Anthropogenic Effects on Sustainability of Fish Biodiversity in Tyhume River, Eastern Cape, South Africa

By

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Declaration

I, the undersigned, hereby certify that this dissertation is my own original work, except where references to the contrary are indicated. This work has not previously been submitted to another university. It may be photocopied for educational purposes and made available on inter-library loan, subject to copyright laws of South Africa.

Jane Njeri Kinya
May 2018

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Dedication

To the loving memory of my son, Master Mbugua Kinya and my father, Mr. Mbugua Ndukui, who both brought sunshine to my life; to my mother, Mrs. Mwihaki Mbugua, for unwavering support. To my husband, Mr. Kinya Gichohi, and to my children, Gichohi, Gacheri and Mwihaki, who believed I had what it takes to complete this journey.

Abstract

To determine the anthropogenic effects on the sustainability of fish biodiversity in Tyhume River, a mixture of ecological, economic and institutional parameters were used. To measure ecological parameters, 10 study sites were selected to represent varying intensities of anthropogenic effects on habitat, to represent typical river zones, and to correspond with historical survey sites for trend analysis. In these study sites, habitat characteristics that represent geomorphology (habitat quantity), water quality and 'alien' (non–native) fishes were used to determine anthropogenic effects on habitat and fish assemblage. The measured geomorphology characteristics included current velocity, wetted width and depth. The water quality characteristics used were temperature, pH and conductivity. To determine the effects of native and non-native on indigenous fish species *in situ,* electro fishing was used in riffles, small pools and runs; as well, *in situ* seine-netting was done in pools. The riches of river fish species was measured, using numbers abundance and longitudinal distribution indices.

It was established that only 11% of the Tyhume River habitat was relatively near natural, while 89% exhibited anthropogenic habitat modification. Three major sources of anthropogenic modification on habitat were identified. The major contributor of anthropogenic effects was Binfield Park Dam which accounted for 43% of modification. The second source of anthropogenic effects on habitat was Alice urban area where storm water runoff accounted for 28% of modification. Agricultural and livestock grazing, the third anthropogenic effect, accounted for 18% of modification.

The Eastern Cape Rocky, *Sandelia bainsii* Castelnau, 1861 and Border Barb, *Barbus trevelyani* Günther, 1868, exhibited reduced distribution. *B. trevelyani* longitudinal distribution was less than 25 km along the river continuum, with sporadic presence in the sandy foothills. *S. bainsii* was not found in the Lowland Zone, while previously this species extended from the mountainous zone to the confluence of the Tyhume and Keiskamma Rivers in the Lowland Zone. These indices supported the homogenization theory, as reflected by increased dissimilarity for two indigenous fish species, *S. bainsii* and *B. trevelyani,* among study sites. *S. bainsii* was previously

distributed from source to confluence, while *B. trevelyani* recorded a 50% decline at the study site below the Binfield Park Dam.

To assign economic value to ecosystem services and assess post Rio-institutional parameters two hypothetical scenarios were developed from the ecological survey; one depicting current conditions and another depicting improved ecosystem services. Using a structured interview questionnaire, five ecosystem services in need of restoration were described to respondents. Applying the contingent valuation method respondents were asked a dichotomous choice question on willingness to pay (WTP).

Results of the economic study from 209 personal interviews revealed, individuals were willing to pay an additional R 32.00 on their monthly water bill or R 384.00 annually. Generalizing this to 2 829 households living in the Alice and Ntselamanzi urban areas, a total value of R 1 086 336 would be realized annually. This was equivalent to the Nkonkobe Municipality annual budget for storm water management in Alice urban area. Costs/benefits revealed a positive net present value (NPV) = 1, which, in line with economic theory, meant gainers were able to compensate losers

The institutional part of the economic survey sought to determine the effects of post Rio Earth Summit institutional measures on sustainable management of Tyhume River fish assemblage. A desk review of Rio Declaration and three South African statutes were used namely; Constitution Act 108 of 1996 (South African Constitution 1996); the National Environmental Management Biodiversity Act No. 10 of 2004 (NEMBA 2004), the National Environmental Management Act (NEMA) No. 107 of 1998 (NEMA 1998), and the National Water Act No. 36 of 1998 (NWA 1998). The Institutional and Analytic Development (IAD) Framework, coupled with requirements for sustainability of Multiple Use Resource Domains were used for the analysis.

De Jure, the statutes had internationalization of environmental costs through “polluter pays principle”, while sustainable use was the overarching goal. *De facto,* the community participation, a requisite of post Rio measures, was low; however

89% of community respondents were willing to join an environmental conservation group. This, coupled with the fact that 77% of those interviewed supported the establishment of a Tyhume River Restoration Fund, provided scope for a broad based community participation framework

This study contributes to sustainable use of Tyhume River and other lotic systems by generating information on the link between anthropogenic effects on fish biodiversity, economic value of ecosystems services and institutional mechanisms.

Key Words: Alice urban area, anthropogenic effects, community participation, Eastern Cape Province, economic value, fish assemblage, institutional mechanisms, ecosystem services, Tyhume River, willingness to pay

Table of Contents

DECLARATION II

ACKNOWLEDGEMENTS III

DEDICATION V

ABSTRACT VI

LIST OF FIGURES XIV

LIST OF TABLES XVI

ACRONYMS XVII

CHAPTER 1: INTRODUCTION 1

1.1: The Tyhume River 1

1.1.2: Geomorphology 2

1.2: Sustainability of Tyhume River Fish Biodiversity 3

1.3: Anthropogenic Effects on Lotic Systems 6

1.4: Anthropogenic Effects on Fish Biodiversity 8

1.5: Economic Valuation of Ecosystem Services and Sustainability 9

1.6: The Aim of this Study 12

1.7: The Hypothesis 12

1.8: The objectives of this Study 12

1.9: The Plan of This Thesis 13

CHAPTER 2: LITERATURE REVIEW 14

2.1: Anthropogenic Effects, Externalities and Sustainable Use of Lotic Systems . 14

2.2: Anthropogenic Effects on Geomorphology 17
2.2.1: Flow Rate (Current Velocity) 18
2.2.2: River Width 19
2.2.3: River Depth 19

2.3: Anthropogenic Effects on Water Quality Characteristics 19
2.3.1: Temperature 20
2.3.2: Hydrogen Ion Concentration (pH) 21
2.3.3: Conductivity 21

2.4: Anthropogenic Effects on Fish Assemblage 22
2.4.1: Tyhume River Fish Assemblage 25

2.5: Fish Abundance and Occurrence 30

2.6: Fish Distribution 31

2.7: Economic Value of Ecosystem Services 32
2.7.1: Concepts of Ecosystem Services Economic Value 34
2.7.2: Methods Used to Value Ecosystem Services 39
2.7.3: Stated Preference Method (SPM) 41
2.7.4: Inferring Economic Value from Legal and Social Consequences 42
2.7.5: Economic Value of Ecosystem Services and Sustainability 42

2.8: Institutional Mechanisms and Degradation of Fish Biodiversity 43
2.8.1: Conventional Property Rights Regimes 46
2.8.2: Institutional Choice Theories 48
2.8.3: Legal Framework for Lotic Resource Governance in South Africa 49

2.9: Post Rio Earth Summit Institutional Reform Measures 52
2.9.1: Complexities of Sustainability 54

2.10 The Changing Role of the State 57

2.11: Methods and Theories Underlying Institutional Analysis 58
2.11.1: Methodological limitations 58

2.12 Summary 59

CHAPTER 3: MATERIALS AND METHODS 62

3.1: Water Management in the Study Area... 62
3.1.1: Economic Activities 63
3.1.2: Income and Employment 63
3.1.3: Vegetation and Land use 64

3.2: Selection of Study Sites... 65
3.2.1: Study Sites Geographic Coordinates 66
3.2.2 Pictorial Record of Selected Representative Study Sites........................... 66

3.3: Measure of Anthropogenic Effects on Habitat Characteristics....................... 66
3.3.1: Geomorphology Habitat characteristics (Quantity)..................................... 66
3.3.2: Water Quality Characteristics (Habitat quality) 67
3.3.3: Statistical Analysis for Habitat Characteristics 69

3.4: Summary Statistics.. 69
3.4.1: Measures of Central Location 69
3.4.2: Data Distribution 69
3.4.3: One way Analysis of Variance (ANOVA) 70
3.4.4: Quantification of Extent of Anthropogenic Modifications on Habitat 71

3.5: Measurement of Anthropogenic Effects on Fish Assemblage 72
3.5.1: Fish Collection... 72
3.5.2: Fish Measurement and Identification 73
3.5.3: Fish Assemblage Analysis 74
3.5.4: Fish Distribution 75
3.5.5: Jaccard’s Index of Similarity... 75
3.5.6: Cluster Analysis 75
3.5.7: Fish Length Frequency Analysis 76

3.6: Assigning Economic Value to Five Ecosystem Services 76

3.7: Application of Contingent Valuation Method (CVM)..................................... 76
3.7.1: Hypothetical Scenarios 77
3.7.2: Ecosystem Services Economic Value and Post Rio Measures Institutional Data Collection Questionnaire 82
3.7.3: Ecosystem Value Economic Data Statistical Analysis 83
3.7.4: Determination of Post Rio De jure Institutional Measures.......................... 85

3.8: Community participation 87

3.9: *De jure* property right... 87

CHAPTER 4: RESULTS.. 88

4.1: Annotated Tyhume River Study Sites Characteristics 88
4.1.1: Geographic Coordinates of the Study Sites 88
4.1.2: Study Sites Characteristics 89
4.1.3: Determined Anthropogenic Effects on Tyhume River Habitat 101

4.2: Determined Anthropogenic Effects on Fish Assemblages in Tyhume River 111
4.2.1: Trend Analysis of Anthropogenic Effects on Fish Assemblage Abundance 111
4.2.2: Fish Assemblage Composition.. 112
4.2.3 Fish Distribution 116
4.2.4: Annotated Length Frequency Distribution and Weight............................ 121

4.3: Determined Economic and Institutional Value of Ecosystem Services 126
4.3.1: Economic Evaluation Questionnaire Responses 126
4.3.2: Institutional Evaluation Questionnaire Responses................................... 130

CHAPTER 5: DISCUSSION.. 137

5.1: Anthropogenic Effects on Tyhume River Habitat.. 137
5.1.1: Anthropogenic Effects on Fish Assemblage.. 138

5.2: Economic Value of Ecosystem Services 143

5.2.1 Economic Efficiency 145

5.3: The post Rio Institutional Measures 145

5.4 Applicability to Other Catchments 146

5.5: Impact of Post Rio Measures on Sustainability of Fish Assemblage in Tyhume River 147

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS 150

6.1: Sustaining Tyhume River Fish Biodiversity 150

6.2: Economic Activities 151

6.3: Recommendations 157

6.4: Limitations of the Study 157

REFERENCES 158

APPENDIX I: DATA GEOMORPHOLOGY HABITAT QUANTITY CHARACTERISTICS 176

APPENDIX II: DATA ON FISH ASSEMBLAGE 178

APPENDIX III: MAP REQUEST LETTER 179

APPENDIX IV: LETTER OF AUTHORITY FROM DEPARTMENT: RURAL DEVELOPMENT & LAND REFORM 181

APPENDIX V: QUESTIONNAIRE: ECONOMIC VALUATION OF TYUME RIVER ECOSYSTEM SERVICES 183

APPENDIX VI: ECONOMIC DATA 187

List of Figures

Figure 1.1: Map of the study area……………………………………………………….2
Figure 1.2: Sustainability Framework……………………………………………………..6
Figure 2.1: Global distribution of Anabantid family……………………………………..28
Figure 2.2: Distribution map of *Sandelia bainsii* and *Barbus trevelyani* in
Eastern Cape Province South Africa…………………………………………………….29
Figure 3.1: Map of Water Management Area 12………………………………………62
Figure 3.2: Land Use Map of WMA 12 Mzimbuvu to Keiskamma……………………65
Figure 3.3(a) Hypothetical Scenarios depicting Current Management of
Tyhume River (Scenario 1a)……………………………………………………………..78
Figure 3.3(b): Hypothetical Scenarios depicting Increased Ecosystem
Services at Tyhume River (Scenario II) (b)……………………………………………..80
Figure 4.1: Study Sites Elevation in Metres above Sea Level (MASL)....................89
Figure 4.2: Study Site 1 (Swallowtail)……………………………………………………90
Figure 4.3: Study Site 2 (Mtloko)…………………………………………………………91
Figure 4.4: Study Site 3 (Sanctuary)……………………………………………………92
Figure 4.5 Study Site 4 (Auckland)………………………………………………………93
Figure 4.6: Study Site 5 (Macfarlan)……………………………………………………..94
Figure 4.7: Study Site 6 (Melani)…………………………………………………………95
Figure 4.8: Rural land use around Study Sites 5 and 6………………………………..95
Figure 4.9 Sawmill Plant Close to Study Site 6…………………………………………96
Figure 4.10: Study Site 7 (Gqumashe)……………………………………………….......97
Figure 4.11: Study Site 8 (Honeydale)…………………………………………………..98
Figure 4.12: Alice urban area and Fort Hare University above Site 8……………….98
Figure 4.13: Aquaculture Activities within Fort Hare University Farm………………..99
Figure 4.14: Study Site 9 (Njwaxa)……………………………………………………..100
Figure 4.15: Study Site 10 (Junction above Confluence)……………………………101
Figure 4.16 Tyhume River Wetted Width………………………………………………103
Figure 4.17 Tyhume River Depth………………………………………………………..103
Figure 4.18 Tyhume River Monthly Current Velocities per Study Site……………..105
Figure 4.19: Tyhume River Current Velocity Mean Variation per Study Site……...106

Figure 4.20: Tyhume River Temperature at Site (4) above and (Site 5) below Binfield Park Dam and Sites 6 & 7above and Site 8 below Alice Urban Area (a) and per Site Temperature Variation (b)……………………………………………..107
Figure 4.21: Tyhume River Conductivity…………………………………………….109
Figure4.22: Tyhume River pH………………………………………………………..109
Figure 4.23: Extent of Anthropogenic Habitat within Tyhume River………………..111
Figure 4.24: Trend analysis showing pre and post impoundment abundance of *Sandelia bainsii* and *Barbus trevelyani* at study site 3 above and below Binfield Dam……………………………………………………………………….112
Figure 4.25: Relative abundance of fish species in Tyhume River 2006/2007…...113
Figure 4.26: Relative abundance of fish species by categories 2006/2007……….114
Figure 4.27: Comparison of relative abundance of fish species at study sites(a) above Binfield and (b) below Binfield Dam…………………………………..115
Figure 4.28: Comparison of relative abundance of fish species at study sites above (a) and below (b) Alice urban area……………………………………………..116
Figure 4.29: Jaccard's Similarity Index for Study Sites Clusters……………………118
Figure 4.30: Fish assemblage community clusters…………………………………...119
Figure 4.31: Length frequency distribution of *Barbus trevelyani*……………………122
Figure 4.32: Length frequency distribution of *Labeo umbratus*……………………..124
Figure 4.33: Length frequency distribution of *Sandelia bainsii* ……………………...124
Figure 4.34: Length frequency distribution of *Tilapia sparrmanii*…………………...126
Figure4.35: Frequency distribution WTP Bid………………………………………….129
Figure 4.36: Tyhume River de facto state of habitat (a) and de facto state of Fish Assemblage (b)…………………………………………………………………..131
Figure 4.37: Current direct users by Alice and Ntselamanzi residents…………….132
Figure 6.1: Tyhume River sustainability framework..151

List of Tables

Table 2.1: Comparison of pre and post impoundment abundances of *Sandelia bainsii* and *Barbus trevelyani* at study sites 3 (above) and 7 (below) Binfield Dam……………………………………………………………………………..31

Table 2.2: Comparison of pre and post impoundment fish distribution; 1983 and 1989……………………………………………………………………………….32

Table 2.3: Analytical framework for governance of common pool resources……….58

Table 4.1: Study sites, zones and land use characteristics…………………………...88

Table 4.2: Summary statistics for habitat characteristics of the study sites………..102

Table 4.3: Tyhume River fish assemblage current distribution 2006/07……………117

Table 4.4: Comparison of fish species distribution in 1983, 1989 and 2006/07j………………………………………………………………………………121

Table 4.5: Comparison of demographic study survey (2007 results with 2001 population censor statistics)…………………………………………………127

Table 4.6: Summary statistics on monthly income, WTP Bid, and Demographics……………………………………………………………………….128

Table 4.7: Descriptive statistics for the WTP analysis………………………………..129

Table 4.8: Logit regression model for parameter estimate on WTP Probability…………………………………………………………………………130

Table 4.9.: Comparison of *De jure* and *De facto* rights……………………………...133

Acronyms

BAU	Business as Usual
CBA	Cost Benefit Analysis
CBD	Convention on Biological Diversity
CVM	Choice Valuation Methods
CEMARE	Centre for the Economics and Management of Aquatic Resources
CMA	Catchment Management Agency
CPUE	Catch per Unit Effort
CSIR	Council for Scientific and Industrial Research (South Africa)
CVM	Contingent Valuation Method
DEAET	Department of Environmental Affairs, Economic and Tourism
DPSIR	Driving force-Pressure-State-Impact-Response
ECA	Environmental Coordination Act
EN	Endangered
EU	European Union
FAII	Fish Assemblage Integrity Index
GMRDC	Govan Mbeki Research and Development Centre
HPM	Hedonic Pricing Method
IBI	Index of Biotic Integrity
IAD	Institutional Analysis and Development
IDP	Integrated Development Planning
IHI	Index of Habitat Integrity
ISP	Internal Strategic Perspective
IRR	Internal Rate of Return
IUCN	International Union for Conservation of Nature
NEMA	National Environmental Management Act
NEMBA	National Environmental Management Biodiversity Act
NRF	National Research Foundation
MASL	Meters Above Sea Level
MAP	Mean Annual Precipitation
MDGs	Millennium Development Goals
MEA	Millennium Ecosystem Assessment

MUCPRD	Multiple Use Common Pool Resource Domains
NDA	National Department of Agriculture
NOAA	National Oceanic and Atmospheric Administration
NSBA	National Spatial Biodiversity Strategy
NPA	Net Present Value
NWA	National Water Act (South Africa)
NWRS	National Water Resource Strategy
PSR	Pressure State Response
RDM	Resource Directed Measures
RHP	River Health Programme
RCC	River Continuum Concept
RQO	Resource Quality Objectives
RUM	Random Utility Models
RVI	Riparian Vegetation Index
SACA	South Africa Constitution Act No. 108 of 1996
SAIAB	South African Institute of Aquatic Biodiversity
SANBI	South African National Biodiversity Institute
SASER	South Africa State of Environment Report
SASS	South African Scoring System
SASS v 5	South African Scoring System Version 5
SEA	Strategic Environmental Assessment
SBSTTA	Subsidiary Body on Scientific, Technical and Technological Advice
SPM	State Preference Method
TCM	Travel Cost Valuation Method
TEVF	Total Economic Valuation Framework
TRRTF	Tyhume River Restoration Trust Fund
UNCED	United Nations Conference on Environment and Development
UNCSD	United Nations Commission on Sustainable Development
UNEP	United Nations Environmental Programme
UNECE	United Nations Economic Commission for Europe
UNITAR	United Nations Institute of Training and Research
USEPA	United States Environmental Protection Agency
WRC	Water Research Commission (South Africa)

WCD	World Commission on Dams
WCED	World Commission on Environment and Development
WCMC	World Conservation and Monitoring Center
WMA	Water Management Area
WSSD	World Summit on Sustainable Development
WTA	Willingness to Accept Payment
WTP	Willingness to Pay
WUA	Water User Association

Chapter 1: Introduction

1.1: The Tyhume River

The Tyhume River located in the Eastern Cape Province, South Africa (Figure 1.1), is the major tributary of the Keiskamma River and is a 5^{th} order stream. It originates from the Hogsback peak of the Amatole Mountains at 1500 metres above sea level (MASL). The high altitude of Hogsback area causes temperatures drop to very low levels with occasional snow in winter. This area has been variously described as a summer rainfall region, and or an autumn maximum rainfall area (Mayekisho 1984; Skelton 2001). It has also been described as a transitional zone between a true summer rainfall area and an all year round rainfall region. This is evident when comparing the mean monthly rainfall for summer months and winter months, respectively, recorded to be 69% and 31% in Hogsback and 67% and 33% in Alice (Mayekisho 1994; South African Environmental Health Monitoring Programme, NAEHMP 2010; Skelton 2001). According to the Keiskamma River Bio monitoring Trends of South African Environmental Health Monitoring Programme (NAEHMP) 2010) report, The Mean Annual Precipitation (MAP) in this area varies from 600 mm in Alice to 1200 mm in Hogsback and 450 mm in the coastal zone. The high altitude of the Amatole Mountains is responsible for the situation, which also causes the high level of local relief rains and contributes to the permanent status of the Tyhume River (Mayekisho 1994; NAEHMP 2010; Skelton 2001).

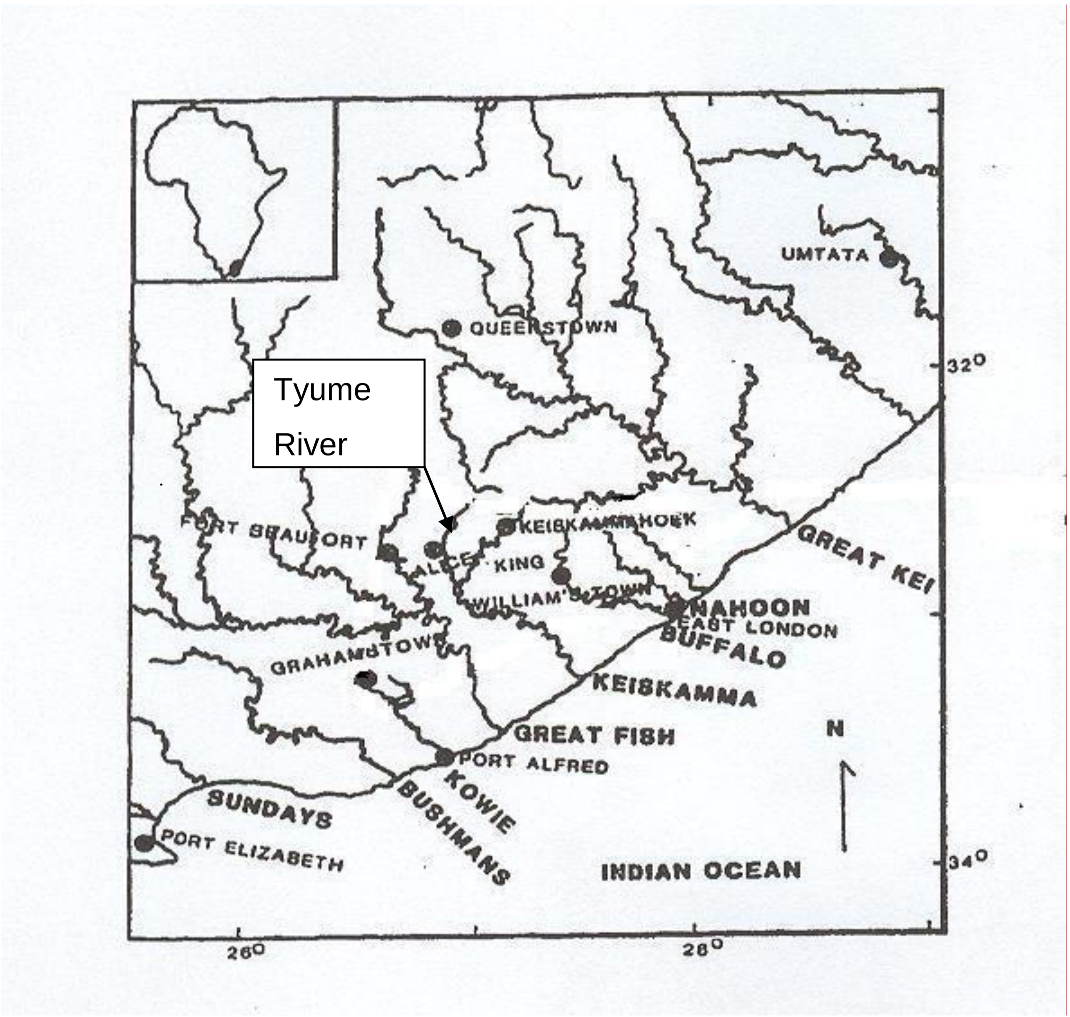

Figure 1.1: Map of the study area (Mayekisho 1994)

1.1.2: Geomorphology

The geomorphology in the Amatole Mountains escarpment is greatly influenced by the eastwards tilted northern plateau which causes the river to flow eastwards at an average gradient of 1: 1000. The river flows for approximately 87 km, then confluences with the Keiskamma River. The dominant rock from source to confluence is granite, interspersed with domes of dolerite and shale. It is these rock formations that contribute to the steep gradients and poor water storage of most rivers which rise from the escarpment. This has necessitated the construction of numerous impoundments to store water for human use (Mayekisho 1994; Skelton 2001).

1.2: Sustainability of Tyhume River Fish Biodiversity

Sustainability of fish biodiversity in Tyhume River, in line with global observations, is threatened by the unprecedented rate of anthropogenic activities. The driving forces are economic and institutional in nature and are a reflection of intensification anthropogenic activities within the watershed. As the Tyhume River flows from the peak of the Amatole Mountains through Binfield Park Dam and Alice Urban area, the home of University of Fort Hare, then confluences with the Keiskamma River; it passes through varying intensity of anthropogenic activities (e.g. Binfield Park Dam, Alice Urban Area, Rural Human Settlements and Agricultural activities) within the landscape.

It is externalities from these anthropogenic activities in the landscape and deleterious in stream modifications, as well as introduction of non - native fish species and other biota, that contributes to unsustainable use. In the absence of market mechanisms for ecosystem services, strong institutional mechanisms are required to internalize benefits or costs generated by various actors and minimize externalities (Birol *et al.* 2007; Pasqual and Souto 2003). The externalities; (modification of stream flows, erosion of riparian area, storm water discharge and introduction of nonnative fish species) are mostly a reflection of landscape activities, either in terms of increased demands for water to sustain agriculture activities, or of increasing reclamation of land for rural and urban development. The resultant effects are declining water quality, reduction of stream flows, altered flooding regimes and increased frequencies of drying out, which have deleterious effects on biodiversity sustainability (Scott 2006).

Unsustainable use promotes the homogenization process in fish assemblages and other biota through loss and gain of fish species. The homogenization process manifests in few common fish species becoming more common while less common or rarer fish species decline. This leads to increase in number of lotic systems degraded by anthropogenic activities or not used in a sustainable manner (Scot 2006; UNEP 1997). The drivers are anthropogenic activities within the landscape which are economic in nature and institutional mechanisms that are ineffective in internalizing costs and benefits (Gatzweiler 2006)

Degradation of water resources is a manifestation of market and policy failures and this corroborates prevalence of non-optimal decisions on the use of lotic systems. The ecosystem goods and services provided by lotic systems are normally not accounted for in market transactions. As a result, inefficient use and degradation from externalities are rampant (Barbier *et al.* 1997; Birol *et al.* 2006; Holmes *et al.* 2004; Wilson 1999). Market failure is attributable to the "public good" characteristic of lotic systems. A "public good" is one whose consumption is characterized by inability to exclude others (Gatzweiler 2006). In most cases it is non-rival, making it difficult to assign a market price. While some goods provided by lotic systems can be assigned a market price, such assignment does not always reflect scarcity rents, both in terms of quantity and quality. If in addition to market failure, a policy failure exists, increased incidences of resource degradation and depletion occur as institutions are unlikely to fully internalize externalities appropriately (Barbier *et al*. 1997; Birol *et al*. 2006; Gatzweiler 2006).

To align policy appropriately, institutional mechanisms have a fundamental role to play in mitigating externalities that characterize lotic resources. This is because degradation of a lotic system is also institutional in nature. Externalities comprise either benefits or costs from economic activities that are not fully internalized by actors (Birol *et al.* 2007; Pasqual and Souto 2003). Hence, institutional mechanisms have a role in reducing externalities through establishment of property rights regimes, as they form the basis of management decision making (Adger and Luttrell 2000). However, allocation of property rights is not without challenges; while proper definition hinges on precision of boundaries, lotic resources are plagued with complexities due to indivisibility of resources, such as lotic ecosystems biodiversity. These complexities are further exacerbated by the high seasonal variability with daily fluctuations in ecotones and habitats, making these resources difficult to partition (Adger and Luttrell 2000; Thornton and Day 1998).

Biodiversity, as defined in the Convention on Biological Diversity, CBD, is the 'intra and inter variability among living organisms' and includes ecological requirements (CBD 1992). This definition encompasses biodiversity at genetic, species and at ecosystem levels. The concept of loss of biodiversity is not defined in the text of the Convention, though it encompasses the decline in the abundance and distribution of species (CBD 2004). The consequences of biodiversity loss are long term reduction of potential to provide ecosystem services. The driving forces of unsustainable use are attributable to anthropogenic activities (CBD 2004; Hooper *et a*l. 2012).

International efforts to redress unsustainable use include; The Rio Earth Summit, that galvanized global consensus on the unprecedented rate of biodiversity decline, arising from anthropogenic activities (Rio Earth Summit 1992). Twenty years later, Rio + 20 Conference was held to secure political commitment for sustainable development and assess progress as well as identify gaps (Rio + 20 Conference 2012). A total of 192 member states attended, including 57 Heads of State and 31 Heads of Government. Arising from these international measures, institutional reforms have been initiated to ensure sustainable use (CBD 1992; Rio 1992; Rio +20 2012; SDG 2015). To date, 196 countries have made commitments to the CBD of 1992, according, it widespread global coverage, as many countries have translated these commitments into national law (Sandberg 2007). More recently, countries have made commitments to the United Nations Sustainable Development Goals (UN-SDGs 2015).

Institutional reforms are thus increasingly driven by international measures: The Rio Earth Summit and the Convention on Biodiversity introduced a paradigm shift in resource governance. This paradigm shift calls for sustainable use based on three pillar integrative framework (Figure 1.2), and new measures in support have been incorporated as national legislative measures in many countries.

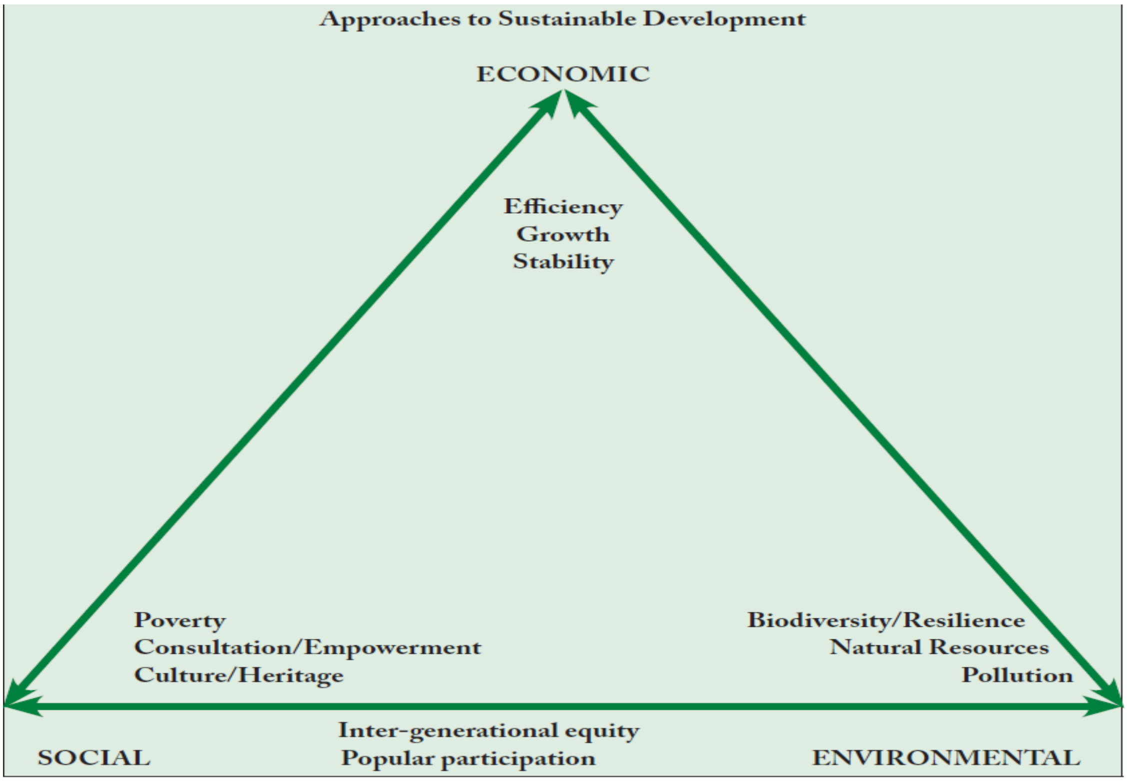

Figure 1.2: Sustainability Framework. Source: Munasinghe, 1996

A sustainability approach, however, introduces new complexities as it necessitates allocation of property rights to future generations (Figure 1.2) and to non-human users (Carlson and Berkes 2005; Sandberg 2007). Often these complexities lead to non-coherence between *de jure* and *de facto* state of resources (Adger and Luttrell 2000).

1.3: Anthropogenic Effects on Lotic Systems

In line with global observations, aquatic biodiversity found in lotic systems is threatened by anthropogenic effects, which manifest in habitat quantity and quality. Habitat quantity modifications manifest in geomorphology characteristics, while quality modifications manifest in water quality characteristics and species diversity. Assessments done on the state of biodiversity resources indicate that anthropogenic effects are threatening sustainable use (Millennium Ecosystem Assessment, MEA, 2005; NAEBP 2006; National State of Environment Report 1999; River Health Program, RHP), 2004; RHP 2006; Chu *et al*. 2014). In the Fourth National Report to Convention of Biological Diversity, South Africa reported that 82% of major river ecosystems are threatened, 44% are critically endangered, 27% endangered and 11% vulnerable. The biota found in these river ecosystems is equally imperiled; although only the conservation status of fish is well documented. Thirty-six percent of freshwater fish are threatened and although none have gone extinct, distribution of fishes has reduced in terms of total absence in hitherto occupied river. Anthropogenic effects on fish biota are usually a combination of those emanating from habitat modification and the introduction of non-native fish species and other biota.

Over the last century anthropogenic effects have contributed to an estimated 50% loss of wetlands (WCMC 1998). Over the same period demand for fresh water has increased six fold (Birol 2006; European Environment Agency, EEA, 2009; Millennium Ecosystem Assessment, MEA, 2005; Van Rees and Reed2014; WCMC 1998). Anthropogenic effects of lotic river systems for developmental goals have a long history. Starting from 1750, the recorded river modifications were geared towards facilitation of navigation and flood control (Allan 1995). In 1900, technological development in the area of dam construction spurred growth in the number of dams developed across the globe. Allan (1995) outlined the stages in river regulation and their proliferation in North America, Europe and Southeast Asia. At the height of adoption of this technology, dams worldwide were constructed at the rate of 700 per year. The World Commission on Dams, WCD, reported at least 45,000 large dams (embankments higher than 15 meters) had been constructed to date, mainly in response to energy needs (WCD 2000). It is only in the last 50 years that decommissioning of dams has been witnessed. This is a reflection of the increased awareness of their social and environmental consequences. Yet the human demands for hydropower energy will double in 2050 necessitating construction of 9,000 new dams (WCD 2013)

Apart from in-stream modification of river habitats through creation of barriers, withdrawals have doubled since 1960s; 60% cater for irrigation agriculture (Allan 1995; Liermann *et al*. 2012; WCMC 1998). The changes induced by these modifications are documented in the literature (e.g. Millennium Ecosystem Assessment 2005; Van Rees and Reed 2014). These include alterations to the natural flow regimes, fragmentation and loss of aquatic habitat. They manifest on lotic systems habitat, abiotic, and biotic characteristics, with deleterious effects on fish assemblage and overall sustainability

(Allan 1995; EEA 2009; Karr 1991; Liermann *et al*. 2012; MEA 2005; Mayekisho 1994; Skelton 2001; WCMC 1996, 1998).

1.4: Anthropogenic Effects on Fish Biodiversity

Anthropogenic effects on fish biodiversity in lotic systems globally are not clear due to paucity of studies (Liermann *et al* 2012; World Rivers Review 2012). It is however, estimated 81 fish species have gone extinct in the world (WCMC 1989) while the number on the IUCN Red List is on the increase over the last century. An additional 11 species are in *ex-situ* populations while their *in-situ* populations are extinct. Other estimates indicate that, of the 24 618 known freshwater fish species, approximately 4% are threatened (Duncan and Lockwood 2001). Duncan and Lockwood (2001) investigations on whether there are common predisposing factors that can be attributed to fish families categorized as vulnerable or at risk of extinction, were not clearly borne out. However, estimates indicate 20% of freshwater fish species are threatened and most of the listed fish species are from well-studied families. Of the majority of fish species at high risk, 71% are from 18 families that include sturgeons, gouramis and salmonids. They are characterized by life history traits that require a specific habitat (e.g. in lotic systems), small range and endemism - all categorized as risk-predisposing factors. Other estimates attribute 43% of predisposing risk factors to non - native fish species and 73% to habitat degradation (Cambray 2000).

In the continental waters of South Africa fish assemblage modifications are aligned to global observations, as they mainly arise from introduced biota and landscape use practices (Cambray 2000; Cowx 2002; Kameyama *et al*. 2007; Mayekisho 1994; Skelton 2001 and 2002; Ward 1998). The number of non-native fish species reported is 24, while 33 fish species are listed as threatened on 1996 IUCN Red List Data Base (Skelton 2001). The majority of introduced fish species are geared towards development of recreational fisheries, or fish farming activities. These include rainbow trout and brown trout, largemouth and smallmouth basses and the bluegill sunfish that have been widely introduced. Other species, such as the African sharptooth catfish have been widely translocated for fish farming (Allan 1995; Mayekisho 1994; Skelton 2001; WCMC 1996; WCMC 1998; Welcomme 1988). While many introductions are intended, others are accidental, such as when fish escape from captivity, or are negligently released into the wild. Introduced fish species compete with indigenous species for space and food; in addition many are predators that forage heavily on indigenous fish species with consequences that may be dire.

Fish assemblage, as used in this thesis refers to fish community organization within a watershed, and denotes numbers, abundance, and distribution. How fish communities are structured longitudinally and divided into distinct communities is important to ecologists as it aids understanding of historical zoogeography and influence of geological characteristics. Geological characteristics such as elevation gradients influence thermal characteristics in a watershed, which normally vary in tandem with elevation gradients. Due to this influence, elevation gradients greatly influence temperature profiles in a watershed and are in most cases used as surrogate measure**.** As elevation declines longitudinally, water temperature increases, and this phenomenon structures fish assemblage distribution as fish are poikilothermic (Logez *et al*. 2013; Quist *et al*. 2004).

1.5: Economic Valuation of Ecosystem Services and Sustainability

Economic valuation of ecosystem services is a powerful tool that can aid sustainable management of global lotic systems (Adger and Luttrell 2000; Barbier *et al.* 1997; Bateman *et al*. 2011). This is because economic valuation of ecosystem services assigns monetary values to ecosystem goods and services regardless of availability of market prices. Economists attribute degradation of aquatic resources to failure to account adequately for non-market ecosystem value (Adger and Luttrell 2000; Barbier 1997; Birol *et al.* 2006). In the absence of economic values, trade-off is made in favour of things that have market value. Assigning economic value to ecosystem services facilitates trade-off decisions with other things of economic value to humans in similar terms (Barbier 1997; Pasqual and Souto 2003).

Economic valuation of ecosystem services can contribute to sustainable use of natural resources by informing decision making. Economic valuation improves management of scarce resources and contributes to efficient allocation by informing decisions on tradeoffs among competing users (Tisdel 1991). Optimal allocation of scarce resources is in line with economic theory on social welfare, where a policy decision is deemed *pareto optimal* or efficient, only when the benefits outweigh the costs and are positive (Birol *et al*. 2006). Efficiency in allocation of resources has additional benefits, as it can contribute to improvement of institutional arrangements. Ultimately these will deliver on sustainability through provision of economic incentives for the equitable allocation of water for both human users, and for maintenance of biodiversity (Birol *et al.* 2006).

The conceptual framework guiding this study envisages unsustainable use of lotic systems due to anthropogenic effects on habitat quantity, quality and biota the driving forces being economic and institutional in nature. Habitat quantity characteristics are geomorphological while quality focuses on water quality and the two including introduced biota affect fish biodiversity.

One area that is gaining widespread use in economic valuation of ecosystem services is micro-economic analysis. Micro-economic analysis facilitates evaluation of the net benefits associated with marginal changes in ecosystem services (Holmes *et al.* 2004). It has practical application against imposition of a new policy because it provides a baseline for costing restoration projects and a conceptual foundation for empirical analysis (Holmes *et al.* 2004). This is hinged on the assumption that specific ecological processes are affected by geomorphology processes and water quality characteristics (Allan and Marcus 2006; Doyle 2006).

A micro-economic approach to economic valuation, however, does not overcome the other problems associated with valuation of ecosystem services. The latter include disagreements on correct discount rates to use in cost/benefit analysis and other valuation methodologies (Pasqual and Souto 2003; Sandberg 2007; Tisdel 1991). There are other arguments that the methodologies used often fail to reflect the true environmental and socio economic value of goods and services provided by water resources. While some scientists contend that economists are monetizing nature and assigning more and more rights to nature, other arguments are that, against a backdrop of continued ecosystem deterioration, some economic valuation to inform decision makers is better than none. It is argued that, in any case, not assigning value to these services would implicitly imply some economic value (Everard 2004; Turner *et al.* 2003).

South Africa is among countries that have taken cognizance of this need for tradeoff between human use and maintenance of ecological processes (National Water Act (NWA) No. 36 of 1998 (NWA 1998). NWA has allocated water rights for human use and for maintenance of stream flows. It has also, through the Department of Water Affairs (DWAF), initiated a River Health Programme (RHP) to monitor the state of rivers and to activate national environmental reporting (South Africa State of Environmental Report, SASER, 1999). The output has been several "State of the River Reports" such as the Buffalo River System, Eastern Cape (RHP 2004 and 2006) and South African Environmental Health Monitoring Programme; Keiskamma River Bio monitoring Trends of NAEHMP (NAEHMP 2010). The findings of this study together with the new policy framework provide a good conceptual basis for micro-economic analysis of the Tyhume River.

The Tyhume River is now subject to new policy and institutional framework arising from enactments of new legislation such as the National Environmental Management Biodiversity Act No. 10 of 2004; the National Environmental Management Act (NEMA) No. 107 of 1998 (NEMA 1998); and National Water Act (NWA) No. 36 of 1998 (NWA 1998). These laws were enacted in response to commitments from the Rio Earth Summit 1992, Convention of Biological Diversity 1992 and World Summit on Sustainable Development 2002. The new policy provides a basis for micro-economic valuation of benefits likely to accrue from restoration of degraded ecosystem services.

Unsustainable state of fish biodiversity in the Tyhume River system is reflective of issues that plague lotic systems globally, due to the connectedness of the services they provide with human basic needs. The sustainability conceptual framework integrating ecological, economic and social considerations seems appropriate in line with the Rio Conference 1992 (Figure 1.2). It calls for a paradigm shift in resource governance towards more integrative approaches in assessment and management of natural systems to more pragmatic approaches (SEA Protocol on Strategic Environmental Assessment 2003; Retief 2007). The reforms required for Implementation of the sustainability as a concept necessitate integration of environment and economics; yet, these have remained dualistic due to the difficulty of creating integrated frameworks (Norton and Noonan 2007).

The results of this study provide lessons that can guide the integration of ecology and economics in order to achieve sustainability. The institutional reforms for water management in South Africa, accords the highest priority to protection of the reserve. This protects rights for basic water for human needs and a reserve for maintenance of biological processes in perpetuity. These results are therefore likely to have applications in other lotic systems in South Africa, as well as in other parts of the globe because the issues are similar.

1.6: The Aim of this Study

To contribute to sustainable use of Tyhume River and other lotic systems by generating information on the link between anthropogenic effects on fish biodiversity, economic value of ecosystems services and institutional mechanisms.

1.7: The Hypothesis

Anthropogenic effects arising from market and institutional failure contribute to unsustainable use of fish biodiversity in Tyhume River.

1.8: The objectives of this Study

- To determine geographic coordinates of identified study sites on Tyhume river together with a pictorial record;
- To determine anthropogenic effects on Tyhume River habitat;
- To determine anthropogenic effects on fish assemblages in Tyhume River;
- To determine the economic value of five ecosystem services provided by Tyhume River; and,
- To determine post Rio institutional measures contribution to the sustainable use of Tyhume River.

