

are also present a diquat-copper tank mixture should be used to control both algae and SAV.

A glyphosate-based herbicide for the treatment of terrestrial weeds and grasses in concrete slab joints is recommended on an as-and-when-required basis. All herbicide applications should be applied when plants are actively growing. Direct spraying with a 4 to 6% active ingredient mix with wetting agent is recommended for this canal.

Acrolein should not be used for the control of algae and SAV in the 4.5km long Balmoral Canal as it will reach the natural ecosystem in the Klein-Vaal River and damage non-target fauna and flora. Acrolein is toxic to aquatic organisms at label concentrations and extreme caution is necessary when applying acrolein in any structure that drains to a natural ecosystem.

6.5.1.1.4 Heyshope Dam:

The treatment of 700ha of SAV biomass in Heyshope Dam was initiated in 2001. A diquat-based herbicide was applied (spot or strip-treated) by sub-surface dosing at a concentration of 50liters/ha/m. The original aim was to reduce the target biomass in the impoundment with 90%, to a level of approximately 70ha.

Detailed herbicidal treatment information:

- From 01/12/2007 to 20/12/2007, 105 hectares of *Potamogeton schweinfurthii* and *Stuckenia pectinata* were treated throughout the impoundment.
- From 01/09/2008 to 12/09/2008 SAV was treated in the vicinity of the dam wall, the boat club and at Driefontein.
- From 07/12/2008 to 11/12/2008 a follow-up treatment of 11ha was performed in the direct vicinity of the extraction grids and dam wall structure, within the demarcated area (Figure 6.1).
- The grid-area was evaluated again in March 2009 and spot treatments to the extent of 5ha were executed from 16/03/2009 to 20/03/2009 in the demarcated area (Figure 6.1).

6.5.1.2 Biological control component

6.5.1.2.1 Geelhoutboom Dam:

Stocking density (original):	38 Individuals of sterile grass carp were stocked per hectare at FSA (36ha). A total of 1,400 sterile grass carp were stocked on two separate occasions in 2002 and 2004.
Stocking rate:	09/10/2002 = 400 individuals 21/05/2004 = 1,000 individuals
Current vegetation area:	Nil ha. The SAV in Geelhoutboom Dam is under total biocontrol at all times (operational and non-operational periods).
Maintenance stocking plan:	Additional sterile grass carp stocking is due as the original biocontrol-agents reached the end of their life expectancy. Biocontrol-agents are between 18 and 20 years old.
Numbers of biocontrol-agent to budget for:	1,000 units (2021)

6.5.1.2.2 Geelhoutboom Canal:

No biocontrol-agent was introduced in Geelhoutboom Canal.

6.5.1.2.3 Balmoral Canal:

No biocontrol-agent was introduced in Balmoral Canal.

6.5.1.2.4 Heyshope Dam:

Stocking density:	51 Individuals of sterile grass carp were stocked per hectare in an original 700ha surface area of SAV infestation. A total of 36,000 sterile grass carp were stocked over a 9 year period from 2001 to 2009.
Stocking rate:	05/03/2001 = 4,000 individuals 14/02/2002 = 4,000 individuals 10/01/2003 = 4,000 individuals 23/06/2003 = 4,000 individuals

31/08/2004 = 3,000 individuals
03/03/2005 = 3,000 individuals
26/08/2005 = 3,000 individuals
22/03/2006 = 3,000 individuals
08/12/2006 = 2,000 individuals
31/01/2008 = 1,000 individuals
21/02/2008 = 1,000 individuals
25/04/2008 = 2,000 individuals
26/01/2009 = 1,000 individuals
29/01/2009 = 1,000 individuals
TOTAL = 36,000 INDIVIDUALS

Current vegetation area: The target of the IAVMP was to reduce the original 700ha SAV infestation by 90% to 70ha. This target was reached in May 2008, but grass carp reduced the SAV area to only 1 hectare in 2010.

Maintenance stocking plan: No additional stockings of sterile grass carp are scheduled at this stage as the SAV in Heyshope Dam is currently under biological control. The SAV needs to recover to at least 70ha before any additional control measures will be considered. At this stage only the area at the dam wall, as demarcated in Figure 6.1, should be kept clear of SAV by herbicidal control.

Numbers of biocontrol-agent to budget for: None for Heyshope Dam at this stage (2021).

6.5.2 Methods of application of control components:

6.5.2.1 Herbicidal control component

The herbicide applications must be conducted from a suitable adapted airboat or motorboat (Plate 5.20) in approved areas at prescribed active ingredient concentrations and as per manufacturer specifications as specified on the product labels. No aerial herbicide applications are recommended for SAV treatments in Heyshope Dam.

6.5.2.2 Biological control component

Sterile grass carp is to be stocked in the future at minimum lengths (fork length) of 200mm at prescribed methodologies to ensure predictable survival estimates.

6.5.2.3 Mechanical control component

The mechanical control plan is based on (a) preventing the escape of the biocontrol-agent (sterile grass carp) from the target areas, and (b) preventing SAV biomass from blocking the pump abstraction locations at the Heyshope Dam and Geelhoutboom Dam pumping stations. Three sets of mechanical grids have been erected at the Geelhoutboom Dam (see Plates 5.22, 5.24 and 5.25) and grids were secured under a low water bridge at the inflow to the sensitive Ngulane wetland area.

6.5.2.3.1 *Geelhoutboom Canal outlet grid at Geelhoutboom Dam:*

This multi-functional structure is equipped with stainless steel grids 50mm apart to prevent *inter alia* the upstream migration of sterile grass carp from the Geelhoutboom Dam into the Geelhoutboom Canal. This is a multi-purpose structure which can also be used to deflect surplus water from the canal to a locked-in wetland area at a lower geographical area as the Geelhoutboom Dam (Plates 5.24 and 5.25).

6.5.2.3.2 *Geelhoutboom Dam spillway grid:*

The Geelhoutboom Dam is equipped with a spillway to handle unexpected high flows. Steel grids were placed on top of the spillway to prevent the biocontrol-agent from escaping Geelhoutboom Dam when the spillway is topping. As it was found to be difficult to maintain these grids, it was decided to adapt the operational rules of the Geelhoutboom Dam whereby the impoundment is operated at lower levels to avoid the biocontrol-agent from reaching the spillway.

6.5.2.3.3 *Geelhoutboom Pumping station grid at the forebay:*

The forebay at the inlet of the Geelhoutboom pump station is equipped with a series of heavy-duty grids that can be lifted and lowered with a mobile crane. These grids protect the pumps from blocking with aquatic vegetation and prevent the sterile grass carp to enter the forebay from the balancing dam (Plate 5.22).

Prior to the implementation of the IAVMP on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme, these grids were frequently blocked by aquatic weeds. As a result, the forebay was rapidly drained by the pumps, causing the high-capacity pumps (5m³/s) to trip. This could happen up to a few times per week. In such an event, divers were hired at high cost to clean the forebay and grids.

6.5.3 Timing and sequence of control application:

Herbicide applications - All herbicide applications should be applied when plants are actively growing. In the case of SAV, the water temperatures should be $\geq 15^{\circ}\text{C}$. Terrestrial vegetation treatments should be initiated in early spring when plant growth begins and continued regularly during the growing season as needed. Isolated high density SAV areas should be treated with caution to avoid oxygen depletion and concomitant fish kills as a result of microbial degradation of the decaying biomass.

Biocontrol agent - Triploid grass carp should be released as soon as possible in selected areas during spring. Note that results from grass carp control efforts may not be evident for two or more years.

6.6 ENTITIES TO MANAGE IAVMP AND CONTRACTORS TO APPLY CONTROL AGENTS

6.6.1 Management of IAVMP:

A professional environmental scientist who is licensed as a Pest Control Operator (PCO) and registered with the Pest Control Services Industry Board (PCSIB) will manage the IAVMP and report to the client. Registration with the Registrar: Act 36 of 1947, as prescribed by the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, 1947 (*Act 36 of 1947*) is a prerequisite. The professional environmental scientist will act as programme manager and coordinate all facets of the IAVMP. The programme manager will have extensive experience in the design, implementation and auditing of IAVMPs as well as in the science of applied limnology. Further experience in the application of herbicides in the aquatic environment and experience with grass carp as biocontrol-agent are essential requirements in the management of IAVMP's.

6.6.2 Herbicide application:

A requirement for a commercial applicator of herbicides in South Africa is to be licensed as a PCO with the Registrar: Act 36 of 1947, as prescribed by the Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act, 1947 (Act 36 of 1947). The licensed herbicide applicator shall act under direct supervision of the project manager, as guided by the IAVMP. The herbicide applicator should have at least five years of experience in the application of herbicides in the aquatic environment to participate in DWS IAVMP's.

6.6.3 Supply of biological control agents:

A commercial supplier of triploid grass carp for aquatic vegetation control in departmental structures must be accredited by the DWS. The accredited commercial biocontrol supplier shall act under direct supervision of the project manager, as guided by the IAVMP(s).

6.6.4 Specifications for grass carp as biocontrol agent:

6.6.4.1 Biocontrol agent species to be used

The biocontrol agent species will be the triploid version of *Ctenopharyngodon idella* Val. The biocontrol agent must be certified sterile by the provincial regulating authority.

6.6.4.2 Accreditation of production facility (hatchery)

Recognised producers of the biocontrol agent will be independently audited and accredited by provincial regulatory authorities. This accreditation is based on the implementation of an approved Environmental Management Plan. As prescribed by DWS, all sterile grass carp must be procured from accredited dealers which are in possession of a Certificate of Accreditation, not older than twelve (12) months, from the provincial regulating authority.

6.6.4.3 Unique marking of all individuals of biocontrol agent

All biocontrol individuals must be verified by internal tagging with coded wire tags. These tags consist of microscopically etched and unique codes on small sections of stainless-steel wire implanted into the fish (most often next to the dorsal fin or into the nasal bone).

