

A Citizen Science water quality monitoring project's contribution to environmental education, social learning and adaptive management

Irene Muller



orcid.org/0000-0000-0000-000X

Thesis submitted for the degree *Doctor* in Water Studies at the
North-West University

Supervisor: Prof J Tempelhoff...

Co-supervisor: Prof M Grösser

Dr L de Sousa...

Graduation: May 2018

Student number:12765074

DECLARATION

I, Irene Muller declare that ***A citizen science water quality monitoring project's contribution to environmental education, social learning and adaptive management*** is my own work and that all the sources I have used or quoted have been indicated and acknowledged by means of complete references.

.....

I Muller

September 2017

Vanderbijlpark

LANGUAGE EDITOR DECLARATION

Dr Bridget Theron-Bushell ***Academic Editing & Text Care***

P.O Box 101460, Moreleta Plaza, Pretoria, 0167

Email: Bridget.edit@telkomsa.net

Cell: (+27) 083 6593947

Tel: (102) 994 0947

Certificate of professional editing

24/08/2017

To whom it may concern:

This is to certify that I have done a full, professional language edit of the thesis to be submitted for a PhD degree in Water Studies by **Irene Muller** (student no: **12765074**) entitled: **A citizen science water quality monitoring project's contribution to environmental education, social learning and adaptive management.**

I am satisfied that from a language point of view, that this study is fully acceptable.

Yours sincerely

Bridget Theron-Bushell

Pretoria

ACKNOWLEDGEMENTS

To complete this research study a community of practice (COP) supported me.

I wish to express gratitude to:

Father God, Provider of strength, courage, and opportunities.

Mom, you would have been proud of me.

My Physical Science students – without you there was no purpose in this research.
Thank you for loyal support during your study years.

My husband – I appreciate your patience my beloved.

My son, Leon Roets, (MIng (Chem)) for his valuable insight in the quantitative data analysis and interpretation.

My children and family – thank you for backing me all the way.

My supervisors, Prof Johann Tempelhoff, Prof Mary Grosser and Dr Luiza de Sousa for patience and fruitful contributions to this research study.

Dr Bridget Theron-Bushell for thorough language editing of the thesis.

Rand Water officials, as expert group, for guidance and support during the research project.

“In the moment of crises the wise build bridges and the foolish build dams”

Nigerian proverb

PREFACE

This thesis is the result of a unique community of practice (COP), formed in a certain timeframe (2015-16) with a group of participants. Often the most enriching journeys we travelled were unplanned. The North-West University (Vaal Campus) water monitoring project provided the researcher and project participants with a real life laboratory, available on site, at the NWU (Vaal) campus. The past two years the researcher learnt that the boundaries between disciplines and people can diminish when they are able to find common ground on matters of mutual benefit. May this research contribute to create awareness of human actions in a natural setting and simultaneously encourage sustainable work in social-ecological systems. This research study underscores the African proverb:

If you want to go fast, go alone; if you want to go far, go together.

ABSTRACT

A citizen science water quality monitoring project's contribution to environmental education, social learning and adaptive management.

This research aimed to report on how a citizen science community-based water quality-monitoring project involving Physical Science pre-service teachers and Grade 10 Physical Science learners contributed to environmental education, social learning and adaptive management of water sources. These participants took part in project-based learning used for research purposes over a two-year period, namely from February 2015 to October 2016. The research aimed to determine the experiences of the different groups of participants in a water quality-monitoring project which focused on the measurement of physical variables in water such as pH, temperature, dissolved oxygen, percentage saturation, biochemical oxygen demand, the concentration of nitrite, nitrate and chloride ions, hardness, turbidity and *E coli* levels.

Objectives of the research included the following: (i) to define and clarify the concepts environmental education, social learning, project-based teaching, water quality monitoring, community-based monitoring and adaptive management at educational institutions with reference to the context of a citizen science community-based water monitoring project at the NWU (Vaal Campus); (ii) to understand how the relation between campus community and natural environment should be understood; (iii) to investigate how environmental education, in the form of citizen science, could be integrated and presented in teaching and learning of pre-service teacher education and Grade 10 Physical Science using project-based teaching to advance environmental learning; (iv) to explore how participation in a community-based water-monitoring project could contribute to making proactive suggestions in developing a citizen science management framework for education institutions; (v) to understand how participation in a community-based water monitoring project that includes a university campus and a high school science class could contribute towards developing and implementing a three-tiered citizen science management systems framework for education institutions; (vi) to identify the challenges and advantages of performing a community-based water-monitoring project to enhance environmental education and social learning at education institutions, and (vii) to draw conclusions and make recommendations to promote citizen science water quality monitoring and management at teaching and learning institutions.

Data were collected in the form of: (i) a literature review and document analysis, which aided to explore the concepts central to the study, namely citizen science; environmental education; social learning, project-based teaching, water quality monitoring, community-based monitoring and adaptive management of water sources; (ii) open-ended questions to both pre-service teachers and Grade 10 learners; (iii) interviews with other relevant role players like Rand Water officials, campus and technical management personnel and GCI members; (iv) a journal kept by the researcher and (v) quantitative measurement of variables in water like pH, temperature, dissolved oxygen, percentage saturation, biochemical oxygen demand, the concentration of nitrite, nitrate and chloride ions, hardness, turbidity and *E coli* levels; as well as (vi) photographs of scenarios at campus dams and the Vaal River to indicate the water quality status.

Qualitative data collected through open-ended questions were analysed by using the Atlas ti data programme. Quantitative data collected through measurement of water quality variables were analysed through descriptive and inferential statistical procedures.