1.9: The Plan of This Thesis

This thesis is divided into six chapters. A brief guide is as follows;

Chapter 1: This chapter provides a general introduction to the study questions, and the plan of this thesis;

Chapter 2: This chapter provides a review of pertinent literature on anthropogenic effects on habitat geomorphology characteristics and water quality as well as fish assemblage and sets the context for the study. This chapter also provides a general literature review for the economic characteristics of resource use. It includes a review of institutional economics pertaining to resource use. It sets the context for the economic valuation of ecosystem services and provides a linkage with institutional economics.

Chapter 3: This chapter provides materials and methods;

Chapter 4: This chapter provides the results;

Chapter 5: This chapter provides a discussion; and,

Chapter 6: This chapter provides a conclusion and recommendations.

Chapter 2: Literature Review

2.1: Anthropogenic Effects, Externalities and Sustainable Use of Lotic Systems

Anthropogenic effects on lotic systems continue to increase, in tandem with increased demands from rising human populations. The anthropogenic activities create externalities on lotic systems which include use of in-stream habitat as a depository for wastes, modification through creation of barriers and introduction of non-native biota (Allan 1995; Everard 2004; Scot 2006). The pressure imposed on natural systems from anthropogenic externalities on habitat has led to problems of water scarcity in terms of quantity and quality, in most parts of the world (Allan 1995; EEA 2009; Karr 1991; WCMC 1998).

Anthropogenic externalities when coupled with improved technology has resulted in diverse sources of impacts on river ecosystems; these include domestic effluents, erosion following conversion of landscapes for agriculture, urbanization, plantation forestry, in-stream modifications (canalizations, dredging for navigation, diversion and impoundments) (Allan 1995). Other impacts are as a result of over-harvesting of water and biota, as well as introduction of non-native species (Dudgeon 1992; Karr 1991; Rapport *et al*. 1985). These excessive harvesting of water and biota, creation of impoundments, introduction of non-native species, as well as pollution loading, are quoted by most studies as the major threats to sustainability (Allan 1995; Karr 1991; Kleynhans 1999; Pasqual and Souto 2003; Reid 2004; Scott 2006; WCMC 1998).

Anthropogenic effects on running waters manifests in increased incidents of declining quantity and quality. In tandem with this is increased numbers of imperiled biota (Allan 2005; Scot 2006; Skelton 2001). According to Millennium Assessment, MA, (2005), water resources are increasingly falling into the realm of scarcity globally. This has necessitated a paradigm shift in management of lotic systems in order to achieve sustainability. The shift requires tradeoff between human needs and ecosystem requirements within the sustainability framework.

The impact of anthropogenic activities on lotic systems has been demonstrated by numerous studies (Donohue *et al*. 2007; N Karr 1991; Lake *et al*. 2007; Lee *et al*. 2004; Ngoye and Machiwa 2004;). For instance in Tanzania, Ngoye and Machiwa (2004) demonstrated that there is a linkage in the proximity of river systems to human settlements and the decline in water quality. They investigated seasonal variations in water quality in the Ruvu River and found that forested areas were high in dissolved oxygen, low in ammonium-nitrogen (NH_4-N) and low in Nitrate-nitrogen (NO_3-N). On the contrary, areas in close proximity to human settlements, exhibited reduced quantities of dissolved oxygen and high levels of both NH_4-N and NO_3-N.

The linkage between catchment characteristics and water quality was further demonstrated, using community structure of benthic macro invertebrates by Donohue *et al*. (2007). On analysis of data collected in 797 sites, a significant inverse relationship was evident between the river condition and anthropogenic activities (Donohue *et al*. 2007). The activities included urbanization, intensification of agricultural activities and increased population densities of humans and cattle. Similarly, a Nationwide Survey undertaken by the United States Fish and Wildlife Service established that 49% of habitat impairment was attributable to physical habitat degradation, out of which 67% was attributed to flow modification (Karr 1991). In a study undertaken in Australia, it was established that 85% of the rivers surveyed had been modified by anthropogenic activities (Lake *et al*. 2007). A majority or 50% of these modifications had habitats degraded by loss of riparian vegetation and increased sedimentation. Yet in many countries buffer widths are legislated for protection of in-stream habitats with modifying factors based on slope, water body size and presence of fish. In Canada and United States for instance, buffer widths for protection of in-stream habitat are legislated between 15.1 m and 29.0 m. This is in recognition that the maintenance of riparian buffers stabilizes river banks to control erosion and protect stream geomorphology (Lee *et al*. 2004).

Despite the negative correlation in the state of biodiversity of running waters in relation to the proximity of human settlements, the development of broad empirical guidelines on land cover for the maintenance of biodiversity integrity in lotic systems lags behind. Another area that is vague is the linkage between ecological integrity and water chemistry. As a result, merging geomorphology and water quality for meaningful evaluation has been difficult.

To overcome this, monitoring systems that historically relied on water chemistry due to ease of legal defence have shifted to biological monitoring. The water chemistry characteristics failed to provide the requisite early warning and resulted in increased occurrence of degraded lotic systems (Donohue *et al*. 2007; Karr 1991). The result was evident as anthropogenic modification effects began to manifest in loss of habitat integrity and erosion of biodiversity in lotic systems, where riparian buffers were degraded or non-existent (Karr 1991; Lee *et al*. 2004). In most cases, invasive non-native fishes have been characterized as cosmopolitan, or generalist species, that tend to out-compete indigenous fish species (Scott 2006). This is especially the case in areas with multiple anthropogenic threats, leading to the problem of homogenization (Marchetti *et al*. 2006; Reid 2004).

South Africa is a water-scarce country and there are substantial pressures on its inland aquatic ecosystems (DEAT 2006). South Africa's freshwater ecosystems vary tremendously in their distribution, size and perenniality due to the geographic variability in the quantity, season and regularity of rainfall across the country. Of the wide variety of organisms that inhabit South Africa's freshwater ecosystems, only fish have been assessed in terms of their conservation status (DEAT 2006). Thirty-six percent of the country's freshwater fish are threatened. Although no freshwater fish have gone extinct in the country, many have been eliminated from particular river systems (DEAT 2006). The condition of main river ecosystems in South Africa was summarised as part of the National Spatial Biodiversity Assessment (NSBA) assessment (Nel *et al*. 2004; Table 1-3). The assessment showed that only 29% of the country's main rivers were unmodified or largely unmodified; 45% modified; and 26% Transformed. Also some 82% of main river ecosystem types are threatened, with 44% critically endangered, 27% endangered, and 11% vulnerable (Nel *et al.* 2004). An assessment of smaller tributaries is required, however, before an accurate picture can be presented for South Africa.

2.2: Anthropogenic Effects on Geomorphology

Anthropogenic effects on geomorphology manifests in streams in altered flow regimes, reducing width and depth of the stream as well as loss of integrity of the riparian zone (Allan 1995; Bain *et al*. 2000; Doyle 2006; Karr *et al.* 1998; Rapport *et al*. 1985). Anthropogenic effects emanate from either in stream modifications, land-based activities or a combination of the two activities. At the extreme, these may result in imperilment of lotic systems when they completely dry out, with grave consequences for stream biodiversity (Allan 1995). In-stream modifications arise from excessive extraction of water, creation of barriers and introduction of non-native biota. Many studies have demonstrated a negative correlation between anthropogenic induced habitat modifications and river health (Grenouillet *et al*. 2004; Quist *et al*. 2004; Reid 2004). The magnitude of impact increases in tandem with proximity to human settlements (Holmes *et al*. 2004; Mitner *et al*. 2004; UNEP 1997). Landscape users arising from increasing population and improved technology introduce diverse sources of pollutants that impact on water quality. These range from domestic effluents, erosion following conversion of landscapes for agriculture, to urbanization and plantation forestry (Karr 1991; Rapport *et al*. 1985). Quantity impacts include excessive extraction, impoundment diversions and conversion to other uses. Habitat modifications that target stream geomorphology affect seasonal flow, reduce the extent of physical habitat and further resonate on all areas of stream ecology (Bain *et al*. 2000; Doyle 2006; Karr 1991; Rapport *et al*. 1985). As a result, the extent of anthropogenic modifications on habitat within lotic systems continues to increase with negative consequences on sustainability of biodiversity.

Geomorphology evolves in response to both natural and anthropogenic effects, and this in turn influences river structure. Natural upheavals, like faults or volcanic eruptions can radically alter stream geomorphology. It is, however, anthropogenic modifications on geomorphology that include; siltation, pollution loading and excessive harvesting of water resources, which are a source of concern (Allan 1995; Doyle 2006; Skelton 2001). The negative impacts of these modifications on lotic systems have provided impetus to the practice of river restoration. Restoration measures hinge on the assumption that specific river ecological processes are impacted by anthropogenic effects on habitat and is increasingly driven by legislative requirements (Allan and Marcus 2006; Doyle 2006).

Within the Tyhume River, competing users identified were in-stream geomorphology modification through altered flow regimes, fragmentation through creation of barriers, excessive harvesting, and overgrazing within the riparian area (Mayekisho 1994: NAEHMP 2010). Increased agricultural activities and changing land use have altered what was previously grassland vegetation, interspersed with wooded vegetation to Karoo veld and macchia vegetation. Karoo veld and macchia vegetation are both poor providers of ground cover, and as a result there is visible evidence of erosion and gully formation (Mayekisho 1994; NAEHMP 2010). In most areas overgrazing within the riparian area is evident and undermines the buffering capacity of the riparian zone. Lee *et al*. (2004) demonstrated that a treed riparian barrier allows the input of fine and organic debris, and this contributes to the maintenance of in-stream ecological integrity. Maintaining a treed riparian barrier also assists in moderation of stream temperature and supports biodiversity.

2.2.1: Flow Rate (Current Velocity)

Flow rate, or current velocity, is lotic system's defining characteristic; it enables transportation of resources, as well as removal of wastes (Allan 1995). It varies along a cross section due to friction with substrate and river banks. It is highest where friction is least, but may increase, or remain constant, as the river progresses downstream. It also varies with depth of river, but generally it is highest at surface of the stream and the centre of the channel. Deep rivers have high current velocity just below the surface due to friction with atmosphere, while in shallow rivers current velocity is greatest at the bottom due to high friction with the bed. Reduction of river flows interferes with flood plain connectivity and riparian areas in a manner similar to that created by impoundments (Allan 1995).

Within the Tyhume River, investigations into post impoundment effects on current velocity revealed that the flow rate was greatest just below Binfield Park Dam (Mayekisho 1994). This area also had the lowest variation flow rate - a reflection of dampening due to regulation. Current velocity exhibited a strong correlation with rainfall patterns. Rainfall patterns varied in tandem with the four seasons, distinguished in South Africa as: Winter months (May, June and July); Spring months (August, September and October); Summer months (November, December and January); and Autumn months (February, March and April). High mean run off is experienced in the months of October-April (Mayekisho 1994).

2.2.2: River Width

River width increases log linearly as the river progresses downstream (Allan 1995). This was demonstrated on Tyhume River where mean width ranged from 4 metres in the escarpment to 20.4 metres at the confluence (Mayekisho 1994). Width is reflective of the stream spatial position within a watershed (Grenouillet *et al*. 2004). Width varies seasonally with precipitations; greater width is observed with increased discharge, and reduces during drought conditions (Allan 1995; Quist 2004). Slope adjusts gradually and exerts influence on stream width, hence high elevation streams are characterized by smaller widths (Alan 1995; Skelton 2001).

2.2.3: River Depth

Depth is important in rivers as it is associated with increase in abundance of fish species. Depth increases longitudinally with declining elevations and changing river zones. Rivers with good pool formation provide havens for protection of species during drought periods (Allan 1995; Quist *et al*. 2004; Skelton 2001). Pools create lentic conditions within running waters, increasing retention of organic material and nutrients (Hägglund and Sjöberg 1999). Previous studies on Tyhume River indicated depth ranged from 0.03 m to 0.07 m (Mayekisho 1994).

2.3: Anthropogenic Effects on Water Quality Characteristics

Water quality modification is a manifestation of the linkage between landscape uses and the lotic systems. As landscape users intensify, there is usually a corresponding increase in runoff, sedimentation loads and transport of chemical or biotic elements (Allan and Marcus 2006; Scott 2006). Extensive conversion of landscapes for agriculture, urban and industrial developments, increases runoff, nutrient and sediment loads transport in aquatic systems, with dire consequences on water quality (Bain 2004; Scott 2006). The consequences are altered water quality characteristics, such as temperature, pH and conductivity (Doyle 2006; Lee *et al.* 2004; Scott 2006; Quist *et al*. 2004). While mechanisms are in place for regulation of point sources of pollution, it is the non-point sources that are a challenge due to their diffuse nature (Karr 1991; Scott 2006). Modification of habitat has been characterized as most insidious due to the deleterious effects on biodiversity and negative consequences on sustainability of lotic systems. This is especially so when the rate of use exceeds the systems natural resilience (Allan 1995; Allan and Marcus 2006; Scot 2006).

In South Africa a comparison of water quality characteristic with standards set by the Department of Water Affairs and Forestry (DWAF) was conducted in Keiskamma River in Eastern Cape Province (Fatoki *et al*. 2003). The results revealed conductivity, orthophosphate and oxygen-demanding substances were all above the South African guidelines for domestic water use.

2.3.1: Temperature

Water temperature in lotic systems increases with declining elevation gradients. Mountain sources characteristically tend to have lower temperatures than downstream areas (Allan 1995). Habitat modification through creation of impoundment causes localized temperature changes, depending on the location, size and mode of water release. Most organisms dwelling in streams are ectotherms whose productivity, life cycles and growth rates are greatly correlated to temperature (Alan 1995; Quist *et al*. 2004). Temperature changes influence lotic systems dynamics through increase or decrease in the rate of organic matter processing and nutrient transformation. A change in temperature is, therefore, likely to alter fish assemblage organization and structuring (Alan 1995; Mayekisho 1994; Quist *et al*. 2004).

Investigations into impoundment effects on temperature in the Tyhume River revealed a change in temperature after impoundment (Mayekisho 1994). This was evident in higher post impoundment temperatures recorded in autumn and summer, and lower temperatures in winter and spring. The changes were also reflected in a slow temperature increase in spring and slow decrease in autumn. The changed temperature profile manifested over a distance of 60 km downstream of the Binfield Park Dam (Mayekisho 1994). Allanson *et al.* (1990) similarly demonstrated reduced amplitude in annual thermal range after river regulation.

2.3.2: Hydrogen Ion Concentration (pH)

Hydrogen ion concentration (pH) measures the amount of hydrogen ion in a water system. The scale is logarithmic to base 10, and a value of 7 represents neutral, while a decrease in value represents acidity and an increase represents alkalinity. An increase in one unit of pH represents a 10 fold decline in concentration of hydrogen ions. There is great interdependence between pH and concentration of carbon dioxide; hence pH at midday can increase by 0.5 units (Allan 1995). A pH measure indicates the general equilibrium of bases, organic acid and carbon dioxide. Most biological organisms are intolerant of pH at extremes; pH that is below 5 or above 9 is harmful to most organisms (Allan 1995, Fatoki *et al*. 2003; Mayekisho 1994). A low pH reduces bacteria activity and slows down the rate at which organic matter is broken down (Allan 1995; Okeyo 2000).

In the Keiskamma River, a mean pH of 6.9 was recorded in the river, while in the impoundment a mean pH of 7.1 was recorded (Fatoki *et al*. 2003). South Africa Department of Water Affairs and Forestry has set a pH range of 6 to 9 for domestic water use and 6.5 to 8.5 for contact or recreation use. Within the Tyhume River, post impoundment effects on pH were revealed as lowered pH for a distance of 7 km below the Binfield Park Dam, with a recovery at 20 km away from the dam. The pH recorded ranged from neutral to alkaline (Mayekisho 1994).

2.3.3: Conductivity

Conductivity is a measure of electric conductance of water in terms of dissociated salts. It is therefore a close predictor of dissolved ions in water. Distilled water has low conductivity and a high resistance to electron flow (Alan 1995; Mayekisho 1994). Conductivity is a useful measure of water quality that is used to assess pollution. Fatoki *et al*. (2003) used conductivity to assess pollution within the Keiskamma River and its impoundment, the Sandile Dam. The mean conductivity in the river was 263.9 mS/m and 164.9 mS/m in the impoundment. This exceeded 70 mS/m, the South African Limit set by DWAF for domestic water use (Fatoki *et al*. 2003). In the Tyhume River, the post impoundment effect on conductivity was a notable increase of conductivity for a distance of 7 km, and a reduction in monthly variation thereafter (Mayekisho 1994).

2.4: Anthropogenic Effects on Fish Assemblage

Anthropogenic effects emanate from landscape activities, in stream modifications and introduced biota; these in turn influence fish assemblage structuring within a watershed. Of particular concern are anthropogenic effects that promote the homogenization process. These findings are in line with impoundment effects observed on fish species in the Speed River in Ontario, Canada (Reid 2004). The effects included reduced downstream distribution and abundance of two lotic specialists while non-native fish species establishment was enhanced. The overall effect was an increase in fish species richness and abundance, attributable to non-native fish species (Reid 2004). Relative influence of habitat versus stream spatial position on local species richness in the Saōne River in France was investigated by Grenouillet *et al.* (2004), who found stream width and gradients to influence local species richness. Silgato *et al*. (2002) working in south-western Germany, found a shift in fish assemblage from limnophilic species to ubiquitous species, and dominance of less pollution-sensitive species in response to anthropogenic effects in a small stream.

Fish assemblage distribution longitudinally within a watershed portrays zonal patterns and division into distinct communities. The zonal patterns are a reflection of habitat characteristics such as temperature, which varies in tandem with elevation. Elevation gradients in turn reflect geological characteristics and zoogeography (Logez *et al*. 2013; Quist *et al*. 2004). Apart from habitat characteristics community, relationship and competition for food and space among fish species influence patterns and divisions into distinct groups (Allan 1995; Palmer *et al* 2010). These fish community relationships are prone to alteration by anthropogenic activities leading to the homogenization process, especially in areas with multiple anthropogenic effects (Liermann *et al*. 2012; Reid 2004; Sayer 2014; Scot 2006).

A number of theories have been used to explain structuring of fish assemblage within a watershed. In temperate regions, the River Continuum Concept (RCC) is a single framework that is used to explain variation from source to mouth (Allan 1995; Ellisand Jones2013). In accordance with this theorem, energy inputs within mountainous regions, where shading prevents penetration of sunlight are dominated by allochthonous coarse particulate organic matter. This is in contrast with lower altitude zones where there is interaction of energy inputs from photosynthesis, downstream migration of allochthonous material, as well as interactions with riparian zones. These processes, as well as other theories of species addition and resource partitioning, are used to explain fish species richness and distribution. Rivers that are wide and those with neutral to alkaline pH characteristically have higher species richness than smaller rivers (Allan 1995; Ellisand Jones2016). These natural processes are, however, under pressure from anthropogenic effects on habitat, which is increasing at unprecedented rates and like fragmentation are explained using the Serial Discontinuity Concept (SDC) (Ellisand Jones2016). Anthropogenic effects on habitat reduces the extent of near natural habitats in lotic systems, and most near natural habitats are either in a state of decline or are non-existent (Grenouillet *et al*. 2004; Palmer *et al* 2010; Quist *et al*. 2004; Sayer 2014; Skelton 2001).

Globally, three fish species have the record of most frequent introduction, having been introduced in at least 50 countries. These are common carp *Cyprinus carpio* (Linnaeus, 1758), Mossambique tilapia *Oreochromis mossambicus* (Peters, 1852) and rainbow trout *Onchorhynchus mykiss* (Walbaum, 1772) (Welcomme 1988). Fish species introduced primarily for recreation include; rainbow trout, brown trout *Salmo trutta* (Linnaeus, 1758), black bass, *Micropterus salmoides* (Lacèpède, 1802) and smallmouth bass *Micropterus dolomieu* (Lacèpède, 1802). African sharptooth catfish *Clarias gariepinus* (Burchell, 1822) are introduced to enhance fish farming while bluegill sunfish *Lepomis macrochirus* (Rafinesque, 1819) are introduced as fodder for a target fishery (Mayekisho 1994; Skelton 2001; Welcomme 1988). Fish farming is the overriding rationale for introduction, accounting for roughly 50% for the practice (Welcomme 1988). Development of recreational fisheries ranks second as rationale for the introduction of non-native fishes. Enhancement of natural fish stocks and use of fish species for biological control are the other reasons for introductions. Some introductions are based on feeble grounds, like simply the desire by colonizers to bring familiar fish species into the new territory from their home country. In other cases the introductions serve multiple functions (Welcomme 1998).

Deleterious habitat modifications, together with introduced of non-native fish species, alter species composition and result in increased incidents of imperiled indigenous fish species (Scott 2006). In the Adriatic catchment in Slovenia, Povz (1995) revealed that out of the 35 fish species in 14 families, 7 families were non-native. Eight endemic fishes were imperiled and listed on the 1980 Red List data base of the International Union for Conservation of Nature, IUCN (IUCN 1980). Five fish were listed as endangered, 2 as vulnerable; and one endemic fish species, *Chondrosoma genei* (Bonaparte, 1839), was listed as extinct from the effects of translocation of a non-native fish, *Chondrostoma nasus nasus* (Linnaeus, 1758). Two species, marble trout *Salmo marmoratus* Cuvier, 1817 and *Lethoenteron zanandreai* (Vladykov, 1955) became threatened. The marble trout was experiencing genetic erosion from cross breeding with brown trout, the latter also being a translocated fish species. On the overall, the richness of fish species in reaches tended to vary with the Saprobic index (a water quality indicator where readings range from 1: good water quality to 4: poor water quality). Similar arguments on the mix of non-native fish and landscape alteration effects on the imperilment of indigenous fish fauna are adduced (Economidis 1995; Benigno 1995).

Introduced non-native fish species have largely been associated with negative consequences. However, in some cases, introductions have enhanced waters that historically had poor fishery potential (Welcomme 1988). This is the case in Lake Victoria where the translocated fish, Nile perch *Lates niloticus* (Linnaeus, 1758); has recorded diverse impacts, one being heavy predation on indigenous fish species. The Nile perch is characterized as a heavy predator and has imperiled the majority of the 300 plus cichlids, some of which are now believed to be extinct (Kinya 2001; Welcomme 1988). The Nile perch has reduced what was a multi-species fishery to a fishery dominated by three species inclusive of Nile perch itself and the silver cyprinid *Rastrineobola argentea* (Pellegrin, 1904), and the Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758); the latter two having been translocated. On a positive note, Nile perch has increased the earnings of fishing communities around the lake through enhanced fish production. In the Eastern Arm of the Rift Valley, Kenya, Okeyo (2003a) observed that 8% of the 66 fish species were nonnative. This has imperiled the un-described indigenous Lake Naivasha lampeye *Aplocheilichthys* species "Naivasha". The major negative consequences include degradation of environment, associated with introduced common carp. In some instances the host community is disrupted through competition for habitat. Other consequences include stunting, genetic erosion of indigenous fish as well as introduction of diseases (Skelton 2001; Welcomme 1988).

Introduction of non-native fish species into the continental waters of South Africa has a long history, starting in 1700, when ornamental carp was introduced (Skelton 2001). Subsequently, other fish species were introduced for angling and fish farming, and included: common carp *Cyprinus carpio* in 1859, brown trout *Salmo trutta* in 1890 and rainbow trout *Oncorhynchus mykiss* in 1897, largemouth bass *Micropterus salmoides* and smallmouth bass *Micropterus dolomieu* in 1928 and 1937, respectively (Skelton 2001). Non-native fish species are broadly divided into exotics (from outside the geographic area) and translocated (native species from within the same geographic region) (Musil and Macdonald 2007; Skelton 2001).

Within the Tyhume River watershed, investigations of impoundment effects relied on biotic and abiotic parameters (Mayekisho 1994). The study revealed a reduction in distribution and abundance of eight species downstream of the Binfield Park Dam. The degraded habitats were easily colonized by non-native and translocated (native) species. The translocated (native) fish species further posed an additional threat of predation on indigenous species. Of the introduced fish species, the translocated African sharptooth catfish was perceived to pose a severe threat, mainly to the Border barb, *Barbus trevelyani* Günther, 1877 and Eastern Cape rocky, *Sandelia bainsii* Castelnau, 1861 (Mayekisho 1994).

2.4.1: Tyhume River Fish Assemblage

The Tyhume River fish assemblage, like that of most South African rivers, is taxonomically depauperate, consisting of four indigenous species (endemic) and five translocated (native) species (Mayekisho 1994; Skelton 2001). In Tyhume River, the situation can also be attributed to relatively other formations (Mayekisho 1994). For instance, the geomorphology does not help either, being granite shale from source to confluence and with poor pool formation (Mayekisho 1994).

The fish fauna of Tyhume River is part of what is described as a temperate fauna and is part of southern fauna (Skelton 2001).The southern fauna has a high level of endemic species, comprising 15 fish species distributed in the Cape Fold, the Amatole and the Drakensberg mountains. The majority of fish species are cyprinids (83%) and two *Sandelia* species; one Cape Kurper *Sandelia capensis* (Cuvier, 1831) found in Eastern and Western Cape coastal rivers and introduced into Clanwilliam Olifants river system. The other, *Sandelia bainsii* Castelnau, 1861 is found in the Tyhume River system. The southern fauna is divided into the Karoo and Cape fauna. The apex of Karoo fish fauna distribution is the Orange River, and consists of species such as *Labeo umbratus* (Smith, 1841) which has been translocated into the Tyhume River system (Skelton 2001).

The Tyhume River is located in high altitude areas of Hogsback, a part of Amatole Mountains, which ensures a high local relief rainfall (Skelton 2001). The lower elevations of the Tyhume River, towards Alice urban area, receive nearly half the rainfall in Hogsback area and possess a Karoo fish fauna (Mayekisho 1994; Skelton 2001). The Cape fauna includes relict species that require high rainfall for existence (Skelton 2001).

2.4.1.1: Indigenous Fish Species

Five fish species are indigenous or endemic to the Tyhume River; these include *Barbus trevelyani* Günther, 1877*, S. bainsii, Anguilla mossambica* (Peters, 1852), *Glossogobius callidus* (Smith, 1937) and *Myxus capensis* (Valenciennes, 1836) (Skelton 2001). *B. trevelyani* distribution is limited to the rocky foothills, while *S. bainsii* exhibits more plasticity as it ranges in distribution from the rocky foothills to the confluence with Keiskamma River (Mayekisho 1994). *A. mossambica* is a catadromous fish species whose life cycle includes returning to the sea to spawn. *G. callidus* species are normally found in inshore areas and estuaries, although many are found in freshwater. *M. capensis* is indigenous to Tyhume River and breeds at sea then migrates into rivers

(Skelton 2001). The Tyhume River is therefore important for conservation of unique fish biodiversity as it provides refugia for two threatened species *B. trevelyani* and *S. bainsii* or 4% of indigenous fish species. These two species were first listed in 1996 on the IUCN Red List; *B. trevelyani* is listed as Critically Endangered and *S. bainsii* is listed as Endangered (Skelton 2001).

2.4.1.2: Translocated (Native) Fish Species

Three fish species indigenous to South African have been translocated into the Tyhume River system. *L. umbratus* is translocated from the Orange River into the Keiskamma River and its tributary, the Tyhume River. *T.sparrmanii* is able to thrive even in degraded habitat conditions. The other fish species *C. gariepinus* is widely distributed in Africa and many parts of the rest of the world (Skelton 2001). The catfish was first recorded in the Tyhume River in 1985; it is believed to have been an accidental introduction from aquaculture ponds in Fort Hare University (Mayekisho 1994).

2.4.1.3: No-native Fish Species

Three fish species are non-native to the Tyhume River system; these are mainly from the northern Hemisphere: *O. mykiss*, *M. salmoides*, and Bluegill Sunfish, *Lepomis macrochirus* (Mayekisho 1994; Skelton 2001). *O. mykiss* was first imported for recreational fishing enhancement in 1877 from England and was introduced into rivers from 1899 (Welcomme 1988). It has been widely introduced in many waters in temperate and high altitude regions (Mayekisho 1994; Skelton 2001; Welcomme 1988). *M. salmoides* was introduced into Cape Rivers and ponds for enhancement of recreational fishing in 1930. The original stock was imported from the Netherlands in 1928 (Mayekisho 1994; Skelton 2001). *L macrochirus* was introduced as fodder fish for bass and for angling fisheries from Maryland, USA in 1938. The Sunfish is considered a pest, because it heavily predates on indigenous fish fauna and also because of its ease of proliferation in virgin waters (Skelton 2001).

2.4.1.4: Threatened Fish Species

Three indigenous species *B. trevelyani* and *S. bainsii* have been listed on the International Union for Conservation of Nature (IUCN) Red List since 1992, while *M. capensis* is on the IUCN Red List under List Concern. *B. trevelyani* is listed as Critically

Endangered and *S. bainsii* is listed as Endangered (Skelton 2001). *B. trevelyani* distribution is restricted to high altitude mountains of Amatole. *S. bainsii* distribution in South Africa is limited to Buffalo, Keiskamma (to which Tyhume River is the main tributary), Great Fish and Kowie Rivers systems. *S. bainsii* is a member of Anabantid family, of which there are four genera, three in South African waters, the other two being *Ctenopoma multispine* Peters, 1844 and *Sandelia capensis* (Cuvier, 1831), and one from Asia (Skelton 2001) (Figure 2.1).

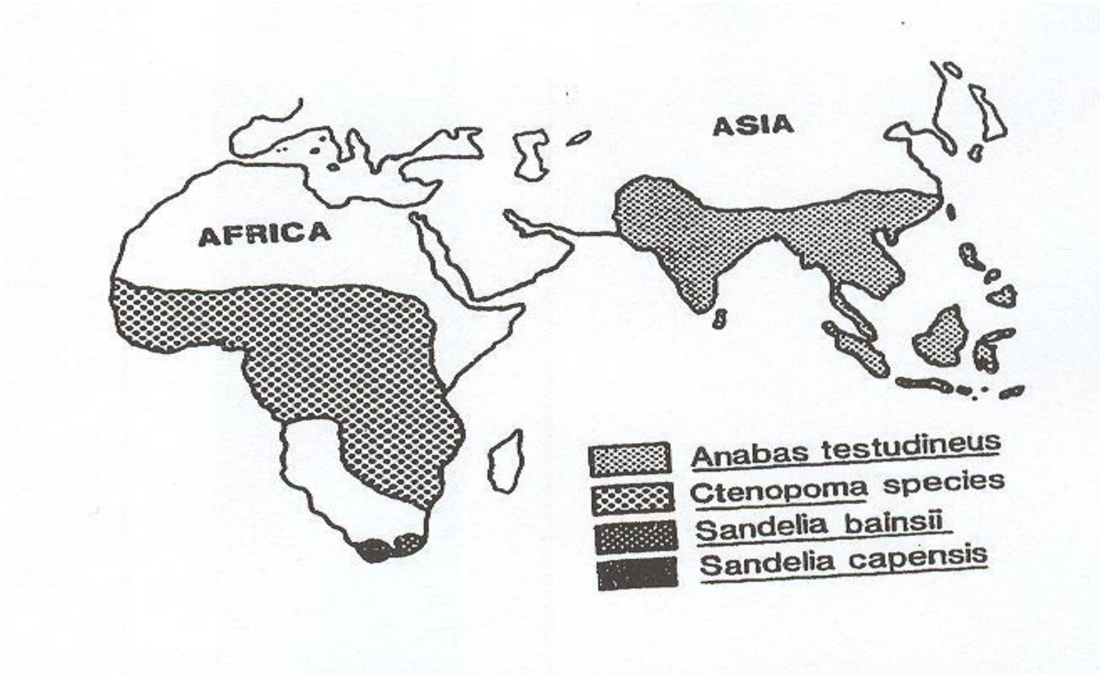

Figure 2.1: Global distribution of Anabantid family: Source Mayekisho 1994

S. bainsii distribution is characterized by low global population and allopathic differentiation with its congener *Sandelia capensis* (Cuvier, 1831) (Figure 2.1).

Locally the species is characterized by limited distribution and low local abundances (Figure 2.2). Their distribution in South Africa is restricted to the Eastern Cape Rivers of Buffalo and Keiskamma, for *B. trevelyani*. *S. bainsii* has a wider distribution occurring in the Buffalo, Keiskamma, Great Fish and Kowie river systems (Figure 2.2). *M. capensis* listing: The IUCN Red List under List Concern means that the species has been assessed but does not fall in the categories of Critically Endangered, Endangered, Vulnerable or Near Threatened.

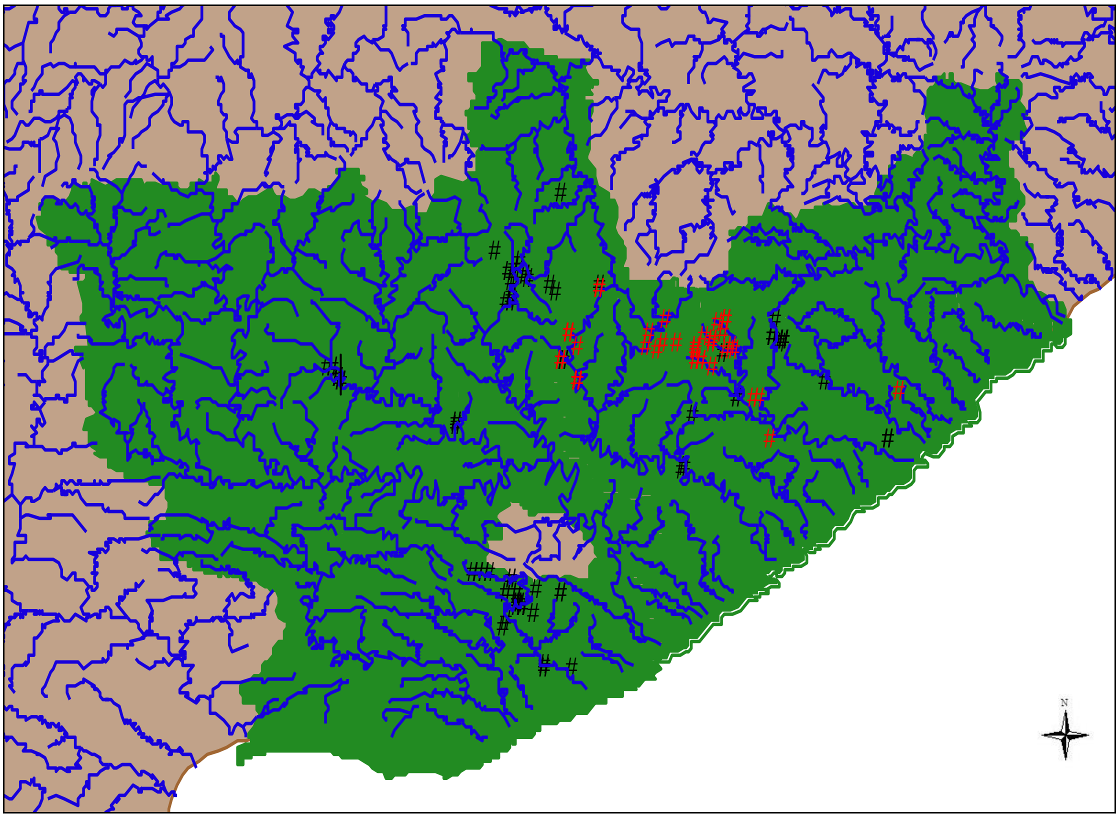

Figure 2.2: Distribution map of *Barbus trevelyani* (#) and *Sandelia bainsii* (#) in Eastern Cape Province (Green), South Africa: Source: Roger Bills South African Institute of Aquatic Biodiversity (SAIAB).

Within the Southern Africa region, 33 freshwater fishes are listed on the 1996 IUCN Red List (Skelton 2001). While no species is known to have become extinct within this region, 11 are listed as Critically Endangered, 6 as Endangered, 9 as Vulnerable and 7 as Near Threatened. The majority of threatened species are endemics with limited geographical distribution in mountain streams (Skelton 2001). The IUCN Red List Criterion is based on risk of species extinction from extent of population decline, estimated population size and extent of occurrence. A listing on Critically Endangered denotes extremely high risk of extinction in the wild in the immediate future (IUCN 2006). While a category of Endangered indicates a species is not Critically Endangered, though *in situ* populations are at a high risk of extinction in the not too distant future. The Tyhume River is therefore important for conservation of unique fish biodiversity as it provides refugia for these two threatened species that have a limited geographic distribution (Mayekisho 1994; Skelton 2001

2.5: Fish Abundance and Occurrence

Fish abundance measure indicates the number of fish species in a given area. Abundance is estimated as the number of fish caught over a given time (Kennen *et al.* 2005). Relative abundance of individual species is a useful measure of species composition (Kennel *et al*. 2005). It is a useful measure of fish species evenness or variations that indicate dominance. Relative frequency is calculated as the number of fish of a particular species out of the entire fish composition. It is a useful measure of homogenization as it indicates proportions of fish species and categories of non-native versus indigenous fish species. The homogenization process manifests in areas with multiple anthropogenic effects arising from land use practices and in-stream modification: In these areas non-native fish species are able to cope better as they tend to be cosmopolitans, leading to the homogenization process (Mayekisho 1994; Reid 2004; Scott 2006).

Investigations on effects of impoundments using biotic parameters revealed a reduced abundance of eight fish species below Binfield Park Dam on Tyhume River (Mayekisho 1994). The indigenous species, the *Barbus trevelyani* Günther, 1877, was most impacted, as it had virtually disappeared on account of reduced abundance. This reduction was recorded at study sites around Binfield Park Dam which, prior to impoundment, formed the apex distribution. While for *Sandelia bainsii* Castelnau, 1861, the major impacts observed were changed food habits, slower growth and delayed gonad maturation, Mayekisho (1994) argued that the translocated sharptooth Catfish *Clarias gariepinus* (Burchell, 1822), a euryphagous predator, was likely to pose a greater threat to indigenous fish species than introduced exotics.

In Eastern Cape, South Africa, Mayekisho (1994) investigated impoundment effects on fishes of Tyhume River. Eight fish species exhibited reduced distribution and abundance below the Binfield Park Dam. A comparison of pre and post impoundments at study site 3 (above impoundment) and study site 7 (below impoundment), revealed that the abundance of *B. trevelyani* declined from 0.36 to 0.33 (study site 3) and from 0.37 to 0 (study site 7). Similarly, the abundance of *S. bainsii* declined from 0.1 to 0.66 (study site 3) and increased from 0.37 to 0.66 (study site 7) (Mayekisho 1994; Table 2.1). Two of the indigenous fish species *S. bainsii* and B. *trevelyani*, recorded reduced abundance from impoundment effects. This same area exhibited altered water quality characteristics; those teased out had lowered pH and reduced monthly variation in conductivity and turbidity over a distance of 7 km from the Binfield Park Dam.

Table 2.1: Comparison of pre and post impoundment abundance of *S. bainsii* and *B. trevelyani* at Sites 3 (above) and 7 (below) Binfield Park Dam (Adapted from Mayekisho 1994)

Site No	Fish Species	Abundance	
		Pre - Impoundment	Post- Impoundment
3 (Rocky foothill)		1993/94	1989
	S. bainsii	0.1	0.07
	B. trevelyani	0.36	0.33
7 (Sandy foothill)	S. bainsii	0.37	0.66
	B. trevelyani	0.37	0

2.6: Fish Distribution

The distribution of fishes is summarized in (Table 2.2). Presence/absence was the main method used to map the longitudinal distribution of fish species along the Tyhume River. Presence records the different number of species caught per study site after each sampling. Those fish species not recorded are absent from the study site. Post impoundment distribution of indigenous fishes within the Tyhume River reduced, relative to pre impoundment distribution (Mayekisho 1994). Post- impoundment *S. bainsii* distribution ranged from rocky foothill, (730 MASL) to 520 (MASL) (Table 2.2). This is a reduction when compared to pre-impoundment distribution range, from escarpment to confluence with Keiskamma River. Post impoundment *B. trevelyani* exhibited a limited distribution from escarpment to Binfield Park Dam (Table 2.2). Previously distribution by the fish ranged from escarpment 730 (MASL) to 530 (MASL) (Mayekisho 1994). *Tilapia sparrmanii*, a translocated species, was the only species judged successful on account of maintaining its range and colonizing new areas (Mayekisho 1994).

Table 2.2: Comparison of pre and post impoundment fish distribution: 1983 & 1989 (E=Escarpment; Y=Presence; 1-15=Sampling Sites) (Mayekisho 1994)

Species		E	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Anguilla mossambicus	1983				Y		Y		Y					Y	Y	Y	Y
	1989				Y		Y		Y					Y	Y	Y	Y
Barbus trevelyani	1983	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y					
	1989		Y	Y	Y	Y	Y										
Clarius gariepinus	1983												Y	Y			
	1989												Y	Y	Y	Y	Y
Glossogobius callidus	1983																
	1989																
Labeo umbratus	1983									Y	Y	Y	Y	Y	Y	Y	Y
	1989									Y	Y	Y	Y	Y	Y	Y	Y
Lepomis macrochirus	1983												Y	Y	Y	Y	Y
	1989							Y					Y				Y
Micropterus salmoides	1983												Y	Y	Y	Y	Y
	1989												Y				
Oncorhynchus mykiss	1983	y	Y		Y	Y											
	1989	y	Y		Y	Y	Y										
Sandelia bainsii	1983				Y	Y	y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	1989				Y	Y	y	Y	Y	Y	Y	Y	Y				
Tilapia sparrmanii	1983									Y	Y	Y	Y	Y	Y	Y	Y
	1989									Y	Y	Y	Y	Y	Y		

2.7: Economic Value of Ecosystem Services

Economic valuation of ecosystem services is a powerful tool that can contribute to the sustainable use of aquatic resources (Barbier *et al*. 1997). Economic valuation attempts to assign quantitative economic values to the goods and services provided by ecosystem services. Economic value is assigned regardless of availability of market prices, although some ecosystem services have market value. Economists attribute ecological degradation to failure to account adequately for non-market value, provided by ecosystem goods and services. Since most ecosystem services lack market value, tradeoff decisions are skewed in favour of goods with a market value. Ultimately this contributes to sub-optimal decisions that are unlikely to deliver on sustainable resource utilization (Barbier *et al*. 1997). Exclusion of ecosystem services in economic value leads to excessive use, conversion to other users, and in some cases, depletion (Adger and Lutrell 2000; Barbier *et al*. 1997; Loomis *et al*. 2000).

Assigning economic value to ecosystem services contributes to sustainability by translating ecosystem value into terms that are comparable with other things that are of economic value to human beings. Indeed, Holmes *et al.* (2004) argues that observations showed that there tends to be negative correlation in the ecological integrity of a river basin relative to the degree of human influence. Methods applied in economic valuation vary, but one area that is gaining widespread use is micro-economic analysis (Holmes *et al*. 2004). Micro-economic analysis relies on net benefits associated with marginal changes in ecosystem services. When a micro-economic approach is closely linked to a clearly defined policy baseline, it provides a good conceptual basis for empirical analysis (Loomis *et al.* 2000; Holmes *et al.* 2004). A micro-economic analysis, coupled with a policy baseline, provides a good basis for assessment of benefits likely to accrue from marginal changes in restored ecosystems (Birol *et al.* 2006; Holmes *et al.* 2004).
A number of studies have demonstrated this; For instance, Loomis *et al*. (2000) undertook economic valuation along the Plate River, near Denver, Colorado, in the United States of America (USA). He presented dichotomous choice questions for the restoration of five ecosystem services. The ecosystem services were: dilution of wastewater, natural purification of water, erosion control, habitat for fish and wildlife, and recreation. In a sample of nearly 100 persons interviewed to solicit support for additional ecosystem services, it emerged that households were willing to pay on average US$ 21 per month or US$ 252 per annum. Extrapolating this figure to all households living along the river yielded an economic value of US$19 million to US$70 million. The figures were, however, dependent on whether those refusing to be interviewed had a zero value or not. The benefits, even on the lower band, exceeded

the cost of water leasing (which ranged between $1.13 million and $12.3 million) for easement of farmland costs, to establish a conservation reserve.

In a similar study undertaken in Yagui River Delta in Mexico, 40 communities in the most populated Delta city of Ciudad, Obregon, were sampled (Ojeda *et al.* 2007). Hypothetical scenarios were developed to give respondents clarity of the situation. The hypothetical scenario depicting the current situation showed that water diversions had degraded riparian ecosystems and reduced water flows. This had affected river flows to the extent that the river had not reached the Gulf of California in decades. The improved hypothetical scenarios depicted restored river flows, healthy riverside vegetation, wetlands, and fish biodiversity and wildlife habitats. The contingent valuation method was used to determine the non-market economic values of in-stream ecosystem services. The results from 148 interviews in person indicated that households were willing to pay 73 Pesos monthly.