Each producer has a unique producer code which remains standard to all tags supplied to the producer. In this manner fish can be distinguished between producers.

6.6.4.4 Minimum size of biocontrol agent

The fork length size of each individual biocontrol agent should be no less than 200mm to (1) ensure survival by minimising predation by piscivores and the stocking of the (2) lowest possible number of the biocontrol agent to combat the nuisance vegetation problem.

6.6.4.5 Health of biocontrol agent

The biocontrol agent should be healthy without any macroscopic defect and certified free of the pathogen *Bothriocephalus* (tapeworm) by the Chief State Veterinarian from the provincial Department of Agriculture. The certificate issued should not be older than twelve (12) months when submitted.

6.6.4.6 Operational Environmental Management Plan (OEMP)

An approved OEMP for the biocontrol-agent production facilities, not older than twelve (12) months, should be obtained by the relevant provincial regulatory authority.

6.7 AREAS FOR APPLICATION OF AQUATIC VEGETATION CONTROL

6.7.1 Geelhoutboom Dam:

The full impoundment area (36ha) needs to be under SAV control on a continuous basis. When the grass carp in the balancing dam reach the end of its lifespan it should be replaced and/or herbicidal treatment should be considered if the biocontrol-agent is not available. Stocking of additional grass carp should be done as soon as the target SAV species re-emerge in the balancing dam.

6.7.2 Geelhoutboom Canal:

The entire 20.1km of canal (1.8km pipeline) with an approximate treatment area of 4ha should be considered for herbicidal control.

6.7.3 Balmoral Canal:

The entire 4.5km of canal with an approximate treatment area of 1.5 ha must be treated as and when required.

6.7.4 Heyshope Dam:

Herbicide spot and strip treatments should be performed in the demarcated area (11.5km²) at the dam wall (see Figure 6.1). The target plants in the rest of the impoundment are currently under biological control.

6.8 ECOLOGICAL SENSITIVE AREAS

Ecological sensitive areas were identified by the monitoring programme and should be regarded as “no-go areas” in order to disrupt sensitive communities as little as possible during maintenance of the IAVMP (see Figure 6.2). Four ecological sensitive areas have been identified in Heyshope Dam: (1) The Ngulane wetland area, (2) area at Ngulane River inflow in Heyshope Dam, (3) a relatively large area at the Assegai River inflow in the Heyshope Dam and (4) a bird breeding area in the Heyshope Dam at the Poendaas River inflow.

6.8.1 Ngulane wetland:

The wetland area at the Ngulane River inflow must be protected against sterile grass carp feeding and no herbicide control will be allowed in this area. The area is protected from grass carp by metal grids in pipes under the low water bridge separating the wetland from the impoundment.

6.8.2 Sensitive area at Ngulane River inflow:

Marsilea macrocarpa (Plate 5.3) is regarded as an indicator (of grass carp activity) floral species in this area (2000 and 2006 censuses). During the 2008 aquatic vegetation census no *Marsilea* was detected and it could be ascribed to grass carp feeding activities at the Ngulane River inflow.

6.8.3 Assegaaai River inflow:

Persicaria amphibia (Plate 5.3) is also regarded as an indicator floral species in this area. A high diversity of waterfowl and other bird species was recorded from this area. Up to 55 bird species are frequenting the Heyshope Dam habitat, many of which accumulate in this area. Some of the scarce bird species, regarded as vulnerable on the South African Red Data List, in this area are: The Grey Crowned Crane (*Balearica regulorum*), Blue Crane (*Anthropoides paradisea*), Southern Bald Ibis (*Geronticus calvus*) and African Marsh Harrier (*Circus ranivorus*). None of these species will, however, be influenced directly by the IAVMP on Heyshope Dam.

6.8.4 Bird breeding area at Poendaas River inflow:

This habitat occurs on a very limited stretch (30m) of the shoreline of the dam (Plate 5.16). The hollows in the bedrock render this habitat very favourable nesting sites for birds. All SAV control activities must be restricted in this area.

6.9 LONG TERM MANAGEMENT STRATEGY:

6.9.1 Long term management goals:

- 6.9.1.1 Support the management objectives, established by the IAVMP: Usutu-Vaal Phase II Inter-basin Water Transfer Scheme, which aim to minimise the impact of nuisance aquatic vegetation on the system's ability to maintain a sustainable water supply to the Vaal River System.
- 6.9.1.2 Manage the distribution and abundance of nuisance aquatic plant populations at levels that minimise adverse impacts to relevant water use activities and the environment through the use of approved control methods.
- 6.9.1.3 Maintain or enhance native aquatic plant populations at levels beneficial to water use, water quality, and aquatic ecosystem stability through selective control of nuisance plant populations, where feasible.
- 6.9.1.4 Sterile grass carp was stocked to control nuisance SAV growth in the two impoundments and approved aquatic herbicides were used to control localised

growth in priority use areas. Future plans include annual maintenance stocking of grass carp, where necessary, to maintain the population at a level sufficient to control nuisance vegetation, but minimise impacts on desirable native plant populations. For the medium term grass carp will not be restocked in Heyshope Dam, but restocking is necessary for the Geelhoutboom Dam.

6.9.1.5 Seek to prevent further introduction and distribution of problem plant species through public education, posting signs at boat ramps, regular surveys of the water body, and enforcement of existing laws and regulations.

6.9.1.6 Periodically revise the management strategy and specific control procedures as new environmental data and SAV control techniques become available.

6.9.2 Monitoring programme:

The basis of any IAVMP is a sound monitoring programme. The lack of a monitoring- and management plan in the early history of local aquatic vegetation control programmes, such as Germiston Lake and Lakeside Dam, resulted in long term failure. Annual monitoring of the aquatic vegetation community and extent of coverage is essential. The successes of the IAVMP on target vegetation, as well as the impact on non-target fauna and flora, need to be monitored to guide the IAVMP to its optimum consequence. An annual report containing monitoring results should be produced at the end of each growing season and forwarded to the DWS as a decision support aid for future planning and budgeting.

6.9.3 Herbicide Control Plan:

6.9.3.1 Geelhoutboom Dam

Keep Geelhoutboom Dam free of all aquatic vegetation on a permanent basis. The management objective for Geelhoutboom Dam is therefore to always maintain a programme of total aquatic vegetation control. At this stage this water body is under full scale biological control.

6.9.3.2 Geelhoutboom Canal

Maintain the Geelhoutboom Canal free of all terrestrial and aquatic vegetation with prescribed herbicidal methods.

6.9.3.3 Balmoral Canal

Maintain the Balmoral Canal free of all terrestrial and aquatic vegetation with prescribed herbicidal methods.

6.9.3.4 Heyshope Dam

6.9.3.4.1 *Ongoing herbicidal treatments:*

The demarcated high priority area, illustrated in Figure 6.1, will be treated with the prescribed herbicides on an annual basis to prevent SAV establishment in the area, because they can have a negative effect on the Heyshope Dam pumps and/or be distributed throughout the Usutu-Vaal Phase II System. By keeping this area clear of aquatic vegetation, the biocontrol-agent will also be discouraged to stay in this area, minimising the risk of being flushed out to the lower Assegai River downstream of the impoundment during unpredicted high flows.

6.9.3.4.2 *Maintain the management objective:*

The management objective of SAV in this impoundment allows for the presence of some SAV in the water body to support fauna associated and dependant on submersed macrophytes. SAV should be allowed to grow back to a surface area of approximately 70ha in all areas except the demarcated dam wall area outlined in Figure 6.1. SAV presence should be monitored by quarterly surveys of the plant community and extent of coverage. This monitoring may include aerial photography, visual surveys, hydro-acoustic transects and other appropriate measures as deemed necessary by the project manager in the annual work plan with the aim to map the plant species and coverage. An annual report of the monitoring results will be completed at the end of each growing season and provided to the DWS prior to preparation of the following year's work plan.

6.9.4 Biological Control Plan:

6.9.4.1 Geelhoutboom Dam

Sterile grass carp will continue to be a major component of the long-term management strategy in the Geelhoutboom balancing dam. To keep the Geelhoutboom Dam free of all aquatic vegetation on a permanent basis, it is necessary to monitor the status of the water body regularly. As the grass carp population in the balancing dam is 18 to 20 years old, it has reached the end of their life expectancy and should be replaced soon.

6.9.4.2 Geelhoutboom Canal

No biocontrol agent was stocked in this structure.

6.9.4.3 Balmoral Canal

No biocontrol agent was stocked in this structure.

6.9.4.4 Heyshope Dam

As the SAV in the impoundment was largely removed by the biocontrol agent, no additional grass carp should be stocked into Heyshope Dam until the monitoring programme indicates a need therefore. The SAV population will be given an opportunity to recover to the original objective of the IAVMP. The project manager will review the monitoring data, evaluate the effect on target and non-target organisms and develop recommendations for maintenance stocking levels and other control strategies, if necessary. The IAVMP should be re-evaluated on Heyshope Dam to establish optimum stocking densities (develop a grass carp stocking model) in a reservoir of this nature.

6.9.5 Auditing of IAVMP:

The IAVMP is a dynamic programme and should be evaluated against set goals, and the achievement thereof, annually - ideally at the end of each growing season in the southern hemisphere (May to July). The IAVMP should be updated and amended at appropriate intervals as necessary. Problem site identification and allocation of specific project funding should be conducted annually.