The research findings include: the benefits of the social nature of project-based learning for advancing opportunities for environmental education and environmental awareness when community members such as pre-service teachers and school learners engage in community-based water monitoring activities; knowledge acquisition about the current water quality status of campus dams and the bordering Vaal River; and adaptive management proposals to manage NWU's (Vaal Campus) dams as part of the Vaal catchment area. In addition, the participants' and the researcher's reflections on their involvement in a real life water monitoring opportunity and relevant literature reviews, guided the construction of a project framework. A three-tiered systems framework was also compiled to serve as a guideline for educational institutions to support environmental education through citizen science.

Key words: citizen science; community-based monitoring; social learning; environmental education and adaptive management

OPSOMMING

‘n Burgerwetenskap waterkwaliteit moniteringprojek se bydra tot omgewingsopvoeding, sosiale leer en aanpasbare bestuur

Die doel van hierdie navorsingstudie is om te rapporteer oor hoe die deelname van voor-diens onderwysers en Graad 10 leerders aan 'n projek wat op die monitering van water kwaliteit as deel van Burgerwetenskap gefokus het, bygedra het tot omgewingsopvoeding, sosiale leer en aanpasbare bestuur van waterbronne.

Die voorafgenoemde deelnemers het oor 'n twee jaar periode, vanaf Februarie 2015 tot Oktober 2016, aan projekgebaseerde leer vir navorsingsdoeleindes deelgeneem. Die navorsingstudie het beoog om die ervaring van die verskillende groepe deelnemers aan die waterkwaliteits moniteringprojek wat op die meting van fisiese veranderlikes in water, soos pH, temperatuur, opgeloste suurstof, persentasie versadiging, bio-chemiese suurstof aanvraag, die konsentrasie van nitriet, nitraat en chloride, hardheid, turbiditeit en *E coli* vlakke gefokus het, te bepaal

Doelwitte van die navorsing het die volgende ingesluit (i) om konsepte sentraal tot die studie, naamlik omgewingsleer, sosiale leer, projekgebaseerde onderrig, waterkwaliteitmonitering, gemeenskapsgebaseerde monitering en aanpasbare bestuur van water in opvoedkundige instansies, met verwysing na die konteks van gemeenskapsgebaseerde watermonitering te Noord-Wes Universiteit (Vaal Kampus), te definieer en te verduidelik; (ii) om die verband tussen die kampusgemeenskap en natuurlike omgewing te begryp; (iii) om ondersoek in te stel hoe Omgewingsopvoeding, as Burgerwetenskap, geïntegreer en aangebied kan word in die onderrig en leer van voor-diens onderwyser opvoedkunde en Graad 10 Fisiese Wetenskap deur die gebruik van projek-gebaseerde onderrig om omgewingsleer te bevorder; (iv) om ondersoek in te stel hoe deelname aan 'n gemeenskapsgebaseerde watermoniteringsprojek kan bydra tot die maak van pro-aktiewe aanbevelings om 'n raamwerk vir die bestuur van Burgerwetenskap aan opvoedkundige instansies te ontwikkel; (v) om te begryp hoe deelname aan 'n gemeenskapsgebaseerde watermoniteringsprojek, wat 'n universiteitskampus en hoërskool wetenskapklasse insluit, kan bydra tot die ontwikkeling en implementering van 'n drie-vlak raamwerk vir die bestuur van Burgerwetenskap aan opvoedkundige instansies; (vi) om uitdagings en voordele van deelname aan 'n gemeenskapsgebaseerde watermoniteringsprojek te identifiseer om

sodoende Omgewingsopvoeding en sosiale leer aan opvoedkundige instansies te bevorder; en (vii) om gevolgtrekkings en aanbevelings te maak wat gemeenskapsgebaseerde waterkwaliteitsmonitering en -bestuur aan onderrig en leer instansies bevorder.

Data is ingesamel in die vorm van: (i) 'n literatuurstudie en dokumentanalise wat die konspete sentraal tot die studie ondersoek het, naamlik Burgerwetenskap, Omgewingsopvoeding, sosiale leer, projekgebaseerde leer, gemeenskapsgebaseerde monitering en aanpasbare bestuur van waterbronne; (ii) oop-einde vrae aan beide voor-diens onderwysers en Graad 10 leerders om hul ondervinding as deelnemers aan te dui; (iii) onderhoude met relevante rolspelers soos Rand Water werknemers, kampus- en tegniese bestuur en Groen Kampus Inisiatief (GKI) lede om hul ondervinding as deelnemers aan te dui; (iv) 'n joernaal bygehou deur die navorser om gedetailleerde beplanning en bestuur tydens die water moniteringprojek aan te dui; (v) kwantitatiewe meting van veranderlikes in water soos pH, temperatuur, opgeloste suurstof, persentasie versadiging, bio-chemiese suurstof aanvraag, die konsentrasie van nitriet, nitraat en chloride, hardheid, turbiditeit en *E coli* vlakke; sowel as (vi) foto's van die toestand by kampus damme en die Vaal Rivier om water kwaliteit status aan te dui. Kwalitatiewe data wat ingesamel is deur die oop-einde vrae, is geanaliseer deur die gebruik van die Atlas ti data program. Kwantitatiewe data, wat versamel is deur die meting van waterkwaliteit veranderlikes, is geanaliseer deur beskrywende en inferensiële statistiese prosedures.