Another study in Japan used contingent valuation to estimate Willingness to Pay (WTP) for conserving Lake Biwa. Nishizawa *et al*. (2006) used contingent valuation to estimate willingness to pay (WTP) for reduction of non-native fish species in Lake Biwa. The resultant increase in indigenous fish composition was indicated as the enhanced benefits that would accrue to communities. An additional benefit cited 'would be' improvement in the overall conservation status of Lake Biwa. Residents sampled expressed willingness to pay an estimated 1850 Yen per year, or a total 376 million Yen when the figure was extrapolated to all residents of Shiga Prefecture.

2.7.1: Concepts of Ecosystem Services Economic Value

The goods and services provided by lotic systems are either private goods (domestic water supply) or public goods and services (fish, water purification, CO_2 sequestration and climate regulation) (Birol 2006; Gatzweiler 2006). Ecosystem services also include erosion control, habitat for fish and other wildlife, dilution of wastewater and recreational use. These ecosystem services provide a host of benefits to humankind, such as, reduction in costs of water purification derived from riparian buffers and wetlands. Other benefits derived from wetlands are CO_2 sequestration, climate regulation and aesthetics (Birol 2006; Loomis 2000). These goods and services contribute utility to individuals and are therefore of value. Though the value may be small, the non-rival nature ensures simultaneous utility by a large number of people and an accumulation of large social benefits (Loomis 2000).

The economic value of ecosystem services in utilitarian economics is based on the utility human beings derives from direct or indirect use (Wilson 1999). In classical utilitarianism, the use of society's resources should aim to maximize the sum total of utility available to individuals (Tisdel 1991). However, utility as a measurement has limitations relating to objectivity and comparability between individuals. Hence the *Pareto* welfare approach is normally applied.

A *Pareto* welfare approach is also based on individual preferences, but avoids comparisons (Farber *et al*. 2002). The approach hinges on the concept that utilization of scarce resources needs to be efficient in satisfying human wants. Since the economist's concept of value is based on satisfaction of wants or utility; decisions are made in order to optimize utility against prevailing constraints. These are usually imposed by resources supply, income and time (Farber *et al*. 2002). However, in real world scenarios, optimization yields deterministic set of decision options with constraints held *ceteris paribus*. When applied to the sustainability concept, this poses a dilemma when optimizing preferences for future generations. Often a change in constraints produces a different set of decision options introducing uncertainty in predictions of future preferences (Farber *et al*. 2002). The *pareto* optimality criterion in natural resources allocation can be fulfilled when there is no other feasible manner which can be allocated to a particular natural resource (Gatzweiler 2006). Satisfying the *pareto* optimality criterion of benefiting all without causing harm to another's, is a challenge. To overcome this, welfare economic relies on the Kaldor- Hicks principle of gainers compensating losers (Gatzweiler 2006; Tisdel 1991). In order for gainers to compensate losers, the benefits must exceed the costs of project implementation. A cost benefit analysis framework can then be used to assess economic efficiency. When the net present value at some appropriate discount rate exceeds net present cost, and is positive, the project is worth undertaking (Gatzweiler 2006; Water Research Commission, WRC 2007).

2.7.1.1: Differing Concepts of Ecosystem Services Value

Ecological economics is often faced with challenges arising from the differing ways in which ecologists and economists conceptualize value (Norton and Noonan 2007). Yet, in order to move beyond what is perceived as monetization of environment goods, a broad based stakeholder consultation process is required. This incorporates differing perceptions of value that can then inform policy decision making (Spash *et al*. 2009). Other contenders argue that the aim is not to monetize the environment but rather to aid decision making. Failing to assign economic value to non-market environmental goods and services, they argue, implicitly infers a zero value (Everard 2004). Ownership of the environment, though, is a contentious issue that lacks a clear theory, either positive or normative, to inform decisions (Schmid 1995). While some economists contend that economic products can be optimized through the manner in which property rights are distributed, others contend the agony of choice can be avoided by use of markets that are oblivious to the original right holder. Another contrasting view is that the burden of moral choice is inevitable against a paucity of facts to inform policy formulation (Schmid 1995). Still other economists contend that the decision on systems for distribution or rights should be left to the people, to optimize the economic product (Schmid 1995).

Another unresolved issue is the differing ways that economists and ecologists conceptualize value. As Farber *et al.* (2002) argues, valuation is in most cases is informed by a combination of intrinsic and instrumental concepts of value. The latter is anthropocentric and the former ecological. The economist's concept of value is based on the marginal utility that an individual derives. Since this is the same across users, it enables money to be used as a standard measure across all users.

In contrast, the ecological concept of value emanates from co-evolution among groups of interacting species. This suggests that some species could have a pivotal value. Extrapolating this logic to human co-evolution; the value of ecosystems can be based on their contribution to human survival. Alternatively, some ecologists and physical scientists argue that the law of thermodynamics can form the basis of economic valuation. Under this scenario, the various ecological processes of capturing and utilizing energy are assigned a value. This translates to a single source of value based on production systems (Farber *et al.* 2002).

Social scientists argue that the process of assigning value to inform policy decisions needs to incorporate the differing perceptions of value held by a wide array of stakeholders. They argue this will assist economic valuation to move beyond what is perceived as monetization of environment, goods and services (Bryan and Noonan 2007; Spash *et al.* 2009). Proponents of a differing view contend assigning value to ecosystem services cannot be avoided, as not assigning value implicitly infers some value (Everard 2004; Loomis *et al.* 2000).

2.7.1.2: Limitations of Ecological Economics

Ecological economics, as a discipline, has been criticized for not overcoming the dualistic approach to evaluation of anthropogenic induced modifications (Norton and Noonan 2007). Norton and Noonan (2007) argued that this places the field at crossroads in terms of methodologies used. When addressing uncertainty, descriptive methods and hypothesis testing are applied. Conversely, in evaluating the anthropogenic changes, economic measurements rely on direct and indirect methods to assign economic value. Yet, to effectively reform environmental policy in line with ecological economics principles, models that integrate in unison are requisite.

At the heart of the criticism is non-inclusion of social scientific methods (Norton and Noonan 2007). This is attributed to dominance of a monistic approach that appeals to rationality, as it provides comparability in a single accounting system. A monistic approach avoids the messy process of encapsulating value that tends to arise when pluralistic theories are incorporated. Proponents, however, argue that excluding these notions of economic value fails to take cognizance of the fact that environmental issues are inherently messy and confusing. It, thus, limits solutions to assigning rights to more elements of nature, which they argue may fall short of finding a lasting solution (Norton and Noonan 2007).

Assigning economic value to environmental goods has nevertheless remained a challenge because of mismatch in production systems. Ecosystem production systems are difficult to partition into discrete units due to the inherent connectivity of ecological process (Turner *et al*. 2003). This mismatch arises because economic methods rely on discrete units of the good to assign economic value to specifiable changes. To overcome this shortcoming, micro-economic analysis is often applied. Micro-economic analysis relies on imposition of a new policy to serve as a baseline for evaluation (Holmes *et al*. 2004). However, it does not redress the issues of multi attributes and connectedness inherent in ecological systems (Holmes *et al*. 2004).

Application of the contingent valuation method in the Tyhume River, Nkonkobe Municipality, Eastern Cape, South Africa, is possible because information on areas in need of restoration has been generated in the ecological study. In addition, a new policy for sustainable use of biodiversity has been adopted under the National Water Act (NWA Act No. 36 of 1998), National Environmental Management Act No. 107 1998 (NEMA 1998) and National Environmental Management Biodiversity Act No. 10 (NEMBA 2004). This forms the basis for development of hypothetical scenarios to facilitate the elicitation of Willingness to Pay (WTP).

2.7.1.3: Economic Efficiency

Economic efficiency occurs when markets are able to attain *pareto* optimality. Under this scenario, economic efficiency is achieved when the net present value is in excess of net present cost, and is positive (Gatweiller 2006; Tisdel 1991). Cost benefit analysis (CBA) is the most used method for aiding social decision-making on efficient use of natural resources. It has been criticized because preferences of future generations are difficult to predict with certainty, while those of present generations can vary unpredictably. Uncertainty is further increased for non-marketed goods by the fact that methods used to assign value are inferred (Tisdel 1991; Farber *et al.* 2002).

Other disagreements are on the discount rate to be applied to cost benefit analysis. The social point held by some economists is that a zero discount rate should be applied. Other views propose that the discount rate should be prioritized as discounted benefit cost ratio based on the conservation or restoration measure likely to deliver the most benefit (Tisdel 1991).

2.7.2: Methods Used to Value Ecosystem Services

Anthropogenic effects externalities manifest in habitat quantity and quality, and in composition of alien fish species in the fish assemblage of Tyhume River. This can be assigned an economic value in order to aid trade decision with other things of economic value to humans. The Total Economic Valuation Conceptual Framework (TEVCF) is the most commonly used method when assigning economic value to both direct and indirect ecosystems services (Birol *et al.* 2006; Holmes *et al.* 2004; MA 2005; Wilson 1999). Direct use value is associated with consumptive use (e.g. drinking water, irrigation, harvesting natural resources and industrial use). Indirect use value is associated with flood control, dilution of waste water, natural water purification; non-use value is derived from maintenance of biota such as rare species. Another value, called 'option use value' is linked to future use or bequest value (Barbier *et al*. 1997; Birol *et al*. 2006).

Valuation methods for ecosystem services fall into two broad categories: revealed and stated preference methods (Birol *et al*. 2006). The most commonly used revealed preference methods are Hedonic Pricing Method (HPM) and Travel Cost Method (TCM). HPM is theoretically based on Lancaster's Characteristic Theory of Value, which is premised on the fact that economic value of a good is a reflection of all characteristics that constitute the bundle (Birol *et al*. 2006). The price of the good is likewise dependent upon these characteristics and their respective levels. The Stated Preference Method (SPM) is normally used to assign economic value to non-traded ecosystems goods and services. The most widely used method is Contingent Valuation Method (CVM), where valuation is contingent upon presentation of a hypothetical scenario to a given population sample (Barbier *et al*. 1997; Birol *et al*. 2006).

A new addition to SPMs is the Choice Experiment Method (CEM) which, like HPM, is theoretically grounded on Lancaster's Characteristic Theory of Value (Birol *et al*. 2006). However; unlike HPM, CEM depends on Random Utility Models (RUMs). RUMs are discrete choice econometric models that assume respondents have perfect discrimination capacity. CEM requires the analyst to factor in uncertainty, posed by the likelihood of respondents having incomplete information (Birol *et al*. 2006). In some cases the legal and social consequences of violating laws are also often used to assign economic value to an intrinsic entity. This method, however, has a high risk of being distorted by the “public good” characteristics of most natural resources (Tisdel 1991).

Two broad categories, Revealed Preference and Stated Preference Methods, are reviewed due to their relevance to this study.

2.7.2.1: Revealed Preference Methods

The most commonly used Revealed Preference Methods are Hedonic Pricing Method (HPM) and Travel Cost Method (TCM) (Birol *et al*. 2006; Tisdel 1991).

2.7.2.2: Hedonic Pricing Method (HPM)

Hedonic Pricing Method (HPM) theoretical basis is in the Lancaster’s Characteristic Theory of Value (Tisdel 1991; Turner *et al*. 2003). This theory describes the linkage between the bundle of characteristics and their individual contributions to overall value. Hedonic Price Valuation relies on the premise that the price paid for property reflects both environmental and non-environmental characteristics. Disaggregating what constitutes environmental value from the bundle is used to infer economic value of ecosystem services. The data is obtained from house prices which vary in relation to proximity to a natural resource, such as an ocean beach front or a park (Birol *et al.* 2006; Green *et al*. 1990; Tisdel 1991).

2.7.2.3: Limitations of Hedonic Pricing Method (HPM)

HPM application in valuation of non-use ecosystems services is limited. While it can measure direct use value of traded goods, it cannot measure non-use services such as flood control, water quality, improvement and provision of habitat for species (Birol *et al.* 2006). Other limitations arise from inaccuracies in price disaggregation of value characteristics from the bundle. Obtaining data on individual properties can be a challenge as data is often aggregate (Green *et al.* 1990; Tisdel 1991).

2.7.2.4: Travel Cost Method (TCM)

TCM measures utilities obtained from visiting recreational sites such as nature trails in forested areas or national parks. It uses travel costs incurred by individuals as surrogate to infer ecosystem value (Green *et al*. 1990). TCM can then be used to estimate Willingness to Pay (WTP) for ecosystem services. The consumer surplus is the difference between value and cost incurred through travel (Birol *et al*. 2006; Green *et al*. 1990; Latinopoulos 2014).

2.7.2.4: Limitations of Travel Cost Method (TCM)

TCM presents limitations in accurate definition of the opportunity cost of time. The limitations arise because substitute sites are evaluated using a random utility model approach (Turner *et al.* 2003). Often this yields information on value characteristics applicable to the site as a whole, which is not desirable. Like HPM, TCM cannot capture the non-use values of the ecosystem (like flood control) and is only used for goods consumed *in –situ:* (Birol *et al.* 2006; Green *et al*. 1990; Turner *et al.* 2003).

2.7.3: Stated Preference Method (SPM)

Stated Preference Method (SPM) is normally used to assign value to non-traded goods and services (Turner *et al.* 2003; Johnston *et al.* 2013). It is usually applied in estimation of non-use value. The most widely used method is Contingent Valuation Method (CVM) (Birol *et al*. 2006; Holmes *et al.* 2004; Loomis *et al.* 2000).

2.7.3.1: Contingent Valuation Method (CVM)

Contingent Valuation Method (CVM) relies on presentation of a hypothetical scenario to a population sample (Turner *et al.* 2003). The methods used are questionnaire, interview or referendum. Individuals are then asked to state their willingness to pay (WTP) or willingness to accept payment (WTA) (Birol *et al*. 2006; Holmes *et al*. 2004; Loomis *et al.* 2000; Nishizawa *et al*. 2006; Ojeda *et al.* 2007).

2.7.3.2: Limitations of CVM

CVM has been criticized for limitations arising from lack of reliability, as well as validity problems (Turner *et al.* 2003). A number of biases relating to design, starting vehicle, and accuracy of hypothetical scenarios are often cited (Birol *et al*. 2006). Limitations also arise from hearsay and strategic biases (free-riding), especially in a referendum (Birol *et al*. 2006). Some empirical studies have, however, proven that free riding is not a significant problem (Green *et al.* 1990).

To redress limitations, the Blue Ribbon Panel under the auspices of U.S. National Oceanic and Atmosphere Administration (NOAA), has addressed these problems (Arrow *et al.* 1993). It has made recommendations for best practice in design and implementations. Among the recommended strategy is use of personal interviews in survey methodology. It is hoped that use of a personal interview will facilitate communication of a shared understanding. It also enables respondents to comprehend exactly what is being restored, and to understand the cost implications (Arrow *et al.* 1993).

2.7.3.3: Choice Valuation Method (CEM)

A new addition to SPMs is Choice Valuation Method (CEM) which, like HPM, is theoretically grounded in Lancaster's Characteristic Theory of Value (Turner *et al.* 2003). However; unlike HPM, it depends on Random Utility Models (RUMs). RUMs are discrete choice econometric models that assume respondents have perfect discrimination capacity. The analyst conversely has incomplete information and must take uncertainty into account (Birol *et al.* 2006; Tisdel 1991; Turner *et al.* 2003).

2.7.4: Inferring Economic Value from Legal and Social Consequences

Finally, the degree of value attached to an intrinsic entity can also be deduced from the legal and social consequences of violating laws (Tisdel 1991). This method, though, has a high risk of being distorted by the "public good' characteristics of most natural resources (Tisdel 1991).

2.7.5: Economic Value of Ecosystem Services and Sustainability

The sustainability concept seeks to bequeath similar benefits to future generations. However, this poses a challenge because preferences change constantly, hence, optimizing for future generations cannot be predicted with certainty (Farber *et al.* 2002). Bequeathing benefits to future generations is further complicated by controversies relating to the discounting rate used in cost/benefit analysis. Future benefits are discounted less than present value, and they vary according to discount rate. The more future benefits diminish, the higher the rate of discount and longer the duration into the future (Pasqual and Souto 2003; Tisdel 1991; WRC 2007). There are also variations among countries, where developing countries have higher discount rates than developed countries. Other suggestions are for use of a mean value around 4% applicable to near future periods and declining to zero for the longer term. In South Africa 8% is recommended as an appropriate discount rate (WRC 2007).

The interest rate leads some economists to argue that net present value is pro current generations. On an intergenerational level the sustainability debate is plagued with disagreements on the appropriate discounting rates. Critics argue that traditional methods of calculating Net Present Value (NPV) and Internal Rate of Return (IRR) are pro current generation (Pasqual and Souto 2003). Other complications arise from uncertainty of predicting future benefits against inherent problems of changing preferences (Farber *et al*. 2002; Schmid 1995; Pasqual and Souto 2003). Hinging sustainability on an ecosystem approach further complicates aquatic resource governance. In essence it entails constraining human resource use, in line with principles of modern evolutionary biology. Against a background of rising populations, it creates conflict between maintenance of ecosystem functionality and human utility (Sandberg 2007).

Other complexities arise from the scarcity created by increasing demands for water resources worldwide (European Environmental Agency, EEA 2009; Millennium Assessment, MA 2005). This has necessitated states recognizing rights for non-human users. In South Africa this is reflected in the National Water Act 1998, which provides leadership in this area by establishing an ecological reserve as the only right (Palmer *et al*. 2002).

2.8: Institutional Mechanisms and Degradation of Fish Biodiversity

Institutional mechanisms have a fundamental role to play in mitigating externalities that characterize lotic systems (Adger and Luttrel 2000). Externalities can be either positive or negative. Negative externalities arise because of costs that are poorly internalized. Conversely, positive externalities result from benefits for which it is unfeasible to assign a charge; hence users maximize on benefits and externalize costs (Pasqual and Souto 2003). Externalities are associated with anthropogenic activities and can arise when benefits or costs are not fully internalized by actors (Birol *et al.* 2007; Pasqual and

Souto 2003). Externalities are also common in lotic resources because of the multiplicity of goods and services provided for competing users. As each user has little or no incentive to adopt rationale use, they maximize their own utility while externalizing costs (Birol *et al.* 2006; Pasqual and Souto 2003). Most of the multiple users are often incompatible, creating problems of scarcity for other users. At the extreme the consequences are dire as they may result in total denial (Colby 1995). Externalities create scarcity of surface waters in terms of availability in the right quantity and quality (World Conservation Monitoring Centre, WCMC 1998). Scarcity created at the current generation level creates externalities for future generations, where aquatic resources are common and undermine the sustainability goal. It is this situation that accentuates the crucial role of institutional mechanisms in internalizing externalities, as this institutes control measures to curb unsustainable use of aquatic resources (Pasqual and Souto 2003).

To minimize these externalities and attain sustainability, institutional mechanisms are usually put in place of social control. Yet, despite the existence of institutional mechanisms, evidence of aquatic resources degradation is rampant (Kinya 2001). The failure of institutional mechanisms to achieve desired goals is a reflection of the lack of perfect mechanism for social control of natural resources (Barbier *et al*. 1997; Randall and Harte 2000). The non-existence of a perfect mechanism means the choice is often guided by the best available alternative between an imperfect market, and government intervention that can address the prevailing problem or vice-versa (Colby 1995; Sandberg 2007). It is often guided by the option best suited to the problem at hand (Barbier *et al*. 1997; Randall and Harte 2000).

The lack of perfect mechanisms for social control makes degradation of lotic systems institutional in nature, driven by lack of political will and overlapping institutional mandates. It occurs when property rights are attenuated and approaches to management are compartmentalized or fragmented (Mackay and Aston 2004). Institutional mechanisms can rationalize users as they have a pivotal role in management decision making and property rights regimes (Adger and Luttrel 2000; Barbier *et al*. 1997; Buck 1998).

Property right regimes are social constructions designed to regulate or govern relations among individuals. They govern use of a benefit stream from a particular natural resource (Sandberg 2007). They specify who is included or excluded, and outline procedures to be followed; including the requisite information needs (Buck 1998). However, while allocation of property hinges on proper definition of boundaries, this is often not achieved for aquatic resources, as they are plagued with complexities due to the indivisibility of resources, such as aquatic flora, fauna and water. By defining responsibilities, as well as opportunities, a natural resource property right regime orders relationships among beneficiaries (Schmid 1995). It constitutes economic power, as it is a bundle of rights relating to access, exclusion, extraction, sale, transfer and inheritance (Adger and Luttrell 2000; Buck 1998; Sandberg 2007; Schmid 1995). Institutional mechanisms are thus established in line with public policy for a particular resource. They govern relations and define the parameters within which the bargaining for access can occur (Colby 1995; Rohlf 1991).

In addition to establishing rights for individuals, institutions can constrain the policy options for individuals, necessitating policy analysis (Buck 1998). A policy that fails to recognize all users can create disparities in *de facto* and *de jure* state of resources and pose constraints. For instance, in the United States, non-coherence was promoted through a water policy that marginalized recreation and water quality users (Colby 1995). These categories of users could not obtain rights, despite having an economic interest linked to maintenance of adequate stream flows and water quality as integration of water allocation laws in most States was poor. Since rights for protection of water quality, as well as recreation users, could not be allocated, the system in place constrained these two categories of users. The policy in place limited protests to existing right holders, hence water quality and recreations users were excluded from lodging protests as (Colby 1995). In addition, the decision making process limited consideration to existing rights holders and did not consider impairment while reviewing water transfers (Colby 1995; Karr 1991). As a result, water resources continued to decline. This approach contributed to continued degradation of water resources, because the point sources approach failed to deliver on biological integrity (Karr 1991).

2.8.1: Conventional Property Rights Regimes

Property rights are the basic institutions in the governance of resources, and conventional conceptualization was based on Roman law which distinguishes four resource domains. The four resource domains (Private goods, Public goods, *res communes* and *res nullius*), dictate the type of institutional mechanism established for management (Adger and Luttrell 2000; Buck 1998; Sandberg 2007). Private goods are normally administered through market mechanisms because exclusion is feasible and subtraction is high (Buck 1998; Sandberg 2007). Public goods are characterized by consumption that is non-rival and non-excludable. A good is non-rival when one person's consumption does not reduce availability for others. It is non-excludable when it is not possible to limit provision only to those who pay, or where high costs are prohibitive (Birol *et al.* 2006; Gatzweiler 2006). The other two categories are goods which are *res communes* and *res nullius*. *Res communes* are goods that cannot be appropriated by either government or private sector and are available to all for use. While *res nullius* are goods that have no property rights attached to them until acquired by those who exploit them (Buck 1998; Birol *et al*. 2007; Gatzeiller 2006). This neat categorization, though, fails to adequately apply to common pool resources as it fails to account for resource dimensions. These complexities are further exacerbated by the high seasonal variability, and in many instances daily fluctuations in ecotones, nature of resource and the resource domain, where it exists making these resources difficult to partition (Carlsson and Berkes 2005; Buck 1998; Adger and Luttrel 2000; Thornston and Day 1998).

2.8.1.1: Complexities Posed by Property Rights for Nature

The inclusion of rights for nature creates additional complexities for water management as it introduces a duality of users belonging to a social and an ecological system. Creating rights for non-humans, in essence, challenges the anthropocentric contemplation of the nature of goods. This conceptualization of goods antecedently dominated the political economy based on the four resource domains. As Sandberg (2007) argues under this scenario, the traditional analytical dimensions of exclusion / non-exclusion, joint use and alternative use, take a different dimension when other creatures are included. Complexities arise when the institutions for this new social-ecological system and allocation of property rights need to embed current human users and non-human use.

The complexities the state must address in alienation of property rights is the bundling of five different rights that constitute ownership rights; these are access, harvesting, management, exclusion and alienation (Hanna *et al*. 1996; Randall and Harte 2000; Sandberg 2007). The State, in most cases, defines the institutional mechanisms that can internalize externalities. This is normally through allocation of property rights and setting priorities among the various users in the event of scarcity (Colby 1995; Birol *et al*. 2007). To gain widespread legitimacy, this needs to be attained in a manner that is consistent with existing traditional, cultural and local values (Buck 1998). Under these circumstances, the state in most cases defines the institutional mechanisms to internalize externalities.

Despite these challenges, there is consensus that successful governance needs to provide alignment at all levels, from community to regional and national levels (Carlsson and Berkes 2005; Sandberg 2007). This will facilitate communication of a shared vision and overcome mismatch in the harmonization of shared vision at the operational level that plagues most water resources management systems (Buck 1998; Carlsson and Berkes 2005). It includes community participation, and in order to gain widespread legitimacy, community participation is advocated as a tool for sustainable management.

2.8.1.2: Rights for Future Generations

The sustainability concept seeks to bequeath similar rights to future generations. However, how to incorporate rights for future generation in current decision making is of concern. Rawls' 'veil of ignorance' has been suggested as one way to address equity on an intergenerational level (Pasqual and Souto 2003). Rawls' veil of ignorance is where individuals make decisions whilst oblivious to the generation to which they belong. However, this would further complicate discounting which is dependent on a timeframe (Farber *et al*. 2002). An alternative proposal is to cede all rights to future generations (Pasqual and Souto 2003). Applicability of the latter is complicated by the fact that future generations do not participate in current political processes. They propose that the only way to ensure protection of rights of future generation is to concede all rights to future generations. In the absence of such concession of rights, an institutional mechanism should be developed to facilitate participation of future generation in current decisions. However, even with such concession, future generations are still disadvantaged by lack of participation in the political process. Issues affecting the future are thus not accorded urgency by current political systems and this undermines sustainability (Pasqual and Souto 2003).

2.8.2: Institutional Choice Theories

Key theories underpinning assessment of global commons are Institutional Analysis Development (IAD), Multiple Use Common Pool Resource Domains and Regime theory (Carlsson and Berkes 2005). According to these theories, institutions operate along three key levels of choices which are parallel in both regime theory and IAD framework. These levels are operational, procedural and constitutional components. At the operation choice level, or implementation component, rights and rules include appropriation, provisioning, monitoring and enforcement. At the collective choice or procedural component, it encompasses policy making, adjudication and management. The constitutional choice or procedural level involves formulation, governance, adjudication and motivation (Buck 1998; Carlsson and Berkes 2005).

The Multiple Use Common Pool Resource Domains framework for institutional analysis underpins recognition of all users as crucial to sustainability in natural resource governance (Adger and Luttrel 2000). Under this framework, community participation is seen as a means to widespread legitimacy among beneficiaries (Buck 1998). Conversely, incomplete recognition of all users is viewed as a source of non-coherence and discrepancy. This is because it often creates disparities in the *de facto* and *de jure* states of resources (Adger and Luttrel 2000).

A *de jure* right originates from a social contract based on what is an acceptable social arrangement. For instance, a *de jure* right to a fishing stock constitutes what is acceptable in terms of the bundle of rights. A *de jure* right stipulates access, exclusion, harvest and management between individuals or members of a collective (Adger and Luttrel 2000; Carlsson and Berkes 2005).

The right, as embodied in legal and institutional arrangements, like ownership, is a social choice. Society consciously makes this choice in order to give legitimacy and social acceptability (Buck 1998; Carlsson and Berkes 2005).

On the contrary, a *de facto* right is often a reflection of reality on the ground which could arise from long held customary practice or poor enforcement of existing rules (Randall and Harte 2000). *De facto* measures are therefore externalities that are outside the scope of *de jure* measures.

Similar arguments have been advanced by Adger and Luttrell (2000) on the fundamental role of institutions in reducing externalities. Institutional mechanisms therefore need to develop proactive strategies in order to minimize externalities. The strategies should aim to improve overall conservation status of lotic systems and to deliver sustainable use (Adger and Luttrell 2000).

Institutional mechanisms are, thus, distinguished from organizations which are well-defined social structures with set boundaries designed to achieve collective goals. Institutional mechanisms, as used here, refer to the set of rules as laid down in laws, treaties, regulations and customs that govern property right regimes (Buck 1998; Gatzweiler 2006; Hanna *et al*. 1996).

2.8.3: Legal Framework for Lotic Resource Governance in South Africa

In South Africa, *de jure* measures are provided in Constitution Act 108 of 1996 (South African Constitution 1996); the National Environmental Management Biodiversity Act No. 10 of 2004 (NEMBA 2004), the National Environmental Management Act (NEMA) No. 107 of 1998 (NEMA 1998), and the National Water Act No. 36 of 1998 (NWA 1998).

De jure institutional mechanisms for governance of water resources are in most instances under government custodianship (Adger and Luttrel 2000). This is due to the public good characteristic associated with water resources, and the fact that the resources provide basic human requirements. Government agencies are therefore responsible for allocation of rights and for setting priority among competing users (Colby 1995). Below is a summary review of these measures;

2.8.3.1: The Constitution

The South Africa Constitution Act No. 108 of 1996 (SACA) bestows custodianship for water on the government.

- It provides every South African person with a right of access to sufficient quantities of water and a healthy environment not harmful to wellbeing. It also provides for sustainability through provision for protection of environment for the benefit of current and future generations.
- It separates the functions of water resource management and water services provision. Water services provision is vested in the local government under the Municipal Water Services Act No. 108 of 1997

2.8.3.2: The National Environment Management Act (NEMA)

The National Environment Management Act No. 107 of 1998 (NEMA) provides the right to healthy environment and to protection of environment for every South African.

- It provides for mainstreaming of sustainable environment management through cooperative governance.
- It does so by stipulating decision making principles, and by designating institutions and procedures for cooperative governance.
- It recognizes that sustainable development intertwines social, economic and environmental factors in planning and decision making.
- It recognizes that poverty contributes to resource degradation and the need to address inequity in distribution of resources.
- It provides for public participation in environment management, as well as civil society participation in enforcement of environment laws. In order to realize its objects it provides for development of environment management plans and for remedial measures where the environment is degraded.
- It provides for remediation of environment degradation guided by the “polluter pays” principle. It also provides for incorporation of international environmental obligations into national laws.

2.8.3.3: The National Environmental Management Biodiversity Act (NEMBA)

The National Environmental Management Biodiversity Act No. 10 of 2004 (NEMBA) operates within the framework of NEMA. NEMBA broadly provides for management and conservation of all South African Biodiversity. It provides measures for protection of species and ecosystems in need of national protection. Below are some of principles and measures relevant to NEMBA:

- It allows equitable sharing of benefits through cooperative governance;
- It gives effect to ratified international agreements relating to biodiversity;
- It also stipulates the functions of the South African National Biodiversity Institute (SANBI);
    I. Among the functions of SANBI is to monitor the status of threatened ecosystems, species and invasive species;
    II. Prepare and coordinate remediation plans for threatened species, degraded ecosystems as well as for the eradication of invasive species, and;
    III. Develop and institute plans for conservation for fish species in need of restoration both *in situ* and *ex situ* as well as education plans on all issues relating to biodiversity (NWA 1998).

2.8.3.4: The National Water Act

The National Water Act of 1998 (NWA) contains the most comprehensive *de jure* measures for management and conservation of water resources. The guiding principles of the NWA are sustainable use and equity and efficiency in use of water resources for the benefit of all South Africans. It defines water use and water rights, thus;

- Chapter 3 of the Act outlines measures for protection of water resources through a strategy of resource directed measures. This strategy is a triangulation that involves classification, establishment of the reserve and setting of resource quality objectives;
- Measures to guard against water pollution are also contained in Chapter 3 of the Act. Pollution control measures contain the “polluter pays” principle for any remediation measures necessary;

- The only established right to water is the “reserve” which takes priority over all other users.

2.8.3.5: Water Use

Water use is defined as any activity that has an impact on quantity, quality and surrounding environment (The National Water Act of 1998, NWA (NWA 1998). Water use includes abstraction, impounding and discharging wastes.

Only one right is recognized - the basic “water right” for all South Africans, and the reserve for maintenance of ecosystem functions. Schedule 1 water users are not required to apply for a license and include domestic water users or users with minimum impact. Other existing water users are required to register their use, while new users outside Schedule 1 or under general authorization are required to apply for a license.

2.9: Post Rio Earth Summit Institutional Reform Measures

In response to the unprecedented rate of anthropogenic resource degradation, the Rio Earth Summit of1992 (Rio Earth Summit 1992), provided a paradigm shift towards governance for sustainability. The sustainability concept was first defined by the World Commission on Environment and Development (WCED) otherwise known as the Brundtland Report of 1987. The sustainability concept aims at ensuring maintenance of the benefit stream from use of a natural resource in perpetuity. The concept was further elaborated during the World Summit on Sustainable Conference (WSSD) (2002) as a triangulation of ecology, economics and social aspects of resource (Figure 1.2). Key concepts that have emerged from these international mechanisms to guide sustainability are the ecosystem approach and community participation. These concepts have been incorporated in the national laws of many countries, thus creating new property rights regimes with new opportunities, as well as complexities for resource governance (Sandberg 2007).

Institutional reforms for natural resource governance, over the last decade, have increasingly been driven by international mechanisms. This is against a background of unprecedented rate of natural resource degradation. The 1972 Stockholm Conference on environment initiated the international process of raising awareness of the need for prudent use of natural resources. Consequently, the Rio Earth Summit of1992 (Rio Earth Summit 1992), addressed many institutional inadequacies, resulting in a paradigm shift in resource governance. In response, many countries promulgated new laws for the realization of sustainability. The sustainability goal calls for an ecosystem approach to resource governance with indicators used to gauge compliance. Sustainability necessitates rights for nature and future generations. It also calls for participatory mechanisms where communities are involved in resource governance. These new measures have created disparities between *de jure* and *de facto* property rights, a situation often compounded by weakness in monitoring and enforcement and the cost involved (Sandberg 2007).

In recent times, the unprecedented rate of aquatic resource decline has spurred international mechanisms on to spearheading institutional reforms. The Post Rio Earth Summit introduced paradigm shifts in natural resource governance (Shelton 2004). Concepts such as sustainability prompted new property rights regimes and necessitated community participation to guide management. The Rio Declaration Principle 10 and Agenda 21 Chapter 23 both support public participation (Shelton 2004). Many countries which are party to these international agreements have introduced new legislative measures or adopted the measures as national. Implementation, however, poses a challenge to conventional institutional arrangements (Sandberg 2007).

The sustainability concept creates complexities because, at an inter-generation level, the environment is a common resource domain. Institutional mechanisms must find a way of incorporating rights of future generations in current decision making (Pasqual and Souto 2003). The sustainability goal as first defined by the World Commission on Environment and Development (WCED) also known as the Brundtland report (WCED 1987), is anthropocentric. Yet, on an intra/intergeneration perspective, the new institutions need to incorporate non-human and human users. Pasqual and Souto (2003) also argued that one approach that could redress equity at the intergenerational level would be to create situations whereby individuals make decisions while oblivious of generation (the already described, so called Rawls' 'veil of ignorance')...

2.9.1: Complexities of Sustainability

All the three Acts (NEMA, NEMBA, and NWA) referred to above are guided by the principle of ensuring sustainable use of aquatic resources. The sustainability goal creates complexity for management of lotic systems against a backdrop of increasing demands. It establishes rights for future generations; hence, current generation use is constrained. To deliver to future generations necessitates tradeoffs between current human use and ecosystem requirements. To overcome this dilemma, states are now recognizing rights for users other than humans. This is reflected in NWA (1998) which is providing leadership in this area. It has established only one right, which is basic water for all people and for maintenance of an ecological reserve to sustain ecosystem functions (Palmer *et al.* 2002). Assigning rights for nature, challenges the conventional property rights regime guided by Roman law, which has been described, traditionally distinguished the four resource domains, namely, private goods, public goods, *res communes* and *res nullius*.

2.9.1.1: Ecosystem Approach

The ecosystem approach as defined by Convention on Biological Diversity (CBD) is a strategic approach. It relies on an integrative framework for management of land, water and living resources. This integrative framework creates a balance in the three objectives of Convention on Biological Diversity (CBD), which has been described above. The ecosystem approach is scientifically based, and focuses on levels of biological organization from essential structures, processes, functions and interactions among organisms and their environment. Humans and their cultural diversity are recognized as an integral part of ecosystems. The ecosystems approach is guided by principles which recognize that management objectives are a societal choice. The ecosystem approach promotes decentralized management to the lowest level, and community participation. A decentralized approach on adaptive management framework facilitates the inclusion of knowledge from a wide sector also including local level indigenous knowledge (Sandberg 2007).

An ecosystem approach promotes incorporation of various forms of economic value into management objectives. These include intrinsic, tangible and intangible aspects of value. They are anthropocentric benefits and are guided by the principle of fair and equitable sharing of benefits. The fact that most governments have made commitments to adapt an ecosystem approach is reflected in the number of countries that signed the Rio Earth Summit Declaration and are party to the Convention of Biodiversity. Implementation of an ecosystem approach creates complexities arising from a lag in epistemological preparation for an evolutionary biology approach to resource governance. Scientists argue that it requires an institutional reorganization that is yet to be developed. It creates complexities when institutional mechanisms have to address whole ecosystems, as opposed to single species. In management of fisheries stocks it creates a need for multispecies optimization models, while the prevailing knowledge is based on single species models (Klemm 1995; Sandberg 2007; Shelton 2004).

In lotic systems, it necessitates a watershed wide approach, but this is constrained by prevailing models. Current models focus on the extent of geographical coverage required to adequately protect a single species, yet the necessities are models that integrate land use practices with lotic system integrity (Karr 1991; Klemm 1995; Sandberg 2007). A watershed approach at the operational level creates fuzziness in definition of boundaries. It is also likely to create a mismatch between scale of management and the scale of user operation (Buck 1998; Sandberg 2007). Further, an ecosystem approach and the resultant adaptive management approach create complexity for the role of the state, as it seems to require more government involvement; yet the current emphasis is on 'lighter governments' and devolution to grass-root level (Sandberg 2007).

An ecosystem approach hinged on adaptive management creates policy ambiguities due to differing ways in which scientists and policy makers deal with uncertainty. While scientists have models to deal with uncertainty, policy making abhors ambiguities. Policy making relies on clear, defensible goals that can be codified into law (Karr 1991; WCMC 1996). The uncertainty problem plagues management of common pool resources due to inadequate information. The inadequacy of information makes management of common pool resources susceptible to manipulation for political and economic gain. To overcome this problem, monitoring systems historically depended on physical and chemical indicators. Their ease of defence made them legally convenient, though they were inadequate at detecting non-point pollution. The physical and chemical indicators failed to link water quality standards with biological integrity or ecological health. As a result, degradation of water resources was evident in most areas despite the existence of institutional mechanisms (Colby 1995; Karr 1991).

2.9.1.2: Community Participation

At the national level, NWA promotes community participation. NWA provides for broad based cooperative governance in the decision making process of water management. NWA provides for the establishment of Catchment Management Agencies (CMAs) to actualize an ecosystem approach. It has also provided for establishment of Water User Associations (WUAs) which are grassroots level organizations. The Rio declaration, Principle 10 and Agenda 21, in the preamble to Chapter 23 promotes community participation in decision making at the appropriate level. Participation is two pronged, involving the right to be heard and the right to be part of the decision making process (Shelton 2004). Participation at the lowest level of resource governance is among the principles guiding implementation of the ecosystem approach (Sandberg 2007). This approach is in line with international trends for integrated resource management. It is also in line with the principle of subsidiarity adopted by the European Union (EU) that decisions that affect people's lives should be made at the lowest possible level (Kinya 2001).

Community participation is, however, plagued with lack of existing community structures. This is a legacy of colonialism which left few community organizations in existence (Agrawal 2001; Kinya 2001; Sandberg 2007). In addition to ensuring that environmental issues maintain policy relevance, community participation can reduce costs involved in monitoring and enforcement (Kinya 2001; WCMC 1998). It is believed that wide participation at grassroots level facilitates communication of a shared vision. It also bridges the problem of poor harmonization at the operational level that plagues most water resources management systems (Buck 1998; Hanna *et al*. 1996; Sandberg 2007). Although not discussed here, NEMA and NEMBA, also promote community participation similar to NWA at the national level.

2.10 The Changing Role of the State

The state has a fundamental role in allocation of property rights as basic institutions for natural resource governance. Incorporation of community participation means states have to share the resource governance role with local communities (Agrawal 2001; Sandberg 2007). The post Rio paradigm shift creates complexity for the role of the state as it seems to require more government involvement. Other opinions are that lighter central government can still function successfully by setting clearer environmental goals for river clean up or rehabilitation. When these goals are codified in law, it sets the standards for adherence by all levels of governance, including civil society. Goal related indicators can then be monitored to assess progress and to inform on areas where effort is needed (Sandberg 2007).

To redress institutional limitations arising due to jurisdiction inadequacies, countries such as Australia, Canada, United States, England and Wales have instituted integrated resource management strategies. These aim to redress the fragmented approaches that are evident in separate economic and environmental administrative regimes (Johnson *et al.* 1996). Similar approaches have been adopted in South Africa through the National Water Resource Strategy (NWRS), which promotes a strategic adaptive management style (Mackay and Aston. 2004). Within this strategy, 19 Water Management Areas (WMA) have been identified for integrated management by Catchment Management Agencies, CMAs (Mackay and Aston. 2004).

Increasingly, institutional mechanisms are integrating market and non-market mechanisms to internalize externalities, and to resolve inherent uncertainty created by lack of information. Under a non-regulatory framework, market mechanisms, through pollution taxes, tradable pollution discharge permits, and more recently, “polluter pays”, requirements are being applied to facilitate internalization of social costs of environment (Sandberg 2007; Shelton 2004; Tisdel 1991). Other ideas are proposing that the ecosystem be provided through a mutual insurance arrangement to which users pay a premium based on the risk posed. Under this scenario, the state, which has a monopoly on the imposition of taxes, would ideally be better placed to institutionalize as commons insurance. The commons insurance goal would be to reduce ecosystem risks with a resultant advantage of lowered premiums (Sandberg 2007; Shelton 2004).

2.11: Methods and Theories Underlying Institutional Analysis

Underlying institutional analysis is the assumption that institutions are limiting factors that constrain policy options for the individuals. They can either be dependent variables for individuals constrained by geography or technology, or independent variables under certain institutional structures or rules (Buck 1998).

Three key theories are applied in assessment of global commons: these are, regime theory, the Institutional Analysis and Development (IAD) Framework for small scale common pool resources and recent scholarship on multiple-use common pool resource domains (Buck 1998). According to Regime Theory, IAD, Multiple-use theories and institutions operate along three levels of choice: operational/implementation, collective/procedural and constitutional/substantive (Buck 1998; Ostrom 2011 Carlsson and Berkes 2005) (also refer to Table 3.1). An additional requirement under Multiple Use Common Pool Resource Domain Theory is ability for the resource domain to support all the various users for sustainability to be achieved (Buck 1998).

Table 2.3: Analytic Framework for Governance of Common Pool Resources (Adapted from Buck (1998)

Level of institutional choice	Level of institutional choice
1: Operation choice or implementation level	1: Rights and rules for appropriation, provision, monitoring and enforcement
2: Collective choice or procedural component	2: Policy making, adjudication and management;
3: Constitutional or Substantive choice	3: Formulation, governance, adjudication and motivation

2.11.1: Methodological limitations

A number of methodological limitations to assessment of common pool property institutions have been noted. Agrawal (2001) in review of common property institutions and their role in sustainable governance; noted that most studies by leading scientists in this field fail to provide considered general measures of their dependent variables. Case studies often fail to explicitly state the problem they are testing; they therefore suffer from problems of method, either omitted variable bias or endogeneity. The set of variables used is large in number and hence likely to create impediments when building a systematic, empirically based theory of the commons. There is consensus among collective action and social theory proponents on what constitutes a successful institution. Key among them is the ability to constrain users, to safeguard resources and withstand the test of time. Additional requirements are the ability to ensure equity among users, and most importantly, to withstand the test of time. However, the studies generated to support these arguments often fail to explicitly state the problem they are testing. In addition, face the challenge that colonialism, in most cases, left few or non-existent community regulatory institutions. It is this reality that complicates devolution to grass root levels, as recommended by many studies and laws; Environmental Management Biodiversity Act (NEMBA) and the National Water Act (NWA).

2.12 Summary

The 1992 Rio Earth Summit raised awareness of the unprecedented rate at which anthropogenic effects are altering natural systems, and their detrimental consequences on biodiversity. It has resulted in a paradigm shift in resource governance and spurred new institutional mechanisms in the form of treaties, protocols and action plans. Allan and Marcus (2006) argues, increasingly, the motivation for studies of biodiversity of lotic systems is driven by institutional needs and is a reflection that states have legislated on international commitments. The aim in most of these studies is to quantify the magnitude of destructive human influence and to recommend measures that can restore natural functionality, or at least ameliorate pressure.