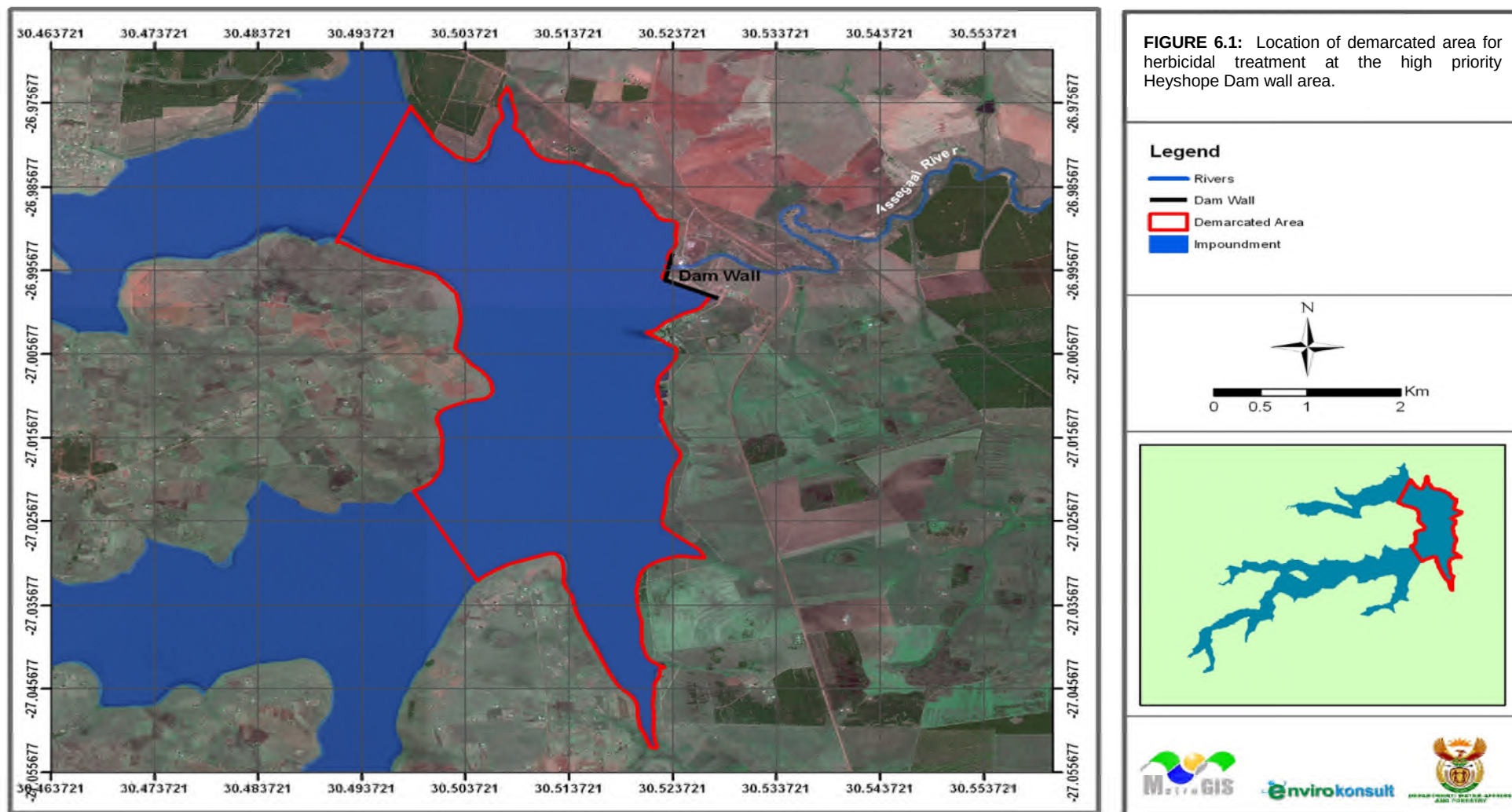


FIGURE 6.1: Location of a demarcated area for herbicidal treatment at the high priority Heyshope Dam wall area.

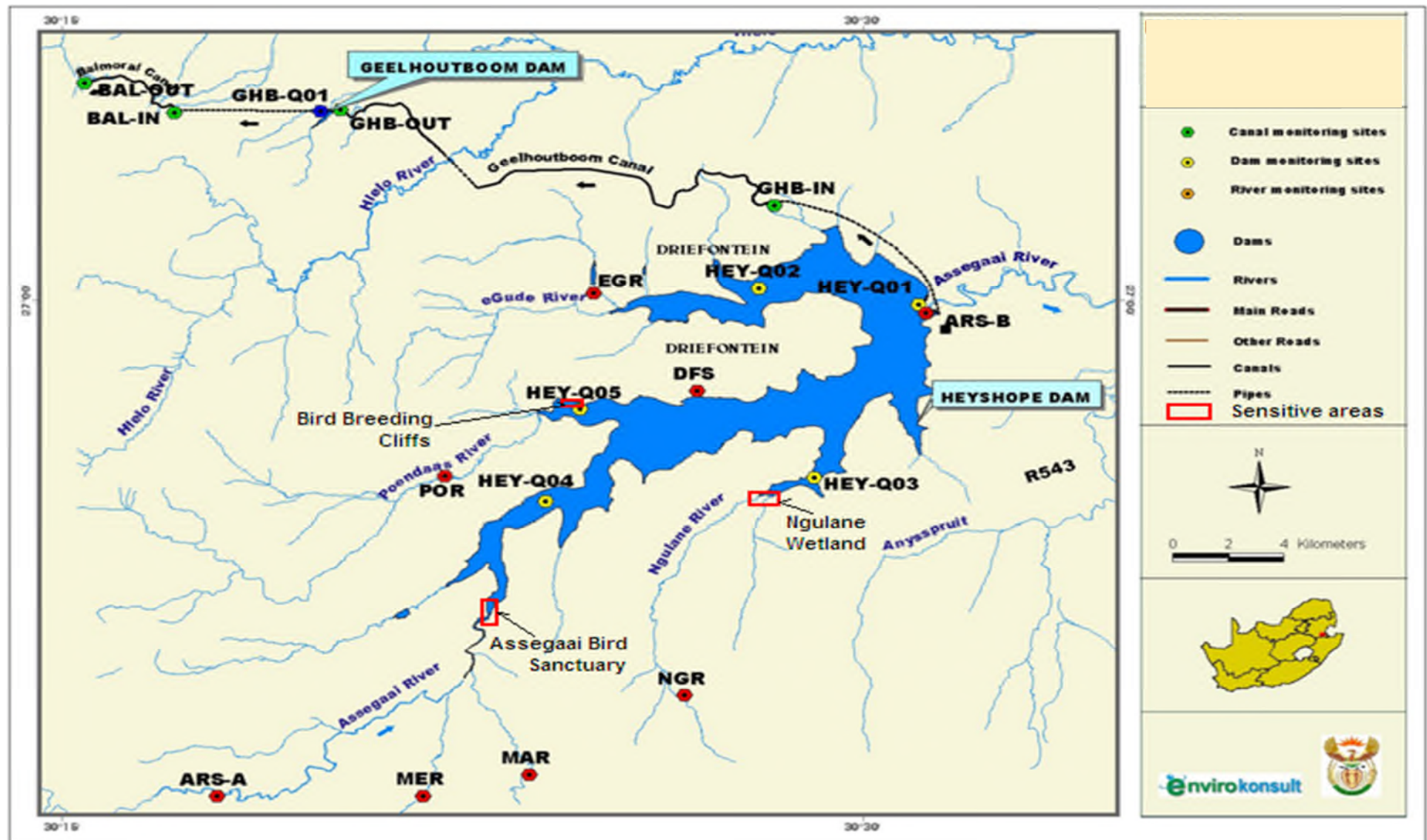


FIGURE 6.2: Locations of ecologically sensitive areas in Heyshope Dam.

CHAPTER 7

THE DYNAMICS OF AN INTEGRATED AQUATIC VEGETATION MANAGEMENT PLAN IN HEYSHOPE DAM

7.1 THE INTEGRATED APPROACH

According to the United Nations Food and Agriculture Organisation (FAO), Integrated Pest Management (IPM) is the coordinated use of pest and environmental information in combination with proven pest control methods to prevent unacceptable levels of pest damage by the most economical means and in a manner that will cause the least possible hazards to persons, property, and the environment (FAO, 2014). As far as nuisance aquatic vegetation is concerned, IPM includes consideration of ecological, biological, chemical, physical and mechanical strategies for the control of nuisance plants.

IPM further emphasises prevention and control methods that provide long-term solutions to pest problems. The optimal complimentary assemblage of all available options is investigated and integrated to obtain the desired objective. In this case an Integrated Aquatic Vegetation Management Plan (IAVMP) was developed around a registered herbicide (diquat) which was combined with a biological control agent, namely the triploid grass carp (*Ctenopharyngodon idella* Val.) with the aim to control certain nuisance aquatic vegetation species in the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme.

In this specific situation, it is important to realise that the nuisance aquatic vegetation in question (target species) is neither exotic, nor declared weeds under Category 1 of the National Environmental Management: Biodiversity Act (Act No. 10 of 2004). They are indigenous aquatic plants with an important ecological function in this specific ecosystem's habitat provision, as well as in its ultimate biodiversity and ecological survival. These plants reached nuisance proportions due to alterations to their habitat where manmade interventions put the aquatic plants in a position to proliferate to such

an extent that they cause problems to the altered ecosystem, as well as the users of that specific waterbody.

It is also important to keep in mind that this water transfer scheme is a manmade structure, designed with the specific purpose to transport surplus water from one catchment, over a watershed, to another catchment with a high demand. The original natural system (rivers) was therefore changed by engineering intervention to support the objectives of the water transfer scheme. The structures are all manmade and the conservation value arising from a changing a natural river to an impounded waterbody (Heyshope Dam) is of secondary concern to the original aims and purpose of the water transfer scheme.

Of further importance in the management of an IAVMP is to base decisions upon facts derived from observation, monitoring and study. Refrain from pre-conceived emotional attitudes, often based upon popular opinions and ignorance rather than facts. This exercise on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme had its successes, but also highlighted potential pitfalls that would require scheduled monitoring and responsible scientific management that is a pre-requisite for IPM to be sustainable and to stay effective on the long-term.