Navorsingsbevindinge sluit die volgende in: die voordele van die sosiale aard van projekgebaseerde leer vir die bevordering van geleenthede vir Omgewingsopvoeding en omgewingsbewuswording, wanneer gemeenskapslede soos voor-diens onderwysers en Graad 10 leerders tydens gemeenskapsgebaseerde watermonitering aktiwiteite verrig; kennisverwerwing deur voor-diens onderwysers en leerders met betrekking tot die huidige waterkwaliteit status van kampusdamme en die aangrensende Vaal Rivier en gemeenskapswaterbronne; en aanpasbare bestuursvoorstelle oor hoe om die Noord-Wes Universiteit (Vaal Kampus) se damme, as deel van die Vaalrivier opvanggebied, te bestuur. Bykomend, het die deelnemers en die navorser se refleksies oor hulle deelname aan 'n lewenswerklike watermoniteringsgeleentheid, sowel as relevante literatuurstudies, bygedra tot die ontwikkeling van 'n projekraamwerk, sowel

as 'n drie-vlak sisteemraamwerk, wat as riglyn kan dien vir opvoedingsinstansies om Omgewingsopvoeding deur Burgerwetenskap te ondersteun.

Kernwoorde: burgerwetenskap; gemeenskapmonitering; sosiale leer;
Omgewingsopvoeding en aanpasbare bestuur

TABLE OF CONTENTS

DECLARATION	i
LANGUAGE EDITOR DECLARATION	ii
ACKNOWLEDGEMENTS	iii
PREFACE	iv
ABSTRACT	v
OPSOMMING	vii
TABLE OF CONTENTS	x
LIST OF FIGURES	xviii
LIST OF TABLES	xxi
LIST OF PHOTOGRAPHS	xxii
 CHAPTER 1 A CITIZEN SCIENCE WATER QUALITY MONITORING PROJECT'S CONTRIBUTION TO ENVIRONMENTAL LEARNING, SOCIAL LEARNING AND ADAPTIVE MANAGEMENT	 1
1.1 INTRODUCTION	1
1.2 ORIENTATION AND BACKGROUND	2
1.3 PROBLEM STATEMENT	8
1.4 RESEARCH QUESTIONS AND OBJECTIVES	11
1.5 CENTRAL THEORETICAL STATEMENT	13
1.6 RESEARCH METHODOLOGY	13
1.6.1 Transdisciplinary research	14
1.6.2 Data collection methods	17
1.6.2.1 Recruitment	17
1.6.2.2 Data gathering techniques – methodological steps	19
1.6.3 Rigour in transdisciplinary research	22
1.6.4 Data analysis	25

1.7	RESEARCH ETHICS	26
1.8	SEQUENCE OF RESEARCH	27
1.9	CHAPTER SUMMARY.....	29
CHAPTER 2 THE LINK BETWEEN CITIZEN SCIENCE, ENVIRONMENTAL EDUCATION AND WATER QUALITY MANAGEMENT IN A WATER MONITORING PROJECT.....		30
2.1	INTRODUCTION	30
2.2	CITIZEN SCIENCE.....	31
2.2.1	Citizen science defined.....	32
2.2.1.1	Current practice of citizen science – globally and nationally.....	34
2.2.1.2	Aspects of a citizen science project.....	37
2.2.2	Monitoring and community-based monitoring	38
2.3	ENVIRONMENTAL EDUCATION	41
2.3.1.1	Environmental education defined	43
2.3.1.2	Development of environmental education in South Africa	43
2.3.1.3	Implementing environmental education	44
2.3.1.4	Ways of including environmental education in the water monitoring project.....	47
2.3.2	Social learning: Teaching-learning framework for water monitoring project	48
2.3.2.1	Social learning defined	48
2.3.2.2	Types and levels of learning as related to social learning	53
2.3.2.3	Social learning and social capital	56
2.3.2.4	Social learning and monitoring	57
2.3.2.5	Social learning and data	57
2.3.2.6	Social learning and values.....	58
2.3.2.7	Social learning and indigenous knowledge.....	59
2.3.2.8	Social learning and transdisciplinary co-production.....	60

2.3.3	Project-based teaching	63
2.3.3.1	Project-based learning: a form of active learning	63
2.3.3.2	Project-based learning: a real-world learning opportunity.....	64
2.3.3.3	Project-based learning as place-based education	65
2.3.3.4	Implementation of project-based learning.....	65
2.4	WATER QUALITY AND WATER QUALITY MANAGEMENT (WQM).....	67
2.4.1	Water quality and water quality management (WQM) defined	67
2.4.1.1	Water Quality Management in South Africa.....	68
2.4.2	Adaptive management	71
2.4.2.1	Implementing adaptive management.....	72
2.4.2.2	Adaptive management and sense of place.....	73
2.4.2.3	Adaptive management and knowledge.....	73
2.4.2.4	Social learning, adaptive management and transdisciplinarity	74
2.4.3	Public participation	76
2.4.3.1	Adaptive management and public participation	77
2.4.3.2	Public participation, social learning and resilience	78
2.4.3.3	Public participation and accountability.....	79
2.5	CHAPTER SUMMARY.....	80
CHAPTER 3 EMPIRICAL RESEARCH AND THE WATER MONITORING PROJECT		82
3.1	INTRODUCTION	82
3.2	RESEARCH PARADIGM.....	82
3.3	EMPIRICAL RESEARCH.....	82
3.3.1	Literature review.....	82
3.3.2	Research design.....	83
3.3.2.1	Transdisciplinary research.....	83
3.3.2.2	Mixed-method research design	86
3.3.2.3	Participatory action research methodology.....	88