The cornerstone of the paradigm shift in resource governance is the sustainability conceptual framework integrating ecological, economic and social considerations. Sustainability calls for integrative approaches in assessment and management of natural systems. Implementation of the sustainability as a concept is both confusing and ambiguous taking into account raising human populations and high poverty levels (WCMC 1996). Integration of ecology and economics, however, has largely remained dualistic due to the difficulty of creating integrated frameworks (Norton and Noonan

2007). There are difficulties arising from differing ways that ecologist and economists value ecosystems (Farber *et al*. 2002). These differences in conception create a dualism which is also reflected in this literature review. Literature on the ecological aspects of lotic systems indicates that large proportions have been modified by human actions. It is also clear from the economic perspective that amelioration or restoration measures have a cost implication that can be used to infer economic value.
Economic valuation of ecosystem functions is further complicated by common good characteristics and difficulties in partitioning (Adger and Luttrel 2000; Thornston and Day 1998). When applying preference based economic valuation methods, this poses a challenge, since they require clarity on the particular ecosystem service that respondents are asked to value (Holmes *et al*. 2004; Loomis *et al*. 2000; Turner *et al*. 2003). To overcome this challenge it is recommended that assessment be hinged on the imposition of a new policy, such as the post Rio Earth Summit sustainability policy, as this provides an empirical baseline for assessment (Holmes *et al*. 2004).

Assigning property rights to nature for maintenance of ecological functionality is inevitable under rising demands for lotic systems and the resultant water scarcity. This creates complexities for institutional mechanisms which require clarity on inclusion/ exclusion and joint use in the description of the nature of goods in assigning property rights. The sustainability concept creates additional complexities for institutional mechanism as it includes rights for future generations as well as nature, and this challenges the hitherto dominant Roman conceptualization of the nature of goods based on four domains (WCED 1997; Sandberg 2007).

The foregoing review provides the context of this study which aims at generating information that can contribute to sustainable use of fish assemblage in Tyhume River, and overall biodiversity. Rohlf (1991) argues that conservation biologists wear multiple hats: as educators, economists, lawyers and bio-politicians. Ultimately, sustainable use of biodiversity hinges on how well conservation biologists translate scientific knowledge into public policy, in order to slow down and prevent erosion of biodiversity (Rohlf 1991).

At national level, governments have instituted new laws to encapsulate the post Rio Earth Summit commitments. These commitments hinge on the sustainability concept and necessitate tradeoffs among competing users. Decisions on tradeoff require incorporation of economic value for ecosystem services. Economic valuation of ecosystem services can assist by translating value into terms that are comparable to other things of value to humans (Everard 2004). Nevertheless, arguments in support of wider multidisciplinary perspectives in determination of value cannot be ignored.

Chapter 3: Materials and Methods

3.1: Water Management in the Study Area

The Tyhume River is located in Amatole catchment area and within the Water Management Area (WMA) 12 (Figure 3.1); this water management area stretches from the Mzimvubu River to the Keiskamma River (Department of Water Affairs and Forestry, DWAF 2005). Amatole catchment area is on the western side of WMA 12; it is divided into Amatole and Kei primary catchment areas. DWAF has developed Internal Strategic Perspective (ISP) for all catchment areas including Amatole and Kei (DWAF 2005). The Tyhume River is within the Kei primary catchment area in Region 10 (Figure 3.1), or Keiskamma sub-area (DWAF 2005).

Figure 3.1: Map of Water Management Area 12: Source DWAF 2005

In accordance with the year 2000 population estimates, 161 000 people resided in this area. The population is projected to stay the same or decline, due to high migration towards cities. This is because the area lacks a strong economic sector (DWAF 2005). Approximately 91% of the population in the Kei primary catchment inhabit rural areas and are highly dependent on agriculture, while about half or (49%) are unemployed (DWAF 2005).

The Tyhume River falls within the administration area of Nkonkobe Municipality (one of the seven Municipalities in Amatole District). The Nkonkobe Municipality was created through an amalgamation of nine former local councils consisting of Alice, Fort Beaufort, Middledrift, Hogsback, and Seymour as well as Victoria East, Mpofu, Middledrift and parts of Adelaide regional councils (The Nkonkobe Integrated Development Plan, IDP 2007-2012). Nkonkobe Municipality has twenty-one wards with 36,116 households and a population of 133, 434. It covers an area of 3, 725 km^{2}, making it the second largest in Amatole District. The rural: urban ratio is 4:1 where 19% of the population resides in urban areas (mainly Alice and Fort Beaufort), 20% on farms, and 61% in villages. The population density is estimated at 43 persons per km^2 (IDP 2007-2012).

Alice Town (Ward 5) and Ntselemanzi (Ward 6), which are the focus of the current economic study, have an average population of 2156 persons per square kilometer. There are 1431 and 1398 households in Ward 5 and Ward 6, respectively. The population in this area is estimated at 65 472 (IDP 2007-2012). The vision for social and economic development is outlined in the Nkonkobe Integrated Development Plan (IDP2007-2012). It is hinged on sustainability and the provision of a safe and healthy environment, attained through an inclusive process that encourages community participation.

3.1.1: Economic Activities

The economic activities are based on commercial forestry, dairy farming and cultivation of pineapples and oranges. Employment opportunities are provided by small scale tourism, as well as commercial forestry of approximately 1000 ha in the Hogsback area and at Fort Hare University. The rehabilitation of irrigation schemes on Tyhume River is seen as the main catalyst for economic growth (DWAF 2005).

3.1.2: Income and Employment

Approximately 74%, or 92 274 people, in Nkonkobe Municipality have no income, or have income levels of below R800 per annum, which is considered inadequate. An estimated 24 712 people earn between R1-R800 p.a. bringing the total of those earning less than R800 p.a. to 93% of the population. Another 2 817 persons earn between R801-R1600 p.a., while 2 391 earn R1601-R6400 p.a. The employment situation is equally bleak, as the municipality is only able to create jobs for 3.5% of the economically active population ((IDP 2007-2012).

3.1.3: Vegetation and Land use

The predominant vegetation within the 482 km^2 of its watershed is indigenous forest and pine plantations, of approximately 1000 hectares. The forest is managed, under protection, by the Department of Water Affairs and Forestry (DWAF). Land in this region is relatively undeveloped and mostly communally held. It is mainly used for stock grazing, and in most places over-grazing is evident (DWAF 2005). The vegetation has thus been altered from what was previously predominantly grassland, interspersed with wooded vegetation, to karroo veld and macchia vegetation. Since the latter two are classified as poor providers of ground cover (Mayekisho 1994), there is visible erosion and gully formation in the watershed. Black and Silver Wattles have also invaded the upper catchment area (DWAF 2005). The land use map of Water Management Area 12 is provided below (Figure 3.2).

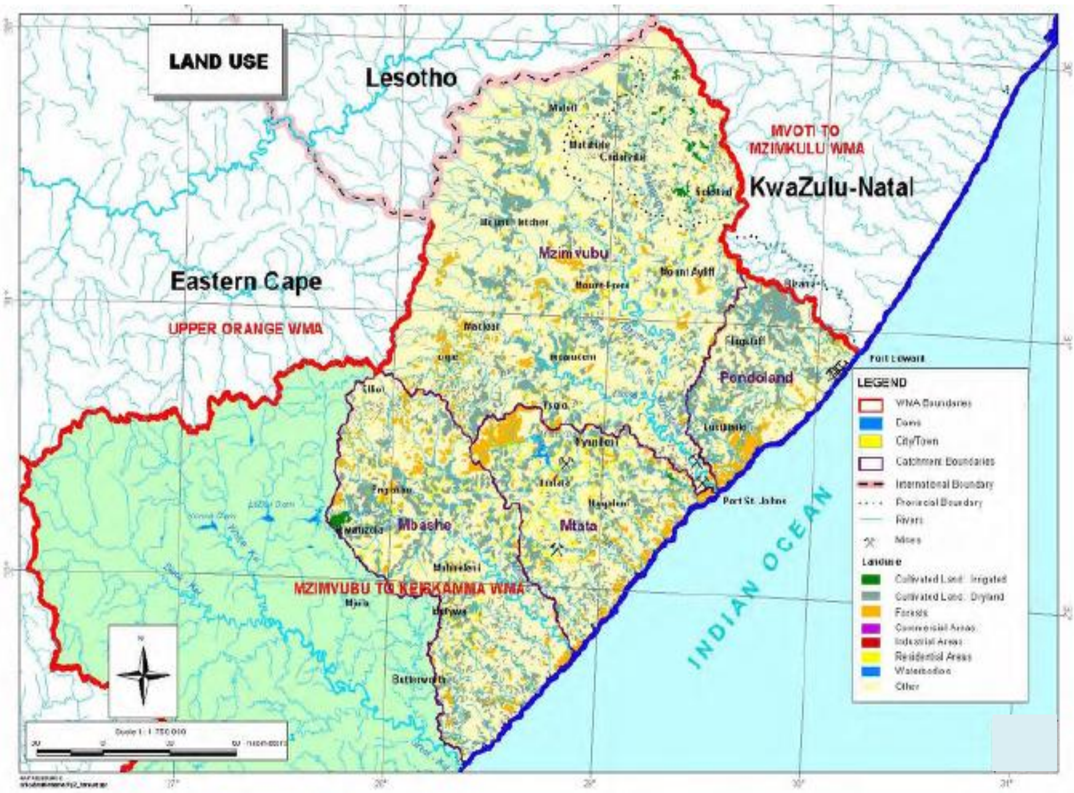

Figure 3.2: Land Use Map of WMA 12 Mzimbuvu to Keiskamma (DWAF 2005)

3.2: Selection of Study Sites

Ten study sites were identified for measurement of habitat characteristics that represent geomorphology and water quality. Criteria used in study site selection included proximity to a variety of land-use patterns. The intention was to sample across a gradient of human disturbances, hence, study sites consisted of areas close to human settlements, agricultural developments and conservation or relatively near natural areas. This was in order to allow for comparisons of study sites with varying degrees of anthropogenic modifications on habitat.

Study sites were also selected to represent the general river zones that typified South African rivers; these were Mountain, Middle and Lower River zones (Gerber and Gabriel 2002; Mayekisho 1994). The criteria used incorporated areas used in earlier studies for purposes of comparison. The study sites were located in the five zones as follows; rocky mountainous; rocky and sandy foothills; midland; and lowland. To allow comparisons between study sites in the same river zones, but with varying degrees of anthropogenic land use patterns, study sites were treated as experimental units (Quist *et al.* 2004).

3.2.1: Study Sites Geographic Coordinates

In all study sites, the Garmin eTrex Legend Geographic Position System (GPS) set on World Geodetic Survey 1984 (WGS 84) was used to determine coordinates and elevation. These readings were cross-checked on Maps, 3226DB Seymour and 3226DD Alice (South Africa Chief Directorate: Surveys and Mappings 2000).

3.2.2 Pictorial Record of Selected Representative Study Sites

A pictorial record of all selected study sites was undertaken; this included pictures depicting the variety of anthropogenic land uses in the landscape. The pictures were recorded from the selected study sites, using a digital camera.

3.3: Measure of Anthropogenic Effects on Habitat Characteristics

A mixture of geomorphology habitat quantity characteristics and habitat quality (water quality) characteristics were used to determine anthropogenic effects on Tyhume River.

3.3.1: Geomorphology Habitat characteristics (Quantity)

Habitat characteristics that represent stream geomorphology were measured as follows: Site dimensions that represent length, wetted width, depth were measured once, while current velocity was measured monthly.

3.3.1.1: Wetted Width

Wetted width was measured using a 50 metre tape at transects perpendicular to stream-flow. It was multiplied three times to set the length of a sampling transect (Quist *et al.* 2004). Measurements of wetted width and depth were made once, at the commencement of the study in March 2006. Measurements were taken along each transect at intervals spaced at 25%, 50% and 75% (Quist *et al*. 2004) and summary statistics calculated using Microsoft Excel (Microsoft Excel 2003/ 2007).

3.3.1.2: Current Velocity (Flow)

Current velocity in (m/sec) was measured monthly for nine months with A. Ott Type 4 portable flow meter (Type Ne "452" No. N6752). Before each measurement, oil levels in the shaft bearing were checked. The oil was changed after each measurement. Three people were required to make measurements, one inserted the precisely calibrated propeller into the river, a second person read the revolutions on a hand held meter, and the third person recorded the readings onto the data book. Sometime was allowed after inserting the propeller into the river, for the instrument to stabilize, before measurement commenced. A minimum of three readings were recorded per study site, in order to get a mean reading per site.

Current velocity was calculated using the formula

$V=0.2530n + 0.004$

Where n is the number of propeller revolutions/ second;

This formula applies for the propeller number (3-17267).

Three measurements were taken per study site and recorded in a data book *in situ*. Current velocity measurements were conducted monthly in study sites 1-10 from March to October 2006, and from study sites 3-10 in February 2007

3.3.2: Water Quality Characteristics (Habitat quality)

Water quality characteristics are useful indicators of anthropogenic modifications on habitat in a lotic system. Water temperature, pH and conductivity were used to determine anthropogenic effects on in-stream habitat in Tyhume River

3.3.2.1: Temperature, Hydrogen Ion Concentration (pH) and Electrical Conductivity (EC) Measurements

Temperature, Hydrogen Ion Concentration (pH) and Electrical conductivity (EC) were measured using a calibrated portable Hanna Meter Model (H1 98129-HI 98130) waterproof meter with an inbuilt probe. The probe was slowly inserted into the river to acclimatize before reading.

Temperature measurements were collected monthly from study sites 1-10 from March to October 2006 and from study sites 3-10 in February 2007. At each study site, temperature measurements (^{o}C) were taken from pools riffles and runs in different biotopes; at least three separate readings were to taken. Efforts were made to ensure temperature data was collected at different times of the day in order to get a representative mean record.

Concentration of Hydrogen Ions **(**pH) readings were collected monthly in study sites 1-10 from March to October 2006 and from study sites 3-10 in February 2007. At each study site, pH measurements were taken from pools, riffles and runs; at least three separate readings of pH were taken. Efforts were made to ensure data was collected at different times of the day each month, in order to get a representative mean record.

Electrical conductivity (EC) readings were collected monthly in study sites 1-10 from March to October 2006 and from study sites 3-10 in February 2007. EC readings (Siemens per meter [S/m]) were recorded *in situ* after stabilization. At each study site, EC measurements were taken from pools, riffles and runs. At least three separate EC readings were to taken *in situ*. Each month data was collected at different times of the day in order to get a representative mean record.

Temperature, pH and EC at study sites 3 & 4 in rocky foothill above Binfield Park Dam and 5 & 6 in sandy foothill below Binfield Park Dam were compared. Study sites 6 & 7 above Alice urban area and 8 & 9 below Alice urban areas were compared. These study sites were also compared with data collected in February 2007 in the same study sites (the latter, which represented a summer month of extreme conditions).

3.3.3: Statistical Analysis for Habitat Characteristics

Statistical analysis was conducted using measures of summary statistics, least square means, pair-wise comparison, confidence intervals and One Way Analysis of Variance (ANOVA).

3.4: Summary Statistics

Summary statistics or descriptive statistics summarized information from a set of observations into measures of central location, dispersion and distribution around the mean. Measures, such as mean, medium, mode, standard deviation and variance are easily recognizable (Brown 2005)

3.4.1: Measures of Central Location

Three measures of central location used to summarize data are arithmetic mean, medium and mode. The mean was used to test differences between study sites. The mean, which is greatly influenced by large numbers, was used to describe extreme conditions (Sokal and Rohlf 1995). The medium served to test differences during non-drought situations. The medium, being less influenced by outliers was used for typical situation of non-drought; study sites (3 & 4) above and (6 & 7) below Binfield Park Dam were compared. Study sites (5 & 6) above and (8 & 9) below Alice urban areas were also compared. The mode represented the variable with the most frequent occurring observations. It was used to assess the frequency distribution of a set of observations.

3.4.2: Data Distribution

Distribution indicated how the data was distributed around the mean. Data distribution exhibits either a normal distribution, binomial and positive or negative skewed distribution. A normal distribution had practical significance in that; a statistical significance occurred at a probability of 95% Confidence Interval.

3.4.3: One way Analysis of Variance (ANOVA)

One Way Analysis of Variance (ANOVA) was the principal method used to test for differences between study sites (Brown 2005; Carver and Nash 2009; Wright 2002). ANOVA was conducted using (Excel 2003/2007. To determine data fit to normality criteria, a prerequisite of ANOVA, a Chi-Square Goodness of Fit test was first conducted. . ANOVA significant F-test ($F < 0.05$) indicated that group differences are big enough not to be attributed to chance. Since ANOVA measures overall variation within and among groups, a significant F test does not indicate which groups differ (Brown 2005). Subsequently tests multiple or pairwise comparison is used to determine where the groups differ (Garson 2008; Sokal and Rohlf 1995; Williams 1993). Pairwise comparison was applied to compare means in order to make out a judgment on significant anthropogenic conditions (Sokal and Rohlf 1995; Williams 1993). This was undertaken through a number of post hoc or tests. Further tests were conducted for data that adhered to normality criteria using a parametric post hoc test. Conversely, for data which were not normally distributed or not fit the Goodness test, Non- parametric tests were usually conducted.

ANOVA was conducted as either for single factor comparison one way or for two factor comparison two-way analysis.

3.4.3.1: Hypothesis testing

Null Hypothesis (H_0): There is no significant difference in sample means for current velocity, pH and EC for study Sites above sites (3 & 4) above and (6 & 7) to samples means below Binfield Park Dam.

There are no significant differences in sample means for current velocity, pH and EC in study sites (5 & 6) above Alice Urban area and study sites (8 & 9) below Alice urban areas.

Alternative Hypothesis (H_1): There are significant difference in sample means current velocity, pH and EC for study sites above sites (3 & 4) above and (6 & 7) below Binfield Park Dam.

There are significant differences in sample means for current velocity, pH and EC study sites (5 & 6) above Alice Urban area and study sites (8 & 9) below Alice urban areas.

Null Hypothesis (H_0): There is no significant difference in sample medium temperature for study sites above sites (3 & 4) above and (6 & 7) below Binfield Park Dam.

There is no significant difference in sample medium for temperature in study sites (5 & 6) above Alice Urban area and study sites (8 & 9) below Alice urban areas.

Alternative Hypothesis (H_2)
There is significant difference in sample medium temperature for study sites above sites (3 & 4) above and (6 & 7) below Binfield Park Dam.

There is significant difference in sample medium for temperature in study sites (5 & 6) above Alice Urban area and study sites (8 & 9) below Alice urban areas.

3.4.4: Quantification of Extent of Anthropogenic Modifications on Habitat

The data gathered in determination of anthropogenic effects on habitat and anthropogenic effects on fish assemblage in March to October 2006 and February 2007 was used to quantify the extent of anthropogenic modification on entire Tyhume River. This was compared with data and information from historical data (Mayekisho 1994). In addition, the proportion of river that has anthropogenic effects on habitat, modifications was estimated using South African Chief Directorate: Surveys and Mappings (2000). The extent of river habitat modification was indexed as proportions along the entire river length, according to after (UNEP 1997). Historical data on flow modification effects on temperature, pH and conductivity modification below impoundment were used to quantify the proportion of river modified by anthropogenic effects on habitat characteristics (Mayekisho 1994). Storm water impact was estimated from study sites below Alice urban area in February 2007 using geomorphology and water quality characteristic. The distance was estimated using South African Directorate Map, and indexed as proportion of the entire river length.

3.4.4.1: Agriculture and Livestock Grazing

The extent of habitat modified by agricultural activity was estimated from observed land use practice during the March to October 2006 and February 2007 surveys. It was estimated from the distance between land and of agricultural lands in close proximity to the river. Close proximity was considered as within 20 metres of the river. The extent of anthropogenic effects on habitat was quantified through measurement of distance between human settlement and river study sites. This was undertaken using a car odometer. In addition, distance was estimated from 3226DB Seymour and 3226DD Alice, according to the Map (scale 1:50,000) by. South Africa Chief Directorate: Surveys

The proportion of river that has anthropogenic modifications on habitat was indexed as proportion modification out of the entire river length following to UNEP (1997). Proportion modified through impoundment effects was calculated as

ld/lr*100

where (ld) =length in km modified and

(lr) = length in km of the entire Tyhume River (UNEP 1997).

The extent of river modified through storm water runoff was calculated in the same manner.

3.5: Measurement of Anthropogenic Effects on Fish Assemblage

To determine anthropogenic effects on fish assemblage, introduced fish species; non-native and translocated (native) composition and presence - absence was assessed. This was also assessed against geomorphology characteristic and pre-impoundment data compared post-impoundment data with current survey data.

3.5.1: Fish Collection

Fish was sampled monthly in riffles, pools, and runs from study sites 1-10 from March to -October 2006 and from study sites 3-10 in February 2007. Two techniques viz. electro-fishing and seining were applied. Electro-fishing was the main method used to sample fish at 8 study sites that represent the mountain, rocky and sandy foothills. It is the method that was applied effectively in shallow riffles and runs (<0.6 m depth).

Electro-fishing was undertaken using a DC Battery-powered back-pack Electro-fisher Model 12 (Smith-root, Inc.) with a timer to quantify effort. Two people undertook the fishing; one to apply multiple electro-fishing passes and the other to catch fish using a hand held dip net. One person with the back-pack electro-fisher waded carefully upstream to reduce effects of turbidity and inserted the anode intermittently into the water. The anode was inserted in the middle and either side of a stream to ensure coverage of each transect and for a fishing period of 15 minutes. Any stunned fish were caught in the scooping probe net. The other person netted fish that escaped downstream.

In the midland and lowland zones seining was the main method of sampling used in pools between 0.6 m and 1.3 m deep. In pools, sampling was undertaken using a 5 m x 2 m seine net with a mesh size 10 mm. The net, with PVC floats and lead weights, was mounted on two wooden poles at each wing. Two operators pulled the net upstream once per site for a period of 15 minutes.

3.5.2: Fish Measurement and Identification

All fish were identified to species level at study sites, using Skelton (2001). Collected fish species were preserved in 10% formalin. Fish were later transferred to 70% ethyl alcohol and taken to the South African Institute of Aquatic Biodiversity (SAIAB) for corroboration of identities. Data was recorded onto appropriate sheets *in situ* at each study site. Data entries per study site were made against total number of fish, number of species – non-native, translocated, indigenous or threatened. These categories were used in calculation of relative frequency of each fish species and relative frequency per freshwater categories.

3.5.2.1: Fish Length

Fish length was measured to the nearest mm using a metre measuring board. To take measurements of Standard length, Fork length and Total length fish was placed on the side and mouth closed. Length measurements were recorded *in situ* for the various fish species, as follows: Standard length (SL) in mm *was measured for S. bainsii* and *T. sparrmanii*. Fork length (FL) was measured in mm for *B. trevelyani, L. umbratus* and *O.*

mykiss. Total length (TL) in mm was measured for *A. mossambicus* and *C. gariepinus*. Detail description of measurement is provided below;

Standard Length (SL)

Standard length (SL) was measured from the tip of the fish snout (upper lip) to the end of lateral line or root of caudal fin in a straight line.

Fork Length (FL)

Fork length (FL) was measured in straight line from the tip of the snout to the end of the middle caudal fin rays.

Total Length (TL)

Total length (TL) was measure in straight line from the tip of the snout to the tip of caudal fin. The caudal fin was compressed in order to get accurate measurement of the longest tip of caudal fin.

3.5.2.2: Fish Weight Measurements

Fish weight was measured using a Sartorius Talent Model TE2101 scale. It was measured to the nearest 0.01 gram. All data was recorded *in situ* on data sheets. The maximum weight for each species was determined and compared to historical data.

3.5.3: Fish Assemblage Analysis

3.5.3.1: Fish Abundance and Catch per unit effort (CPUE)

Fish abundance was calculated using catch per unit effort (CPUE) formula, as follows;

Abundance / CPUE= $Number\ fish\ /time$

3.5.3.2: Relative Frequency

Relative frequency of each fish species at each study site was computed as follows;

$$Relative\ Frequency = \frac{Frequency\ of\ one\ species}{Totalfrequency\ of\ all\ species}$$

3.5.4: Fish Distribution

Presence/absence was the main method used to map the longitudinal distribution of fish species along the Tyhume River. Presence recorded the different number of species caught per study site *in situ*. Those fish species not recorded were considered absent at the study site. This information was used to map longitudinal distribution of all fish species. The information was used to compare pre and post impoundment distribution; using data from Mayekisho 1994 (refer to Table 2.2).

3.5.5: Jaccard's Index of Similarity

Jaccard's Index of similarity, a numeric method, was used to compare diversity of species at different study sites. It quantified overlap of species in two or more communities.

Jaccard's Index of similarity was calculated as follows;

Jaccard's Index =j/(j+r)

(where j is the total number of species common in both communities and r is a product of species unique to either study sites.

The matrices of similarity developed were clustered using hierarchical clustering (Wallwork 1976).

3.5.6: Cluster Analysis

The matrices of similarity indices developed, using Jaccard's Index of similarity, were clustered using an un-weighted pair-group method to identify main fish assemblage (Quist *et al*. 2004). Cluster analysis allowed identification of groupings in data. This was the main method used to compare study sites with different anthropogenic intensities. It was used to compare study sites above and below Binfield Park Dam as well as above and below Alice urban area.

3.5.7: Fish Length Frequency Analysis

Length frequency distribution in biological studies was used to inform on population structure. Length frequency of fish was analyzed using (Excel 2003/2007 for all fish species collected.

3.6: Assigning Economic Value to Five Ecosystem Services

In order to adhere to guidelines of the Blue Ocean Panel for Contingent Valuation Method (Arrow *et al.* 1993) recommends that respondents be accorded a clear indication of what they are valuing. Two hypothetical scenarios were developed to clearly depict in a pictorial format the ecosystem services provided by Tyhume River in need of restoration. This was in order to facilitate a shared vision of what exactly is being restored. In this valuation of goods and services that are not traded the Stated Preference Methods of economic valuation was applied in line with (Turner *et al.* 2003). To ensure clarity of what is being valued, a clear depiction of what is being restored was undertaken. Two hypothetical scenarios are used, accompanied by a verbal description as contained in the administered questionnaire before elicitation willingness to pay, from respondents in line with (Arrow *et al*. 1993).

3.7: Application of Contingent Valuation Method (CVM)

Contingent valuation method (CVM) was applied to determine economic value of ecosystem services provided by Tyhume River. Contingent valuation method facilitates elicitation of economic value for ecosystems services from respondent's willingness to pay responses. The economic value elicited will hinge on benefits likely to accrue from restoration of five degraded ecosystem services. The degraded ecosystem services identified from the determination of anthropogenic effects on Tyhume River f biodiversity were; habitats for rare and endangered fish species, as well as other biodiversity, erosion control, improved water quality, dilution of waste water and recreation. These ecosystem services provide, in addition, existent or bequest values for which CVM is best placed to assign value and to fit in the sustainability framework.

3.7.1: Hypothetical Scenarios

In the first step two hypothetical scenarios were developed from information generated in ecological part of this study to correspond with local conditions (Figure 3.3 a & b) adopted from Loomis *et al.* (2000). The first scenario (Figure 3.3 a) depicted the current conditions of ecosystem services in Tyhume River (Scenario I). The second scenario (Figure 3.3 b) depicted the proposed future condition in Tyhume River (Scenario II). The enumerators first presented to the respondents the pictorial descriptions of the current condition of ecosystem services in Tyhume River (Scenario I). They then outlined the consequences of maintaining a 'business as usual' scenario. Once they were sure the respondent understood the situation, they then presented a picture of the proposed hypothetical scenarios that would improve ecosystem services (Scenario II). Finally, they gave respondents an opportunity to indicate through a questionnaire (Appendix IV) willingness to pay for restorations. Respondents whose response was affirmative were given an opportunity to pick an amount in Rands they would be willing to pay monthly, or to indicate an amount of their choice. The respondents were informed that the payment vehicle would be an increased monthly water bill in order to restore the current scenario (I) to an improved ecosystem services scenario (II).

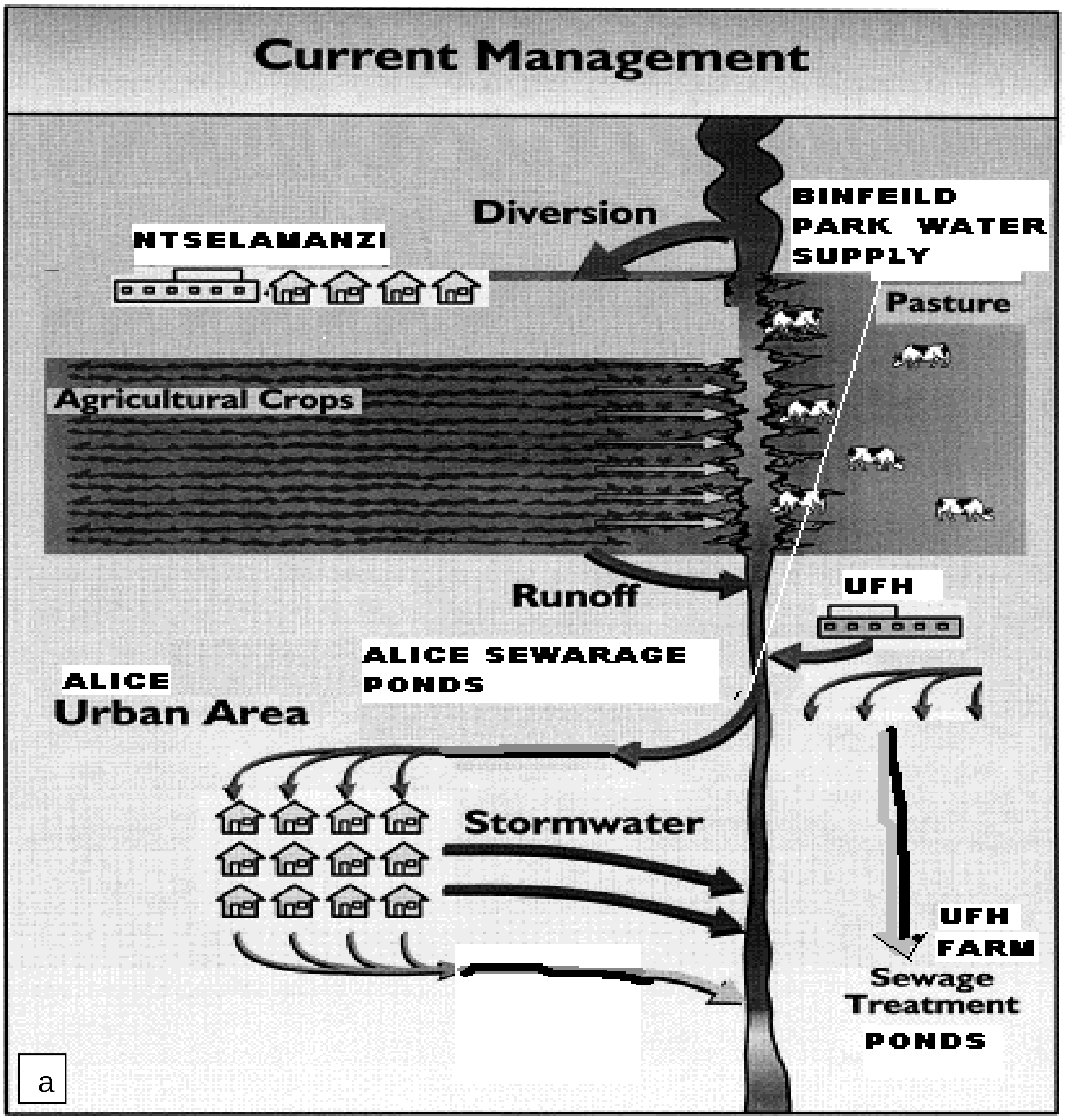

Figure 3.3(a): Hypothetical Scenarios depicting Current Management of Tyhume River (Scenario I) (a) Source: Eco-diagrams adapted from Loomis *et al.* (2000)

3.7.1.1: Consequences of Business as Usual Scenario (Current Management (Scenario I: Figure 3.3 a).

- Biodiversity deteriorates to low level;
- Increased incidence of algal blooms and poor water quality;
- Education and research potential may decline; and,
- Locals would lose employment opportunities from loss of agricultural and livestock watering opportunities.

3.7.1.2: Hypothetical scenario II: (Improved Ecosystem Services)

The proposed management interventions that could mitigate current management scenario I (Figure 3.3 a) and lead to improved ecosystem services (Figure 3.3 b) are as follows:

- Creation of an artificial wetland to deal with storm water runoff from Alice Municipality. It would also improve the aesthetics and recreational value of Alice urban area;
- Establishment of 20 metre conservation buffer between Ntselamanzi and Alice town down to Honeydale. This will control runoff arising from land use activities and enhance the natural water purification capacity;
- Restoring native vegetation in the form of buffer strips while eliminating cropland within the buffer zone. Cattle grazing within the buffer zone would be minimized, or regulated cattle grazing introduced;
- To manage the Tyhume River as shown under scenario II (Figure 3.3 b).

Respondents were informed that these activities would be undertaken through the establishment of a Tyhume River Restoration Trust Fund (TRRTF) with inbuilt mechanism for community participation. Its long term goal would be to support conservation measures, and the research and development of Tyhume River.

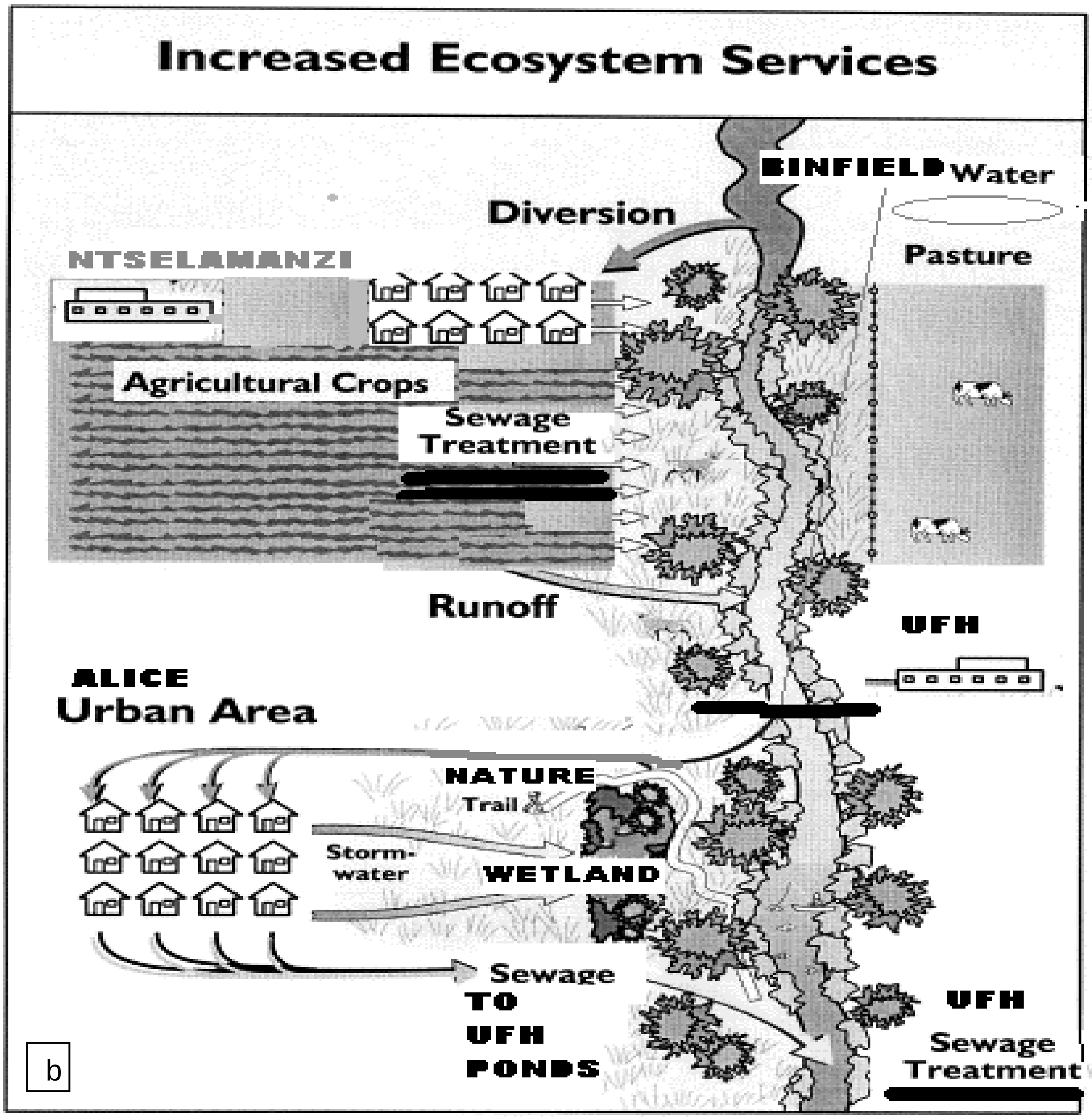

Figure 3.3(b): Hypothetical Scenarios depicting Increased Ecosystem Services at Tyhume River (Scenario II) (b) Source: Eco-diagrams adapted from Loomis *et al.* (2000)

3.7.1.3: Associated ecosystem services

- Dilution of Waste Water: Dilution ensures water quality suitable for use by humans and livestock, and which is non-toxic to fish and other aquatic organisms. Retention of ecological reserve is in line with provisions of the National Water Act No. 36 of 1998 (NWA). Maintenance of streamside vegetation provides a buffer at the land and water inter-phase to abate sedimentation. It keeps water cool, which is beneficial for fish and other aquatic organisms and improves recreational aesthetics. This has potential to promote the re-establishment of indigenous fish species and reduce algae growth. It also helps to improve research and educational values.

- Biodiversity conservation: Conservation of biodiversity is ensured through maintenance of a healthy habitat for fish and wildlife, where health, as used here, implies sustainable use. This is measured through the maintenance of fish assemblage in terms of identities, numbers, abundance, distribution and water quality close to near natural conditions. Conservation of four fish species indigenous to Tyhume River.
- Development of recreational facilities which can be a source of revenue and employment opportunities.
- Establishment of a Tyhume River restoration Trust Fund would provide a permanent avenue for funding research and development along the Tyhume River. It would also provide an avenue for community participation in the decision making process.

3.7.1.4: Payment Vehicle

After presentation of the two hypothetical scenarios, respondents were informed that, in order to implement the improved ecosystem services scenario, "*Your support is needed to establish a Tyhume River Restoration Trust Fund". "Your support is required in the form of monetary contributions where the mode of payment is through increased monthly water bills. You are therefore kindly requested to indicate how much you are willing to contribute to this fund, after careful consideration of the two scenarios."*

The following bid amounts were presented: Rands (1, 2, 3, 5, 6, 10, 12, 15, 18, 20, 25, 30, 35, 40, and 50) with an option for respondents to indicate an amount of their own preference. These amounts were informed by prevailing practice where residents of a rural village in KwaKayaletu and Njwaxa were paying between 30-40 Rands for a 200 litre drum of water drawn from the river, on a donkey cart or on a bakkie.

3.7.2: Ecosystem Services Economic Value and Post Rio Measures Institutional Data Collection Questionnaire

A structured interviewing method using a written questionnaire was used for both the economic survey and institutional analysis. This mode of survey is adapted to an extent in line with recommendations of Blue Ocean Panel for Contingent Valuation Method (Arrow *et al.* 1993). A questionnaire consists of questions and other prompts that serve the purpose of gathering data from respondents. When the questionnaire is structured, it is used to gather data through interview methodology and can gather quantitative or qualitative data. The questions in a structured interview questionnaire may be structured to minimize context distortions arising from the preceding question.

3.7.2.1: Administration of Questionnaire

A structured interviewing method using a written questionnaire was administered by the researcher, assisted by two enumerators. The two enumerators conducted random interviews among residents in Alice Town and Ntselamanzi that were willing to be interviewed. A trial run was conducted in 9th August 2007 and adjustments made to the questionnaire. The survey was conducted on 10th - 23rd August 2007. This mode of survey was adopted in line with recommendations of the Blue Ocean Panel for Contingent Valuation Method (Arrow *et al.* 1993). In this study it also proved useful in overcoming the language barrier created by the use of English in the questionnaire, while the majority of respondents are Xhosa speaking.

A requisite of Contingent Valuation Methodology (CVM) is an accurate description of services being valued, in order to elicit WTP bids. Hence the first task was to get an accurate pictorial description of degraded services through two hypothetical scenarios discussed in preceding section. This information was generated from ecological study undertaken in March-October 2006 and February 2007. Development of management interventions that would address degradation was generated from *de jure* provisions contained in the NWA (1998). The other legislations used were NEMA No. 107 of 1998 (NEMA 1998) and the National Environmental Management Biodiversity Act No. 10 of 2004 (NEMBA 2004)

The questionnaire was in four parts: the first part gathered demographic information on the respondent. This included information on income, number of dependents, monthly water bill, age, gender and level of education. The second part gathered information on the participant's knowledge of the Tyhume River, while the third part was used for economic valuation. The fourth part sought to determine respondent participation in resource management (Appendix IV). A total of 211 questionnaires were administered in Alice urban area, and in Ntselamanzi, Nkonkobe Municipality, Eastern Cape, South Africa.

3.7.2.2: Data Collection to Determine Economic Efficiency

To determine economic efficiency, data on costs of storm water management were obtained from the Integrated Development Plan (IDP) (Nkonkobe Municipality 2006/2007). The year 2006/07 was allocated R 1 043 939.00 and the year 2007/2008, R 1 130 000.00. These financial allocations were under the category of infrastructure development. The amount spent on storm water management at the time was R 11 3852. 57. This amount was used for drainage infrastructure that directed storm water to the river, untreated. The project was 40% complete and was projected to be finalized by June 2007.

3.7.3: Ecosystem Value Economic Data Statistical Analysis

The binary responses elicited from in person interview questionnaires were analyzed using a random utility model (Hanemann 1984 in Holmes *et al*. 2004). Logit and probit models fall under the category of general linear model (GLM). This category also includes regression analysis and ANOVA models that are suitable binary responses, or dichotomous choice responses (Garson 2008). The logit model is the inverse of the sigmoid curve where the probability of votes falling between 0 and 1 can be described by the formula;

Probability of voting yes =log (p) –log (1-p)

This model was suitable for dichotomous choice questions where the respondents' votes either agreed (Yes) or disagreed (No). The probability of voting "yes" was expressed as follows:

$\text{Probability (Yes)} = 1 - \{1+\exp[B_0 - B_1(RX)]\}^{-1}$ Equation 1

Where RX represents the Rand amount that a household is willing to pay, and B's are the coefficients.

The model was initially analyzed using binary logit regression model SPSS 16.0 for estimation of coefficients. This also facilitated incorporation of additional coefficients in the final model as follows:

$\log(\text{yes})/(1-\text{yes}) = B_o - B_1(\text{bid}) + B_3(\text{income}) + B_4(\text{average water bill}) + B_5(\text{age})$ Equation 2

Where $B_{0\text{-}5}$ are coefficients"

The median was adopted as measure of economic welfare. The mean as a measure of central tendency had limitations arising from effects of numbers at the extreme or outliers. Use of the median was adopted because it is more robust, and it also indicated that the programme had received the support of 50% of the respondents (Holmes *et al.* 2004). Consequently, the median was used as a conservative estimate of WTP, after (Hanemann and Kanninen 1999 in Holmes *et al.* 2004). The median WTP was computed from parameter estimates as follows:

$\text{Median WTP} = (1/B_1)^{*}\ln(1+e^{B_o})$ Equation 3

Where B_1 is the co-efficient estimate on the bid amount and B_o is either the estimated constant (when no other independent variables are included) or the grand constant.

The grand constant was calculated as the sum of the estimated constant plus the product of the other independent variables, times their respective means. WTP values for the population were then estimated using population mean (Loomis *et al* 2000; Holmes *et al.* 2003).

A noted merit of logit is that it produces results that are easy to interpret and are statistically sound. Limitations of logit are similar to other regression models where multi-colinearity is likely to occur if variables are related (Garson 2008).

Economic efficiency was determined using cost benefit analysis, based on the Kaldor-Hicks principle of compensation of losers by gainers. Under this scenario, economic efficiency was achieved when the net present value was in excess of net present cost and was positive (Gatweiller 2006; Tisdel 1991). Economic efficiency was determined using the formula:

$$NPV = (A)x(1+r) - t/(WTP)x(1+r)$$

Equation 4

Where NPV = net present value, WTP=Willingness to pay amount, A = cost amount, r=discount rate and t=time in years.