Designing a cost-effective and environmentally sound IAVMP is a challenge. Identification of reservoir uses is fundamentally important because management options for different uses may be incompatible. A management plan for a drinking water reservoir, for example, will likely differ from one developed for a flood control reservoir or a bulk water supply reservoir with specific ecological value. Choosing the appropriate course of action in the face of competing interests and solutions is the ultimate goal of an aquatic vegetation management plan. A number of control methods for aquatic plants (physical, mechanical, chemical, and biological) are available. Like the nuisance plants themselves, all management activities have potential negative environmental impacts. They also vary widely in cost and effectiveness.

Developing a course of action can be made easier by careful development of an IAVMP. The management plan provides a means to make informed decisions for managing nuisance aquatic plants that protect all water users, including the receiving environment. It also assures that aquatic plant management is consistent with other

management plans affecting the specific waterbody, such as operational programmes and catchment management plans.

An IAVMP must consider concerns such as:

- How intense is the aquatic vegetation problem?
- How severe is the impact on the operation of the water transfer system?
- What are the economic implications of this problem?
- At what level will aquatic vegetation become harmful (to different water users) and when should action be taken to control them?
- When is the best time of year to eradicate or suppress the nuisance plant species?
- Which methods will best deal with the target vegetation species and for how long?
- How will the treatment methodologies affect the different water users (including the receiving non-target environment)?
- Are control costs reasonable and affordable?
- Which modifications in management strategies will be needed as nuisance plant conditions change over time?

7.2 THE EXPECTED MAGNITUDES OF COMPONENT-ENVIRONMENT INTERACTION IN HEYSHOPE DAM

7.2.1 The herbicidal component:

The pesticide industry of today is highly disciplined and well regulated. The herbicides used are tested in the aquatic environment and are, if applied according to the legal label instructions, much safer than most household chemicals and terrestrial herbicides. The personnel involved are experienced and registered as Pest Control Operators (PCO's). They are Association of Veterinary and Crop Associations of South Africa (AVCASA) qualified and work in unison with a scientific management component. The environmental impact from this component is localised (focused at the target area), with a limited duration of activity and no significant chemical residue.

On Heyshope Dam the target species were identified as specific SAV (*Potamogeton schweinfurthii* and *Stuckenia pectinata*) and no emergent or terrestrial vegetation was affected by herbicidal applications. Potentially sensitive ecological areas at the inflow of rivers, obvious fish and waterfowl breeding sites, and wetlands were regarded by the IAVMP as “no-go” areas and demarcated as such to manage the application of herbicides responsibly towards non-target organisms.

Only a bipyridyl herbicide (diquat) was used on SAV in Heyshope Dam during this project. Diquat proved to be highly effective on the target organism, allowing fish to escape readily to adjacent areas without any observed discomfort or any fish kills over the operational period of the IAVMP. Areas were treated as spots or strips and were not so large (label indicates <25% of surface area) as to cause oxygen depletion or organic bacterial decomposition.

When diquat is applied to open water, it disappears rapidly because it binds strongly to suspended particles in the water. Diquat is moderately to practically non-toxic to fish and aquatic invertebrates, but food chain organisms such as *Daphnia* can be affected at label concentrations. Diquat is a short-lived (12-36 hours), broad-spectrum liquid herbicide with rapid action and limited drift. Diquat's half-life is less than 48 hours in the water column and may be in the order of 160 days in sediments due to its low bioavailability. The results become visible within 7 days and underground portions (roots, rhizomes and tubers) are not affected as diquat is a contact herbicide. The plant cell membranes of exposed vegetation and photosynthesis are disrupted on contact and control time varies according to plant species and rate of regrowth. In practice typical control is attained for 60-140 days. Diquat is neutralised on contact with soil particles and dissolved organic matter.

The application techniques were refined concerning important fields such as:

- Effective concentration and dosage;
- Timing, temperature and weather conditions;
- Depth of subsurface application and effective dispersion;
- Water quality compensations;
- Size of area to be treated at a time; and
- Re-treatment regime and duration of control attained.

The risks involved are damage to non-target organisms and unsatisfactory control. Neither of these was encountered during the duration of this project. All currently registered herbicides employed for aquatic vegetation control in natural systems are rated as slightly toxic, or non-toxic to fish, birds, insects, and other aquatic organisms provided that proper application rates and techniques are employed. Pesticide labels should be carefully observed to ensure that the non-target aquatic environment is not endangered during pest control efforts.

The effect of the herbicidal component:

The herbicidal component was effective, well conducted and with a very limited environmental risk factor. It interacted with the biological component insofar as to create and maintain a grass carp free area in the vicinity of the Heyshope Dam dam wall and water extraction structures (Figure 6.1). Once this herbicidal component is regarded as unnecessary, it may be an indication that equilibrium is reached between the control methodologies and the SAV presence in the impoundment and no more grass carp should be stocked until a recovery of the aquatic vegetation community is observed. This should be monitored in conjunction with the status and composition of the wetland vegetation and other indicative ecological sensitive areas at river inflows.

The use of aquatic herbicides is not a listed activity under current environmental legislation and is adequately regulated by the product registration process (product label) and PCO training as is stipulated in terms of The Fertilizers, Farm Feeds, Agricultural Remedies and Stock Remedies Act (Act No. 36 of 1947). It is a contravention of the Act to use any of these products contrary to label instructions.

However, as pollution of South African surface waters is on the increase, there can be no doubt about the escalation of nuisance macrophytes and algae in water bodies as a result of increased eutrophication. It can, therefore, be expected that water resource managers will increasingly make use of consultants to manage their nuisance aquatic vegetation problems with various control options. Although the use of herbicides is not a listed activity in terms of environmental legislation, the action of aquatic vegetation management should be regulated to ensure that competent and sufficiently trained environmental scientists manage these actions to its optimum with the minimum negative effect on the receiving environment. In countries such as the USA, Canada and others, a permit from environmental authorities is necessary to implement any

form of aquatic vegetation management in natural water bodies, whether it is an herbicidal, biological or integrated intervention.

7.2.2 The biocontrol component:

The National Environmental Management: Biodiversity Act (NEM:BA Act No: 10 of 2004) and subsequent amendments regulate the release of alien biota in South Africa. The basic requirements in the case of grass carp (*Ctenopharyngodon idella* Val.) are sterility, escape control and the protection of habitat in pristine aquatic environments, as well as the accompanying biodiversity. These activities are also regulated by Sections 24 and 24D of the National Environmental Management: Act (NEMA Act 107 of 1998). A grey area that remains is the stocking density and subsequent interaction with the receiving environment (indicated by the grey area in Figure 7.1).

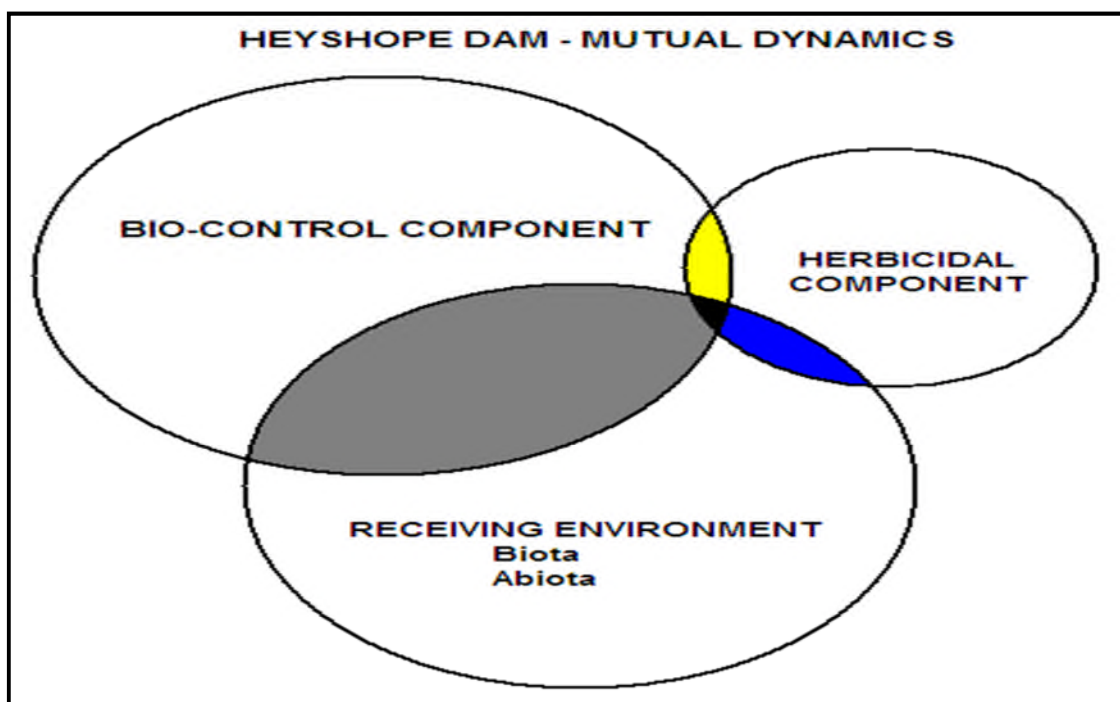


FIGURE 7.1: The relative magnitudes of the expected interaction of the different components of the IAVMP on Heyshope Dam.

To revisit the phases of this programme:

Phase A: Year 2001 to Year 2005:

A reduction of the infested SAV area from 700ha to 375ha was established. This represented a 46% reduction in biomass (as surface area) over a period of 5 years. If

the reduction was linear, it would result in a decrease in SAV of 75 ha/annum. The target SAV species were *Potamogeton schweinfurthii* and *Stuckenia pectinata*. Herbicidal control actions were not monitored, but apparently were $\pm 1,000$ ha. 30,000 Sterile grass carp were stocked over this period (scheduled).

As it was at this stage anticipated that the piscivores in the impoundment would have a significant effect on the survival of the smaller size grass carp, it was decided that 2,000 fish would be added to the target system per annum to compensate for an anticipated 10% annual loss.