3.3.3	Research strategies	94
3.3.4	Data collection methods	95
3.3.4.1	Position of the researcher in the research study	95
3.3.4.2	Recruitment	96
3.3.4.3	Data gathering techniques – methodological steps	97
3.4	RIGOUR IN TRANSDISCIPLINARY RESEARCH	100
3.5	DATA ANALYSIS	106
3.6	COMPLYING WITH ETHICAL PRINCIPLES.....	108
3.7	THE WATER MONITORING PROJECT PROGRAMME	109
3.7.1	Volunteers – the heart of the monitoring project.....	112
3.7.1.1	The training of volunteers in the NWU (Vaal Campus) water monitoring project.....	112
3.7.2	Evaluating the water monitoring project	114
3.8	CHAPTER SUMMARY.....	116
CHAPTER 4 INTERPRETING THE VIEWS OF PARTICIPANTS IN THE WATER MONITORING PROJECT		118
4.1	INTRODUCTION.....	118
4.2	DATA ANALYSIS AND INTERPRETATION OF PRE-SERVICE TEACHER EXPERIENCE AND SOCIAL LEARNING	118
4.2.1	Activity 1: The initial stages of the project with pre-service teachers (before commencing with the monitoring activities)	118
4.2.2	Activity 2: The pre-service teachers’ visit to Rand Water.....	126
4.2.3	Activity 3: Reflection of pre-service teachers after three monitoring sessions on campus in 2015	130
4.2.4	Activity 4: Pre-service teacher reflections after monitoring activities on campus and the presentation at the NWU (Vaal Campus) Teaching and Learning Symposium.....	142
4.2.5	Activity 5 Pre-service teachers’ reflection on their classroom practices and experience when performing monitoring activities with Grade 10 Physical Science learners in local schools in 2016 ..	148

4.2.5.1	Reflections by the researcher after monitoring activities performed by pre-service teachers with Grade 10 Physical Science learners.....	153
4.2.6	Data analysis and interpretation of Grade 10 Physical Science learners' experience.....	153
4.3	RESEARCHER'S REFLECTIONS ON ROLE PLAYER INPUT IN THE WATER MONITORING PROJECT	164
4.3.1	Green Campus Initiative (GCI) meetings	165
4.3.2	Campus management	165
4.3.3	Technical services.....	166
4.3.4	Rand Water	166
4.3.5	Schools	167
4.3.6	Final reflections by the researcher on participation in the NWU (Vaal Campus) water monitoring project.....	168
4.4	CHAPTER SUMMARY.....	169
	CHAPTER 5 WATER QUALITY MONITORING DATA ANALYSIS AND ADAPTIVE MANAGEMENT AT THE NWU (VAAL CAMPUS)	171
5.1	INTRODUCTION.....	171
5.2	QUANTITATIVE DATA COLLECTION MATERIALS AND METHODS USED: WATER MONITORING PROJECT AT THE NWU (VAAL CAMPUS) (2015–2016)	172
5.2.1	Site description of the water monitoring project.....	172
5.2.1.1	Dam 1.....	174
5.2.1.2	Dam 2.....	175
5.2.1.3	Dam 3.....	176
5.2.1.4	Dam 4.....	176
5.2.1.5	Dam 5.....	176
5.2.1.6	The Vaal River.....	178
5.3	WATER QUALITY DATA FROM NWU (VAAL CAMPUS) DAMS AND BORDERING VAAL RIVER.....	178
5.3.1	Results of the chemical variables	181

5.3.1.1	Discussion of the temperature, dissolved oxygen, percentage saturation and biochemical oxygen demand	182
5.3.1.2	Discussion of conventional variable (pH), nutrients and turbidity	191
5.3.1.3	Discussion of the total coliform bacteria	202
5.3.2	Conclusion.....	204
5.3.3	Adaptive management and the water monitoring project at the NWU (Vaal Campus).....	206
5.3.4	Public participation in the water monitoring project at the NWU (Vaal Campus)	206
5.3.5	Proposed adaptive management practices.....	207
5.3.6	Response to Rand Water's proposals	209
5.3.6.1	Campus management and technical services	209
5.3.6.2	Reflections by the researcher on adaptive management of campus dams.....	211
5.4	CHAPTER SUMMARY.....	213
CHAPTER 6 A CITIZEN SCIENCE FRAMEWORK FOR WATER QUALITY MONITORING		215
6.1	INTRODUCTION.....	215
6.2	FRAMEWORKS OF CITIZEN SCIENCE PROJECTS.....	215
6.2.1	Danielsen <i>et al.</i> monitoring scheme	216
6.2.2	The three Pouliot (2009) frameworks.....	217
6.2.3	Frameworks by Bonney <i>et al.</i> (2009a & b) on public participation in scientific research.....	218
6.2.4	The Citizen Science Programme Framework by Bonney <i>et al.</i> (2009a).....	221
6.2.5	The Newman <i>et al.</i> (2011) framework for a multi-scale citizen science project	221
6.2.6	Typology of citizen science by Wiggins and Crowston (2011).....	223
6.2.7	Public participation frameworks suggested by Shirk <i>et al.</i> (2012)...	224
6.2.8	Other aspects to take into account when designing a citizen science framework	225