3.7.4: Determination of Post Rio De jure Institutional Measures

To determine compliance with Post Rio De jure institutional measures a desk review of three South Africa legislations was undertaken as follows;

The Constitution Act 108 of 1996 (South African Constitution 1996);

- The National Environmental Management Biodiversity Act No. 10 of 2004 (NEMBA 2004),
- The National Environmental Management Act (NEMA) No. 107 of 1998 (NEMA 1998); and,
- the National Water Act No. 36 of 1998 (NWA 1998).

To compare *de jure* measures with *de facto* measures a two pronged approach was applied that included the ecology part of this study and findings from questionnaire (Appendix IV).

Key post Rio concepts examined were;

- Sustainable use;
- Ecosystem approach;
- Community participation;
- Polluter pays principle;
- Precautionary approach.

3.7.4.1: Demographics

The 'in person' interview questionnaire was used to collect demographic information on age, gender and employment (Appendix V).

3.7.4.2: Current users

Through the questionnaire, respondents indicated who the current users are. The users reside in Alice urban area and Nstelemanzi, which are less than 3 km from the Tyhume River. It also sought to establish the respondents' knowledge on the source of domestic water supply

3.7.4.3: *De facto* scenario

The primary objective of the questionnaire was economic valuation of Tyhume River ecosystem services. Economic valuation, using contingent valuation, depends on an accurate description of ecosystems services in need of restoration. The second activity was to determine the state of fish assemblage in Tyhume River. The information generated was used to develop two hypothetical scenarios depicting current management and the desired future scenario. The hypothetical scenarios were developed from a survey of habitat quantity and quality characteristics. They were also informed by the survey on fish assemblage. Both these methods are described below.

3.7.4.4: Determination of Extent of Anthropogenic induced Habitat Modification

How current users impact on Tyhume River habitat and fish assemblage was determined through review of literature, and in ecological part of this study. Two aspects (habitat characteristics and fish assemblage) of the Tyhume River habitat were examined.

3.8: Community participation

Membership of an environmental group was used to determine community participation. The respondents were asked to indicate membership of an environmental group. They were also asked to indicate willingness to join an environmental conservation group.

3.9: *De jure* property right

To determine *de jure* provisions on property rights and community participation, three main legislations which provide for governance of the Tyhume River system were used. These are the National Water Act, No. 36 of 1998; the National Environmental Management Act, No of 107 of 1998; and the National Environmental Management Biodiversity Act, No. 10 of 2004.

The ecological study of Tyhume River has generated information on areas of the ecosystem in need of restoration (Chapters 3 & 4). In addition, a new policy for sustainable use of biodiversity has been adopted under NWA No. 36 of 1998, NEMA No. 107 of 1998 and the National Environmental Management Biodiversity Act No. 10 of 2004. The new policy forms a baseline for micro-analytical valuation of restoration measures using CVM. Hypothetical scenarios can be created, contingent upon which WTP can be elicited. The bidding sessions can be held with a random sample of the population in Alice urban area and Ntselamanzi

Chapter 4: Results

4.1: Annotated Tyhume River Study Sites Characteristics

A total of 10 identified study sites were sampled along the Tyhume River, from source at Hogsback (study site 1), to the confluence with Keiskamma River (study site 10).

The study sites were located in five river zones, traversing different land use characteristics and varying intensities of anthropogenic activities (Table 4.1).

Table 4.1 Selected Study Zones, Sites, and Distribution

Zone	Representative Study Sites and Distribution
• Mountain Zone • Rocky foothill • Sandy foothill • Midland River • Lowland River	1 & 2 Sites within a conservation forest 3 & 4 Above Binfield Park Dam 5 & 6 Below Binfield Park Dam and Above Alice Urban 7 & 8 Site 7 above Alice and 8 below Alice 9 & 10 Below Alice urban Area

4.1.1: Geographic Coordinates of the Study Sites

The geographic coordinates of the study sites were recorded and elevation depicted in a map (Figure 4.1). For instance, study site 1 was located at an altitude of 1126 meters above sea level (MASL), and coordinates of S 32^0 35'758'' and E 26^0 56' 830'', while study site 10 was located just above the confluence with Keiskamma River, at an altitude of 319 MASL and coordinates of S 32^0 54'622'' and E 026^0 56'031''. The 10 study sites were locally named as follows: Swallowtail (Site 1), Mtloko (Site 2), Sanctuary (Site 3), Auckland (Site 4), Macfarlan (Site 5), Melani (Site 6), Quamashe (Site 7), Honeydale (Site 8), Njwaxa (Site 9), and Junction above Confluence (Site 10).

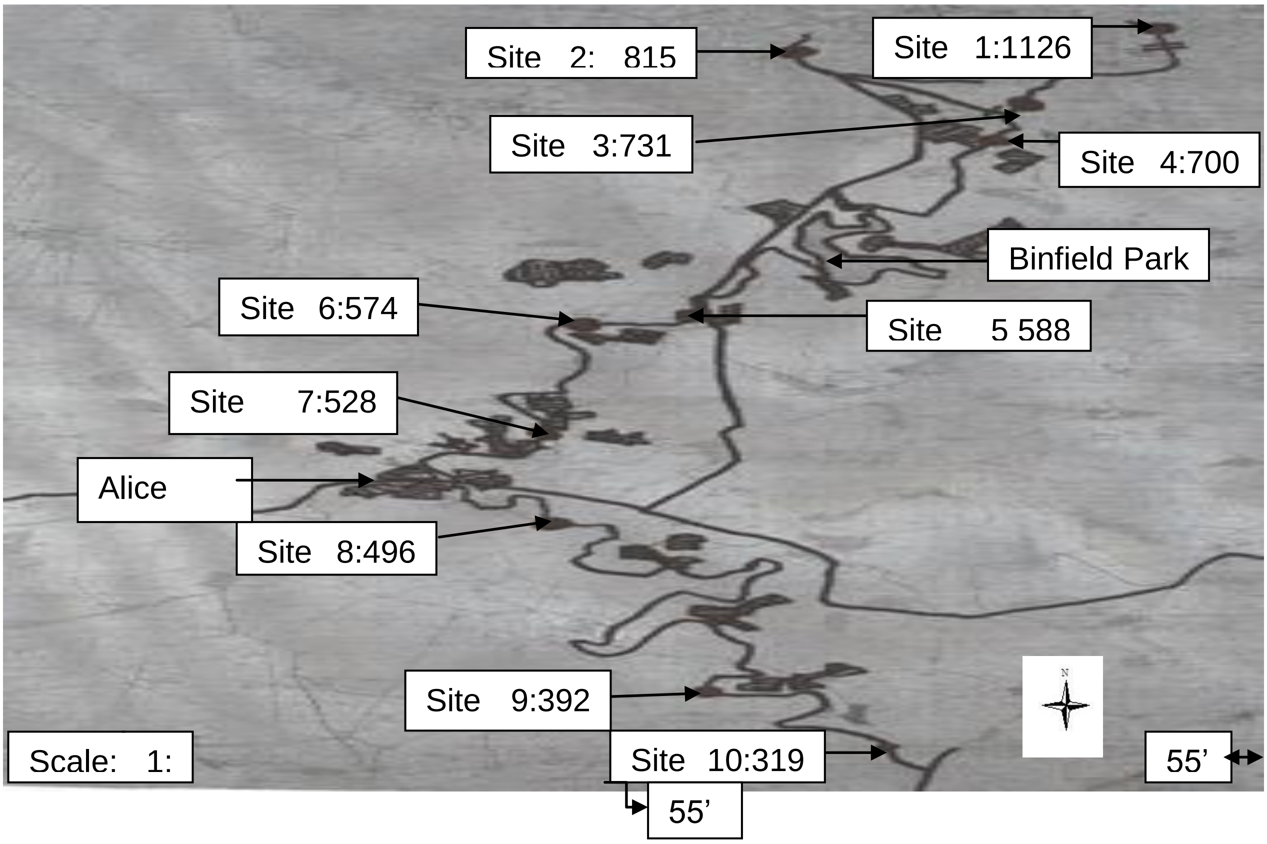

Figure 4.1: Study Sites Elevations in Meters Above Sea Level (MASL) (courtesy of Chief Directorate of Surveys and Mappings (2000): 3226DB Seymour and 3226DD Alice, South Africa)

4.1.2: Study Sites Characteristics

a. Study Site 1: Swallowtail, Hogsback Elevation: 1126 MASL; Study Site Coordinates: S 32^{0} 35’758’’ and E 26^{0} 56’ 830’’

Study site 1 (Figure 4.2) was located within the Auckland Forest in Hogsback area; it was relatively Near Natural, with minimal human impacts. Three impoundments were located in this area, creating deep pool habitat in an area that was predominately bedrock. An indigenous forest interspersed with exotic tree species existed, out of which approximately 1000 hectares were under plantation forest. This forest, together with the running waters of Tyhume River, formed a basis for small recreational tourism.

The mean temperature recorded at study site 1 was 12.8…^{0}C (range: 9.5^{0}C-19.3^{0}C). Mean conductivity in this site was 0.04 mS/m (range: 0.3-mS/m - 0.31 mS/m). Mean current velocity was 1.78 m/sec (range: 1 m/sec -3.6 m/sec). Mean pH recorded was 6.59 (range: 6.43-6.79).

Figure 4.2: Study Site 1 (Swallowtail)

No fish was sampled in study site 1, although there was an indication that recreational trout fishing existed in Hogsback. A large waterfall on this river acted as a barrier to upward and downward fish migration.

b. Study Site 2: Mtloko: Elevation 815 MASL; Coordinates S 32^0 36'653 and E 026^0 54' 575

Study site 2 (Figure 4.3) was just below the forested area where the in-stream geomorphology was dominated by bedrock. Pool formation was therefore poor. Mean water temperature at study site 2 was 12.3 ^{0}C (range: 7.3 ^{0}C -19.0 ^{0}C). Mean current velocity was 1.3m/sec (range: 0.6 m/sec - 1.9 m/sec); while a mean conductivity of 0.01 mS/m (range: 0 mS/m-0.03mS/m) was recorded. Mean pH of 6.6 (range: 6 - 7) was recorded at the site. No fish were sampled at study site 2, although there was no visible fish barrier. It was possible that the bedrock substrate and poor pool development, as well as low in-stream cover, were conditions not suitable for habitat for fish (Figure 4.3).


Figure 4.3: Study Site 2 (Mtloko)

c. Study Site 3: Sanctuary; Elevation 731 MASL; Coordinates S 32^0 37’513 and E 026^0 55’951

The in-stream habitat of study site 3 (Figure 4.4) in this area was predominately bedrock and boulders, although a certain proportion contained silt from vehicles driving across the stream (Figure 4.4). This study site was located 0.5 km above Kwakayaletu Village. Communities from Kwakayaletu used the river for livestock watering, and washing clothes as well as extracting water for domestic use. Mean water temperature at study site 3 was 15.7 ^{0}C (range:-10 ^{0}C-25.4 ^{0}C). The mean conductivity was 0.02 mS/m (range: 0 mS/m-0.06 mS/m). Mean current velocity was 1.57 m/sec (range: 0.6 m/sec to 2.8 m/sec); and mean pH was 6.6 (range: 6 -7-). Study site 3 was the first area where fish were collected. Three fish species namely, *O. mykiss, B. trevelyani* and *S. bainsii,* co-occurred at this study site.

Figure 4.4: Study Site 3 (Sanctuary)

d. Study Site 4: Auckland; Elevation 700 MASL; Coordinates S 32^0 38’421 and E 026^0 55’126’’

Agricultural farming in study site 4 (Figure 4.5) was in close proximity to the river at 25 m, while Auckland sub-village, which is part of KwaKayaletu Village, was 1 km from the river. This study site also had a weir and a bridge. The communities used the river for drinking water, watering livestock and for domestic chores, such as washing clothes. Mean water temperature at study site 4 was 15.3^0 C (range: 8.5 ^{0}C - 26.5^{0}C Mean conductivity was 0.02 mS/m (range: 0 mS/m -0.05 mS/m), while mean current velocity was 1.75 m/sec (range: 1 m/sec-2.7 m/sec). Mean pH was 6.7 (range: 7-7). While the majority of *B. trevelyani* were sampled below the bridge and beneath rocks; the juveniles of the fish species were sampled just above the weir close to the banks.

Figure 4.5: Study Site 4 (Auckland)

e. Study Site 5: Macfarlan; Elevation 588 MASL; Coordinates S 32^0 42’678’’ and E 026^0 53’117’’

Study site 5 (Figure 4.6) was located below the Binfield Park Dam. The predominant substrate at this site was pebble, although there were areas of bedrock and deep pools. Human induced modifications included a major road, a bridge, and the fact that it was below the Binfield Park Dam. A derelict citrus farm, earmarked for rehabilitation, was also located around this area. Communities mainly use the river for livestock watering. Macfarlan village was nearby, approximately 2 km from the river. Mean temperature was 17.06 ^{0}C (range: 11 ^{0}C - 27.8 ^{0}C. Mean conductivity was 0.1 mS/m (range: 0.05 mS/m - 0.26m S/m). Mean current velocity was 1.39 m/sec (range: 0.6 m/sec-2.1 m/sec), and a mean pH 6.8 (range: 6- 7. Only one fish species *S. bainsii* was recorded, most of which were caught in the bedrock areas in riffles.

Figure 4.6: Study Site 5 (Macfarlan)

f. Study Site 6: Melani; Elevation 574 MASL; Coordinates S 32^{0} 43'202 and E 026^{0} 51'618

The substrate in study site 6 (Figure 4.7) was bedrock with siltation effects from a small bridge and overgrazed landscape. The in-stream habitat had emergent vegetation cover above and below the bridge. The study site was highly modified by anthropogenic activities that include two weirs, one of which also serves as a bridge (Figure 4.7).

Figure 4.7: Study Site 6 (Melani)

Human activities included watering livestock and small holder agricultural lands in close proximity. There were two human settlements on either side of the river namely, Tyler Village and Melani. Tyler Village had no running water, while Melani, which was approximately 4 km from the river, had running water within 2 km of households. The agricultural lands (Figure 4.8) and Sawmill Plant (Figure 4.9) were close to the river at plus or minus 13.4 m.

Figure 4.8: Rural Land Use around Study Sites 5 and 6

Figure 4.9: Sawmill Plant Close to Study Site 6

Mean water temperature was 17^0C (range: 11.6 ^{0}C - 24.6 ^{0}C). Mean conductivity was 0.1 mS/m (range: 0.06 mS/m - 0.21 mS/m). Mean current velocity was 1.46 m/sec (range: 1 m/sec-1.9 m/sec), and mean pH 6.9 (range: 6 - 7). Four fish species, *S. bainsii, Anguilla mossambica, B. trevelyani* and *T. sparrmanii* were found to inhabit this study site.

g. Study Site 7: Gqumashe; Elevation 528m MASL; Coordinates S 32^0 45' 505 and E 026^0 51'097

Study site 7 (Figure 4.10) was just below Gqumashe Village. Small scale farming was practiced in close proximity to the river. There was a bridge nearby and communities used the river water for animal watering and small scale farming (Figure 4.10). Heavy mat of algal bloom was recorded in the summer month. Mean temperature was 18.08 ^{0}C (range: 11.3 ^{0}C - 25.5 ^{0}C). Mean conductivity was 0.09 mS/m (range: 0.06mS/m - 0.16 mS/m). Mean current velocity was 1.59 m/sec (range: 0.9 m/sec3 m/sec), and mean pH 6.8 (range: 6 - 7). Only two species of fish, *L. umbratus* and *T. sparrmanii*, were found to inhabit this Site.

Figure 4.10: Study Site 7 (Qumashe): (showing anthropogenic users and algal bloom in the summer month)

h. Site 8: Honeydale; Elevation `496 MASL; Coordinates S 32^0 48 ’128’’ and E026^0 51’589’’

Present at study site 8 (Figure 4.11) were two weirs, one of which was bridged Mean temperature was 18.98 ^{0}C (range: 12 ^{0}C - 24.7 ^{0}C). Mean conductivity was 0.19 mS/m (range: 0.09 mS/m - 0.42 mS/m). Mean current velocity was 1.19 m/sec (range: 0.9 m/sec-3 m/sec) and mean pH 7 (range: 6 -7).

Figure 4.11: Study Site 8 (Honeydale)

Extensive algae bloom was observed in this study site during the summer month of February 2007, when water levels were low. This study site was just below Alice urban area (Figure 4.12).

Figure 4.12: Alice urban Area and Fort Hare University above Study site 8

This study site is within the Fort Hare University farm, where small scale aquaculture was practiced (Figure 4.13). Fish species farmed at Fort Hare University Aquaculture farm include *Labeo umbratus* (A. Smith, 1841), *Anguilla mossambica* (Peters, 1852) and *Myxus capensis* (Valenciennes, 1836).

Figure 4.13: Aquaculture activities within Fort Hare University Farm

Two species, *S. bainsii* and *L. umbratus*, were found to naturally co-occur in study site 8.

i. Study Site 9: Njwaxa; Elevation 392 MASL; Coordinates S 32^{0}52’526 and E 026^0 53’528

There was a weir at study site 9 (Figure 4.14) with a wall that was at least 1.2 m high. This had changed the substrate due to accumulation of silt, and there was a large area of emergent vegetation. Below the weir, the dominant substrate was bedrock (Figure 4.14). This study site was located 2 km for Njwaxa Village.

Figure 4.14: Study Site 9 (Njwaxa)

Mean temperature at study site 9 was 17.77 ^{0}C (13 ^{0}C- 26 ^{0} C). Mean conductivity was 0.19 mS/m (range: 0.12 mS/m - 0.33 mS/m). Mean current velocity was 1.33 m/sec (range: 0.9 m/sec-2.2 m/sec), and mean pH 7 (range: 7- 7). Three fish species namely, *Tilapia sparrmanii, Clarias gariepinus* and *L. umbratus* coexisted at this study site. Twenty percent of the fish caught in this study site had external parasites. The parasitic infections, possibly trematode (fluke) infections, presented as black spot cysts on the skin of mainly *T. sparrmanii*.

j. Study Site 10: Junction above Confluence; Elevation 319 MASL; Coordinates S 32^{0} 54’622’’ and E 026^{0} 56’031’’

The substrate at study site 10 (Figure 4.15) was bedrock with areas of deep pools, where pebbles and silt had accumulated. This site was 0.5 km above the confluence with the Keiskamma River.

Figure 4.15: Study Site 10 (Junction above Confluence)

Apart from cattle watering, this study site was relatively Near Natural as there were only a few human settlements. Mean water temperature at study site 10 was 18.07 ^{0}C (range: 12 ^{0}C - 26 ^{0}C). Mean conductivity was 0.17 mS/m (range: 0.01 mS/m -0. 43 mS/m). Mean current velocity was 1.19 m/sec (range: 0.6 m/sec - 1.6 m/sec), and mean pH 7.2 (range: 7 - 8). Three fish species (*T. sparrmanii, L. umbratus* and *G. callidus*) were found to inhabit this area.

4.1.3: Determined Anthropogenic Effects on Tyhume River Habitat

Anthropogenic effects on habitat geomorphology characteristics (habitat quantity) and water quality characteristic (habitat quality) were examined using geomorphology characteristics of elevation, flow rate (current velocity), wetted width and depth, while water quality characteristics examined were; temperature, pH and conductivity.

The habitat geomorphology characteristics of elevation, flow rate, wetted width and depth are summarized (Table 4.2). Habitat water quality characteristics of temperature, pH and conductivity are calculated and also summarized (Table 4.2).

Table 4.2 Summary statistics for habitat characteristics of the study sites (N=10) 2006/07

Characteristic	Mean		Minimum	Maximum
Stream Geomorphology				
Elevation (MMASL	599.7		319.0	1139.0
Wetted Width (m)	13.4		2.2	42.0
Depth (m)	0.6		0.2	1.4
Flow rate (m/sec)	1.4		1.2	1.9
Water quality				
pH	6.8		6.1	7.7
Temp (^{o}C)	16.4		7.3	27.0
Cond (mS)	0.09		0	0.43

4.1.3.1 Geomorphology Habitat Characteristics

a. Wetted Width

Wetted width increased longitudinally with declining elevations (Figure 4.16; Table 4.2). A maximum width of 42 m was recorded at Lowland zone (e.g. study site 9); the zone where the greatest mean depth of 1.4 m. was also recorded. Study site 9 had a wall, creating a dam, hence, the higher than usual width. Study site 5, below Binfield Park Dam, had the lowest mean wetted width of 7 m, with a range from 4.5 - 9.1 m. A mean wetted width of 4.5 m was recorded below Binfield Park Dam (study site 5) during the summer month of February 2007, when precipitation was normally at its lowest. Study sites below Alice urban area, recorded gradual increase in wetted width, though it was not easy to tease out storm water contribution. This area was previously damned (see Figure 4:11 above).

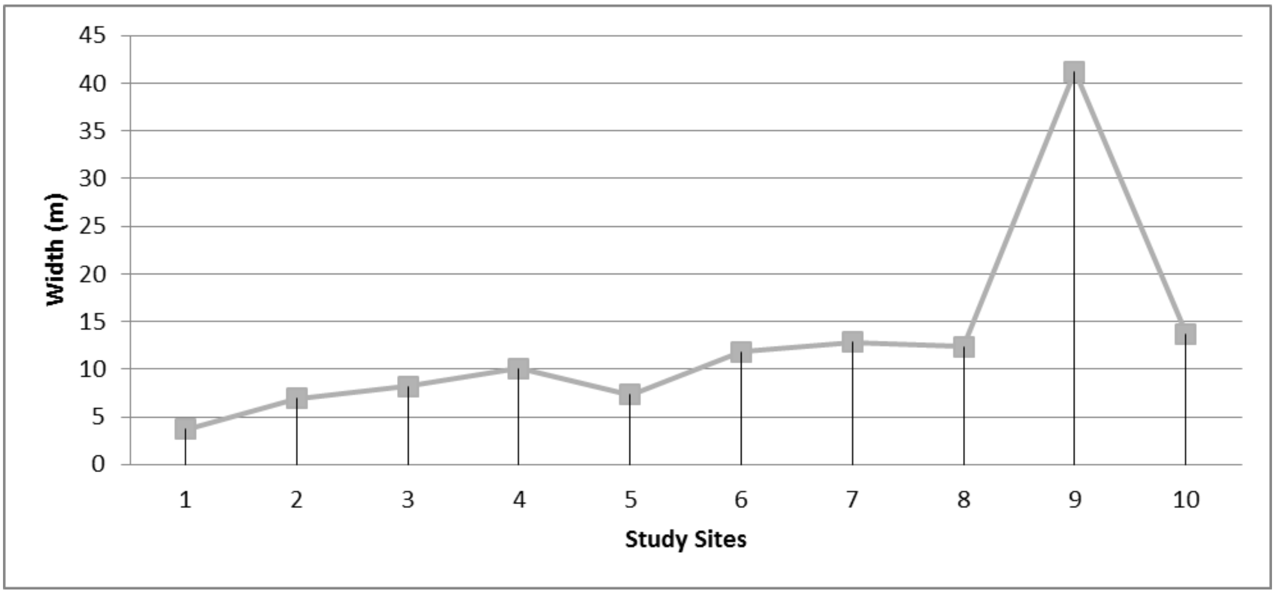

Figure 4.16 Tyhume River Wetted Width

b. Depth

The depth in Tyhume River increased with declining elevation; depth ranged from 0.2 m-1.4 m and a mean depth of 0.6 m (Figure 4.17; Table 4.2). Mean depth was least (…0.2m) at study site 5, below Binfield Park Dam; ranging from 0.2 m -1.1 m.

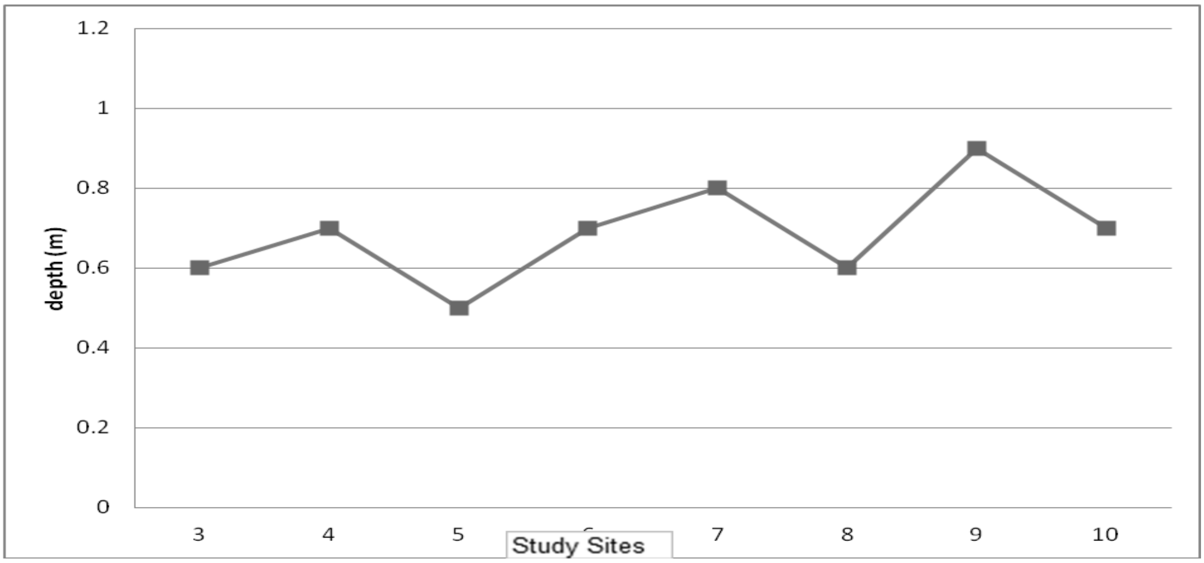

Figure 4.17 Tyhume River Depths

The least depth (0.2 m), at this study site, was recorded in the month of February 2007. Areas with well-developed pools coincided with weirs.

No strong correlation was evident between depth and study sites. Analysis of Variance (ANOVA), established significant differences between study sites above and below Binfield Park Dam ($F=1.91$, $p<0.05$).

c. Current Velocity

Current velocity or flow exhibited bimodal distribution with peaks in March, April and May (Figure 4.18). These peaks were more prevalent at all sites, consistent with rains. The regulation effects created by Binfield Park Dam were clearly discernible in study sites 5 and 6 (this recovered at study site 7; Figure 4.18). At study sites 5 and 6 variations between months were clearly dampened.

The correlation of reduced rainfall and low current flows can be glimpsed from the month of February 2007 (Figure 4.18). This month exhibited low current velocity rates prevalent at all study sites, and which created conducive conditions for algae blooms that were recorded in five study sites (sites 5, 6, 7, 8 and 9). The first clear decline in current velocity was recorded at study site 5, which was below the Binfield Park Dam (this recovered at study sites 6 and 7). High current velocities were recorded for the month of August. Summer months (October, November, December and January), were wet. As a result, no data was collected for these months due to the risk of storm events.

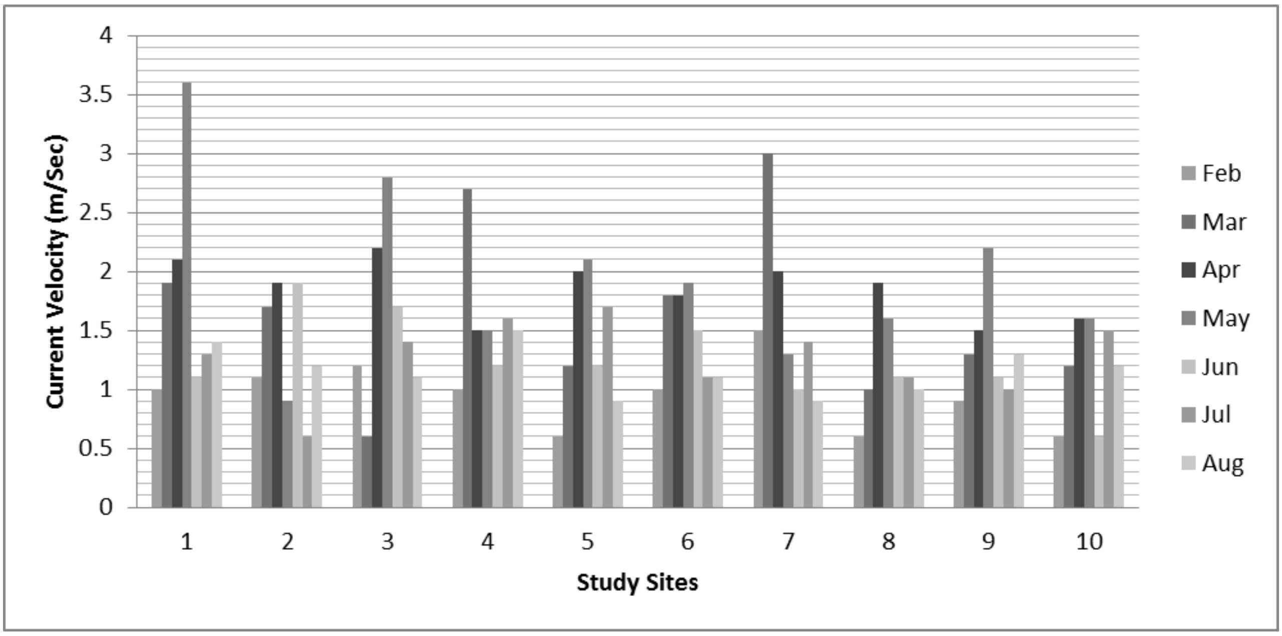

Figure 4.18 Tyhume River Current Velocity Monthly Variation per Study Site

Mean annual variation in current velocity was analyzed (Figure 4.19). The reduced variation (1.4m/sec), from the dampening effect of impoundment, was not readily apparent in study site 5 from within means variation (0.6m/sec - 2.1m/sec). This could be the effect of compensatory dam releases, which helped to stabilize the long term effect. The higher variation (1.1m/sec -1.95m/sec) observed in study site 6, could be explained by the very compensatory water released from the dam, which was masked by the mean (1.5 m/sec), due to its sensitivity to extreme values. Variation in mean current velocity was highest in study site 1 (0.9 m/sec - 2.7 m/sec) and lowest in study sites 8, 9 and 10 (site 8=1.2m/sec, site 9=…1.3 m/sec, site=10… 1.2 m/sec) (Figure 4.19). Study sites 1, 4, 6, 8 and 9 all had weirs; sites 6 and 8 actually had two weirs each. Study site 6 was located below the dam, while at study site 8 the weir was abridged; double weirs and abridging, found at study sites 6 and 8, could have contributed to the lowest mean annual current velocity (1.5 m/sec and 1.2 m/sec), respectively.

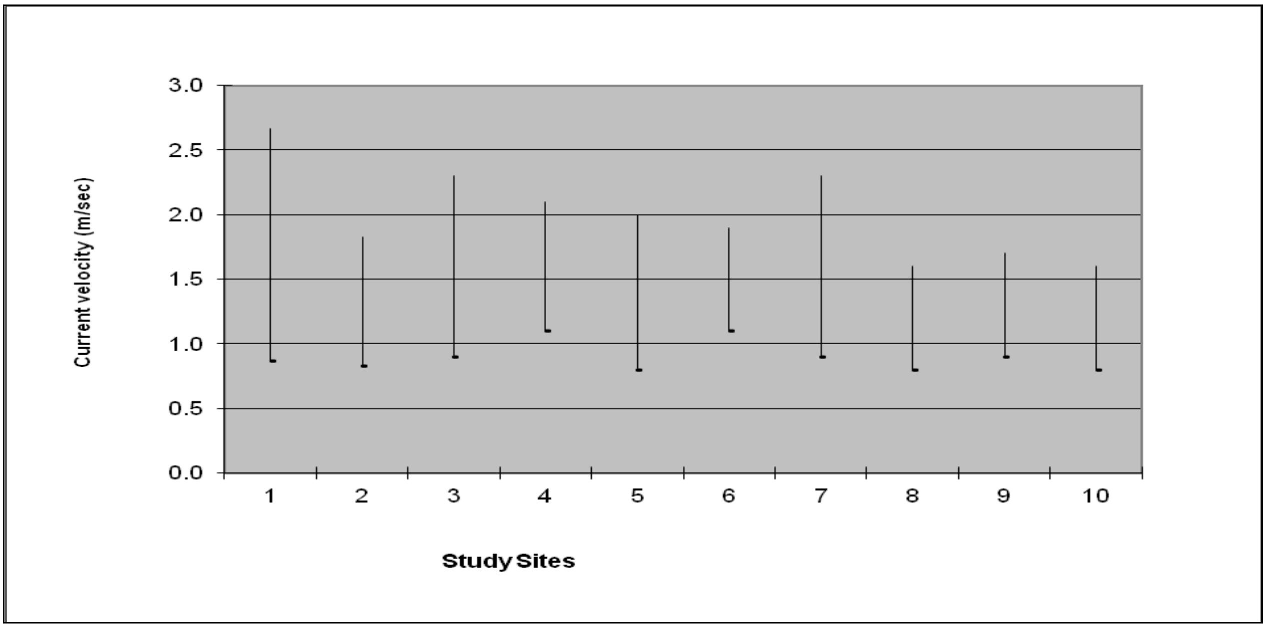

Figure 4.19: Tyhume River Mean Current Velocity Variation per Study Site

The mean current velocity variation were statistically significant $F_{(6,\ 14)} = 3.09$ and p= 0.045 and confidence interval at level 95.0 % = 0.14. Twenty-five percent of the variation could be attributed to conditions between sites (e.g. precipitation). The mean annual precipitation (MAP) in this region varied from 1200 mm in the mountainous zone to 450 mm in the dryer plateau area, and peaking up to 600 mm along the coastal areas (DWAF 2004; also refer to the summary of Tyhume River habitat characteristics provided in Table 4.2 of this thesis). Normally the median, which is considered more robust, as it is not affected by extreme values, would have been used to compare variation between study sites. However in this case, mean and median had few disparities.

4.1.3.2: Water Quality Habitat Characteristics

Anthropogenic induced changes in water quality characteristics were determined through measurement of temperature, pH and conductivity.

a. Temperature

Temperature exhibited longitudinal variation and increases downstream, in tandem with declining elevation and reduced canopy (Figure 4.20a and b). The mean temperature for the months of March to October for the entire river, was 16.35 ^{0}C, with a confidence interval at level 95% =1.5 (Table 4.2). The impact of temperature on biotic organisms was likely to have severe deleterious effects at the extremes. Effects of extreme temperatures could be glimpsed from data collected in February 2007 (Figure 4.20 a). For instance, at Hogsback, which represented the mountain zone, the mean temperature at study site 1 was 25.5 ^{0}C in February 2007 - a deviation of 9.15 ^{0}C from the overall mean.

The deviation was higher when compared to the mean at the particular study site, of 12.6 ^{0}C, as this amounted to a difference of 15.2 ^{0}C. The deviations were similarly high in other sites; for instance, study site 5, which is below Binfield Park Dam, experienced the highest temperature of 27.8 ^{0}C - a deviation of 11.4 ^{0}C from the overall mean (Figure 4.19 a). The second lowest temperature was also recorded in the winter month of June (Figure 4.20b), while just above the confluence with Keiskamma River, the mean temperature was 17.8 ^{0}C. ANOVA revealed that the means were not statistically significant $F_{(7, 32)}$ =45.5, and P>0.05.

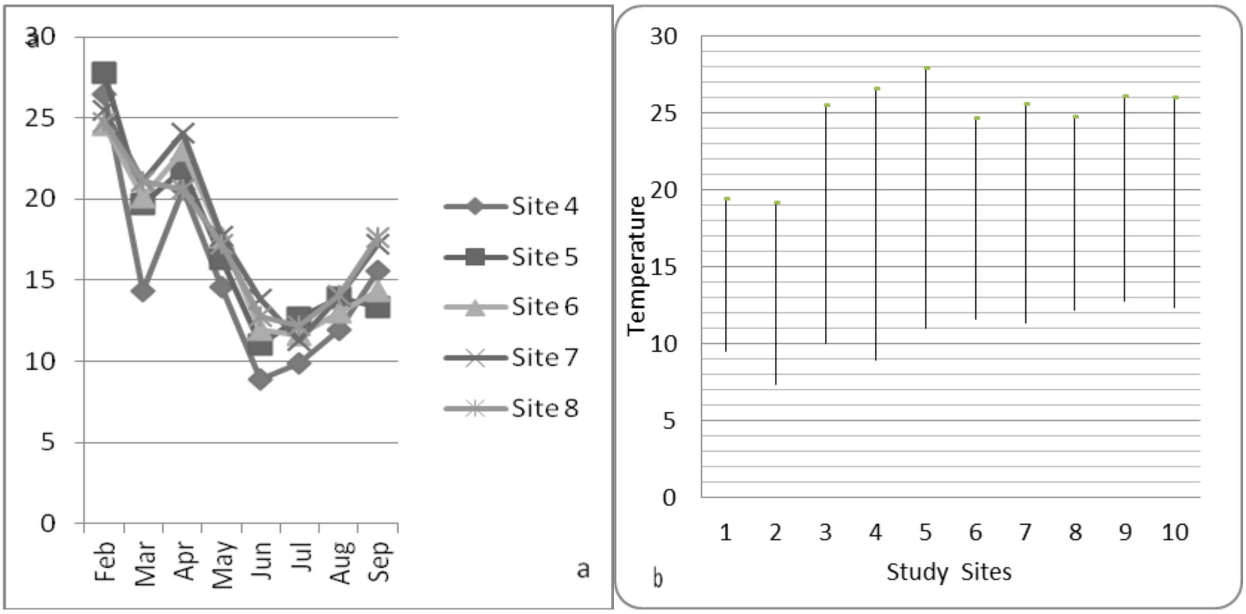

Figure 4.20: Tyhume River Temperature (^{o}C) at (Study Site 4) above and (Study Site 5) below Binfield Dam, and Study Sites 6 & 7 above and Study Site 8 below Alice urban area (a) and Temperature variations per Study Site (b)

The effects of reduced rainfall and low current flows could be glimpsed from the month of February 2007. This month exhibited high temperatures prevalent at all study sites

(Figure 4.20a). This created conducive conditions for algae blooms that were observed in Sites 5, 6, 7, 8 and 9. Study site 5, located below Binfield Park Dam and study sites 8 and 9 located below Alice urban area, had the highest level of algal blooms.

The mean temperature was not suitable to represent typical drought situations as it was greatly influenced by large numbers and was used to represent extreme conditions. The medium was less influenced by outliers, and was used for analysis of typical situations of non-drought.

The Alternative Hypothesis (H_2): There is significant difference in sample medium temperature for study sites above sites (3 & 4) above and (6 & 7) below Binfield Park Dam and there is significant difference in sample medium for temperature in study sites (5 & 6) above Alice Urban area and study sites (8 & 9) below Alice urban areas is accepted.

b. Conductivity

Conductivity increased with declining elevation. The mean conductivity was 0.09 mS/m, with a confidence interval at level 95% = 0.05 for the entire Tyhume River (Figure 4.21; Table 4.2). The mean conductivity was highest at study site 8 (= 0.30 mS/m), which was just below Alice urban area. Conductivity recovered slightly at study site 9 and study site 10. Study site 5 recorded the second highest level of conductivity (0.17 mS/m), which recovered to 0.12 mS/m at study site 7, but shot up again at study site 8, which is just below Alice urban area. Study site 8 also had the second largest differences in range (from 0.09 mS/m minimum to 0.42 mS/m maximum). Conductivity was high for all study sites in the month of February; the difference between study sites 4 and 5 was 0.21 mS/m compared to 0.13 mS/m from the overall mean. The difference between study site 7 and study site 8 for the month of February was 0.26 mS/m, compared to 0.18 mS/m from the overall mean (Figure 4.21). These findings supported arguments that extreme conditions occurred when flow rates were at their lowest levels. The means were statistically significant for study sites, from effects of Alice urban area, ($F_{(6, 14)}$ = 3.09 and p= 0.045), and fifty eight per cent of total variation was attributable to differences among study sites.

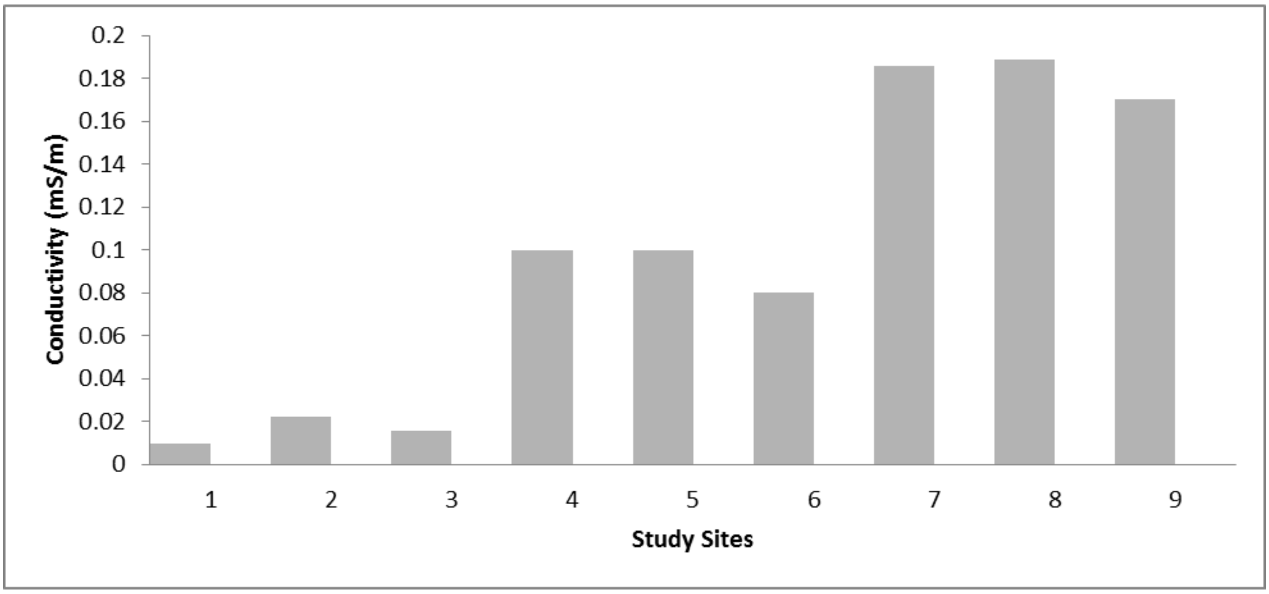

Figure 4.21: Tyhume River Conductivity

c. pH

The pH of Tyhume River ranged from neutral 6.6 to near alkaline (7.2). The mean pH increased gradually, longitudinally with declining elevations (Figure 4.22). pH was slightly below neutral (6.6) in the high elevation mountainous zone and increased to just above neutral (7.2) in the confluence with Keiskamma River, which is within the lowland zone (Table 4.1).

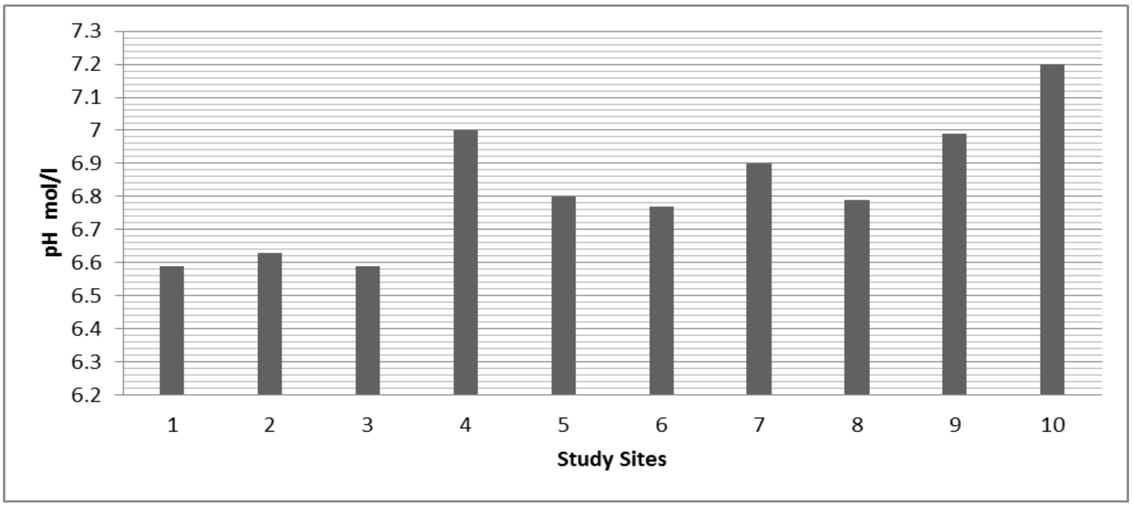

Figure 4.22: Tyhume River pH

The mean pH 6.8 was recorded for all study sites (Figure 4.22), with a confidence interval at level 95% =0.14. An alkaline (pH 7.7), was recorded once in study site 10 in the month of February 2007; during this month a pH of 7.0 and a pH 6.4, were recorded in study sites 5 and 6, respectively. These were the lowest pH recorded in this month, as compared to study sites 3 to10. In general, high elevation (refer Table 4.1) study sites, had a mean pH value of just below neutral (pH value), while those downstream, had a mean pH value of just above neutral (pH 7.7). Study site 10 registered the sharpest pH differences with ranged from acidic (pH 6.13) to neutral (pH 7.2). The mean pH were statistically significant $F_{(7, 32)}$ =4.5 and P=0.001. Ninety percent of the pH variation was from in between sites; conditions mainly from the anthropogenic effects of Binfield Park Dam and Alice urban areas.