Phase B: Year 2006 to 2008:

A reduction of the infested SAV area from 375ha to 69ha was reached. This is a (further) 82% reduction in SAV (as surface area) over a period of 2 years. If this reduction was linear, it would result in a decrease in the SAV area of 155 ha/annum. The target vegetation was reduced to only *Potamogeton schweinfurthii*, as *Stuckenia pectinata* was removed by May 2006 from the impoundment. Scheduled herbicidal control actions were monitored to 105ha. 4,000 Sterile grass carp were stocked (all in 2008). As no fish was available in 2007, both the 2007 and 2008 stockings were done early in 2008.

Phase C: Year 2008 to 2010:

In May 2008 the management objective, to reduce the infestation of nuisance aquatic vegetation (700ha in year 2000) in Heyshope Dam to 10% (70ha) of the original infestation, was reached. At this stage it was realised that the anticipated vulnerability of the grass carp to predation by piscivores at the commencement of the study was overvalued. It was decided to put a hold to the annual maintenance stocking of the biocontrol-agent and to restrict herbicidal treatments to the dam wall area in order to prevent the total eradication of all submersed vegetation in Heyshope Dam. An 11ha area was treated with herbicides at the dam wall area to protect pump infrastructure and to restrict the escape of the biocontrol-agent from the target area. Another 2,000 fish were unfortunately released during January 2009. This was unauthorised by the project management team as the management objective was already reached by May 2008.

With the May 2010 SAV survey, it was confirmed that almost all SAV in the impoundment was removed to an area of just about 1ha. The potential implications of over stocking with the biocontrol-agent can be summarised as follows:

- (a) Loss of non-target flora e.g.:
 - (i) *Persicaria amphibia* at the Assegaa River inlet
 - (ii) *Marsilea macrocarpa* at the Ngulane River inlet
- (b) Loss of shoreline vegetation which could lead to bank erosion
- (c) A possible increase in lake turbidity, or
- (d) a shift from a macrophyte dominated aquatic flora community to an undesirable phytoplankton domination.

The project was terminated after the May 2010 SAV survey, which was very unfortunate as the impact of the absence of SAV in the waterbody could not be studied in more detail.

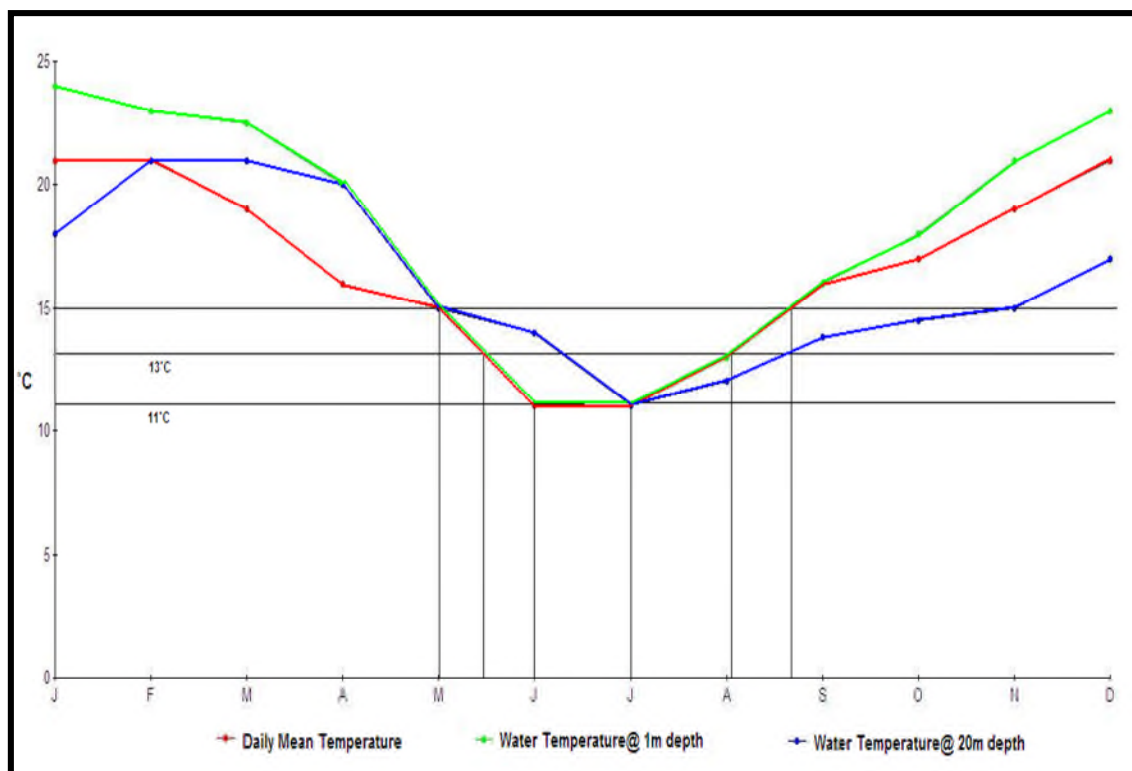


FIGURE 7.2: Principal temperatures that influence the dynamics of an IAVMP at Heyshope Dam.

The behaviour and dynamics of the biocontrol-agent, as well as its principal nourishment (*Potamogeton* and *Stuckenia* spp.) were largely driven by temperature and daylight hours. From Figure 7.2 it is interesting to note the relationship between

water temperature (at a 1m depth and at 20m depth) and recorded daily mean temperature. The lowest water temperature ever recorded during the study in Heyshope Dam was 11°C (during winter destratification) and the highest surface water temperature (not on this graph) was found to be 27°C.

Grass carp still feeds at 11°C. Steady plant consumption starts at 10 to 16°C (Stroganov, 1963; Krupauer, 1989). Grass carp would therefore feed throughout the year at Heyshope Dam, albeit at very different feeding rates. Optimal feeding occurs at 20°C and higher, with the upper temperature limit for consumption of plants about 35°C (Opuszyński, 1972). Adults survive comfortably in a temperature range from 0°C to >35°C. Aquatic vegetation resumes active growth from about 13°C and herbicide dispersion and activity is acceptable from about 15°C. Like all South African dams, Heyshope Dam is a monomictic waterbody which implies that the impoundment stratifies and destratifies only once per season. Lake stratification in Heyshope Dam is not very strong due to relative shallowness (average depth of 7-9m), FSA (5,023.8ha) and proneness to wind-action. Temperature stratification disappears altogether from May to August when the impoundment destratifies and the whole water column is mixed from top to bottom. It is anticipated that the rate of grass carp feeding from May to August (winter months) will be much lower than during the stratified period of the impoundment.

The effect of the biocontrol component:

The IAVMP on SAV in the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme was the largest of its kind in the history of South Africa. From the initiation of this project, the ideal sterile grass carp stocking density was uncertain as it was based on mainly overseas literature, and local experience in much smaller impoundments. A difference in opinion also existed between the project managers (vegetated area) and the suppliers of the biocontrol-agent (total impoundment area), in terms of the approach to be followed to determine stocking density.

Furthermore, no data existed on the feeding behaviour of grass carp on *Potamogeton schweinfurthii*, the primary target species in Heyshope Dam. As this SAV species is more fibrous textured it was assumed to be less palatable than *Stuckenia pectinata*. The optimum stocking density in a large reservoir with a FSA of 5,023.8ha was also difficult to anticipate and the synchronisation with the herbicidal component was complex. However, it was always anticipated that the removal of vegetation biomass

by the biocontrol-agent will follow an exponential curve. The timeframe where the programme would establish a balance between aquatic vegetation growth and removal of biomass could only be determined by an ongoing monitoring programme.

The management objective of 70ha of submerged vegetation was reached earlier than expected. Bearing all these uncertainties in mind, it was clear that a very conservative approach was necessary to prevent overstocking and the consequent eradication of all SAV in target reservoirs.

7.3 ADVANTAGES AND CONSTRAINTS OF THE AQUATIC VEGETATION CONTROL COMPONENTS APPLIED IN THE IAVMP FOR HEYSHOPE DAM

7.3.1 The herbicidal component:

Component:

The herbicide used for this specific programme on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme was Midstream® or Aqua-Quat®, HRAC Herbicide Group Code D (Considered Harmful), Yellow coded contact herbicide with diquat ion (bipyridyl) 200 g/l as active constituent.

Principle:

Diquat is a contact herbicide, available in both a liquid and granular formulation, but only the liquid formulation is available locally. The diquat cation is the active agent of control, which is absorbed rapidly by the foliage. Localised systematic action was noted, but diquat kills primarily by contact.

Control effectiveness and duration:

A contact herbicide (like diquat) will give a faster kill than a systemic herbicide (like glyphosate). As far as the aquatic environment is concerned, diquat can be applied in flowing irrigation canals, ditches, drainage ditches, ponds, lakes, and other waterways.

In early season, when submersed vegetation growth has not reached the water surface, diquat may be applied by dosing directly from the container into the waters of ponds, lakes, and reservoirs by boat. It should be distributed evenly over infested areas in strips situated 5 meters apart. The recommended dosage for high

infestations of submersed species is 50 litres per hectare-meter. In late season, or where submersed vegetation growth has reached the water surface throughout the area to be treated, the herbicide may be applied directly to the water as prescribed or by spraying a diluted solution (10 or 20 to 1) on the water surface.

For control of filamentous algae the same application methods described above should be used. The application dosage should be between 0.5 to 1.5 parts per million of herbicide in the water. Where algae are present with submersed aquatic weeds, pre-treatment with a copper compound is advised for best results, however, care should be taken using copper in the natural environment. A copper-diquat tank mixture can also be applied. Regrowth of target species may occur within the same season of treatment and follow-up treatments are normally necessary to achieve success.

Advantages:

Because diquat can be dosed directly into water, it is under certain conditions very effective against SAV. Diquat is most effective early in the growing season when SAV growth has not reached the water surface. It is easily applied to the waterbody by specialised apparatus on boats or airboats as well as via aerial application. In through flowing systems, such as canals, diquat may be applied to the waterbody by using the inflow of water to both transport and mix the herbicide into the water column.