6.3	DEVELOPMENT OF A CITIZEN SCIENCE FRAMEWORK FOR A WATER MONITORING PROJECT AT THE NWU (VAAL CAMPUS) ...	227
6.3.1	Reflection on both prototype frameworks	242
6.3.2	Reflection on the design of the NWU (Vaal) citizen science framework	245
6.4	CHAPTER SUMMARY.....	245
CHAPTER 7 DESIGN OF A TIERED CITIZEN SCIENCE PROJECT SYSTEM.....		247
7.1	Introduction	247
7.2	Systems and system elements	247
7.2.1	Organisational element.....	249
7.2.2	Social element	253
7.2.3	Human element.....	254
7.3	COMPONENTS REQUIRED IN FUTURE CITIZEN SCIENCE PROJECT SYSTEMS	256
7.4	TRANSDISCIPLINARY RESEARCH AND A SYSTEM REPRESENTING A CITIZEN SCIENCE PROJECT	258
7.5	A THREE-TIERED WATER MONITORING SYSTEM PRESENTING RELEVANT COMPONENTS OF THE NWU (VAAL CAMPUS) WATER MONITORING PROJECT	259
7.6	REFLECTION ON THE THREE-TIERED SYSTEM AND THE DESIGN OF A SYSTEM FOR USE IN FUTURE CITIZEN SCIENCE PROJECTS	265
7.7	CHAPTER SUMMARY.....	268
CHAPTER 8 OPERATIONALISING ENVIRONMENTAL EDUCATION THROUGH CITIZEN SCIENCE: CONTRIBUTIONS, CHALLENGES AND LIMITATIONS, RECOMMENDATIONS, SUGGESTIONS AND CONCLUSION		269
8.1	INTRODUCTION.....	269
8.2	A SUMMARY OF THE FINDINGS FROM THE LITERATURE REVIEW	269
8.3	A SUMMARY OF THE FINDINGS FROM THE EMPIRICAL RESEARCH	274
8.4	A SUMMARY OF THE FINDINGS IN RELATION TO THE AIM AND OBJECTIVES OF THE STUDY.....	281

8.5	RECOMMENDATIONS FOR CITIZEN SCIENCE PROJECTS	289
8.6	CONTRIBUTIONS OF THIS RESEARCH STUDY	290
8.7	CHALLENGES AND LIMITATIONS OF THE STUDY	291
8.8	SUGGESTIONS FOR FURTHER RESEARCH	294
8.9	CONCLUSION	295
	BIBLIOGRAPHY	299

LIST OF FIGURES

Figure 1.1:	Campus plan of the NWU (Vaal) 2010–2020 to indicate the position of dams and the Vaal River (NWU, 2012).....	4
Figure 1.2:	Phases of research: NWU (Vaal Campus) community-based water monitoring project.....	15
Figure 1.3:	Concurrent embedded mixed-method research	17
Figure 2.1:	Conceptual framework of relevant concepts in a community-based water monitoring project	31
Figure 2.2:	Mind map of social learning.....	62
Figure 3.1:	Phases of research of community based monitoring at the NWU (Vaal Campus)	85
Figure 3.2:	Concurrent embedded mixed-method participatory action research design.....	88
Figure 3.3:	Step-by-step process of participatory action research (PAR) in the community-based water monitoring project (Mertler, 2012:37)	91
Figure 3.4:	The water monitoring project programme (USDA, 2010 (IV):1-2)	111
Figure 3.5:	Evaluation programme for the water monitoring project NWU (Vaal Campus) (USDA, 2012 (XVI):4)	115
Figure 5.1:	Campus plan of the NWU (Vaal Campus) 2010–2020 indicating the position of dams and the Vaal River (NWU, 2012)	173
Figure 5.2:	The average temperature from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016.....	183
Figure 5.3:	The average dissolved oxygen (DO) from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016.....	184
Figure 5.4:	The average percentage saturation from six sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016.....	185
Figure 5.5:	The average biochemical oxygen demand (BOD) from six sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016	186

Figure 5.6:	The average pH from six sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016.....	192
Figure 5.7:	The average chloride ion concentration from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016.....	194
Figure 5.8:	The average nitrite concentration of water from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016.....	195
Figure 5.9:	The average nitrate concentration of water from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016.....	196
Figure 5.10:	The average hardness of water from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016	197
Figure 6.1:	Step 4 b: The inter-project dimension of the water monitoring project (NWU Vaal Campus) in comparison to other citizen science projects in South Africa (Newman <i>et al.</i> , 2011:226)	236
Figure 6.2:	Step 5: Create a citizen science framework from available information: Prototype 1a: The dimension framework	238
Figure 6.3:	Step 6: Application prototype 1b: Dimension framework with information on the NWU (Vaal Campus) monitoring project.....	239
Figure 6.4:	Step 5 (repeat): Create a citizen science framework from available information: Prototype 2a: The activity-based framework.....	240
Figure 6.5:	Step 6 (repeat): Application prototype 2b: Activity-based framework with information of the NWU (Vaal Campus) monitoring project	241
Figure 6.6:	Step 7a: Create a citizen science framework from available information: The generic citizen science framework designed for the NWU (Vaal Campus) project indicating contextual and real-life relevance.....	243
Figure 6.7:	Step 7b: Apply information to the framework designed for the NWU (Vaal Campus) citizen science project: contextual and real life relevance	244
Figure 7.1:	A three-tiered social-ecological system framework for the water monitoring project at NWU (Vaal).....	260

Figure 7.2:	A generic system for citizen science projects which promote natural resource management	267

LIST OF TABLES

Table 5.1:	Turbidity readings in NTUs for 2015–2016 in NWU (Vaal Campus) dams and Vaal River	201
Table 5.2:	Total coliform bacteria indications for 2015–2016 in NWU (Vaal Campus) dams and Vaal River	202
Table 6.1:	Step 1: Project goals and outcomes (Bonney <i>et al.</i> , 2009b:43).....	229
Table 6.2:	Step 2: Framework for developing a citizen science project to indicate the intra-project dimension suggested by Bonney <i>et al.</i> (2009a: 979).....	230
Table 6.3:	Step 3: The framework for multi-scale citizen science support as relevant to the NWU (Vaal Campus) water monitoring project (Newman <i>et al.</i> , 2011:220).....	232
Table 6.4:	Step 4a: An inter-project dimension comparison of the position of the NWU (Vaal Campus) water monitor project with similar projects in South Africa	234