The Alternative Hypothesis (H_1): There are significant difference in sample means current velocity, pH and EC for study sites above sites (3 & 4) above and (6 & 7) below Binfield Park Dam and there are significant differences in sample means for current velocity, pH and EC study sites (5 & 6) above Alice Urban area and study sites (8 & 9) below Alice urban areas is accepted.

4.1.3.3: Anthropogenic Effects on Habitat

a. Anthropogenic Modifications on Habitat

Study sites 5 and 6 were considered anthropogenic impaired from a large impoundment (Binfield Park Dam). Study sites 8 and 9 were considered to be impaired from storm water runoff from Alice urban area. Alice urban area was within less than 3 km of Tyhume River and had the second highest human population density in Nkonkobe Municipality. Alice urban area consisted of Alice Town and Ntselamanzi Village. The number of persons per km^2 was 1278 and 3034 in Alice and Ntselamanzi, respectively (Integrated Development Planning (IDP) Nkonkobe Local Municipality 2007-2012).

b. Extent of Anthropogenic Induced Habitat Modification

The extent of anthropogenic modified habitat in Tyhume River was summarized (Figure 4.23). Dam related modifications were the highest proportion, and accounted for 43 %. This was closely followed by urban runoff at 28 %. Agricultural runoff and livestock grazing were together estimated at 18 %. The relatively Near Natural area was estimated to consist of 11 %, mainly in the Hogsback, where an indigenous forest interspersed with exotic trees existed.

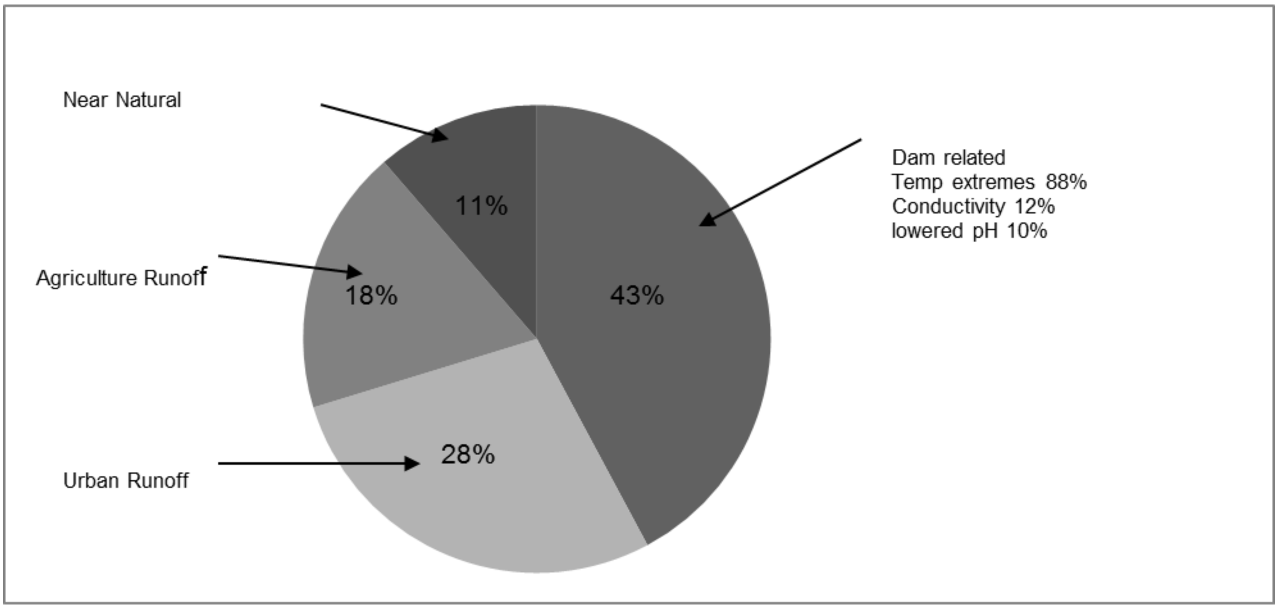

Figure 4.23: Anthropogenic effects on Tyhume River Habitat

4.2: Determined Anthropogenic Effects on Fish Assemblages in Tyhume River

4.2.1: Trend Analysis of Anthropogenic Effects on Fish Assemblage Abundance

Prior to construction of Binfield Park impoundment, *B. trevelyani* was more abundant (0.33) in study site 3 than *S. bainsii* (0.07), while at study site 7, the two species were equal (0.37) in abundance (Figure 4.24). After construction of impoundment, the levels of *S. bainsii* increased to 0.66 while *B. trevelyani* disappeared from study site 7. During this survey only *S. bainsii* was collected in study site 6 below the Binfield Park Dam, which is the study site that corresponded with earlier surveys, while no *B. trevelyani* was collected. The means of fish abundance were not statistically significant ($F_{(2, 9)}$ = 3.09 and p= 0.9).

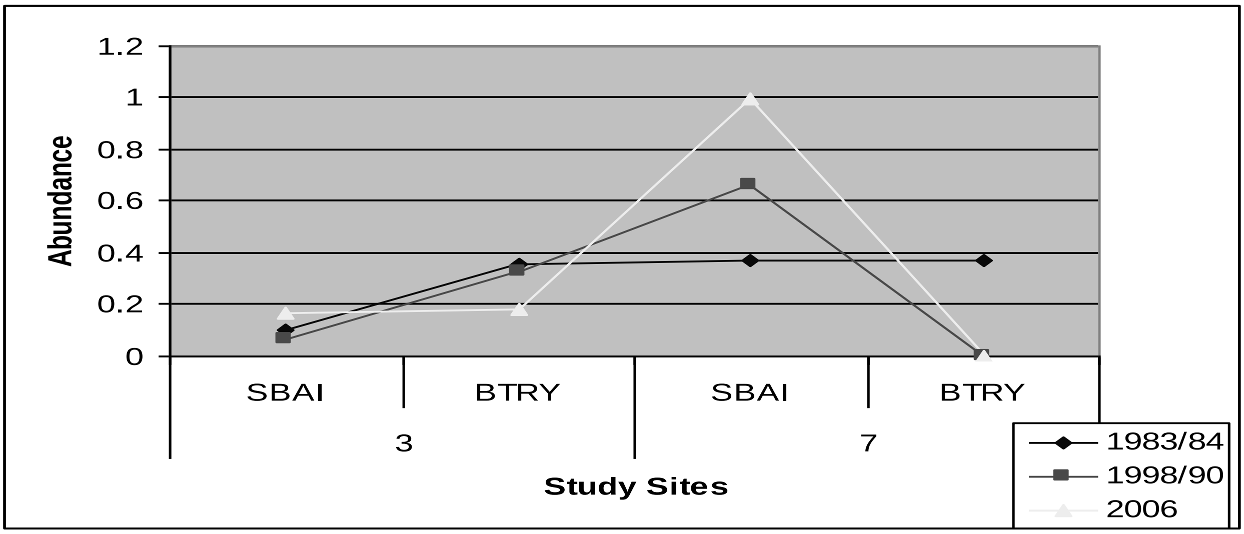

Figure 4.24: Trend analysis showing pre and post impoundment abundance of *S. bainsii* and *B. trevelyani* at Sites 3 and 7

B. trevelyani recorded a reduced distribution below the Binfield Park Dam, as it was found only in study site 6 (573 MASL). *S. bainsii* is more widely distributed and was found ranging from study site 4 (731 MASL) above Binfield Park Dam up to study site 8 (514 MASL) which is just below Alice town.

The abundance of *B. trevelyani* at study site 6 during this survey was sporadic due to the low incidence of encounter; this site corresponded to site 8 of Mayekisho (1994) survey. Trend analysis of pre and post impoundment abundance of *S. bainsii* and *B. trevelyani* revealed no presence of *B. trevelyani* from site 7 and also a further decline at site 3 (Figure 4.24).

4.2.2: Fish Assemblage Composition

In total 250 fish, consisting of eight fish species, representing eight families, were collected from Tyhume River, between February and October 2006 and in February 2007. The fish comprised four indigenous species, three translocated and one non-native species. The four indigenous species were *S. bainsii, B. trevelyani, A. mossambica* and *Glossogobius callidus*. The three translocated species were *L. umbratus*, *T. sparrmanii* and *C. gariepinus*. The one non-native species was *O. mykiss.*

Numerically, the translocated fish species dominated the catch, with a relative frequency of 64 %, followed by the indigenous fish species, at 32 % (Figure 4.25). Of the translocated fish species, *L. umbratus* had the highest proportion of 34 %, followed by *T. sparrmanii,* 26 % (Fig 4.25). Only one non-native (alien) species a Salmonid *O. mykiss* was collected. *C. gariepinus* composition was negligible as only one individual fish specimen was collected (Figure 4.25). The proportion of indigenous fish species was 16 % for *S. bainsii* and 12 % for *B. trevelyani,* while *G. callidus* was 6 % and that of *A. mossambica* was negligible too (Figure 4.25).

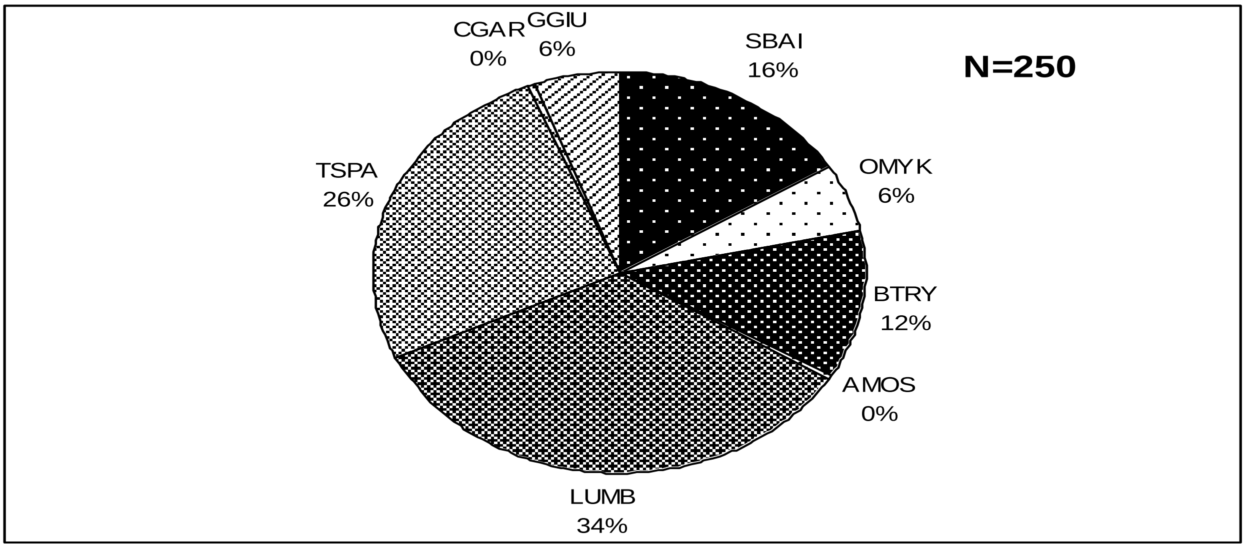

Figure: 4.25: Tyhume River fish species relative frequency 2006/2007. Species are as follows: AMOS, *Anguilla mossambica*; BTRY, *Barbus trevelyani*; CGAR, *Clarias gariepinus*; GGIU, *Glossogobius callidus*; LUMB, *Labeo umbratus*; SBAI, *Sandelia bainsii*, TSPA, *Tilapia sparrmanii*; OMYK, *Oncorhynchus mykiss*

The non-indigenous fish species comprised only one alien (non-native), *O. mykiss*, and three translocated species, *L. umbratus, C. gariepinus, and Clariidae* and *T. sparrmanii*, a Cichlidae. The indigenous species consisted of two primary freshwater species *S. bainsii* and *B. trevelyani*, one secondary freshwater species *G. callidus* and one diadromous species *A. mossambica* (Figure 4.26).

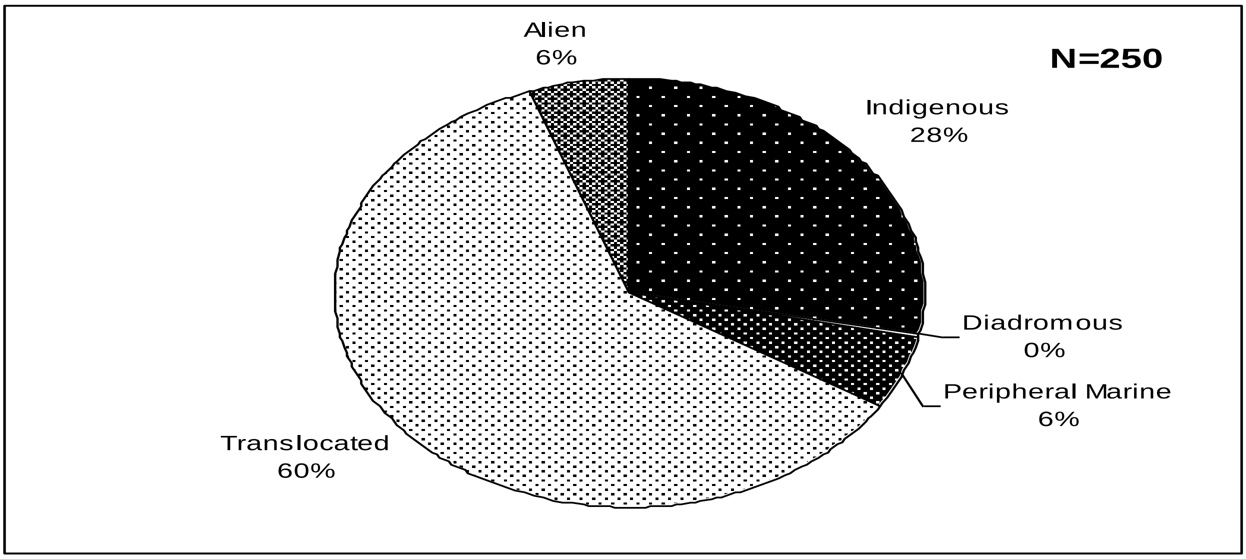

Figure 4.26: Tyhume River fish assemblage relative frequency by categories

4.2.2.1 Comparison of Relative Frequency Above and Below Binfield Park Dam

Comparison of species in terms of composition revealed a drastic reduction in relative frequency of *B. trevelyani* below the dam (Figure 4.27a & b). *S. bainsii* dominated the composition in study sites below the dam (Figure 4.27b). Species richness in terms of diversity increased in line with the theory of species addition as the river progressed downstream (Figure 4.27b). The creation of an impoundment, however, interrupted the downstream progression species abundance; hence at study site 5 (Figure 4.1 and Table 4.1), where habitat substrate had been greatly altered by high current velocity, only *S. bainsii* was sampled.

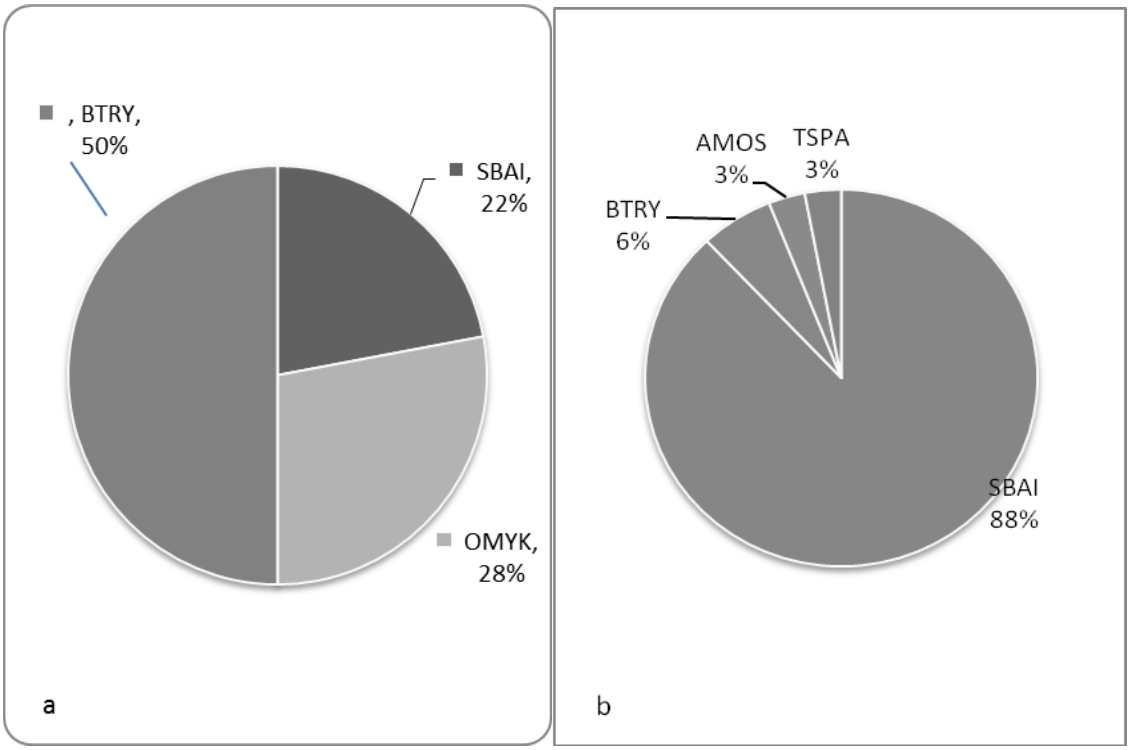

Figure 4.27: Comparison of relative frequency of fish species at study sites a) above Binfield Park Dam and (b) below Binfield Park Dam. Species are as follows: AMOS, *Anguilla mossambica*; BTRY, *Barbus trevelyani*; CGAR, *Clarias gariepinus* SBAI, *Sandelia bainsii*, TSPA, *Tilapia sparrmanii*; OMYK, *Oncorhynchus mykiss.*

4.2.2.2 Comparison of Relative Frequency Above and Below Alice Urban area

Comparison of species composition above and below Alice urban area showed reduced relative frequency of *B. trevelyani* below (Figure 4.28a & b). The relative frequency of indigenous fish species also decreased drastically below Alice urban area (Figure 4.28a). The increase in relative abundance of alien fish, especially translocated fish species, was equally substantial (Figure 4.28b). *C. gariepinus* composition was very low at 1%, which is far below earlier predictions for this species (Figure 4.287 b).

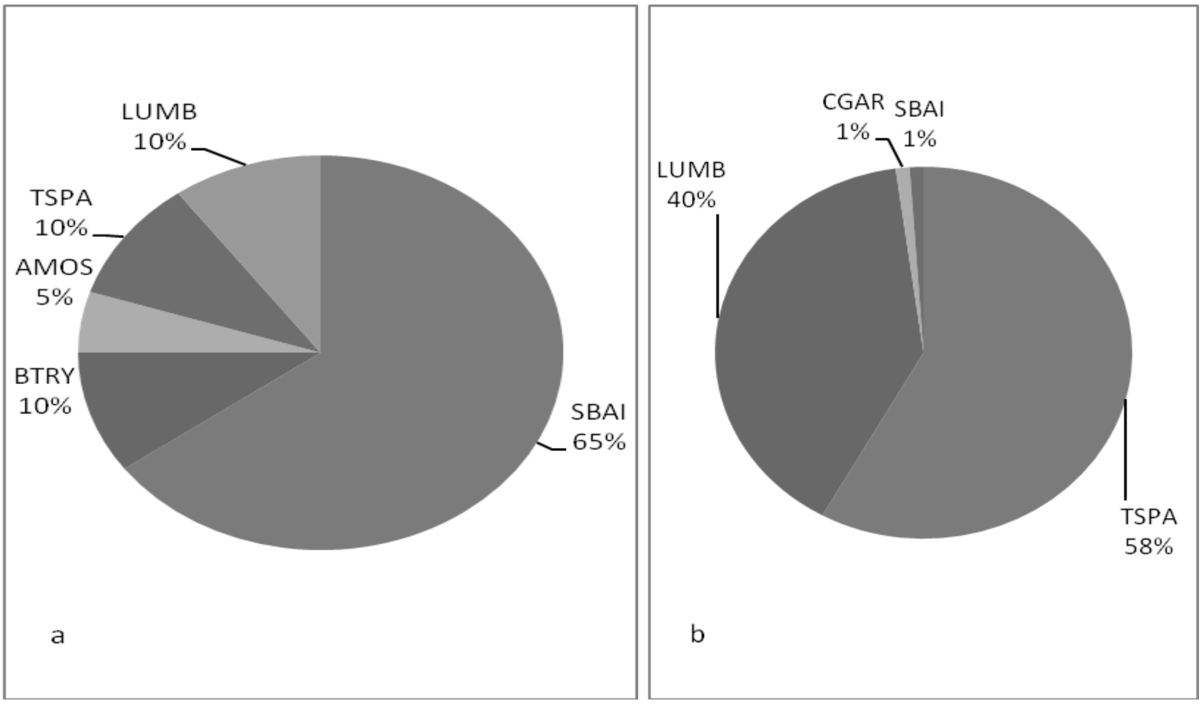

Figure: 4.28: Comparison of relative abundance at study sites above (a) and below (b) Alice urban area. Species are as follows: AMOS, *Anguilla mossambica*; BTRY, *Barbus trevelyani*; CGAR, *Clarias gariepinus;* GGIU, *Glossogobius callidus*; LUMB, *Labeo umbratus*; SBAI, *Sandelia bainsii*, TSPA, *Tilapia sparrmanii.*

4.2.3 Fish Distribution

Incidence of occurrence, using presence/absence at study sites, was used to map longitudinal distribution (Table 4.3). No fish was collected at study sites 1 and 2, while only one *A. mossambicus* was collected at study site 6, which is below Binfield Dam. *B. trevelyani* was sampled in three study sites, 3 and 4 above Binfield dam and study site 6 below. *S. bainsii* was caught from study site 3 down to study site 8. *G. callidus* was caught only in study site 10. Of the translocated fish species, *C. gariepinus* was found only in study site 9; *L. umbratus* was found in all study sites from 7 to 10, while *T. sparrmanii* was sampled in study sites 6, 7, 9 and 10. Only one alien fish species, *O. mykiss* was recorded in study sites 3 and 4 (Table 4.3).

Table 4.3: Tyhume River Longitudinal fish Distribution in 2006/07. Fish species are as follows: AMOS, *Anguilla mossambica*; BTRY, *Barbus trevelyani*; CGAR, *Clarias gariepinus*; GGIU, *Glossogobius callidus*; LUMB, *Labeo umbratus;* SBAI, *Sandelia bainsii*, TSPA, *Tilapia sparrmanii*; OMYK, *Oncorhynchus* mykiss. FS=Fish Species; Sites=1-10 are study

FS / Sites	AMOS	BTRY	CGAR	GGIU	LUMB	SBAI	TSPA	OMYK
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

4.2.3.1 Jaccard's Index of Similarity

Jaccard's index of similarity (Figure 4.29) ranged from 0.11 to 0.91. Values from 0.6 were considered biologically significant. Six study sites clusters recorded significant similarity; the first was recorded at study sites 5 and 6 (588 and 574 MASL) where Jaccard's index 0.9 was recorded for *S. bainsii*. The second significant index was recorded at study sites 7 and 8 (528 MASL and 496 MASL), where a Jaccard's Index of 0.91 was recorded for *L. umbratus*. In study sites 7 and 9 (528 MASL and 392 MASL), a Jaccard's Index of 0.6 was recorded for *T. sparrmanii*. Two study sites: 7 and 10 (528 MASL and 319 MASL) and 8 and 9 (496 392 MASL and 392 MASL), recorded a Jaccard's index of 0.6 for *L. umbratus*, and 8 and10 (496 MASL and 319 MASL), recorded Jaccard's index of 0.7 for the same species.

The Jaccard's index of similarity (Figure 4.29) analysis revealed alien species *O. mykiss* index at study sites 3 and 4 (731 MASL and 700 MASL) as only 26 %, while for indigenous species and *B. trevelyani,* were 21 % and 53 %, respectively. There was more revealing longitudinal reduction for *B. trevelyani* of 19 % similarity with study sites 3 and 6 (731 MASL and 574 MASL). In study site 4 (rocky foothill above the Binfield Park Dam) and site 6 below the dam, (sandy foothill), *B. trevelyani* similarity suffered a 50 % reduction relative to study sites 3 and 4 above Binfield Park Dam. The Jaccard's similarity index for *S. bainsii* ranging from 10 % to 90 % was lowest for study sites 3 and 8 (731 MASL and 496 MASL). Also, the Jaccard's similarity index for the invasive translocated species *T. sparrmanii* at study sites 6 and 7 (574 MASL and 528 MASL), was 11 %, the lowest; at study sites 7 and 10 (528 MASL and 319 MASL), it was 15 %. The lowest Jaccard's index of 32% for *L. umbratus* was for sites 7 and 9 (528 MASL and 392 MASL). No similarity indices were developed for three fish species; *A. mossambica, C. gariepinus* and *G. callidus,* as occurrence was recorded at a single study site. Ten study site clusters had no similarity; 3 and8 (731 MASL and 496 MASL); 3 and9 (731 MASL and 392 MASL); 3 and10 (731 MASL and 319 MASL); 4 and7 (700 MASL and 528 MASL); 4 and9 (700 MASL and 392 MASL) ; 4 and10 (700 MASL and 319 MASL); 5 and7 (588 MASL and 528 MASL); 5 and8 (588 MASL and 489 MASL); 5 and9 (528 MASL and 319 MASL);, and 6 and 9 (574 MASL and 319 MASL).

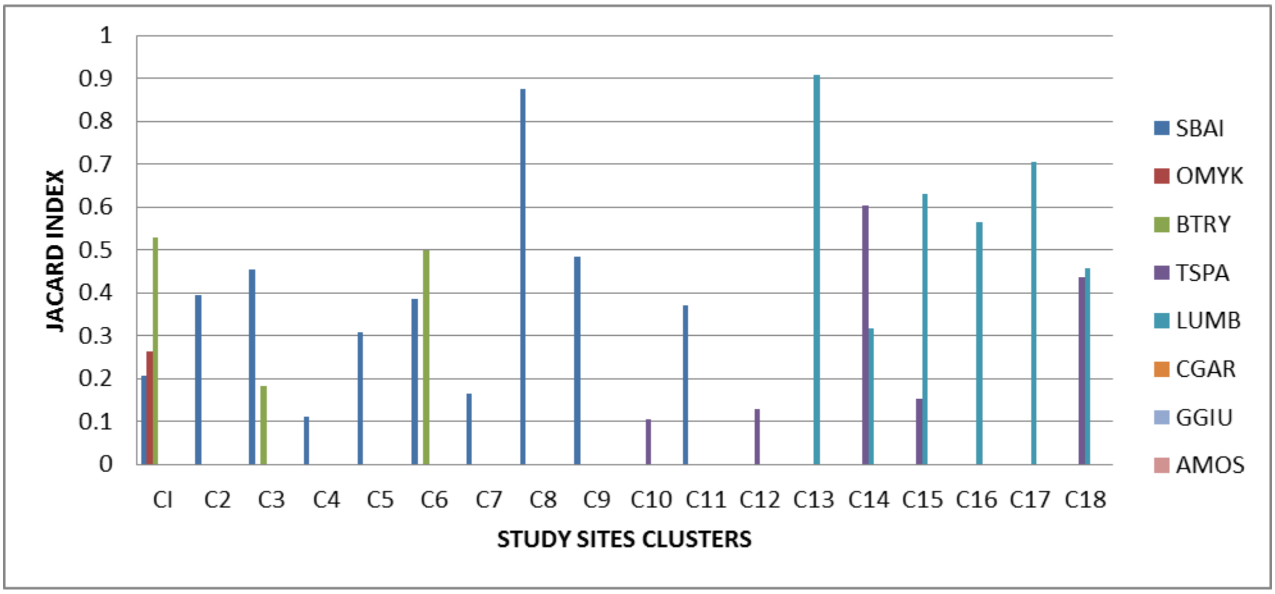

Figure 4.29: Jaccard's Index of Similarity for Study Sites Clusters: C1 (3 and 4 or 3&4), C2 (3&5), C3 (3&6), C4 (3&8), C5 (4&5), C6 (4&6), C7 (4&8), C8 (5&6), C9 (5&8), C10

(6&7), C11 (6&8), C12 (6&10), C13 (7&8), C14 (7&9), C15 (7&10), C16 (8&9), C17(8&10) and C18 (9&10)

4.2.3.2 Cluster Analysis

Single distance nearest neighbour cluster analysis did not produce clear clusters. Cluster analysis, using Excel 2010, revealed seven fish assemblage community clusters (Figure 4.30). The *S. bainsii, B. trevelyani* and *O. mykiss* cluster was found in the high elevation study sites 3 and 4 (731 MASL and 703 MASL). The fish assemblage at study site 6 (574 MASL) had the greatest diversity, as four species (*S. bainsii, B. trevelyani, T. sparrmanii and A. mossambica*) were found to co-exist. The frequency of *B. trevelyani* at study site 6 was sporadic due to low incidence of occurrence. Two fish species (*L. umbratus* and *Tilapia sparrmanii*) co-existed at study sites 7 and 9 (525 MASL and 393 MASL). *Clarias gariepinus* was sampled only at study site 9 (393 MASL), but its abundance was sporadic due to low incidence of occurrence. Three fish species (*L. umbratus, Tilapia sparrmanii* and *G. callidus*) were found at study site 10 (319 MASL).

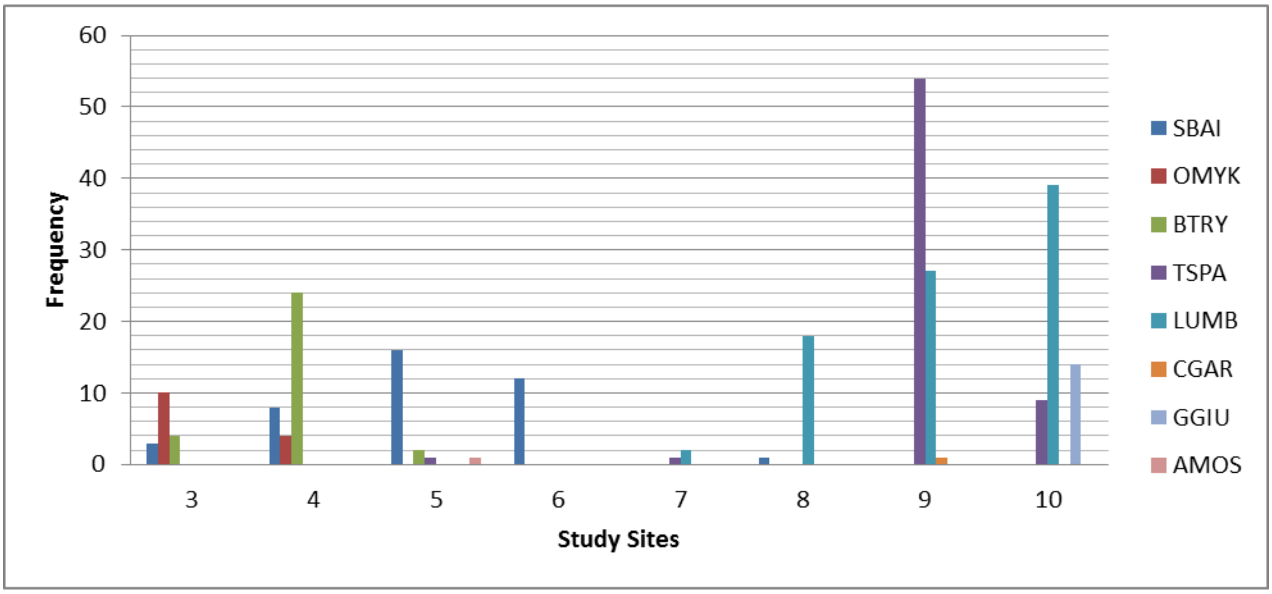

Figure 4.30: Fish assemblage community clusters

4.2.3.3 Threatened Fish Species

Two of the indigenous fishes, *S. bainsii, B. trevelyani,* sampled in Tyhume River, are threatened and are on the IUCN Red List 2006, while M. *capensis* is listed under 'Least concern. The current survey revealed *B. trevelyani* presence at only three study sites, 3, 4, and 5,, while the distribution of *S. bainsii* reduced below Alice urban area and was not sampled in study sites 8 and 9, whereas previously it was sampled up to the confluence (Tables 4.4).

4.2.3.4: Comparison of Current and Historic Fish Assemblage Longitudinal Distribution

Trend analysis of 2006/07 fish distribution with historical (1983, 1989) data, revealed reduced distribution of four fish species: *A. mossambicus, B. trevelyani, C. gariepinus* and *S. bainsii* (Table 4.4). Two non-native fish species (*M. salmoides* and *L. macrochirus*), previously (1983 & 1989) recorded, were not recorded in 2006/7. The longitudinal distribution of two fish species (*O. mykiss* and *L umbratus*), had remained constant (Table 4.4). One fish species (*G. callidus*) was collected from the Tyhume River system in 2006/7 for the first time. Only one translocated species *T. sparrmanii* increased longitudinal distribution between 2006/7, 1983, 1989 and. *M. capensis* was not sampled at all in 2006/7 (see Table 4.4).

Table 4.4: Comparison of current (2006/07) and historical (1983, 1989) fish assemblages Longitudinal Distribution on Tyhume River. Where: E=Escarpment; 3-10 Study Sites; Y= (presence)

Species		E	3	4	5	6	7	8	9	10
Anguilla mossambicus	1983		Y		Y			Y	Y	Y
	1989		Y		Y			Y	Y	Y
	2006					Y				
Barbus trevelyani	1983	Y	Y	Y	Y	Y	Y	Y		
	1989		Y	Y	Y					
	2006		Y	Y		Y				
Clarius gariepinus	1983							Y		
	1989							Y	Y	Y
	2006								Y	
Glossogobius callidus	1983									
	1989									

	2006									Y
Labeo umbratus	1983						Y	Y	Y	Y
	1989						Y	Y	Y	Y
	2006						Y	Y	Y	Y
Lepomis macrochirus	1983							Y	Y	Y
	1989							Y		
	2006									
Micropterus salmoides	1983							Y	Y	Y
	1989							Y		
	2006									
Oncorhynchus mykiss	1983	Y	Y	Y						
	1989	Y	Y	Y						
	2006	Y	Y	Y						
Sandelia bainsii	1983		Y	Y	Y	Y	Y	Y	Y	Y
	1989		Y	Y	Y	Y	Y	Y		
	2006		Y	Y	Y	Y		Y		
Tilapia sparrmanii	1983						Y	Y	Y	Y
	1989						Y	Y	Y	
	2006					Y	Y		Y	Y

4.2.4: Annotated Length Frequency Distribution and Weight

4.2.4.1: Longfin Eel

Anguilla mossambica Peters, 1852, (AMOS)

Only one specimen of *A. mossambica* was sampled during the February-October survey in 2006**.** It had a standard length SL of 80.8 mm and weighed 33 grams (g). The length of the fish was way below the minimum length of fish collected in 1994, which had a total length (TL) of 120 mm and a length frequency modal of 300-399 mm TL. The largest specimen collected in 1994 was 890 mm TL. *Ex-situ* populations of this species existed in Fort Hare University aquaculture ponds (D.O. Okeyo, personal communication).

4.2.4.2: Border Barb

Barbus trevelyani Günther, 1877, (BTRY)

The length frequency distribution of *B. trevelyani* is bimodal, which can be explained by the sampling of a large number of juveniles at study site 4 in May. A maximum length of 103 mm Fork Length (FL), weight of 15.9 g and a modal frequency of 70-75 mm FL (Figure 4.31) was recorded for *Barbus trevelyani* during this survey. Mayekisho (1994) reported a maximum size of 115 mm FL and a modal length frequency 69-79 mm (FL) for males.

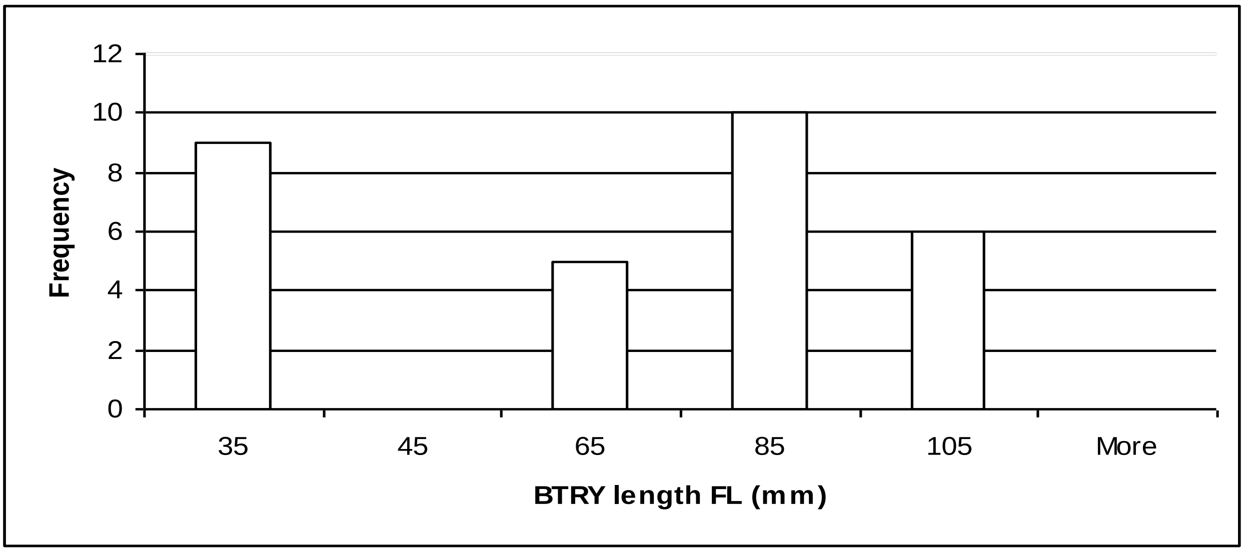

Figure 4.31: Length frequency distribution for *B. trevelyani*

4.2.4.3: Sharptooth Catfish

Clarias gariepinus (Burchell, 1822), (CGAR)

Only one specimen *C. gariepinus* of TL 302 mm and weight 232.5 g was caught near the edge of a deep pool in study site 9, just above a weir. In 1994, the modal length frequency of *Clarias gariepinus* was 400-499 mm TL compared to the largest specimen of 930 mm TL (3980 g) (Mayekisho 1994). Ex-*situ* populations of this species existed in Fort Hare University aquaculture ponds (D.O. Okeyo, personal communication).

4.2.4.4: River Goby

Glossogobius callidus (Smith, 1938), (GGIU)

G. callidus was only sampled in study site 10; most frequent TL 60 mm. Skelton (2001) indicated this species can attain a maximum size of 120 mm. *G. callidus* was classified as a secondary freshwater species, which meant it lived in freshwater though it can tolerate marine estuarine waters (Skelton -2001). Mayekisho (1994) did not report this fish in the Tyhume River system, although records from South African Institute of Aquatic Biodiversity SAIAB indicated its presence in Keiskamma River (B. Rogers, personal communication). A total of 14 fish species were recorded from study site 10 during this research. The maximum total length (TL) was 85 mm and minimum TL 32 mm.

4.2.4.5: Moggel

Labeo umbratus (A. Smith, 1841), (LUMB)

Labeo umbratus was numerically the most dominant fish species in this study: in total 85 specimens of *L. umbratus* were recorded in study sites 7, 8, 9, and (Figure 4.32). The most frequent length was 60 mm while TL 150 mm was the maximum recorded (Figure 4.32). The distribution was positively skewed indicating a high prevalence of juveniles. *Labeo umbratus* is a translocated fish species common to Orange-Vaal system that can attain a TL of 500 mm (Skelton 2001). Mayekisho (1994) reported a modal frequency of occurrence of 120-149 mm FL. During this current survey (2006), the modal frequency of occurrence was 49-60 mm TL for the fish species, whilst 220 mm TL was the maximum size recorded. Ex-situ populations of this species existed in Fort Hare University aquaculture ponds (D.O. Okeyo, personal communication).

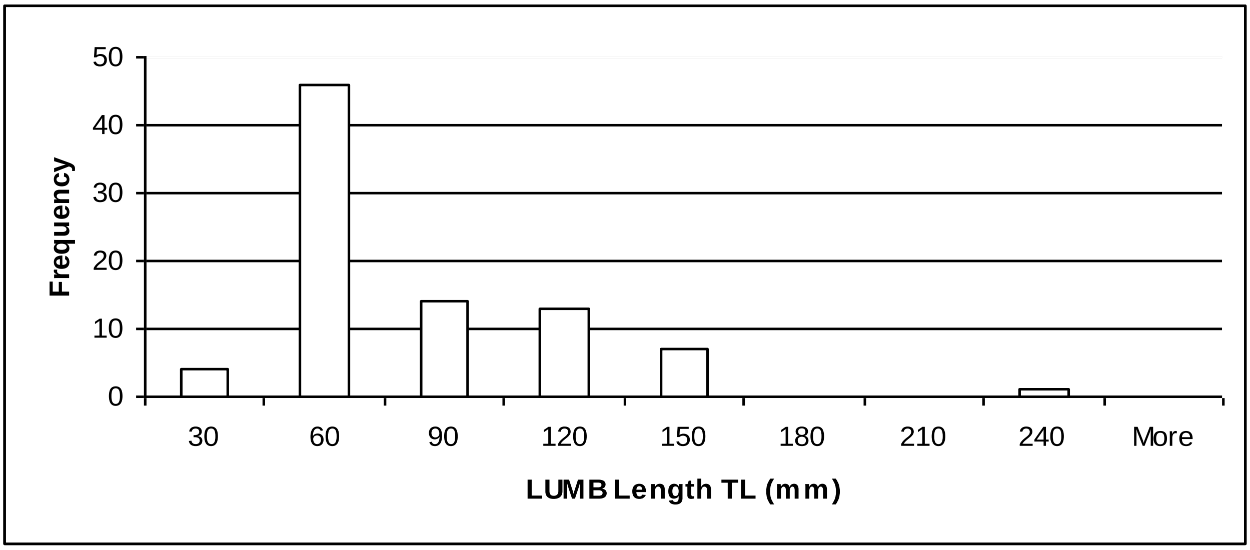

Figure: 4.32: Length frequency distribution for *L. umbratus*

4.2.4.6: *Sandelia bainsii* Castelnau, 1861 (SBAI) Eastern Cape Rocky

During the current survey, 40 specimens of *S. bainsii* were recorded in study sites 3, 4, 5, 6 and 8; showing negatively skewed length frequency distribution (Figure 4.32). Higher composition of larger sized species was observed; the maximum size recorded for *S. bainsii* during this survey was SL 195 mm. Skelton (2001) indicated: the fish can attain a SL 260 mm. The 1989/1990 survey recorded a maximum size of 135-144 mm SL for combined males and females (Mayekisho 1994). *S. bainsii* is currently listed as 'Endangered' IUCN 2006 Red List, from effects of introduced species, habitat deterioration and extent of occurrence (IUCN Red List 2006).