Aquatic herbicides can be applied target specifically and uncontrolled drift are minimal in the water column. Thus, a specific application can be regulated with no or minimal effect on non-target vegetation. The half-life of the herbicide is short and residues are irreversibly bound to suspended particles with no significant side effects. The most important advantage of herbicides is that it gives the applicator full control of his intervention in the aquatic environment with no long-lasting impacts on the receiving environment (non-target species) after treatment.

Constraints:

Diquat is a post-emergent, non-selective contact herbicide used primarily to control submersed vegetation but it may also be used to control some floating and emergent weeds. The mode of action for diquat is inhibition of photosynthesis and disruption of cell membranes. Diquat is not typically used for algae control and most algal species are not affected by diquat. Diquat does not have a significant effect on survival

structures of target vegetation, such as tubers and seeds. The water temperature needs to be $>13^{\circ}\text{C}$, preferably above 15°C to achieve good control.

Costs and availability:

Diquat is a relative costly herbicide and treatments may cost up to R20,000-00/hectare (2021). Seasonal applications may be necessary to reach the set objectives. Stock is not always freely available in South Africa and often has to be pre-ordered.

Permits:

Herbicide contractors awarded DWS contracts are registered PCO's, AVCASA and Croplife trained and regulated by the product label under Act No. 36 of 1947 and amendments. Further training and advice are often provided by the chemical principal company. Contractors typically receive their final orders from a project work committee, managed by suitable qualified professional aquatic scientists.

The application of herbicides is not seen as a listed activity and is therefore not regulated by specific environmental legislation in this country.

7.3.2 The biocontrol component:

Component:

Grass carp (*Ctenopharyngodon idella* Val.) are exotic, plant consuming fish native to large rivers in China and Russia. Known for their high growth rates and wide range of plant food preference, these fish can control certain nuisance aquatic plants under suitable circumstances. Only triploid grass carp is allowed in South African waters under a strict permit system and environmental legislation.

Principle:

Grass carp is used for lake-wide, low intensity control of submersed aquatic plants. Stocking rates are dependent upon climate, water temperature, type and extent of plant species and other site-specific constraints. The stocking of grass carp requires a permit by environmental conservation authorities as they are non-selective grazers and may cause ecological problems by consuming non-target vegetation. Furthermore, this biocontrol-agent is controlled by environmental legislation requiring a positive Record of Decision (RoD) after the completion of an Environmental Impact Assessment (EIA-BAS) as regulated by the NEM:BA legislation.

Control effectiveness and duration:

Effectiveness of grass carp in controlling aquatic vegetation depends on feeding preferences and metabolic rates that are temperature dependent. Grass carp exhibits distinct food preferences which apparently vary from region to region. Under suitable conditions young grass carp can consume as much as their own mass in vegetation per day. This means that if one tonne of fish is stocked, one tonne of vegetation will be removed per day under optimum conditions. Studies in the United States of America (Miller and Decell, 1984; Hestand and Carter, 1978; Osborne, 1978; Nall and Schardt, 1980; Van Dyke et al., 1984; Sutton and Vandiver, 1986; Bowers et al., 1987 and Leslie et al., 1987) have shown that some plant species are highly preferred, such as the pondweeds *Potamogeton crispus*, *P. zosteriformis* and *Stuckenia pectinata*; others were variably preferred, such as coontail (*Ceratophyllum demersum*), while other plants, such as reeds (*Phragmites* spp.), bulrush (*Typha capensis*) and watershield (*Brasenia schreberi*) are not taken at all.

Grass carp control effectiveness and duration is site-specific. Most management studies on vegetation control by grass carp indicate that substantial removal of vegetation may not become apparent until 3-5 years after introduction into a waterbody. This may be due to difficulties in surveying submersed vegetation. To compensate for the possible lag time in the visual observation of the impact of the biocontrol-agent, a conservative approach to aquatic vegetation control with grass carp is advised.

Advantages:

Depending on the problem plant species and other site constraints, proper use of grass carp can achieve long-term reductions in nuisance growth of vegetation, although not with immediate effect. The introduction of grass carp may result in improved water quality conditions, in areas where water quality deterioration is associated with dense aquatic plant growth. Compared to other long term aquatic plant control techniques (e.g., bottom tillage and bottom barriers), costs for grass carp as biocontrol agent are relatively low. Biocontrol is also significantly cheaper than herbicidal control methodologies (Du Plessis, 2003). Where total control of all vegetation is required, such as in a balancing dam (e.g., Geelhoutboom Dam) the management objective can be reached and maintained for several years by the overstocking of a waterbody with the biocontrol-agent. In these cases the waterbody is

recognised as an artificial structure with no conservation value and the optimal functioning of the reservoir is the principal priority.

Constraints:

Impacts caused by grass carp introductions are complex, and contradictory results are reported in literature. Because grass carp are voracious feeders, they may consume all the palatable aquatic macrophytes present in a waterbody, especially if they are overstocked. Since grass carp exhibits distinct food preferences, they do not graze all plants equally well, limiting their applicability. Food selectiveness, on the other hand, will be emphasised in under stocked situations. The fish may avoid areas of the waterbody experiencing heavy recreational use, resulting in less plant removal. They may also avoid areas where vibrations of pumps and other operational equipment discourage their movement, limiting their effectiveness. These are, in many cases, the areas in an impoundment where SAV causes operational problems and needs to be controlled first, often requiring herbicidal assistance.

Plant reductions may not become evident in several years. Grass carp is also not recommended as biocontrol agent for plant species proliferating by fragmentation. In fact, grass carp may indirectly increase these populations in a waterbody and facilitate the distribution of target species.

Overstocking of grass carp could result in the eradication of beneficial plants and may have significant impacts on the overall ecology of the waterbody. Escape barriers on the in- and outlet are often required to prevent movement of fish out of the system and avoid impacts on downstream or upstream vegetation. Fish loss due to predation by piscivores, such as otters, bass, tiger fish and trout and other fish is possible and need to be considered in the calculations of stocking densities.

Grass carp also disturbs sediment, enhancing turbidity. Grass carp may compete for food with invertebrates and other fish, alter a habitat by reducing macrophyte cover, cause bank erosion, disturb spawning substrates, enrich water with nutrients in expelled faecal matter, and promote secondarily algal blooms (Pípalová, 2006). As a result, food webs and trophic structure of aquatic ecosystems may be drastically altered if over stocking occurs. In contradiction to herbicidal control, adverse impacts may be long lasting, because grass carp can live for many years (18 to 20 years recorded during this study in South Africa). In addition, grass carp may carry parasites

and diseases transmissible to native fish, and may be responsible for introduction of the Asian tapeworm (*Bothriocephalus* spp.) to the fish community.

Costs and availability:

In South Africa there are currently only two producers of sterile grass carp. Costs can range between R9,000-00 to R12,000-00/hectare (2021), depending on the supplier, stocking density, transport, and average size of the fish. Certified sterile grass carp is available in South Africa at a cost ranging from R250-00 to R350-00 per 200mm fish (fork length). Optimal stocking results in continuous control for several seasons where herbicidal treatments may have to be repeated to obtain desirable control.

Permits:

Grass carp is an alien and potentially invasive species that was erroneously imported into South Africa during the 1970's and retrospectively banned in all provinces, except Natal, in 1989. Fish export and import permits are required from local (provincial) conservation authorities prior to sterile grass carp introduction into a waterbody. When this biocontrol-agent is stocked in natural waterbodies the formal Environmental Impact Assessment (EIA) procedure is applicable, according to local environmental legislation. In terms of Section 24 and 24D of the National Environmental Management Act of 1998 (Act No. 107 of 1998), the production and distribution of triploid grass carp are listed activities subjected to environmental authorisation through the EIA process. These activities include:

- The concentration of animals for the purpose of commercial production,
- The release of genetically modified organisms into the environment, and
- The release of any organism outside its natural area of distribution that will be used for biological pest control.

Furthermore, all of these restricted activities are also regulated by Sections 64 and 65 of the National Environmental Management: Biodiversity Act (Act No. 10 of 2004).

7.4 CONCLUSIONS

Grass carp can be effective in controlling aquatic vegetation, but potential adverse impacts to aquatic ecosystems may be significant and should be anticipated in the design phase of the IAVMP. Where only partial control of aquatic vegetation is

desirable, the herbicide component should weigh more than the biocontrol component (sterile grass carp). Where total eradication of vegetation is desirable, the target area should initially be treated with herbicides, and then stocked with sterile grass carp to limit the need for high biocontrol-agent numbers.

The risks and benefits associated with this biocontrol-agent should be carefully weighed on a site-specific basis. Some guidelines and cautions include the following:

- Fertile, diploid grass carp should never be deliberately introduced to any waterbody. Introduction of diploid grass carp into any waterbody is prohibited by South African legislation (NEM:BA, Act No. 10 of 2004).
- Every grass carp intended for release should be genetically tested and certified to verify that they are triploid.
- Sterile grass carp should only be introduced into contained, isolated waterbodies where their chance to escape is limited. Fish barriers should be adequate and rigorously maintained.
- Stocking densities of sterile grass carp should be kept as low as possible to achieve desired effects.
- Large, sterile grass carp provides more effective plant control than smaller individuals and their survival rate is much higher and more predictable. First of all, small fish suffer high mortalities due to predation by birds and piscivorous fish, but survival numbers are highly unpredictable as indicated by this study. In addition, although feeding rates of small fish are high, quantities of plants eaten by smaller fish are not necessarily higher than those eaten by larger individuals. Because of their larger body weight, the use of larger fish can result in larger absolute quantities of plants consumed per fish. Large, triploid grass carp, however, are difficult and more costly to obtain commercially, so this often necessitates the stocking of smaller fish and the use of alternative control methodologies. Considering these motivations, a minimum stocking size of 200mm is prescribed for stocking in DWS reservoirs and water distribution structures.
- Sterile grass carp stocking densities should be reduced to a minimum once undesirable aquatic macrophytes have been controlled. In practice, it is almost impossible to remove carp by mechanical means once they have been introduced into a waterbody. Where annual maintenance stockings are prescribed, numbers should be adapted downwards, or a hold should be placed

on further stockings when vegetated areas are reduced lower than the programme objective.