LIST OF PHOTOGRAPHS

Photo 4.1:	The use of tools during monitoring activities: (a) initially and (b) after re-design (MPA, 2 (20/02/2015 & 08/05/2015))	132
Photo 4.2:	Mrs Nyree Steenkamp, a Rand Water monitoring expert (MPA, 2 (20/07/2015)).....	133
Photo 4.3:	The monitoring group presenting at the Teaching and Learning symposium at the Riverside Hotel, Vanderbijlpark in October 2016 (MPA, 2 (26.10.2016)).....	147
Photo 4.4:	Monitoring activities at schools.....	149
Photo 5.1:	Dam 2 overgrown with reeds (MPA 2 (11/03/2016))	175
Photo 5.2:	Students created their own walkway beside Dam 4's storm water channel (MPA 2 (18/09/2015))	176
Photo 5.3A:	Dam 5 with student residences in the background (MPA 2 (18/09/2015)).....	177
Photo 5.3B:	The decorative weir of Dam 5 and the bridge over the tarred road to building 25 (MPA 2 (11/09/2015)).....	177
Photo 5.4:	The Somerset Microlife Water Quality Test Kit with contents (MPA 2 (12/02/2017)).....	181
Photo 5.5 A:	Dead fish found at Dam 3 in February 2016 (MPA 2 (12/02/2016)) ...	190
Photo 5.5 B:	Algae bloom at Dam 3 in February 2016 (MPA 2 (12/02/2016))	190
Photo 5.6:	The construction of gabions at Dam 4 to limit erosion (VAAL eNUUS, 2017).....	213

CHAPTER 1

A CITIZEN SCIENCE WATER QUALITY MONITORING PROJECT'S CONTRIBUTION TO ENVIRONMENTAL LEARNING, SOCIAL LEARNING AND ADAPTIVE MANAGEMENT

1.1 INTRODUCTION

This research aimed to incorporate pre-service teachers and Grade 10 school learners in Physical Science as participants in a citizen science community-based water monitoring project. The NWU (Vaal Campus) provides ample dams and access to the Vaal River to perform tests on water quality and was used as a training ground for pre-service teachers. Pre-service teachers, in the context of this research, are students majoring in Physical Science in the B.Ed. programme and had to perform practical work as demanded in the formal curriculum. Performing water quality tests on campus dams and the Vaal River, the pre-service teachers gained skills and knowledge regarding water quality. After conducting a series of monitoring tasks on the water in campus dams and the Vaal River, the pre-service teachers went to local schools as part of their work-integrated learning opportunity and performed the same experiments on communal water samples provided by Grade 10 Physical Science school learners. The water quality tests were carried out using a water quality test kit the size of an ordinary canned fruit bottle. No laboratory was required to perform the tests that were done in a classroom or in the school grounds. Grade 10 learners taking Physical Science at school worked with the pre-service school teachers, gaining knowledge and learning the appropriate skills while undertaking these tests. The Grade 10 South African Physical Science Curriculum and Assessment Policy Statement (CAPS) calls for water quality tests to be performed as part of practical assessment (DBE, 2011a). Rand Water, the regional expert in water quality monitoring was also involved in this project, acting as a guiding agent to check on monitoring activities, validate findings and to aid with the management of dams at the NWU (Vaal Campus). Rand Water's role was therefore one of adaptive management which is defined as an interactive process involving the integration of project design, management and monitoring with the aim of promoting adaptation and stimulating the learning process (Salafsky, Margoluis & Redford, 2001). The main aim of this research was to explore how environmental learning opportunities could be enhanced by enabling pre-service Physical Science teachers and Grade 10

Physical Science learners with opportunities to learn about water monitoring and water quality. Opportunities offered to participants in this research project included gaining knowledge of testing procedures; social learning; problem-solving; practical investigation techniques and communicating about water quality. Using water that was available to the local community, performing the quality tests, indicated not only the health of the local water resource, but also contributed to the environmental education on water – that it is a very valuable and scarce resource. This study focused on the learning and experience of participants, especially pre-service teachers and Grade 10 school learners, who monitored water quality as citizen scientists. The community-based monitoring project aimed to promote societal enablement with the involvement of educational institutions.

1.2 ORIENTATION AND BACKGROUND

South Africa is a water scarce country (Turpie *et al.*, 2008:789) and local struggles for access to clean water have been prominent in the media in recent times. The quality of water and the availability of clean drinking water are of vital importance to all communities. In May 2015, AfriForum, a non-governmental organisation (NGO), reported on drinking water tests carried out at 11 sampling sites in the towns of Vereeniging and Vanderbijlpark – the urban hubs of the Emfuleni Local Municipality in Gauteng Province. Of the 11 localities, only one sample was free of *Escherichia coli* (*E. coli*) a bacterium commonly found in the intestines of people and animals (Prinsloo, 2015). *E. coli* is an indicator of pathogens which cause diarrhoea and fever if ingested and may lead to the outbreak of pandemic conditions.

Water monitoring and water health are global concerns. This is evident from relevant statements by political dignitaries and senior government officials at international summits. In 1987, the World Commission on Environment and Development outlined the concept of sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). In 1992, The United Nations’ Earth Summit at Rio de Janeiro defined sustainable development as a long-term perspective with broad-based participation in policy formulation, decision-making and implementation. Its successor, the Johannesburg Summit on Sustainable Development of 2002, posed a challenge to civil society to embrace science in order to

prepare nations and communities to take responsible action regarding the environment (Potschin & Haines-Young, 2006:163).