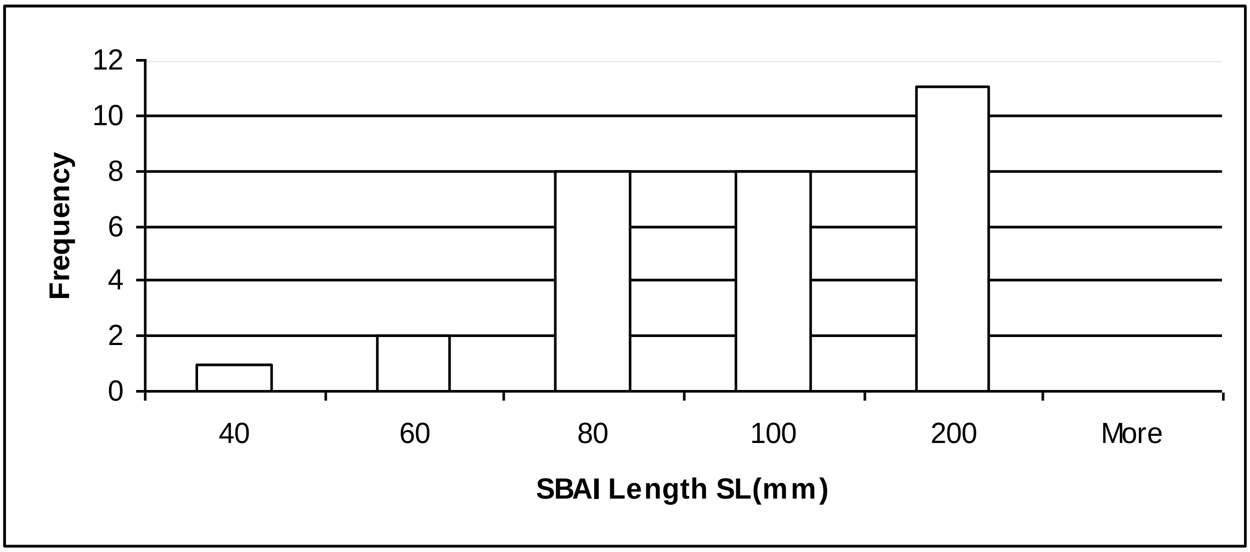

Figure 4.33: Length frequency distribution for *S. bainsii*

4.2.4.7: Rainbow Trout

Onchorynchus mykiss (Walbum, 1792), (OMYK)

Only fourteen specimens of *O. mykiss* occurred from study sites 3 and 4 during this thesis; however, length measurements were taken for only 7 specimens, which were insufficient for analysis. The maximum size recorded in this survey was 200 mm FL, which was less than 300 mm FL, the maximum size recorded by Mayekisho (1994) for river fish and 386 mm FL for Binfield Park Dam fish. Skelton (2001) indicated, this fish can attain a maximum length of 1.2 meters in the native Pacific area, while for South Africa, lengths of 600 mm are considered large (Skelton 2001). During this survey, Binfield Park Dam was considered lentic and not sampled. From trials undertaken by Zoology Department, University of Fort Hare, there were no indications of *O. mykiss* occurring in Binfield Park Dam (D.O. Okeyo, personal communication).

4.2.4.8: Banded Tilapia

Tilapia sparrmanii A. Smith, 1840, (TSPA)

This translocated species had the second highest numerical presence, with 65 specimens recorded from study sites 7 to 10 combined (Figure 4.34). Previously, Mayekisho (1994) had recorded collecting the fish species from study site 6 down to just above the confluence (study site 10). The length frequency distribution appeared bimodal, indicating two populations (Figure 4.34). The maximum length recorded during this survey was 60 mm; majority of the specimens were in 31-40 mm frequency mode. Mayekisho (1994) recorded a maximum size of 116 mm SL with a modal frequency distribution of 5-79 mm SL for the fish, while Skelton (2001) indicated; the fish can attain SL of 230 mm. A high level of external parasites was observed in most fish collected during this (2006) survey.

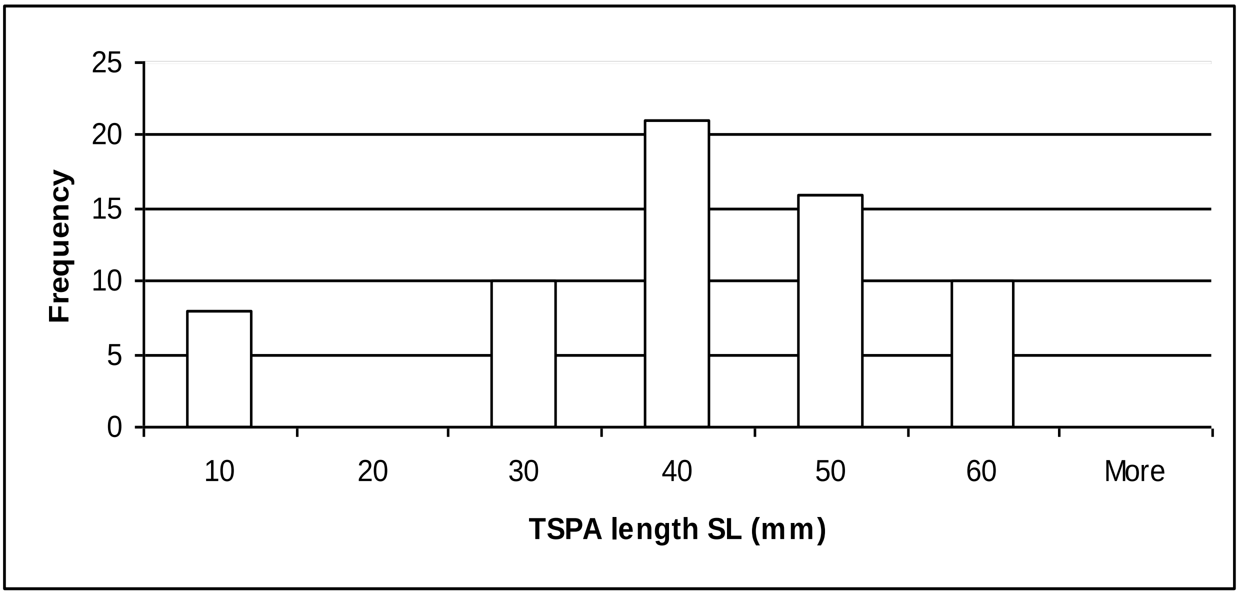

Figure: 4.34: Length frequency distribution for *T. sparrmanii*

4.3: Determined Economic and Institutional Value of Ecosystem Services

4.3.1: Economic Evaluation Questionnaire Responses

Two hundred and eleven questionnaires were administered, out of which 209 (a ratio of 99% administered to valid responses) were used in the analysis. The majority of the respondents resided in Alice Town area (39 %), followed by Gulf (27 %) and Ntselamanzi (14 %); the other 16 % were from 2 rooms combined, E. Maplager and Happy rest, , while 5 % of respondents did not indicate their residential area. All these areas were in Alice urban and were within less than 5 km from Tyhume River. Thus, 97% of the respondents were aware that the river provided for their domestic water supply needs.

4.3.1.1: Demographics

Out of 209 persons interviewed, 47 % were male and 43 % were female, consisting of a mean age of 45 years (Table 6.1). Only 50 persons (24 %) had attained University level of education. Regarding membership of an environmental conservation group, a paltry 3 % belonged to a group; however, 89 % of respondents were willing to join. Among those “not interested” in joining, the reasons given were, old age or lack of time, while others were only willing to join for a fee. The “not interested” were treated as negative responses. Demographic information contained in IDP Nkonkobe Municipality (2007-

2012; Table 4.5), was used to assess representativeness of the survey demographic data.

4.3.1.2: Income

The demographic questionnaire analysis indicated the average monthly income of respondents as R4562 (Table 4.5). The average age was 45 years, while the average number of dependents was 3. The average monthly water bill for households was R85 (Table 4.5). The results from the survey were compared with those of Nkonkobe Municipality census data of 2007-2017 (Table 4.5)

Table 4.5: Comparison of Survey Results (2007), demographics with 2001 population censors' statistics: Source IDP Nkonkobe, Municipality 2007-2012

Characteristics	Study Survey 2007	IDP Nkonkobe Municipality 20072012 Alice (Ward 5) and Ntselamanzi (Ward 6)
Population	209	12000
Households		2829
Income	4562	2817
No income, unemployed	82%	74%
plus less than R 800		93%
University Education	24%	20%
Age	45	30
Males	47%	40%
Females	53%	60%
Dependents	3	

a. Willingness to Pay for Improved Ecosystem Services

Seventy-seven percent of the respondents voted in support of establishment of a Tyhume River Restoration Trust Fund and for the proposed hypothetical improvement scenarios. Nineteen percent of the respondents indicated they could not afford to contribute; 3% did not believe the funds would be well managed, while 1% indicated they were not willing to contribute. Four percent were of the view that, it was the government's responsibility, which considered true protest, together with those who were of the view that funds would be mismanaged.

Table 4.6: Summary Statistics of Monthly Income, WTP Bid, and Demographics

Characteristic	Mean	Median	Standard Error	SD	Minimum	Maximum
Monthly Income (Rand)	4562	4000	1.7	4847	0	14000
WTP Bid	18.6	10	1.7	24.9	0	125
Age	45	41	1.0	13.9	22	85
Monthly Water Bill (Rand)	85.07	20	8.0	115.9	0	900
Dependents	3	3	1	1.8	0	11

b. Frequency Distribution of the Bid Amount

Distribution of the WTP bid amount (in Rands) and the frequency of bid amounts at each interval were analyzed (Figure 4.35). The distribution was negatively skewed, perhaps, due to the high (82 %) unemployment rate in this area. A large proportion (90 %) of residents received low wages or were dependent on government grants, while others recorded no income at all: (Integrated Development Planning, IDP, Nkonkobe 2007-2012)

Overall, the bid frequency declined with the higher amount (Figure 4.35). The most frequent bid bin was 0-5 followed by the 6-10, while the mean overall bid frequency was 18.6. The data variation was largely influenced by the high number of low bids which made a frequency of 90 % and the 2-3 high value outliers whose frequency was low.

The first four bids accounted for 80% of the data; hence, the median in this case would be the most appropriate measure of central tendency to use.

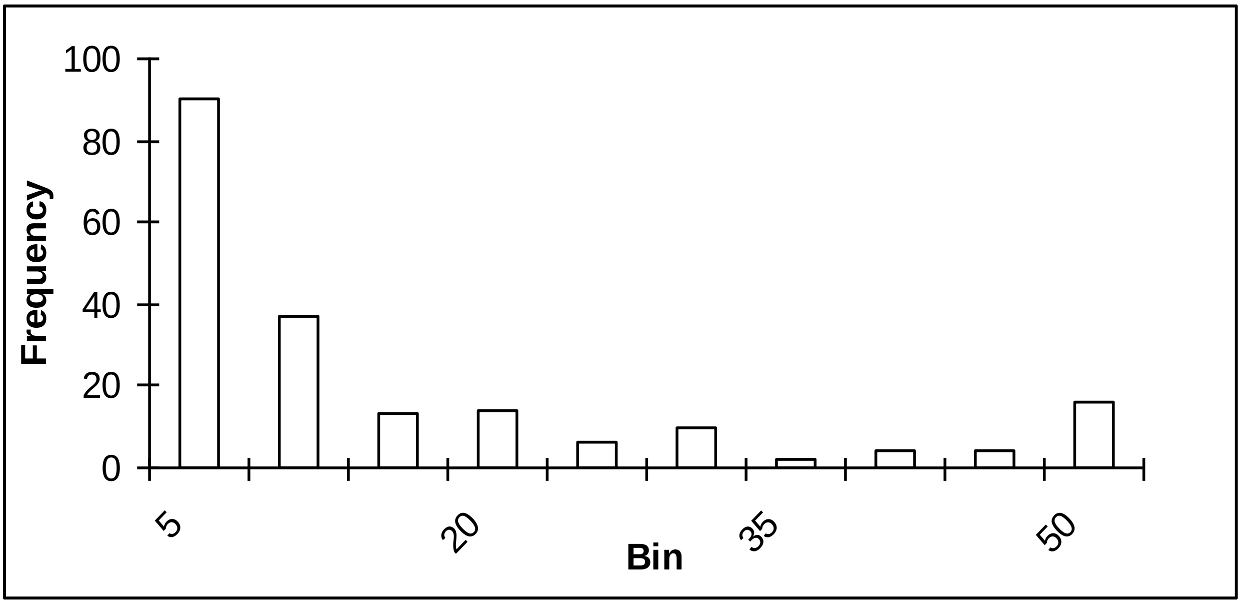

Figure 4.35: WTP Bid Frequency Distribution

c. WTP Binary Responses Analysis

In order to run the logit model, the binary responses descriptive statistics were coded as depicted in (Table 4.7).

Table 4.7: Descriptive Statistics for the WTP Analysis

WTP-BID: Mean of Median Willingness to Pay bid amount

LNINCOM: Natural Logarithm of monthly income

LNWBILL: Monthly water bill

LNAGE: Natural Logarithm of respondent’s age

DEPEND: Number of dependents in household

Results showed that the validity of the model was uncertain, perhaps due to the high number of zero votes. Due to the uncertainty of model validity and lack of significant Wald (> 0.05), the coefficients generated from the median bid amount were used to generate WTP value (Table 4.8).

Table 4.8: Logit regression model parameter estimate on WTP probability

Variable	Coefficient	Std error	Wald statistics	Exp (B)	Median
Constant	3. 709	19.586	.036		10
Ln Water bill	.000	.013	.004	.999	.20
Income	-.223	30.965	.000	.800	4000
lnage	.002	.117	.000	1.002	41
Mcfadden	.204				
Observations	209				

The monthly willingness to pay was R 32 or R 384 per year.

4.3.2: Institutional Evaluation Questionnaire Responses

4.3.2.1: *De facto* State of Tyhume River Habitat and Fish Assemblage

De facto near natural habitat was estimated as covering 11 % of Tyhume River study sites; the rest of the study sites had been modified by impoundment (48 %), storm water runoff (28 %) and agriculture (18 %) (Figure 4.36 a) The fish assemblage had been drastically altered. Indigenous species composition constituted 34 %. The rest (66 %) were all non-native and mainly translocated fish species (Figure 4.36b).

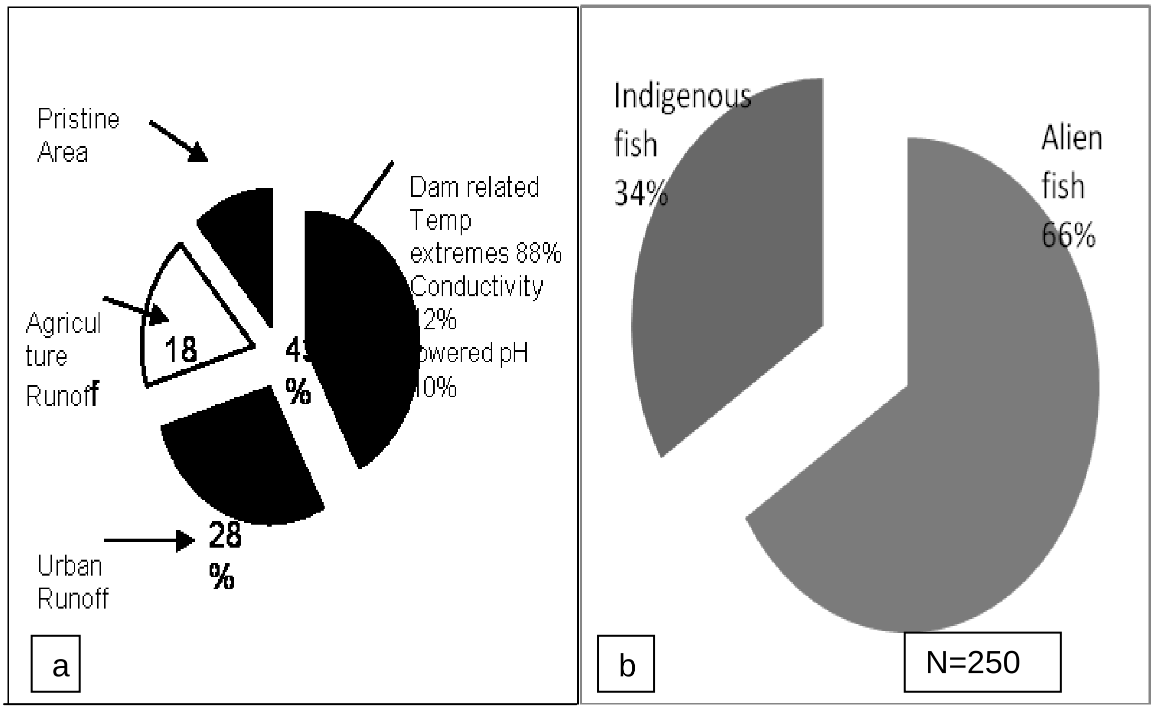

Figure 4.36: Tyhume River *de facto* state of habitat (a) and *de facto* state of Fish Assemblage (b)

The users interviewed in economic survey, when correlated with anthropogenic impacts at the Tyhume River, revealed that the effects of the creation of large impoundments, such as dams, constituted 43 % (Figure 4.36). These manifested alterations in physical parameters below the dam, with temperature alteration constituting 88 %, conductivity increase 12 % and lowered pH 10 % (Figure 4.36). Agricultural activity effects constituted 18 % of modification, and urban runoff was second at 28 %. Information from Figures 4.36a & b was used in development of two hypothetical scenarios I and II (Figures 3.3a & b.).

4.3.2.2: Current Direct Users - Alice Urban Area

The survey revealed 59 % of the households sampled experienced water shortages, while 8 % boiled their water before drinking. The majority (49 %) considered the water safe to drink. Eight five-eight percent of the respondents used the river directly for various activities. Out of these, washing including washing clothes constituted 31 % (Figure 4.37).

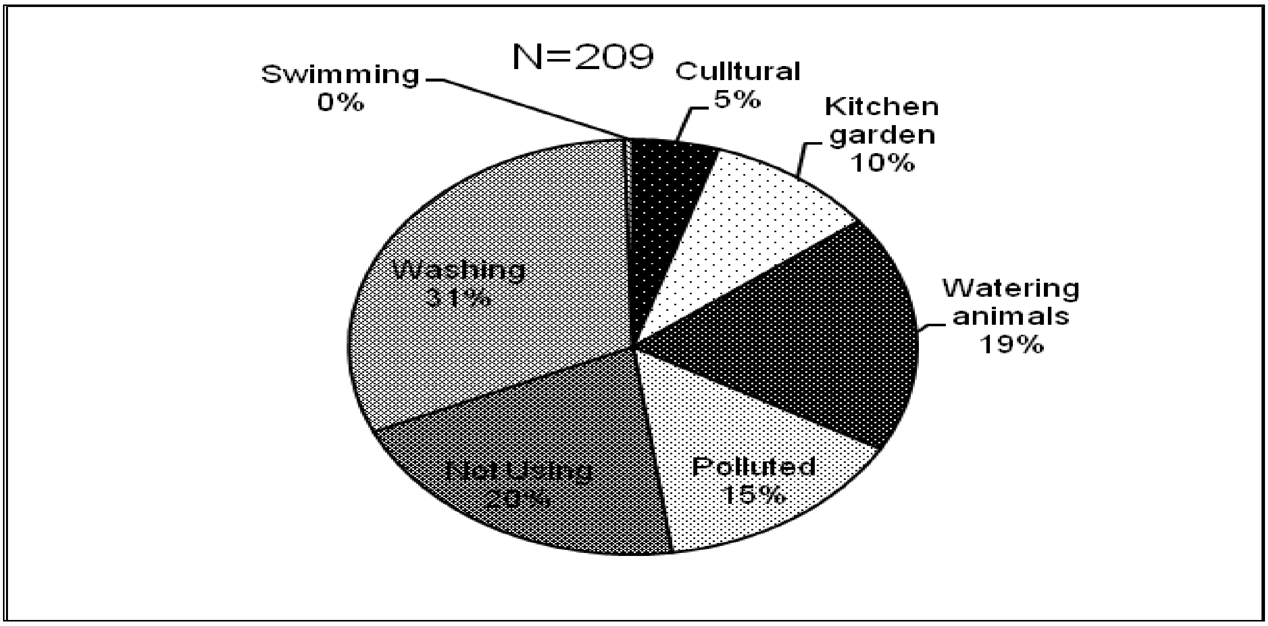

Figure 4.37 Current Direct Users - Alice Residents in 2007

The other uses were cultural ceremonies five percent and watering animals nineteen percent (Figure 4.37). Zero% of respondent indicated use of the river for swimming. Out of the fifteen percent who do not use the river for any activity, fifteen percent were of the view the river was not safe to use due to pollution. Most of residents, who used the river directly, lived in Ntselamanzi area.

4.3.2.3: Comparison of Rio Measures, *De jure* Rights and De facto Situation

The Declaration on Environment and Development Rio (1992) was anthropocentric in approach, putting human beings at the centre of sustainable development. Many of the emerging principles are captured in South Africa legislation post 1992 (Table 4.9). The South African Constitution established the right to clean and healthy environment for all South Africans. The National Water Act established only one right; that included the right to basic water requirements for all South Africans and the right minimum flows of maintenance of ecosystem functions. The sustainability concept established rights for future generations. All three environmental legislations (Table 4.9) had provisions for remediation measures guided by the 'polluter pays' principle, and community participation

Table 4.9 Comparison Post Rio Measures with *De jure* Measures and *De facto* Rights

Post Rio Institutional Measures	De jure measures	De facto externalities
Declaration on Environment and Development: - 27 principles reaffirms Stockholm declaration but differs in emphasis on Sustainable development; Anthropocentric approach: Principle 1 proclaims human beings are at the center of concerns for sustainable development Emerging principles include "precautionary principle", "Polluter pays principle" (which internalizes environmental damage costs" and "environmental impact assessment". Principle 10 is on individual's rights to information, participation and remedies in environmental matters. Principle 20 and 22 are on inclusiveness of women, youth and indigenous peoples. Agenda 21: Action plan for actualization of Rio Declaration. Convention on Biological Diversity (CBD); - whose objectives are conservation of Biodiversity, Sustainable use and equitable, fair sharing of benefits. At the Conference of Parties 5, Ecosystem Approach was adopted as framework for implementation Other agreements outside the focus of this study included the United Nations Convention on Climate	Resource Protection The South Africa Constitution Act No. 108 of 1996 provides.; 24. Environment.- Everyone has the right(a) to an environment that is not harmful to their health or well-being; (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that(i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development NEMA No 107 of 1998: Guiding principles no 2 and 3 include: (2) Environmental management must place people and their needs at the forefront of its concern, and serve their physical, psychological, developmental, cultural and social interests equitably. (3) Development must be socially, environmentally and economically sustainable. Community Participation: (f) The participation of all interested and affected parties in environmental governance must be promoted, and all people must have the opportunity to develop the understanding,	Habitat Storm water ; land use externalities; alien (non-native) fish species and flow modification Riparian overgrazing Soil erosion Habitat quality Degradation of habitat quality from storm water runoff, agriculture runoff and cattle grazing Fish Assemblage Decline of indigenous fish species and 2 listed on IUCN Red List since 1994 Introduction of alien (non-native) fish species including the invasive fish species *T. sparrmaii* No *in situ* conservation measures for *S. bainsii* and *B. trevelyani* Community Participation Community organizations rudimentary.

Change and, Non Legally Binding Authoritative Statement of Principles of a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests	skills and capacity necessary for achieving equitable and effective participation, and participation by vulnerable and disadvantaged persons must be ensured. (p) The costs of remedying pollution, environmental degradation and consequent adverse health effects and of preventing, controlling or minimising further pollution, environmental damage or adverse health effects must be paid for by those responsible for harming the environment. (h) Community wellbeing and empowerment must be promoted through environmental education, the raising of environmental awareness, the sharing of knowledge and experience and other appropriate means. The National Water Act of 1998 (NWA) : PREAMBLE Recognising that water is a scarce and unevenly distributed national resource which occurs in many different forms which are all part of a unitary, interdependent cycle; Recognising that while water is a natural resource that belongs to all people, the discriminatory laws and practices of the past have prevented equal access to water, and use of water resources; Acknowledging the National Government's overall responsibility for and authority over the nation's water resources and their use, including the equitable allocation of water for	

beneficial use, the redistribution of water, and international water matters;

Recognising that the ultimate aim of water resource management is to achieve the sustainable use of water for the benefit of all users;

Recognising that the protection of the quality of water resources is necessary to ensure sustainability of the nation's water resources in the interests of all water users; and

Recognising the need for the integrated management of all aspects of water resources and, where appropriate, the delegation of management functions to a regional or catchment level so as to enable everyone to participate;

Resource directed measures

Protection of riparian areas and River banks. Provisions for protection of water quantity and quality.

Contains guidelines for aquaculture activities.

Restoration guided by ‘polluter pays’ principle

NEMBA No. 10 of 2004 has provided definition of terms used to measures provided therein;

“alien species” means: (a) a species that is not an indigenous species; or (b) an indigenous species translocated or intended to be translocated to a place outside its natural distribution range in nature, but not an indigenous species that has extended its natural distribution range by natural means of migration or dispersal without human

	intervention; **“biological diversity”** or “biodiversity” means the variability among living organisms from all sources including, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part and also includes diversity within species, between species, and of ecosystems; **The objectives** of this Act are~ ~ ~- (a) within the framework of the National Environmental Management Act, to provide for (i) the management and conservation of biological diversity within the 5 (ii) the use of indigenous biological resources in a sustainable manner; and iii) the fair and equitable sharing among stakeholders of benefits arising (b) to give effect to‘ ratified international agreements relating to biodiversity	

4.3.2.4 Community Participation

None of the respondents sampled in 2007 (N=209), in personal economic surveys, were members of an environmental conservation group. However, 89 % of the respondents were willing to join. Three people were willing to join on condition of receiving remuneration; one cited constraint of time and another, old age, while one respondent indicated it depended on conditions.

The NWA provided for formation of water user associations, and already the Department of Water Affairs and Forestry (DWAF), in concert with the Department of Agriculture had started the formation of Edekeni Water Users Association (information provided by Department of Agriculture in Alice).

Chapter 5: Discussion

5.1: Anthropogenic Effects on Tyhume River Habitat

Sustainability of Tyhume River Fish biodiversity was determined using a mixture of ecological, economic and institutional parameters in line with the three pillars of sustainability framework. To determine anthropogenic effects on Tyhume River habitat and fish assemblage within a sustainability framework, ten study sites representing varying intensities of landscaper users and typical river zonation were identified. The extent of anthropogenic effects on habitat had significantly increased, affecting eighty nine per cent of the river. Flow related modifications (measured as current velocity) within the Tyhume River accounted for forty three percent and included lowered pH and increase in conductivity and temperatures modifications, while urban storm water runoff accounted for twenty eight percent of anthropogenic effects. One effect of impoundment is reduction of the amplitude of annual thermal range (Allanson *et al*. 1990. The effects of anthropogenic habitats modifications are likely to have severe impacts during the periods when river discharge was low, leading to increased incidence of water scarcity. Water scarcity occurs when availability in terms of right quantity and quality for flora and fauna in Tyhume River and for human use is constrained (Allan 1995; EEA 2009; Karr 1991; WCMC 1998). The numerous in stream barriers created through impoundment have fragmented river continuity (two hundred and twenty nine reported by Mayekisho (1984), changed water quality characteristics and reduced connectivity with floodplain, which has impacted fish assemblage as observed in other lotic systems (Allan 1995; Quist et al. 2004). Sustainability of lotic systems geomorphology habitat characteristics was investigated in line with, the River Continuum Concept (RCC), a single framework that is used in temperate regions to explain variation from source to mouth (Allan 1995; Ellis and Jones 2013) and has been found to hold for tropical regions. Anthropogenic effects on Tyhume River have interfered with river continuity to the extent that the Serial discontinuity concept (SDC) is more applicable (Ellis and Jones2016). The Binfield Park Dam was a major source of anthropogenic effects on flow (current velocity), temperature, river width and depth.

Anthropogenic effects are sources of externalities that create water scarcity for other users in terms of water availability in the right quantity and quality and comprise at availability at intra and inter generation equity in benefit sharing. Externalities are costs and benefits that are not fully internalized by markets or institutional mechanisms. The cost and benefits at intra generation level require application of equity for attainment of sustainability at both levels.

The findings this study are in line with observations that; there tends to be an inverse correlation of state of river to proximity of human settlements (Holmes *et al*. (2004). Study sites below Binfield Park Dam impoundment and Alice urban area exhibited higher degrees of anthropogenic effects on habitat. In study sites located within close proximity to Binfield Park Dam and Alice urban area, ninety per cent of between-site, pH variation was attributable to anthropogenic effects emanating from the two localities. Variation in between sites conductivity accounted for fifty eight per cent while within rural settlements the major effects were localized agricultural activities and riparian area overgrazing.

This study supported arguments that physical chemical measures used in monitoring systems were inadequate in detecting biological change (Karr 1991; Kleynhans 1999) Despite significant variations of flow, pH and conductivity recorded, neither was beyond the standard set for fish (Fatoki *et al*. 2003). This means that by the time the set standards are reached in the future, fish assemblage may have been drastically altered. Incorporating a biological criterion in water resources monitoring systems and incorporating a wide range of users such as recreation and cultural users seems appropriate for early warning (Karr 1991; Kleynhans 1999; Scott 2006).

The other major source of anthropogenic effects along the Tyhume River was storm water from Alice urban area. Only eleven percent of Tyhume River habitat is near natural and this has impact on fish assemblage.

5.1.1: Anthropogenic Effects on Fish Assemblage

Anthropogenic effect on fish assemblage in Tyhume River was revealed in frequency of fish occurrence where translocated native fish composition constitutes sixty per cent. The frequency of occurrence for indigenous fish species was thirty four percent and non-native fish was six per cent The most revealing was *S. bainsii* with a frequency of occurrence of sixteen per cent coupled with reduce longitudinal distribution most cases, invasive non-native fishes have been characterized as cosmopolitan, or generalist species, that tend to out-compete indigenous fish species (Scott 2006). This is especially the case in areas with multiple anthropogenic threats, leading to the problem of homogenization (Marchetti *et al*. 2006; Reid 2004). The findings of this study are in line with the findings of (DEAT 2006) which revealed that thirty-six percent of the country's freshwater fish are threatened. DEAT 2006 revealed that although no freshwater fish have gone extinct in the country, many have been eliminated from particular river systems.

The Tyhume River fish assemblage is experiencing the homogenization process. This manifests in a few common species becoming more common, with a resultant decline in rare species. The drivers of this process are anthropogenic biotic and abiotic modifications. Indices of abundance, relative frequency of occurrence, longitudinal distribution, length frequency and weight were used to determine the homogenization process in Tyhume River. Abundance of two indigenous fish species continued to decline after the impoundment at Binfield Park Dam. The abundance of the two indigenous fish species *S. bainsii* and *B. trevelyani* were impacted by habitat degradation, in particular flow and changes in temperature profiles..

The relative frequency of translocated species composition now accounts for sixty one per cent and indigenous fish species account for twenty nine percent while alien (non - native) species make up four per cent. The homogenization process results in a few common species, *L. umbratus* and *T. sparrmanii*, which are translocated, were becoming more common. Usually this is accompanied by a resultant decline in rarer fish species, in this case the indigenous fish species *S. bainsii, B. trevelyani, M. capensis* and *A. mossambicus,* making them less common (Reid 2004; Scott 2006; UNEP 1997). Aliens (non - natives) tend to be cosmopolitans or generalists that out-compete indigenous fish species leading to the homogenization process (Reid 2004).

The homogenization process was also evident from the longitudinal distribution of fishes. Reduced longitudinal distribution of four indigenous fish species *S. bainsii, B. trevelyani, A. mossambicus* and *M. capensis* was recorded. Only one translocated *T. sparrmani*i recorded increased longitudinal distribution. This species is categorized as an invasive fish species under the South African Biodiversity Act (No. 10 of 2004). *S.*

bainsii was previously most common in Sandy foothill study sites 5 and 6 where Binfield Park Dam now stands, and where it co-occurred with *B. trevelyani*. Trend analysis, using historical data, revealed that the fish diversity in the Sandy foothill zone reduced to two species 1983/84 and one 1989/1990, while previously five species co-existed *B. trevelyani, S. bainsii, T. sparrmanii, O. mykiss* and *L. umbratus*, as indicated by the1972/1973 survey.

Only one alien (non- native) exotic fish species, *O. mykiss,* was recorded although a reduction in longitudinal distribution was observed. Its distribution previously ranged from escarpment down to Binfield Park Dam. Two populations of this species are believed to exist, one in Binfield Park Dam, introduced in 1988 by the Department of Zoology, Fort Hare University, and the other introduced in 1960 and 1970. None of the two other alien species *L. macrochirus* and *M salmoides* was sampled although they are believed to be present in Binfield Park Dam (Prof. D. O. Okeyo, personal communication).

S. bainsii, a cyprinid, has the widest distribution that ranged from study site 3 at 734 MASL down to study site 8 at 514 MASL. This is an indication of ecological elasticity. The distribution has, however, reduced as it was previously distributed up to the confluence. Its distribution at study site 8 below Alice urban area was sporadic due to low incidence of occurrence. *B. trevelyani* longitudinal distribution was recorded at study sites 3 and 4 above Binfield Park Dam and study site 6 below Binfield Park Dam. *B. trevelyani* low incidence of occurrence at study site 6 indicates a sporadic presence.

Anthropogenic effects were also reflected in reduced similarity against study sites clusters. Jaccard's index of similarity ranged from 0.11 to 0.91 and six clusters study sites recorded significant similarity against twenty seven study sites cluster. Seventy eight per cent of study site clusters were dissimilar. A Jaccard's index of 0.6 and above was considered biologically significant. These indices support increased homogenization theory as reflected by increased dissimilarity for *S. bainsii* in most zones. The Jaccard's index for *S. bainsii* ranged from ten to ninety per cent was lowest for study sites 3 and 8 (731 and 496 MASL). This species was previously distributed from source to confluence. *B. trevelyani* similarity index at study sites 3 and 4 (731 and

700 MASL were twenty one and fifty three per cent respectively The Jaccard's Index of similarity analysis revealed alien species *O. mykiss* index at study sites 3 and 4 (731 and 700 MASL) as only twenty six per cent. Anthropogenic effects of impoundment were further revealed from longitudinal reduction for *B. trevelyani* of nineteen per cent similarity with study sites 3 and 6 (731and 574 MASL) above and below Binfield Park Dam respectively. Study site 4, rocky foothill above the Binfield Park Dam and 6 is below the dam in the sandy foothill. *B. trevelyani* similarity suffered a fifty per cent decline from study sites 3 and 4 rocky foothill above Binfield Park Dam when compared with study sites 6 in the sandy foothill below the dam. *L. umbratus* a native translocated species recorded similarity In study sites 7 and 9 (528 and 392 MASL) where a Jaccard's Index of 0.91 and Jaccard's index of 0.6 7&10 and 8&9 all below Binfield Park Dam and Alice urban area Jaccard's index of 0.. In study sites 7 and 9 a significant Jaccard's Index of 0.6 was recorded for *T. sparrmanii*. No similarity indices were developed for three fish species; *A. mossambica, C. gariepinus* and *G. callidus,* as occurrence was recorded at a single study site and eleven study sites clusters had no similarity.

Seven fish assemblage clusters were evident, fish assemblage spatial longitudinal distribution and formation of distinct assemblages is normally reflective of habitat characteristics within the watershed. Temperature and elevation play a crucial role in determination of zoning patterns distinct assemblages. The most common zonation patterns are a reflection of cold water and warm water (Allan 1995; Quist et al (2004); Skelton 2001). The *S. bainsii, O. mykiss* and *B. trevelyani* cluster were found in high elevation stream segments in the escarpment area where the substrate is dominated by bedrock. *O. mykiss* and *B. trevelyani* distribution is restricted to high elevation areas with clean highly oxygenated waters and low temperature minimum 10^{o}C during winter and a maximum 26^{o}C in summer. Study site 6 at 573 MASL had the highest species diversity as four species were found to coexist at this range, as follows; *S. bainsii, B. trevelyani, T. sparrmanii* and *A. mossambica*. This observation supports the theory of fish species addition that occurs with declining elevation gradients longitudinally (Quist *et al*. 2004). From 525 MASL *L. umbratus* was sampled at study site 7 where it coexists with *T. sparrmanii*. At this study site, where elevation is 514 MASL, *L. umbratus* was found to coexist with *S. bainsii*. All species found below study site 8 and study site 9 at 393 MASL had external parasites or fungal infections. Study site 9 Njwaxa is greatly modified through installation of a weir 1.5 metres high and is below Alice Urban area; three species were found to co-exist in this area, namely *L. umbratus, Tilapia sparrmanii* and *C. gariepinus.* Areas degraded by anthropogenic modification of habitat tended to have reduced species assemblages when compared to earlier surveys. However, unlike the assertion that degraded areas were colonized by aliens, the two areas study sites 5 and 8 harboured *S. bainsii*. At study site 8 *S. bainsii* is sporadic and co-exists with *L. umbratus* a translocated species.

Three of the indigenous fish species are listed on the IUCN Red List 2006. *S. bainsii* is listed as 'Endangered'. The associated threats are introduced fish taxa, competition, pathogens, parasites and pollutants. A fish species is categorized as 'Endangered' when *in situ* populations face a high risk of extinction but are not critically endangered. *B. trevelyani* is listed as 'Critically Endangered' meaning *in situ* populations face an extremely high risk of extinction in the near future. Additional criteria for this category are a reduction in extent of occurrence to less than 500 square kilometres due to either severe habitat fragmentation, or occurrence at less than five localities (IUCN Red List 2006). *B. trevelyani* in this survey was recorded at three study sites, and at study site 6, its presence was sporadic. *M. capensis* is listed under 'List Concern' which means it has been assessed but does not fall under the categories of Critically Endangered, Endangered, Threatened or Near Threatened.

Trend analysis with historical data reveals reduced distribution of four species *Anguilla mossambicus, B. trevelyani, C. gariepinus* and *S. bainsii.* Two alien species previously recorded were not sampled these are; *M. salmoides* and *L. macrochirus*, this most probably due to not sampling the Binfield Park Dam. Two species longitudinal distribution has remained constant: *O. mykiss* and *L umbratus*. One species was sampled for the first time *G. callidus* while only one trans-located species (*T. sparrmanii*) increased longitudinal distribution (Table 4.3)

No clear patterns could be deduced from three fish species *C. gariepinus*, *A. mossambicus* and *O. mykiss*, due to low incidence of occurrence. *A. mossambicus* is an indigenous species of which only one was caught. *B. trevelyani* most frequent mode of 70-75 mm FL is close to that observed by Mayekisho (1994) of 69-79 mm FL. *G. callidus* was not recorded by Mayekisho (1994) hence comparative analysis could not be undertaken. The South African Institute of Aquatic Biodiversity (SAIAB) has a record of this species in the Keiskamma River (B. Rogers, personal communication). *L. umbratus* modal length frequency was 40-60mm. TL is half that reported by Mayekisho (1994) of 120-149 mm FL. This could be due to a large sample of juveniles encountered in the month of March. *S. bainsii* modal length frequency declined to 60-80 mm SL compared to 135-144 mm SL recorded by Mayekisho (1994). The maximum size in this survey was 195 mm SL.

C. gariepinus has drastically reduced, both in abundance and distribution, despite being a very hardy fish. It possesses an accessory air-breathing organ that equips it for adverse conditions. It was first introduced in 1985 and recorded in all study sites from Midland River down to the confluence. Its optimal range was the lowland zones where it was postulated it would out- compete *S. bainsii*. What was surprising then was its inability to extend beyond study site 10 in six years, as only two emaciated species were caught in study site 10 (Mayekisho 1994). It was believed then that there is chemical barrier posed by pollution from Alice town, University of Fort Hare, Lovedale Teachers College, Victoria Hospital, Ntselamanzi and Gqumashe townships (Mayekisho 1994). During this survey 2006/2007 the area between Gqumashe and Njwaxa not only had low species presence but recorded the highest number of native translocated fish species.

5.2: Economic Value of Ecosystem Services

Economic valuation of ecosystem services is a powerful tool that can aid sustainable management of global lotic systems (Adger and Luttrell 2000; Barbier *et al.* 1997; Bateman *et al*. 2011). One area that is gaining widespread use in economic valuation of ecosystem services is micro-economic analysis. Micro-economic analysis facilitates evaluation of the net benefits associated with marginal changes in ecosystem services (Holmes *et al.* 2004). This theory was applied to Tyhume River residents in Alice and Ntselamanzi why five ecosystems services in need of restoration were describe to elicit willing to pay bids. Residents per each household in Alice and Ntselamanzi, near Tyhume River, Eastern Cape, were willing to pay R32 in increased monthly water bills.

This translates to R384 annually. When applied to all households in Alice and Ntselamanzi a figure of R1 086 336 per annum is obtained. The ability to generalize on the entire community is limited due to the high level of low income votes.

The WTP bid frequency distribution had a high number of zero bids, a reflection of the high level of unemployment. This is to be expected in line with economic theory. However, the bid amount is well within the R30-R40 that communities were paying in rural areas for a 200 litre drum of water. It is further corroborated by the high percentage (seventy seven per cent) of residents WTP for establishment of Tyhume River Trust Fund.

Economic valuation of ecosystem services provided by Tyhume River has a role to play in management decision making. It can support decisions on tradeoffs among competing users. It facilitates translation of services provided by ecosystem, into a single accounting system with terms that are comparable to other users of economic value. Assigning value to ecosystem services is a prerequisite of “polluter pay principle” has it will facilitate determination of costs for restoration of degraded ecosystem services and payment of damages.

Priority environment programmes that would receive support include restoration of habitat for rare and endangered fish species, as well as other biodiversity. Erosion control, improved water quality from natural purification, dilution of waste water and recreation are the other measures that would be supported.

The high unemployment level and the resultant high number of people without income is a real threat to sustainability of the Tyhume River system. This was reflected in the high number of zero bids. Of equal concern is the consequence of disruption of the services provided to the livelihoods of rural communities. In part, this was reflected in the high level of support indicated for restoration of ecosystem services.

The main challenge for economic valuation arose from the need to create clarity to respondents on the link between ecosystem services and the things they value. This study delineated five ecosystem services in need of restoration. Restoring these services would improve the habitat and the status of threatened indigenous fish species. This benefit was also clearly linked to improvement of water quality for direct human needs of downstream users and agricultural activities.

5.2.1 Economic Efficiency

The improvement of storm water is allocated a budget of R1 043 934.50 and is projected for completion in June 2007 (IDP Nkonkobe 2007-2012). Cost/benefit analysis gives a net present value (NPV) = 1. In line with Kaldor Hicks' principle, this indicates the project would adhere to the economic efficiency criterion that gainers can compensate losers.

5.2.1.1 Concepts of Economic Value

The building of bridges towards more connectedness between ecology and economics is required. This will ultimately rest on creating a shared understanding of value, not just among ecologists and economists but through a wider multi-disciplinary approach. A wider disciplinary approach would also resonate well with current integrated approaches to resource governance.

5.3: The post Rio Institutional Measures

Post Rio measures of sustainable development community participation, ecosystem approach, polluter pays principal and precautionary approach have been internalized in the three South Africa statures that were assessed in this study namely**;** Constitution Act 108 of 1996 (South African Constitution 1996); the National Environmental Management Biodiversity Act No. 10 of 2004 (NEMBA 2004), the National Environmental Management Act (NEMA) No. 107 of 1998 (NEMA 1998), and the National Water Act No. 36 of 1998 (NWA 1998) as *de jure* measures. There is however a lag in implementation, especially for small rivers such as the Tyhume River. Hence despite existence of institutional mechanism which are aligned to international policy, the state of fish biodiversity is Tyhume River is threatened by anthropogenic activities

5.4 Applicability to Other Catchments

One of the hopes of this study was that lessons learned can be applied to other watersheds. Some of these lessons include the need to base micro economic valuation on a clearly defined policy baseline. In this study the policy baseline was provided by Post Rio Earth Summit measures instituted in national legislative measures as reflected in the NWA No. 36 of 1998; NEMA No. 107 of 1998; and the National Environmental Management Biodiversity Act (NEMBA) No. 10 of 2004. These policies are national in scope and linked to commitments that arose as part of the Post Rio Earth Summit international measures. They can therefore be applied to assessments of other lotic systems in the country, and at global levels. They therefore facilitate monitoring of these commitments for comparability at multiple levels. The study, however, concentrated on one watershed and it is not clear how the value of restoring this watershed may influence other watersheds. What is apparent is that, on a national scale, various ecosystems values may be categorized either as complements or substitutes. This may, however, not reflect the importance attached to the local level where it is likely to be demonstrated through the inter-linkage with livelihoods. The availability of opportunities for alternative livelihoods will have great influence on outcomes (Loomis *et al.* 2000). This clearly resonates well with the aspirations of sustainability use and the need to ensure equity in distribution of benefits at both intra and inter generation levels.

The costing for restoration of water quality through creation of an artificial wetland would be localized. The creation of a buffer zone, though, may require characterization. This is in order to map hotspots of anthropogenic activities arising from cattle grazing, agricultural and domestic use. While recreational value is accorded high priority in developed countries, studies show a lack of similar priority in less developed countries (Loomis *et al.* 2000; Birol *et al.* 2006). However, this preference was not clearly borne out in this study, due to the integrated nature of recreation and water quality functions accorded by creation of an artificial wetland, as well as restoration of a riparian buffer zone.