- Adequate monitoring should be conducted to ensure that significant negative impacts of sterile grass carp will be detected as early as possible.
- No sterile grass carp should be allowed in reservoirs without an approved management programme and no grass carp should be allowed in any river system at all.

CHAPTER 8

GENERAL CONCLUSIONS

8.1 OVERALL SUCCESS OF THE IAVMP ON THE USUTU-VAAL PHASE II INTER-BASIN WATER TRANSFER SCHEME

The most important conclusion is that the implementation of the IAVMP on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme was a success. No pump failures due to interference by aquatic vegetation were experienced during the study period. Unscheduled downtimes could not be attributed to nuisance aquatic vegetation blockages of grids or water transfer pumps.

Although all the management objectives of the project have been met, this exercise on the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme had its successes, but also highlighted potential pitfalls. The near eradication of SAV from Heyshope Dam was a disappointment but underlines the importance to investigate a generic grass carp stocking model with site-specific adaptations for South African conditions.

8.2 SUCCESS OF IAVMP ON MANAGEMENT OBJECTIVE 1 – GEELHOUTBOOM DAM

The first management objective, to keep Geelhoutboom Dam free of all aquatic vegetation on a permanent basis by implementing a programme of total aquatic vegetation control at all periods, was successfully reached in year 2005, three years after the first stocking (2002) of a total of 1,400 (38units/ha) sterile grass carp in this balancing dam.

8.3 SUCCESS OF IAVMP ON MANAGEMENT OBJECTIVE 2 – GEELHOUTBOOM AND BALMORAL CANALS

The second management objective, to keep the two concrete-lined canals free of all aquatic and terrestrial vegetation at all operational times by implementing a programme of total aquatic vegetation control at all operational periods, was successfully reached in year 2002, mainly by treatments with a diquat-based herbicide.

8.4 SUCCESS OF IAVMP ON MANAGEMENT OBJECTIVE 3 – HEYSHOPE DAM

The third management objective was to reduce the infestation of nuisance aquatic vegetation (700ha in year 2000) in Heyshope Dam to 10% (70ha) of the original infestation and to minimise the impact on non-target fauna and flora of the receiving environment. The management objective for the Heyshope Dam was therefore to implement a programme of partial aquatic vegetation control in order to reduce problem vegetation (1) to the extent that they do not interfere with the water transfer pumps at the Heyshope Pumping Station, and (2) to a level where the contamination of the rest of the water transfer system was restricted.

This management objective was successfully reached in May 2008 with the SAV surface area reduced to 69ha, but with the May 2010 SAV survey it was realised that the biocontrol agent had removed almost all the SAV from the impoundment.

8.5 EVALUATION OF THE IMPACT OF IAVMP ON HEYSHOPE DAM

8.5.1 Conservation status of Heyshope Dam:

It is important to keep in mind that this water transfer scheme is a constructed manmade structure, designed with the specific purpose to transport surplus water from one catchment, over a watershed, to another catchment with a higher demand. The original natural system (rivers) was therefore changed by engineering intervention to support the objectives of the water transfer scheme. The structures are all manmade and the conservation value arising from changing a natural river system to an impounded waterbody (Heyshope Dam) is of secondary concern to the original aims and purpose of the water transfer scheme.

Although the Heyshope Dam is an unnatural constructed reservoir, the altered habitat created after construction (from a lotic to a lentic ecosystem) has a definite conservation value as the impoundment plays refuge (especially during drought periods) to many waterbird species frequenting the area. The conservation value of the adapted aquatic ecosystem should be protected as far as possible and the impact of the IAVMP on the non-target species should be kept to a minimum without compromising the original intentions for construction.

8.5.2 Trophic Status of Heyshope Dam:

Heyshope Dam, with a mean annual chlorophyll a concentration (CHL-a) of 3.53µg/l, a mean annual total phosphate concentration (TP-P) of 13.1µg/l and mean annual Secchi disk depth of 0.78m, can currently be classified as an oligotrophic, turbid system.

8.5.3 Impact of the IAVMP on SAV in Heyshope Dam:

- 8.5.3.1 From this study it is clear that grass carp preferred the more palatable softer and finer structured *Stuckenia pectinata* to the more fibrous and hardy *Potamogeton schweinfurthii*, as *S. pectinata* was removed by preference from the impoundment before *P. schweinfurthii*.
- 8.5.3.2 The original SAV infestation of 700ha in 2001 was reduced by 46% to 375ha in 2006 and by 90% of the original infestation to 69ha in 2008 (the target SAV surface area) using a combination of herbicidal and biological control. However, by May 2010 the IAVMP target of a 10% SAV reserve was exceeded and SAV was almost totally removed to a remaining surface area of 1ha.
- 8.5.3.3 The overall aims of the IAVMP were met and the IAVMP on the different components of the scheme was successful. However, the complete removal of SAV from an impoundment with a conservation value is an undesirable outcome as SAV plays an important role in a balanced aquatic ecosystem.
- 8.5.3.4 It is clear that the anticipated impact of piscivores on the fingerling/juvenile sized grass carp in Heyshope Dam was overestimated and hence it can be concluded that the impoundment was overstocked with the biocontrol agent.
- 8.5.3.5 The palatability of the hardy *Potamogeton schweinfurthii* was also no problem for the grass carp. As there was no international information available about grass carp forage on this species the grass carp food preference of *P. schweinfurthii* was uncertain.
- 8.5.3.6 Project funding was unfortunately terminated before the effect of a lack of SAV on the ecological components in the impoundment could be established.

8.5.4 Macro-invertebrate composition of Heyshope Dam:

Twenty-four invertebrate taxa were sampled during April 2000, in comparison to 19 taxa observed during April 2007. Thus, five taxa were not sampled after the implementation of the IAVMP. These taxa are associated with vegetation habitats, and it is anticipated that

the loss of physical habitat was primarily responsible for the loss of macro-invertebrate taxa.

Impact of IAVMP on receiving environment: The result of less diversity of aquatic vegetation in the Heyshope Dam because of the success of the IAVMP has had an impact on the macroinvertebrates associated with a vegetative habitat.

8.5.5 Macro-invertebrate composition of the tributaries of Heyshope Dam:

The diversity of sensitive and flow dependent invertebrate taxa in the rivers was found to be lower than expected. The abundance of filter feeding taxa below the Heyshope Dam is an indication of the relative high concentrations of phytoplankton in the impoundment.

Impact of IAVMP on receiving environment: No indication of a direct impact of the IAVMP could be found in the macro-invertebrate composition of the tributaries of Heyshope Dam. The tributaries were excluded from the IAVMP target areas and no evidence of grass carp activity could be found in any of the rivers upstream or downstream of the impoundments over the study period.

8.5.6 Fish species composition of Heyshope Dam:

Three indigenous fish species (*Barbus polylepis*, *Clarias gariepinus*, and *Tilapia sparrmanii*), and three exotic species (*Cyprinus carpio*, *Micropterus salmoides* and *Gambusia affinis*) were sampled at the selected sites in Heyshope Dam. The only noticeable change in the fish community since the inception of the study was the disappearance of *Pseudocrenilabrus philander*, which needs to be verified in a follow-up monitoring programme.

Impact of IAVMP on receiving environment: The possibility exists that habitat reduction by the removal of aquatic vegetation may be responsible for the current absence of *Pseudocrenilabrus philander* in Heyshope Dam.

8.5.7 Fish species composition of the tributaries of Heyshope Dam:

Of the twelve fish species expected (from historical data) in the Assegaa River, only six were collected during the study period. This decrease in biodiversity may be attributed to the effect of the lentic conditions of impounded water, high altitude and deterioration of

habitat due to other impacts than the introduction of the IAVMP as no evidence of grass carp activity could be found in the rivers.

No grass carp were sampled up- or downstream of the Heyshope Dam over the study period. It can be concluded that the biocontrol agent was successfully contained within the target areas (Heyshope and Geelhoutboom dams) although upstream migration is a possibility during high flow conditions.

Impact of IAVMP on receiving environment: It was concluded that the lower than anticipated fish species diversity in the Assegaa River System cannot be attributed to the implementation of the IAVMP.

8.5.8 Relative abundance of fish species in Heyshope Dam:

The Small-scale yellowfish (*Labeobarbus polylepis*) was found to be the most abundant fish species throughout the study period (2000-2007). The presence of Small-scale yellowfish should be seen as the most important biological component of the Heyshope Dam and this species has done very well and actually increased in abundance since the introduction of the IAVMP in Heyshope Dam.

Impact of IAVMP on receiving environment: The positive effect of the implementation of an IAVMP on the fish community is that the Small-scale yellowfish numbers increased significantly from year 2000 to 2007.

8.5.9 Health condition of fish in Heyshope Dam:

Impact of IAVMP on receiving environment: A positive consequence of the implementation of an IAVMP was that no deterioration of fish health could be observed over the period after introduction of the IAVMP.

8.5.10 Containment of sterile grass carp in target areas:

No grass carp, or evidence of their presence in any of the tributaries of Heyshope Dam, was recorded during the survey period. However, it cannot be concluded that they are largely absent in the Assegaa River and its tributaries. High flow periods in these rivers could provide the necessary stimuli and accessibility for grass carp to migrate into these rivers. Obstructions to migration, such as weirs, may be negotiated over these high flow

periods. A follow-up monitoring programme is necessary to verify the absence of sterile grass carp in the tributaries.