“Citizen science” is a concept responding to the call for sustainable development as outlined above. The idea of citizens engaging in science emerged in the 1980s and promoted better public understanding of science as well as public participation in environmental action and decision-making (Potschin & Haines-Young, 2006:165). Citizen science refers to actions taken by individuals or organised groups to collect data for research or management-oriented environmental monitoring (Conrad & Hilchey, 2011:274). The data gathering objectives and protocols are usually established by scientists or management. Citizens therefore have a meaningful role in data gathering but rarely challenge the role or method followed in conventional science (Conrad & Hilchey, 2011:274; Fernandez-Gimenez, Ballard, & Sturtevant, 2008:2).

As institutions or organisations, universities are much the same as companies in the private sector. Campuses consume energy and materials and tend to have loads of waste contributing to pollution, e.g. in lecture halls and research laboratories (Viebahn, 2002:3). It is therefore reasonable to expect of universities to maintain sustainable practices similar to those of corporate businesses, as required by various environmental laws (Disterheft, Ferreira da Silva Caeiro, Ramos & De Miranda Azeiteiro, 2012:80). The emphasis is thus on the urgency for universities to attend to environmental activities on campuses and to incorporate practices that enhance learning and protect the environment (James & Card, 2012:166).

The NWU’s Vaal Campus (NWU Vaal Campus) hosts a variety of water storage resources in the form of four storm-water dams and has a 3km waterfront on the famous Vaal River Barrage. The campus is situated on 117,7ha of riverside real estate on the south-eastern end of the town of Vanderbijlpark in Gauteng, South Africa (NWU, 2010). Figure 1.1 shows the position of the dams and river on the campus plan of the NWU (Vaal Campus) for 2010–2020. The water storage resources are indicated in blue. All the dams have inlets and outflows and are filled with water from the Vaal River as well as by rain, and precipitation.

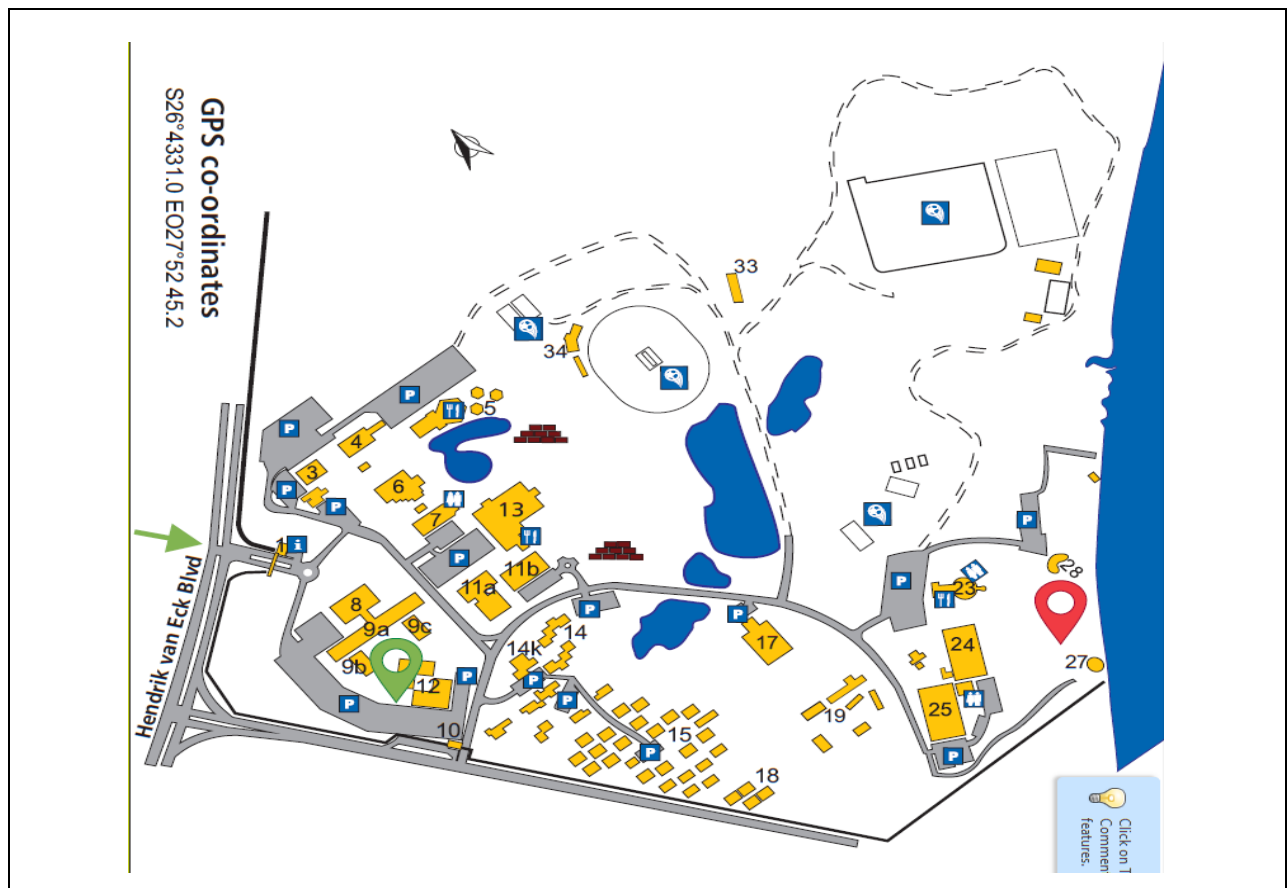


Figure 1.1: Campus plan of the NWU (Vaal) 2010–2020 to indicate the position of dams and the Vaal River (NWU, 2012)

The Vaal Campus supports the Green Campus Initiative (GCI), an international initiative for sustainable campuses and engages in different activities such as recycling waste, Earth Hour and National Water Week, all of which are aimed at raising environmental awareness and educational engagement between staff and students. In 2013–14, the researcher conducted a resilience assessment of the social-ecological system of the NWU (Vaal Campus) (Resilience Alliance, 2010:4) as part of a Master’s degree in Environmental Management. This research project brought to light the environmental literacy of students and identified students as the main driver of social change at the NWU (Vaal Campus) (Muller, 2014:94). The GCI committee of the NWU (Vaal Campus) met in February 2015 and discussed the status of the water quality of the dams on the campus and the adjacent river. The researcher volunteered to initiate a monitoring project of the campus dams and Vaal River which sparked off a full research study in community-based water monitoring.