5.5: Impact of Post Rio Measures on Sustainability of Fish Assemblage in Tyhume River

The Post Rio Earth Summit (1992) paradigm shift in resource governance has catalyzed development of new national legislative measures. These include the National Environmental Management Act (NEMA), the National Environmental Management Biodiversity Act (NEMBA) and the National Water Act (NWA). They all have incorporated sustainability as the goal for management of lotic systems. The new institutional measures have redistributed water rights in line with the sustainability goal. The institutional arrangements are nested, in line with the Regime Theory, the Institutional Analysis and Development (IAD) framework for small scale common pool resources, and the recent scholarship on Multiple-Use Common Pool resource domains (Buck 1998).

The institutional framework is nested along the three levels of governance. These are: operational/implementation, collective/procedural and constitutional/substantive (Buck 1998; Carlsson and Berkes 2005). An additional requirement under the Multiple Use Common Pool Resource Domain Theory is the ability for the resource domain to support all the various users, for sustainability to be achieved (Buck 1998). It is at the operational/implementation level that attention is needed to strengthen monitoring and enforcement of appropriate measures.

The complexities envisaged with the creation of rights for nature have been internalized by the NWA, which has established a reserve as the only right to water. The reserve includes water for basic human needs and rights for maintenance of stream flows to protect ecological processes and biota. All existing users are required to register their user if it does not fall under Schedule 1. Users listed under Schedule 1 are not required to lodge an application, while new users will have to make an application. Some uses, such as cattle grazing, may have a large cumulative effect that needs management measures. Already overgrazing within the riparian area is a problem for in-stream habitat integrity in some areas.

Some additional new legislative measures, dealing with invasive species and protection of endangered fish species, have been enacted. All the new statutes provide for remediation measures based on the principle of “polluter pays”. NEMBA accords protection to biodiversity and to individual species. They all promote community participation and cooperative governance of natural resources.

Yet, despite these measures, sustainable resource utilization of the Tyhume River system is threatened by discrepancy between *de jure* and *de facto* rights. The main problem is not lack of *de jure* measures to ensure sustainability, but is the lag in implementation of institutional reorganization for an integrated approach. The type of institutional reorganization required in line with sustainability poses a challenge. It creates complexities arising from an ecosystem approach and the need for community participation.

The establishment of the reserve as the only right has jointed current human user rights with those of future generations and rights for nature. This makes community participation crucial to sustainability, in line with the theory of multiple use common pool resources. The fact that the rights for humans and non-humans are jointed means that whenever humans seek remediation they will be speaking for non-humans to some degree. Lotic systems are unique in that there are issues of equity in the distribution of resource benefits among downstream users and upstream users. In a way this provides an avenue for protection of stream flows in order to ensure adequate quantity and quality for all users. Protection of rights for non-humans and equity ensures that rights for future generations are also protected. Community participation is therefore crucial for the attainment of sustainability, for it is only through community participation that all these rights can be protected. This makes community participation an integral part of protection of this right. It is also an avenue for maintaining the issue as a relevant policy agenda. Participation will promote self-reliance, which is integral to the development process and poverty eradication (Bailey and Jentoft 1990). Long term education and awareness creation will facilitate information-sharing and strengthening of decision- making capacity at grass-roots level. A prerequisite for public participation is community organization and division of responsibility between state actors and community groups or conservation groups. This study revealed that the majority of respondents depend on Tyhume River for livelihoods, such as livestock grazing and small scale agriculture.

Establishment of community participation structures will require capacity building at all levels in order to ensure a shared understanding at the operation choice level. Some measures, such as rights for non-humans and for future generations, are in disparity with local and cultural perspectives. Although this disparity is overcome at the reserve, where current/future generations and ecosystem rights coincide, there is a need for capacity building for a shared understanding.

Economic growth for the area hinges on rehabilitation of large scale citrus irrigation. Issues of equity in the distribution of resources will require special consideration of organization, and control of who benefits, because rights for non-humans and future generations will constrain development options for all individuals. Hopefully, many of these issues will be addressed when integrated resource management, as envisaged in the Catchment Management Agencies, is operational.

Chapter 6: Conclusion and recommendations

6.1: Sustaining Tyhume River Fish Biodiversity

The concept of sustainable use of natural resources captures human desire to rationally use natural resources in order to bequeath similar benefits to future generations. The sustainability concept was first coined by the Brundtland Commission (1997) and adopted at the Rio Earth Summit (1992). It was further elaborated at the 2002 World Summit on Sustainable Development (WSSD) to include ecological, economic and social aspects of resource use. It is best actualized through an ecosystem approach in order to balance human users against maintenance of ecological functionality. An ecosystem approach would constrain human use of resources within boundaries of natural resilience. It creates complexities viewed against rising human population and the resultant increasing demands. The greatest challenges arise from the radical reforms in epistemologies and management systems that it necessitates. These complexities were apparent during this study, and are summarized in (Figure 6.1).

The Post Rio Earth Summit (1992) paradigm shift in resource governance has catalyzed development of new national legislative measures. These include National Environmental Management Act (NEMA), the National Environmental Management Biodiversity Act (NEMBA) and the National Water Act (NWA). In these statutes, sustainability as a goal for management is incorporated. These new institutional measures have redistributed water rights in line with the sustainability goal.

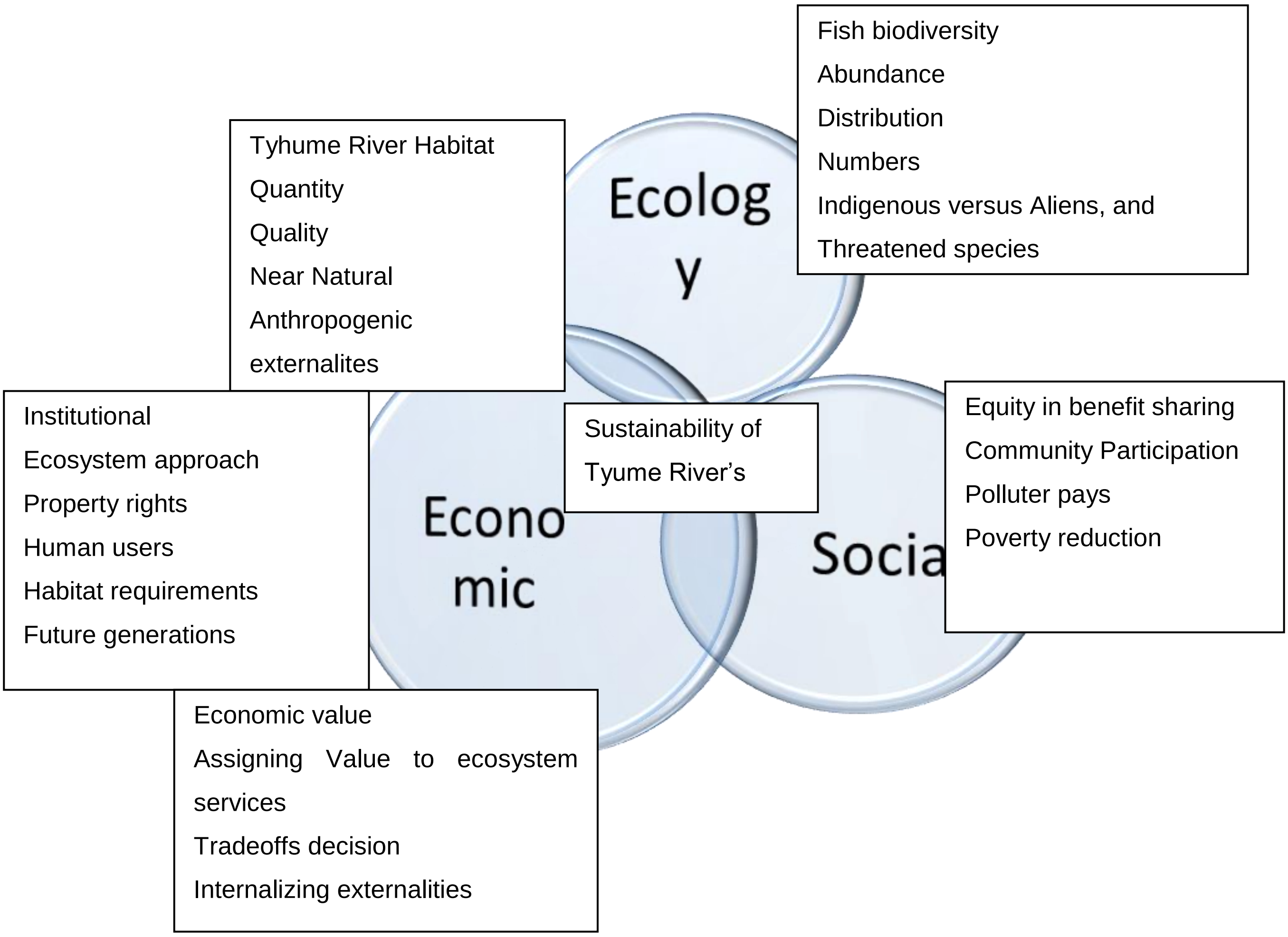

Figure 6.1: Tyhume River Ecological-Economic Sustainability Framework

The ecology of the Tyhume River, as assessed, using fish assemblage, is experiencing the homogenization process. This process results in a few common fish species becoming more common, while a rarer species become less common. The drivers are anthropogenic activities of habitat modification and introduced alien fish species. The underlying causes of these anthropogenic modifications are economic and institutional in nature.

6.2: Economic Activities

The economic activities include the creation of impoundments for domestic water supply and for agricultural activities. Other activities include externalities from urban and rural developments where an increase in impervious surface generates storm-water runoffs. Apart from storm-water, mainly from urban developments, there are direct demands of cattle watering in rural areas and the use of rivers for domestic activities. The use of water for domestic activities, such as washing clothes, is a reflection of inequities in access to piped water, between urbanites and rural dwellers. However, even within an urban setting there were disparities in access between residents of Ntselemanzi and Alice town more affluent neighbourhoods.

Disparities were also reflected in the Willingness-To-Pay (WTP) bid frequency distribution which had a high number of zero bids - a reflection of the high level of unemployment. This is to be expected in line with economic theory. A high unemployment level and the resultant high number of people without income is a real threat to sustainability of the Tyhume River system. Of equal concern is the consequence of disruption of the services provided in the livelihoods of rural communities. In part, this was reflected in the high level of support indicated for restoration of ecosystem services.

The main challenge for economic valuation arose from the need to create clarity for respondents, on links between ecosystem services and the things they value. This study delineated five ecosystem services in need of restoration. Priority environment programmes that would receive support, included restoration of habitat for rare and endangered fish species as well as other biota, erosion control, improved water quality from natural purification, dilution of waste water, and recreation. Restoring these services would improve the habitat and the status of threatened indigenous fish species. This benefit was also clearly linked to improvement of the water quantity for direct human needs of downstream users and agricultural activities. Restoration of these ecosystem services also passed the economic efficiency test; the gainers would theoretically be able to compensate losses in line with the Kaldor Hicks principle.

Building the bridges towards more connectedness between ecology and economics is required. This will ultimately rest on creating a shared understanding of value, not just among ecologists and economists, but through adopting a wider multi- disciplinary approach. A wider disciplinary approach would also resonate well with current integrated approaches to resource governance.

One of the hopes of this study was that lessons learned could be applied to other watersheds. It is not clear, however, how restoring this watershed is likely to influence other watersheds. On a national scale, various ecosystems are likely to be valued either as complements or substitutes. In the five ecosystem services, where economic value was determined, costing for restoration of water quality through creation of an artificial wetland would be largely localized. The creation of a buffer zone, though, may require characterization in order to map out hotspots. The hotspots would be areas of intensive anthropogenic activities arising from cattle grazing, agricultural activities and rural and urban settlements. While recreational value is accorded high priority in developed countries, studies show a lack of similar priority in less developed countries. This preference was, however, not clearly borne out in this study, due to the integrated nature of recreation and water quality functions brought about by the creation of an artificial wetland, as well as the restoration of a riparian buffer zone.

At the local level, value is likely to be linked to importance attached by local communities. It will be demonstrated though inter-linkage with livelihoods, and opportunities for alternative livelihoods that are available. This clearly links with the aspirations of sustainability and the need for equity in the distribution of benefits.

Institutional reforms have overcome complexities envisaged with creation of rights for nature. The National Water Act (NWA) has established a reserve as the only right to water. The reserve includes water for basic human needs and rights for maintenance of stream flows to protect ecological processes and biota. All existing users are required to register their uses that are not listed under Schedule 1. Users listed under Schedule 1 are not required to lodge an application, while new users will have to make application. Some uses such as cattle grazing may have a large cumulative effect that needs management measures. Already overgrazing within the riparian area is a problem for in-stream integrity.

Some additional new legislative measures, dealing with invasive species and protection of endangered fish species, have been enacted. All the new statutes provide for remediation measures based on the principle of “polluter pays”. NEMBA accords protection to biodiversity and to individual species. They all recognize community participation.

Yet, despite these measures, sustainable resource utilization of the Tyhume River system is threatened by discrepancies between *de jure* and *de facto* rights. The main problem is not lack of *de jure* measures to ensure sustainability, but the lag in implementation of institutional re-organization for an integrated approach. The type of institutional reorganization required in line with sustainability, poses a challenge. It creates complexities arising from an ecosystem approach and the need for community participation.

The NWA establishment of the reserve as the only right has created joint current human user rights with those of future generations and rights for nature. However, this may require awareness creation among communities in order to create a shared vision. Strengthening mechanism for community participation is crucial to sustainability, in line with the theory of multiple use common pool resources. Equity in distribution of resource benefits will also protect the rights of downstream users and maintenance of stream flows. Protection of rights for non-humans and equity ensures that rights for future generations are also protected. Wide community participation, that includes users, conservation groups and local community groups, is therefore crucial to attainment of sustainability, for it is only through community participation that all these rights can be protected.

This makes community participation an integral part of protection of this right; it also creates an avenue for maintaining the issue as a relevant policy agenda. Community participation will promote self-reliance which is integral to the development process and poverty eradication (Bailey and Jentoft 1990). Long term education and awareness creation will facilitate information sharing and strengthening of decision - making capacity at grass-roots level. A prerequisite for public participation is community organization and division of responsibility between state actors and communities groups or conservation groups. The study revealed that the majority of respondents depend on Tyhume River for livelihoods such as; livestock grazing and small scale agriculture.

Establishment of community participation structures will require capacity building at all levels in order to ensure a shared understanding at the operation choice level. Some measures, such as rights for non-humans and for future generations could be in disparity with local and cultural perspectives. Although this disparity is overcome at the reserve where current/ future generations and ecosystem rights coincide, there is a need for capacity building for a shared understanding.

Improving economic growth is important for sustainability, as it creates employment opportunities and alternative livelihoods. Economic growth in this area hinges on rehabilitation of large scale citrus irrigation. Expansion of agriculture is among the areas likely to be constrained by requirements of maintenance of stream flows to protect rights for nature. Ensuring rights for future generations and current generations hinges on equity in distribution benefits for current generations. Hopefully, many of these issues will be addressed when integrated resource management, as envisaged in the Catchment Management Agencies, are operational.

Successful sustainable resource governance rests on how well scientific knowledge is translated into public policy Rohlf (1991). Ultimately, the effectiveness of the entire process lies in the sustainability of ecological systems and the human subsystem. This is in order to maintain benefits in perpetuity, in line with sustainability. For the Tyhume River fish assemblage this is not the case, as two indigenous fishes are imperiled from the effects of habitat and introduced alien species. The Tyhume River system is reflective of issues that plague lotic systems globally, due to the connectedness of the services they provide with human basic needs. The results of this study provide lessons that can guide the integration of ecology and economics in order to achieve sustainability. The NWA accords the highest priority to protection of the reserve, which includes basic water for human needs and a reserve for maintenance of biological processes in perpetuity. These results are therefore likely to have applications in other lotic systems in South Africa, as well as in other parts of the globe because the issues are similar.

The integrative science of sustainability rests ultimately on our ability to translate theoretical solutions into policy, and into practice. To date, having recognized sustainability as a goal, a prime question has been how to develop real and effective indicators of sustainability. Economic development and environmental protection are still perceived to be intrinsically competing agenda. Development connotes economic growth, while considerations of ecological factors translate to constraints on growth. How the two can be resolved for sustainability to be attained against a background of increasing population, is best described as "*the political art of scientifically informed comprise*" (Keysar and Steinemann 2002).

While there is little doubt that integrative approaches are needed to support sustainability, the transition that integrates this into rigorous and useful research programmes remains problematic. Local solutions' greatest utility lies in their ability to help break this policy freeze in global sustainability solutions (Keysar and Steinemann 2002). The Tyhume River is representative of many watersheds in the Eastern Cape Province, and South Africa in general, as well as other watersheds in Africa. The results hence provide information on sustainability of ecological and economic subsystems that can be used to guide conservation activities.

These findings support the hypothesis that the state of a river is inversely correlated to proximity to human settlement. All human settlements along the Tyhume River are within 5 kilometres (Figure 2.10). Study Sites below Binfield Park Dam impoundment and Alice urban area recorded a high degree of anthropogenic habitat, while within rural settlements the major effects were riparian area overgrazing.

From the findings of this study it is recommended that physical chemical measures used in monitoring systems be augmented with biological criteria, in line with measures in place (RHP 2004& 2006 NAEBP 2006;Palmer et al. 2004). Although significant variations of flow, pH and conductivities where observed, neither were beyond the standards set for fish. Incorporating a biological criterion in water resources monitoring systems seems appropriate to safeguard biological integrity.

As much as possible, indices that quantify the extent of anthropogenic habitat should be used. These indices create a picture that speaks to a wide audience of stakeholders. This is useful, as it creates a link with economic assessment methodology. It also has scope for policy relevance and for comparability at local, national, regional and international level.

6.3: Recommendations

- More awareness and mainstreaming of sustainable use framework in integrative research work of lotic systems ;
- Community participation was found to be rudimentary at grassroots level and more needs to be done to build the requisite structures as well as create awareness;
- “Polluter pay” principle is one of the post Rio concepts that emerged and to actualize this principle, assigning value to ecosystem services is necessary in determination of costs of restoration projects;
- The proximity of University of Fort Hare to Tyhume River places it in a unique position to work with government departments and local governments in sustainability studies on Tyhume River ecosystem including studies on community capacity building; and,
- Poverty level and high dependence of natural resource are issues that require more research as well as interventions.

6.4: Limitations of the Study

- Limited data collected for ecology part of this study;
- Comparability with historical data is limited because of differences in sampling methods and differences in catchability of gears used;
- Differences in gear catchability were not computed, although it is acknowledged they exist;
- Applicability of study findings to other catchment cannot be guaranteed in light of micro economic characteristics unique to every town; and,
- The methodology applied in assigning economic value could be improved through use of focus groups discussions.

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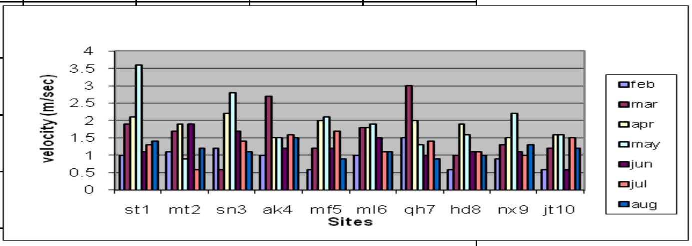
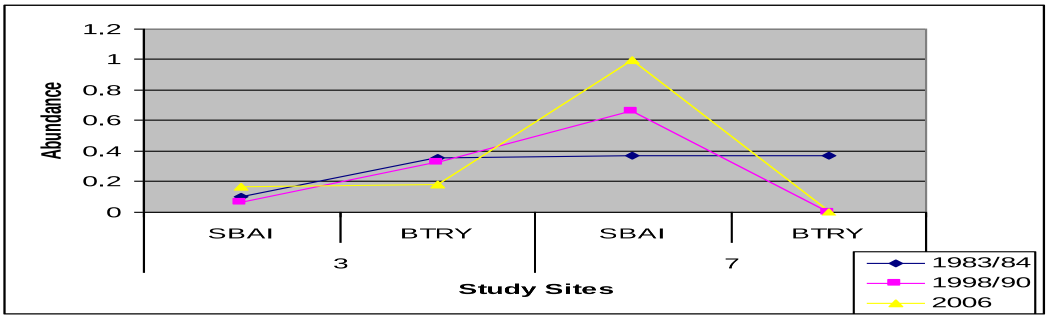
Appendix I: Data Geomorphology Habitat Quantity Characteristics

Tyhume River Current Velocity								
Month	1	s2	3	st4	st5	st6	7	8
Feb	1	1.1	1.2	1	0.6	1	1.5	0.6
Mar	1.9	1.7	0.6	2.7	1.2	1.8	3	1
Apr	2.1	1.9	2.2	1.5	2	1.8	2	1.9
May	3.6	0.9	2.8	1.5	2.1	1.9	1.3	1.6
Jun	1.1	1.9	1.7	1.2	1.2	1.5	1	1.1
Jul	1.3	0.6	1.4	1.6	1.7	1.1	1.4	1.1
Aug	1.4	1.2	1.1	1.5	0.9	1.1	0.9	1



Site	Species	Abundance		
		1983/84	1998/90	2006
3	SBAI	0.1	0.066	0.17
	BTRY	0.36	0.33	0.18
7	SBAI	0.37	0.66	1
	BTRY	0.37	0	0



Abundance
1.2
1
0.8
0.6
0.4
0.2
0
SBAI
BTRY
SBAI
BTRY
3
7
Study Sites
1983/84
1998/90
2006

Appendix II: Data on Fish Assemblage

Species	No
SBAI	40
OMYK	14
BTRY	30
AMOS	1
LUMB	85
TSPA	65
CGAR	1
GGIU	14
Total	250

	indigenous to
BTRY	Keiskamma
AMOS	diadromous
OMYK	Alien

Categories	No.
Indigenous	70
Diadromous	1
Peripheral	14
Translocated	151
Alien	9
Total	245

Appendix III: Map Request Letter

Department of Zoology,
University of Fort Hare,
Private Bag X1314,
Alice 5700

6th August, 2007

Municipal Manager,
Nkonkobe Municipality
Fort Beaufort, 5720

Dear Sirs,

Re: Research on Sustainability of Tyhume Fish Biodiversity and Community Livelihoods.

Ms. Jane Njeri Kinya is a doctorate student here at Fort Hare University undertaking a research on Tyhume River as outlined above.

The Sustainability Goal links ecology to economic and institutional responses as well as rights of future generations to enjoy similar ecological benefits as the current generation.

The first part of this research which involved the ecology was completed last year. The second part of the study which looks into the economics as well as institutional response measures is currently under way.

The purpose of writing to you is to elicit your support for the second part of the study. This entails an institutional survey questionnaire where your institution is relevant. It also entails a household survey questionnaire for residents of Alice suburbs between Ntselamanzi and Alice urban area for which you need to be aware.

The findings will be shared with all institutions involved.

We look forward to your support and cooperation in this undertaking.

Yours Sincerely,

Prof. DO Okeyo
Coordinator Aquaculture, Aquatic and Marine Sciences

Appendix IV: Letter of Authority from Department: Rural Development & Land Reform

rural development
& land reform

Department:
Rural Development & Land Reform
REPUBLIC OF SOUTH AFRICA

Chief Directorate: National Geo-spatial Information
Private Bag X 10, Mowbray, 7705; Tel: 021-6584300; Fax: 021-6891351;
Van der Sterr Building, Rhodes Avenue, Mowbray, 7705 Lat 33 57 03 S Long 18 28 06 E

Ref:PRM3

University of Fort Hare
Aquatic & Marine Sciences
Private Bag X1314
Alice
5700

9 October 2009

Attention: Prof Daniel O Okeyo

PERMISSION TO USE MAPS: 3226DB SEYMOUR AND 3226DD ALICE

Dear Prof Okeyo

Thank you for your request for copyright permission on behalf of Ms. Jane Njeri Kinya a doctorate student at the University of Fort Hare. Copyright permission to use maps

3226DB and 3226DD form the Chief Directorate: National Geo-spatial Information (CD: NGI) has been approved.

The maps are to be used to outline the study sites along Tyume River.

Permission is given subject to the following conditions:

1: CD: NGI must be acknowledged as the source of the data.
2: State copyright remains.
3: Data may not be supplied to a third party without permission from the CD: NGI.

Kind regards

S Kirschner
For/CHIEF DIRECTOR: NATIONAL GEO-SPATIAL INFORMATION

Appendix V: Questionnaire: Economic Valuation of Tyume River Ecosystem Services

Enumerators will explain to randomly selected respondents who they are, who they represent, what they want to do, why and how the information will be used. Need to provide respondents with a guarantee of their anonymity.

Section A: background information

Questionnaire No.	Date	Time	Area

Section B: Respondent's details and Social Economic Status

Gender	Age	Highest education level
Income	No of dependents	

1: Do you have access to running water**?**

Yes--------------------------------No-------------------------

If yes, who is your water service provider--?

If no, from where do you get your water--?

2: Are you billed **weekly**, **monthly or annually**-------------------------------------?

3: How much do you pay for water on average--------------------------------------?

4: Do you experience any water shortages?

Yes ------------------No----------------------

If yes, how do you get water during those times---------------------------------?

5: What is the source of this water?

Yes-------------------------------No----------------------------------

If yes, which River--------------or Dam---------------------

6: Is this the River that is closest to you home?

Yes--------No----------

If no, what is the name of the River------------------------?

7: Do you boil or treat your water before use?

If yes, why----------------------------------?

8: Do you use this river for any activity?

Yes-----------No-----------------

If yes, which activities------------------------?

If no, what is your reason -------------------------?

11: Do you use the River for watering animals?

Yes-------------No-----------

If yes, No. cows ------No. goats--------------No. Sheep---------other--------------

12: Do you use River water for irrigation?

Yes---------No-----------------

If yes, Agriculture------------------Size of agricultural parcel-----------------Type of crop------------- water quantity used----------------------------

Valuation of Tyume River Ecosystem Services

The Tyume River provides a number of non-use services which require to be maintained in order for the current generation to continue enjoying these services whilst preserving them for future generations. The ecology study undertaken in the first part of this study using fish as an indicator of sustainability reviewed the following;

- The Trans-located and Alien fish constitute 68%
- Catch per unit effort was lowest in the sites near Gquamashe, Ntselamanzi , Alice and Honeydale
- 60% of fish caught in Njwaxa had external parasites
- High algae blooms were found at Honeydale, which is just below Alice Town
- Storm water runoff from Alice town is directed to the River
- Overgrazing, watering animals in the river, and agricultural runoff were a problem

Two scenarios are presented below, one is the current situation and the other is improved situation. In order to implement the improved scenario, your support is needed for **Establishment of a Tyume River Restoration Trust Fund**. Your support is required in the form of monetary contribution where the mode of payment is through increased water bill. You are therefore kindly requested to indicate how much you would be willing to contribute to this fund after considering the two scenarios. The first scenario depicts the current situation of the Tyume River Ecosystem and the second scenario depicts an improvement of ecosystem services.

Scenarios 1: No management (Business as Usual BAU)

Consequences (1)

- biodiversity deteriorates to a low level
- increased algal blooms and poor water quality
- education & research potential declines
- Locals would become unemployed. Loss of agriculture and livestock watering

Scenario 2 Improved Ecosystem Services

1) To create a wetland for storm water management within Alice Town and a recreational park.
2) To establish a 20 meter riparian buffer zone
3) To manage the Tyume river as shown under scenario II.

The benefits from this are;

1) Improved water quality
2) Development of recreational facilities which can be a source of revenue
3) Conservation of four fish species indigenous to the Tyume River Ecosystem
4) Sustenance of the scientific value of the Tyume River Ecosystem
5) To uphold the cultural value to the communities
6) Sustain employment opportunities

All citizens living in Gquamshe, Ntesalamanzi, Gqumashe and Alice are requested to kindly indicate from how

much they would be willing to pay as a contribution to restoration of the outlined ecosystem services?

Are you willing to pay a contribution for establishment of a Tyume River Ecosystem Restoration Fund?

Yes---------

No------------

If yes, please circle one amount from the following bid amounts in Rands (**1, 2, 3, 5, 8, 10, 12, 15, 18 20, 25, 30, 35, 40, 45, 50**) or indicate other R**----------------------------?**

If no, answer the follow up questions

True Zero Value

1. I do not care about Tyume River
2. I cannot afford to contribute to the fund

Protests responses

1) The government is responsible for management
2) I do not believe funds will be used well appropriately.

4: Are you a member of a conservation or environmental organization

Yes ----------------No--------------------

If no, would you be willing to join a conservation organization---------------

Appendix VI: Economic Data

Income	Bid	Income	Age	ln Income	ln age	ln bid	lnWatebill	Wate bill	source of water
13000	0	13000	37	9.47	3.61	0	5.01	150	Tyume
0	0	0	32	0.00	3.47	0	0	0	Tyhume
4000	0	4000	80	8.29	4.38	0	0	0	Binfield
6000	0	6000	53	8.70	3.97	0	5.30	200	Tyhume
0	0	0	41	0.00	3.71	0	0	0	Tyhume
3000	0	3000	54	8.01	3.99	0	0	0	Tyhume
200	0	200	36	5.30	3.58	0	0	0	Tyhume
200	0	200	34	5.30	3.53	0	0	0	Tyhume
800	0	800	60	6.68	4.09	0	0	0	Tyhume
0	0	0	37	0.00	3.61	0	0	0	Binfield
0	0	0	32	0.00	3.47	0	0	0	Binfield
0	0	0	35	0.00	3.56	0	0	0	Tyhume
0	0	0	29	0.00	3.37	0	0	0	Tyhume
0	0	0	48	0.00	3.87	0			Tyhume
6000	0	6000	35	8.70	3.56	0	0	0	Tyhume
6000	0	6000	74	8.70	4.30	0	3.00	20	Binfield
0	0	0	39	0.00	3.66	0	0	0	Binfield
0	0	2.905031	32	2.90	3.47	0	0	0	Binfield
200	0	200	39	5.30	3.66	0	0	0	Binfield
0	0	0	52	0.00	3.95	0	0	0	Binfield
800	0	800	67	6.68	4.20	0	0	0	Binfield
0	0	0	43	0.00	3.76	0	0	0	Binfield
8000	0	8000	66	8.99	4.19	0	0	0	Tyhume
200	0	200	48	5.30	3.87	0	6.80	900	Binfield
800	0	800	68	6.68	4.22	0	0	0	Binfield
200	0	200	36	5.30	3.58	0	0	0	Binfield
800	0	800	61	6.68	4.11	0	0	0	Tyhume
800	0	800	63	6.68	4.14	0	0	0	Tyhume
3000	0	3000	55	8.01	4.01	0	0	0	Tyhume

200	0	200	36	5.30	3.58	0	0	0	Tyhume
800	0	800	67	6.68	4.20	0	0	0	Tyhume
800	0	800	61	6.68	4.11	0	0	0	Tyhume
8000	0	8000	46	8.99	3.83	0	0	0	Binfield
40000	0	40000	60	10.60	4.09	0	5.70	300	Binfield
200	0	200	35	5.30	3.56	0	6.31	550	Tyhume
200	0	200	49	5.30	3.89	0	0	0	Tyhume
200	0	200	42	5.30	3.74	0	0	0	Binfield
2000	0	2000	32	7.60	3.47	0	0	0	Tyhume
3000	0	3000	41	8.01	3.71	0	0	0	Tyhume
200	0	200	27	5.30	3.30	0	0	0	Tyhume
200	0	200	39	5.30	3.66	0	0	0	Tyhume
3000	10	3000	52	8.01	3.95	2.30	0	0	Binfield
200	0	200	28	5.30	3.33	1.67	0	0	Tyhume
0	0	0	43	0.00	3.76	0	0	0	Tyhume
0	0	0	67	0.00	4.20	0	0	0	Tyhume
0	0	0	36	0.00	3.58	0	0	0	Tyhume
0	0	0	29	0.00	3.37	0	4.61	100	Tyhume
0	0	0	33	0.00	3.50	0	0	0	Tyhume
15000	50	15000	63	9.62	4.14	3.91	0	0	Tyhume
6000	15	6000	43	8.70	3.76	2.71	5.16	175	Binfield
4000	40	4000	49	8.29	3.89	3.69	5.01	150	Binfield
6000	15	6000	43	8.70	3.76	2.71	5.01	150	Binfield
5500	10	5500	70	8.61	4.25	2.30	4.32	75	Tyhume
6000	30	6000	59	8.70	4.08	3.40	5.30	200	Binfield
6000	45	6000	63	8.70	4.14	3.81	5.01	150	Binfield
2000	2	2000	40	7.60	3.69	0.69	5.01	150	Binfield
17000	100	17000	29	9.74	3.37	4.61	3.91	50	Binfield
4000	25	4000	39	8.29	3.66	3.22	5.30	200	Binfield
0	5	0	29	0.00	3.37	1.61	5.52	250	not known
2500	15	2500	35	7.82	3.56	2.71	4.32	75	Binfield
7000	35	7000	53	8.85	3.97	3.56	3.91	50	Binfield

12000	50	12000	43	9.39	3.76	3.91	5.52	250	Binfield
5000	50	5000	49	8.52	3.89	3.91	5.01	150	Tyhume
8000	100	8000	35	8.99	3.56	4.61	5.01	150	Tyhume
2500	5	2500	43	7.82	3.76	1.61	5.52	250	Tyhume
8000	15	8000	56	8.99	4.03	2.71	4.61	100	Binfield
13000	75	13000	39	9.47	3.66	4.32	5.16	175	Binfield
3000	2	3000	43	8.01	3.76	0.69	5.52	250	Binfield
2500	5	2500	46	7.82	3.83	1.61	4.32	75	Binfield
5000	10	5000	70	8.52	4.25	2.30	4.61	100	Tyhume
15000	25	15000	59	9.62	4.08	3.22	5.01	150	Tyhume
5000	35	5000	29	8.52	3.37	3.56	5.52	250	Binfield
9000	30	9000	39	9.10	3.66	3.40	5.16	175	Binfield
11000	30	11000	70	9.31	4.25	3.40	4.61	100	Binfield
5500	10	5500	29	8.61	3.37	2.30	5.01	150	Binfield
12000	100	12000	49	9.39	3.89	4.61	5.01	150	Tyhume
4000	15	4000	42	8.29	3.74	2.71	5.52	250	Tyhume
3500	45	3500	26	8.16	3.26	3.81	5.01	150	Binfield
13000	75	13000	41	9.47	3.71	4.32	5.01	150	Binfield
2000	2	2000	39	7.60	3.66	0.69	5.01	150	Tyhume
6000	50	6000	49	8.70	3.89	3.91	3.91	50	Tyhume
4900	22.5	4900	39	8.50	3.66	3.11	5.01	150	Tyhume
1500	5	1500	33	7.31	3.50	1.61	5.01	150	Tyhume
4000	10	4000	43	8.29	3.76	2.30	3.91	50	Tyhume
11000	100	11000	39	9.31	3.66	4.61	3.91	50	Binfield
7000	10	7000	67	8.85	4.20	2.30	5.52	250	Binfield
2500	1	2500	31	7.82	3.43	0.00	5.01	150	Tyhume
2000	10	2000	36	7.60	3.58	2.30	4.61	100	Tyhume
2500	10	2500	85	7.82	4.44	2.30	0	0	Tyhume
800	20	800	67	6.68	4.20	3.00	0	0	Dam
3000	5	3000	38	8.01	3.64	1.61	0	0	Binfield
800	5	800	63	6.68	4.14	1.61	0	0	Tyhume
200	5	200	29	5.30	3.37	1.61	0	0	Binfield

3000	10	3000	40	8.01	3.69	2.30	0	0	Tyhume
4000	10	4000	37	8.29	3.61	2.30	0	0	Binfield
800	5	800	85	6.68	4.44	1.61	0	0	Binfield
5000	10	5000	29	8.52	3.37	2.30	0	0	Binfield
3000	10	3000	33	8.01	3.50	2.30	0	0	Not known
1500	20	1500	43	7.31	3.76	3.00	0	0	Binfield
4000	10	4000	40	8.29	3.69	2.30	0	0	Binfield
200	10	200	29	5.30	3.37	2.30	0	0	Binfield
3000	2.5	3000	40	8.01	3.69	0.92	0	0	Tyhume
6000	50	6000	25	8.70	3.22	3.91	5.30	200	Tyhume
18000	125	18000	56	9.80	4.03	4.83	5.01	150	Tyhume
6000	20	6000	29	8.70	3.37	3.00	5.52	250	Tyhume
1500	0.5	1500	.	7.31		-0.69	4.32	75	Tyhume
8000	42.5	8000	63	8.99	4.14	3.75	0.00	0	Tyhume
4000	30	4000	42	8.29	3.74	3.40	5.52	250	Binfield
3000	8	3000	46	8.01	3.83	2.08	5.70	300	Binfield
800	50	800	64	6.68	4.16	3.91	5.30	200	Tyhume
7000	15	7000	32	8.85	3.47	2.71	5.30	200	Tyhume
3500	10	3500	29	8.16	3.37	2.30	0	0	Tyhume
200	0	200	52	5.30	3.95		0	0	Binfield
200	10	200	41	5.30	3.71	2.30	0	0	Binfield
800	5	800	68	6.68	4.22	1.61	0	0	Binfield
1500	10	1500	34	7.31	3.53	2.30	0	0	Tyhume
200	15	200	46	5.30	3.83	2.71	0	0	Tyhume
3000	5	3000	37	8.01	3.61	1.61	0	0	Binfield
14000	30	14000	39	9.55	3.66	3.40	0	0	Tyhume
14000	20	14000	45	9.55	3.81	3.00	0	0	Tyhume
10000	25	10000	36	9.21	3.58	3.22	5.30	200	Tyhume
9000	10	9000	42	9.10	3.74	2.30	5.30	200	Tyhume
200	12.5	200	39	5.30	3.66	2.53	0	NA	Tyhume
7000	5	7000	50	8.85	3.91	1.61	0	no rent	Tyhume
10000	105	10000	63	9.21	4.14	4.65	0	NA	Not known

4000	10	4000	38	8.29	3.64	2.30	5.01	150	Tyhume
17000	25	17000	55	9.74	4.01	3.22	0	0	Tyhume
13000	17.5	13000	53	9.47	3.97	2.86	3.91	50	Tyhume
6000	5	6000	25	8.70	3.22	1.61	5.16	175	Tyhume
.	40	.	.			3.69	5.86	350	Tyhume
200	5	200	34	5.30	3.53	1.61	5.35	210	Tyhume
200	5	200	29	5.30	3.37	1.61	0	0	Tyhume
2500	10	2500	33	7.82	3.50	2.30	0	0	Tyhume
3000	20	3000	37	8.01	3.61	3.00	0	0	Tyhume
800	5	800	79	6.68	4.37	1.61	0	0	Tyhume
6000	10	6000	29	8.70	3.37	2.30	0	0	Tyhume
5000	30	5000	35	8.52	3.56	3.40	0	0	Tyhume
3500	10	3500	59	8.16	4.08	2.30	5.01	150	Tyhume
5000	50	5000	57	8.52	4.04	3.91	4.32	75	Tyhume
4000	15	4000	43	8.29	3.76	2.71	5.30	200	Tyhume
7000	50	7000	39	8.85	3.66	3.91	5.01	150	Tyhume
8000	50	8000	48	8.99	3.87	3.91	5.42	225	Tyhume
0	5	0	29	0.00	3.37	1.61	5.30	200	Tyhume
7000	2	7000	70	8.85	4.25	0.69	0	0	Tyhume
800	5	800	68	6.68	4.22	1.61	3.00	20	Tyhume
9000	10	9000	80	9.10	4.38	2.30	0	0	Tyhume
0	40	0	26	0.00	3.26	3.69	5.52	250	Tyhume
5000	20	5000	43	8.52	3.76	3.00	4.61	100	Tyhume
4000	50	4000	25	8.29	3.22	3.91	0	NA	Tyhume
800	5	800	67	6.68	4.20	1.61	0	0	Tyhume
1000	5	1000	52	6.91	3.95	1.61	0	0	Tyhume
5000	15	5000	28	8.52	3.33	2.71	0	0	Tyhume
9000	5	9000	73	9.10	4.29	1.61	5.11	165	Tyhume
6000	15	6000	38	8.70	3.64	2.71	3.00	20	Tyhume
0	5	0	27	0.00	3.30	1.61	0	0	Tyhume
200	3	200	35	5.30	3.56	1.10	0	0	Tyhume
11000	20	11000	39	9.31	3.66	3.00	0	0	Tyhume

6000	5	6000	22	8.70	3.09	1.61	0	0	Binfield
3000	10	3000	40	8.01	3.69	2.30	0	0	Tyhume
6000	10	6000	37	8.70	3.61	2.30	0	0	Binfield
5000	10	5000	48	8.52	3.87	2.30	5.30	200	Binfield
7000	20	7000	32	8.85	3.47	3.00	5.01	150	Binfield
4000	5	4000	40	8.29	3.69	1.61	5.01	150	Binfield
200	3	200	39	5.30	3.66	1.10	5.01	150	Binfield
800	10	800	69	6.68	4.23	2.30	0	0	Binfield
10000	20	10000	31	9.21	3.43	3.00	0	0	Binfield
200	3	200	43	5.30	3.76	1.10	0	0	Binfield
10000	10	10000	64	9.21	4.16	2.30	0	0	Binfield
12000	12.5	12000	35	9.39	3.56	2.53	5.52	250	Binfield
6000	17.5	6000	35	8.70	3.56	2.86	5.86	350	Tyhume
4000	1	4000	35	8.29	3.56	0.00	0	0	Binfield
6000	40	6000	40	8.70	3.69	3.69	5.99	400	Binfield
5000	75	5000	39	8.52	3.66	4.32	4.32	75	Binfield
8000	0	8000	39	8.99	3.66		5.30	200	Binfield
13000	100	13000	49	9.47	3.89	4.61	5.52	250	Binfield
5000	50	5000	39	8.52	3.66	3.91	5.01	150	Binfield
10000	30	10000	53	9.21	3.97	3.40	5.01	150	Binfield
10000	5	10000	68	9.21	4.22	1.61	4.61	100	Binfield
2500	50	2500	43	7.82	3.76	3.91	4.61	100	Tyhume
8000	30	8000	63	8.99	4.14	3.40	5.30	200	Tyhume
12000	100	12000	43	9.39	3.76	4.61	5.52	250	Tyhume
3000	10	3000	61	8.01	4.11	2.30	4.61	100	Tyhume
0	5	0	28	0.00	3.33	1.61	3.40	30	Binfield
4000	2	4000	49	8.29	3.89	0.69	4.32	75	Tyhume
6000	50	6000	39	8.70	3.66	3.91	5.01	150	Tyhume
7000	45	7000	26	8.85	3.26	3.81	5.30	200	N
800	10	800	69	6.68	4.23	2.30	0	0	Binfield
7000	20	7000	45	8.85	3.81	3.00	5.01	150	Binfield
15000	30	15000	32	9.62	3.47	3.40	0	0	Binfield

6000	10	6000	31	8.70	3.43	2.30	5.01	150	Tyhume
300	5	300	45	5.70	3.81	1.61	5.01	150	Tyhume
6000	10	6000	31	8.70	3.43	2.30	0.00	0	Tyhume
800	10	800	73	6.68	4.29	2.30	0.00	0	Tyhume
800	10	800	63	6.68	4.14	2.30	0.00	0	Tyhume
4000	50	4000	35	8.29	3.56	3.91	3.91	50	Tyhume
11000	5	11000	42	9.31	3.74	1.61	4.61	100	Tyhume
0	5	0	37	0.00	3.61	1.61	3.91	50	Tyhume
6000	20	6000	60	8.70	4.09	3.00	4.32	75	Tyhume
2250	15	2250	39	7.72	3.66	2.71	3.81	45	Tyhume
3250	22.5	3250	42	8.09	3.74	3.11	3.00	20	Binfield
5000	75	5000	43	8.52	3.76	4.32	5.01	150	Binfield
0	5	0	31	0.00	3.43	1.61	0.00	0	Binfield
0	10	0	42	0.00	3.74	2.30	0.00	0	N
1500	10	1500	32	7.31	3.47	2.30	0.00	0	Tyhume
4500	50	4500	47	8.41	3.85	3.91	0.00	0	Binfield
1500	20	1500	58	7.31	4.06	3.00	0.00	0	Dam
4000	30	4000	39	8.29	3.66	3.40	4.61	100	Tyhume
8500	100	8500	48	9.05	3.87	4.61	5.52	250	source of water
9000	50	9000	49	9.10	3.89	3.91	5.62	275	Binfield