Impact of IAVMP on receiving environment: A positive effect of the implementation of an IAVMP is that no evidence could be found of the biocontrol-agent migrating out of the target area.

8.5.11 Life expectancy of grass carp:

The sterile grass carp stocked in Geelhoutboom balancing dam in 2002 (400 units) and 2004 (1,000 units) died out towards the end of 2021 as the original target SAV was returning to the waterbody and no grass carp activity was observed in the balancing dam. It can therefore be concluded that the biocontrol agent has a life expectancy of up to 18 years under local conditions.

8.5.12 Minimum stocking size of grass carp:

Studies in research ponds in Florida in the US revealed that the number of grass carp lost to predation ranged from 7% to 70% one year after stocking (AERF, 2014). Many site-specific variables will influence a grass carp stocking model. To limit unpredictable survival rates a minimum stocking size of 200mm fork length is proposed for sterile grass carp as the survival rate of smaller fish may vary extensively.

8.5.13 Impact of the IAVMP on the waterbirds of Heyshope Dam:

As expected, a decrease in Red-knobbed coot (*Fulica cristata*) numbers was experienced after the implementation of the IAVMP in Heyshope Dam. The primary food source of coot is *Stuckenia pectinata* which is now totally eradicated from Heyshope Dam as a result of the IAVMP. It is anticipated that this waterfowl species will find refuge in the many surrounding wetland areas and smaller dams and that their numbers on Heyshope Dam will be limited. White-backed duck (*Thalassornis leuconotus*) numbers also decreased from historical surveys to none observed in the 2005-2007 surveys. They also feed largely on submersed and floating plants.

Impact of IAVMP on receiving environment: The introduction of the IAVMP on Heyshope Dam resulted in a sharp decline in the numbers of the two true open water avian herbivores on the impoundment, *Fulica cristata* and *Thalassornis leuconotus*.

However, *Thalassornis leuconotus* is known as a very strong nomadic bird and their absence during the study period is not a cause for concern. *Fulica cristata* aggressively protects its territory and scares away other competitive waterbird species and they are therefore considered as very strong territorial birds. It is anticipated that the reduction in their numbers may facilitate waterfowl species diversity.

8.5.14 Impact of the IAVMP on non-target aquatic vegetation:

During 2008, seven years after the introduction of the IAVMP in the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme, two non-target aquatic plants have disappeared from the impoundment. As these plant populations were not treated with herbicides, it is believed that they were removed as a result of grass carp feeding. The impact of the biocontrol-agent on non-target floral species needs to be verified in a follow-up monitoring programme.

Impact of IAVMP on receiving environment: The negative effect of the biocontrol-agent on the receiving environment is that the non-target flora species, *Marsilea macrocarpa* and *Persicaria amphibia*, were removed from the impoundment before removal of the target vegetation.

8.5.15 Submersed Aquatic Vegetation Potential Growth Area (SAVPGA) in Heyshope Dam:

The SAVPGA₁₀₀ at a dam level of 100% was calculated to 1,074ha which is 21.36% of the water surface at FSL. In the case of an 80% dam level, SAVPGA₈₀ will be 1,031ha which calculates to 23.30% of the water surface at 80% of the FSL. The SAVPGA needs to be adapted to exclude areas not supporting SAV growth and the SAV reserve (SAV not controlled to support a balanced aquatic ecosystem) to calculate a more accurate figure for budgeting purposes.

8.6 DEVELOPMENT OF IAVMP'S FOR OTHER SOUTH AFRICAN IMPOUNDMENTS

This study was the first on the implementation and evaluation of a large scale IAVMP on submersed aquatic vegetation in South Africa. The study highlights the successes and shortcomings in the development of an IAVMP for the Usutu-Vaal Phase II Inter-basin Water Transfer Scheme. With this knowledge and experience gained, the developed

IAVMP can be extrapolated and adapted for other waterbodies and water conveyance structures that experience similar problems with nuisance aquatic vegetation.

CHAPTER 9

RECOMMENDATIONS

9.1 MONITORING PROGRAMME

It is recommended that the second phase of the monitoring programme should be activated as soon as possible with the aims to:

- 9.1.1 Audit the IAVMP on a regular basis to maintain the success of the Usutu-Vaal Phase II Inter-basin Water Transfer System programme.
- 9.1.2 Evaluate the impacts of the IAVMP on non-target fauna and flora and sensitive ecological areas. It will be of value for the development of future IAVMP's to establish the effect of the near total absence of SAV on the aquatic ecology of the impoundment over a longer monitoring period.
- 9.1.3 Optimise all components of the IAVMP.

9.2 ISSUES TO BE ADDRESSED IN THE IAVMP MONITORING PROGRAMME

- 9.2.1 Establish the dynamics of the impact of the IAVMP on nuisance aquatic vegetation and its effects on the overall water transfer operation.
- 9.2.2 Continue the evaluation of the impact of the programme on target species in the two impoundments and the two canals.
- 9.2.3 Monitor escaping of the biocontrol agent, sterile grass carp, from the target areas and implement mitigation actions, if necessary.
- 9.2.4 Establish the impact of the programme on non-target species in Heyshope Dam, with special attention to the sensitive areas identified.
- 9.2.5 Establish the minimum percentage of vegetation cover necessary to maintain the ecological integrity of a large water body such as the Heyshope Dam.
- 9.2.6 Establish the effects of the biocontrol agent on the possible disappearance of the aquatic plants *Persicaria amphibia* and *Marsilea macrocarpa*, as well as the fish species *Pseudocrenilabrus philander* (Southern mouthbrooder) from Heyshope Dam.
- 9.2.7 Develop a more sensitive stocking density model for sterile grass carp on specific target species for South African conditions. Establish the restocking rate necessary to maintain a successful preventative maintenance programme.

- 9.2.8 It is recommended that the herbicidal control component should be optimised and other newly registered herbicide formulations evaluated on SAV.
- 9.2.9 The first round SAVPGA (presented in this study) should be improved by characterising areas where SAV will typically grow, as well as areas where they will be absent or growth restricted.
- 9.2.10 The impact of the near total eradication of SAV in Heyshope Dam should be evaluated as soon as possible. As the stocked sterile grass carp are approaching the end of their life expectancy, monitoring of the recruitment of SAV, in the absence of grass carp, will be invaluable for the development of subsequent IAVMP's on impoundments in South Africa. It will be interesting to see if *Potamogeton schweinfurthii* will return as the dominant SAV species or if other SAV species, previously absent from the waterbody, will be introduced to the impoundment in the absence of the biocontrol-agent.

9.3 CONTINUANCE OF THE IAVMP ON THE USUTU-VAAL PHASE II INTER-BASIN WATER TRANSFER SCHEME

9.3.1 Herbicidal control component of IAVMP on Heyshope Dam:

For the second phase of the IAVMP, herbicidal treatments will be restricted to the dam wall area on an as-and-when-required basis, as dictated by observations/surveys during the monitoring programme. This is necessary to keep the water transfer pumps clean from aquatic vegetation and to restrict movement of sterile grass carp at the dam wall area, preventing them from escaping the target area and contaminating the Assegaa River System.

9.3.2 Biological control component of IAVMP on Heyshope Dam:

For the second phase of the IAVMP, no additional sterile grass carp will be stocked in the Heyshope Dam.

9.3.3 IAVMP on Geelhoutboom Dam:

Continue to monitor the status of Geelhoutboom Dam and implement control measures as soon as an increase in SAV biomass is observed in the impoundment.

9.3.4 IAVMP on Geelhoutboom Canal:

Continue to monitor the status of the Geelhoutboom Canal and implement control measures as soon as an increase in aquatic plant biomass and algae are observed in the conveyance structure. It is recommended that the aquatic vegetation in this canal should be managed with an acrolein-based herbicide on a scheduled preventative maintenance programme.

9.3.5 IAVMP on Balmoral Canal:

Continue to monitor the status of the Balmoral Canal and implement restoration measures as soon as an increase in aquatic plant biomass and algae are observed in the conveyance structure. It is recommended that the aquatic vegetation in this conduit should be managed by spot-treatments on an as-and-when- required basis. An acrolein-based herbicide is not recommended as it will have a negative impact on non-target fauna and flora in the receiving Klein Vaal River.

9.4 DETERMINATION OF BIOCONTROL AGENT BEHAVIOUR IN HEYSHOPE DAM

Movement is an important factor in the evaluation of grass carp effectiveness. Fish that move extensively over time may become more likely to migrate to areas where they are unwanted and less likely to remain in target areas. Information on diurnal movements is also valuable to determine if fish are visiting secondary feeding areas at night.

The implementation of a grass carp biotelemetry programme will shed new light on the ethology of this species within the Heyshope Dam. The outcome of this investigation will assist in the development of a sterile grass carp stocking density model for large dams in South Africa.

9.5 DEVELOPMENT OF IAVMP's FOR WATER MANAGEMENT ENTITIES

It is recommended that the Water Management Plans of irrigation schemes and the Resource Management Plans for reservoirs should accommodate IAVMP's in its initial development to enable water managers to plan for an aquatic vegetation management programme as early as possible.

9.6 SUITABILITY OF WATERBODIES WHERE GRASS CARP CAN BE APPLIED AS BIOCONTROL AGENT

Biocontrol by grass carp is the most cost-effective method for long-term control of SAV. Grass carp are, however, best applied where the loss of all palatable submersed vegetation is an acceptable outcome for an extended period. Thus, the use of triploid grass carp as biocontrol agent is recommended only for waterbodies with a low or no conservation value. For waterbodies with a higher conservation status the EIA protocol should be followed to establish whether it is safe to use grass carp as part of an IAVMP.

9.7 REFINEMENT AND EXTRAPOLATION OF IAVMP

The recommendations made in this chapter are necessary for the final refinement of the IAVMP for the Usutu-Vaal Phase II Water Transfer Scheme for application with site-specific adaptations in other South African impoundments experiencing similar problems with nuisance aquatic vegetation.

CHAPTER 10

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