The NWU (Vaal Campus) water monitoring project was therefore a response to the call made to university campuses to act responsibly in terms of the environment. It provided

an opportunity to display the campus' effort to respond to the societal problem of poor water quality.

There has been extensive research in the field of community-based monitoring projects as a form of citizen science in countries such as Canada and the USA (Whitelaw, Vaughan, Craig, & Atkinson, 2003:411; Conrad & Hilchey, 2011:275; Savan, Morgan & Gore, 2003:563). Whitelaw *et al.* (2003:410) defined community-based monitoring as a process where concerned citizens, government agencies, industry, academia and community groups collaborate to monitor, track and respond to common community concerns.

Most research in the field of citizen science emphasises abundant quantitative data when reporting on water quality, but there is a complex community-based need for qualitative data (Conrad & Hilchey, 2011:284; Pollock & Whitelaw, 2005:225; and Stem, Margoluis, Salafsky & Brown, 2005:305–306). A research study using qualitative data, focusing more on the experience of participants in a water monitoring project, aims to fill the gap in current research in the field of water monitoring. The literature also suggests that in current research, far too little attention has been given to adaptive management of water storage resources and learning in the process of reporting on community-based monitoring (Overdevest, Orr & Stepenuck, 2004:184). In this regard, the present study aims to extend the knowledge base on adaptive management of water storage resources by developing a citizen science framework for education institutions.

Community-based monitoring in South Africa tends more to biological monitoring. The South African National Biodiversity Institute (SANBI) reports that the University of Cape Town's Animal Demography Unit (ADU) is the driving force behind most of the country's prominent citizen science initiatives. Avian-related citizen science initiatives such as the South African Bird Ringing Unit, Coordinated Waterbird Counts, Coordinated Avifaunal Road Counts, the Southern African Bird Atlas Project and My Birdpatch (South Africa National Biodiversity Institute, 2016) are coordinated by the ADU.

In the field of water monitoring, the following initiatives are reported: A mini-stream assessment scoring system (SASS), an initiative which incorporates school learners to identify organisms in water resources in Hilton, KwaZulu-Natal, is run by Mark Graham (Matthews, 2014:13). In another project, as outlined by Rivett, Champanis & Wilson-Jones (2012:409) the use of a cellular phone-based information system was

investigated. Borehole operators reported on pH, turbidity and conductivity of groundwater supplies in boreholes. Thirdly, Tandlich, Luyt, & Ngqwala (2014:46) reported on the monitoring of rain water quality in the Eastern Cape. Eight volunteers used a hydrogen-sulphide test kit to detect microbial contamination in rain water (Tandlich *et al.*, 2014:48).

Mvula Trust is a South African water and sanitation non-governmental organisation (NGO). It noted recently that there are examples of active stakeholder participation in catchment management forums and that these awareness campaigns are driven by civil society. However, the only national programmes that use volunteers are the newly formed “adopt-a-river” and “working for water and wetlands” projects (Tibane & Vermeulen, 2014:444). This report indicated that citizen monitoring held considerable potential in the field of South African water quality monitoring (Munnik *et al.*, 2011:10). In addition to support this notion, Savan, Morgan and Gore (2003:561, 567) indicated more than a decade ago that universities could indeed play an important collaborative role in environmental monitoring.

To give substance to these recommendations, this current research project aims to give pre-service teachers introductory training on water monitoring at the local water storage resource at the NWU (Vaal Campus), thus providing environmental education. Environmental education is a complex term and is widely defined as an interdisciplinary effort, aimed at helping students and learners to gain knowledge and skills which will give them an understanding of the complex environmental issues facing society and the ability to deal effectively and responsibly with such issues (Hungerford, 2009:2). Environmental education follows a holistic approach in the United States of America and is incorporated in the curriculum from primary school up to university level (Carter & Simmons, 2010:14). In Nordic countries such as Sweden and Denmark, as well as in New Zealand and Australia, environmental education is an integrated effort to enable students and learners in this regard (Breiting & Wickenberg, 2010:11), while in Latin America and Turkey, environmental education has developed in a non-formal educational context (Ruiz-Mallen, Barazza, Bodenhorn, Del la PlazCeja-Adame, & Reyes-Garcia, 2010:1767).

In South Africa, environmental education was pioneered by non-governmental agencies in the early 1980s (Le Grange, 2002:84). In 1995, the White Paper on Education and Training included environmental education as one of its key principles. Outcomes-based

education, as proposed in Curriculum 2005, promoted environmental education as an inherent part of learning activities, but with limited evidence of success in this regard (Le Grange, 2002:84). Currently, an international Eco-Schools programme supports environmental learning in South African classrooms. This programme has been active since 2003 in South Africa and is financially supported by a non-governmental society, the Wildlife and Environmental Society of South Africa (WESSA) (Wildlife and Environmental Society of South Africa, 2016).

Social learning takes place during environmental education. Social learning is defined as individual learning, which occurs in a social context and is influenced by social norms (Bandura, 1971:1; Wenger, 1998a:1). According to Bandura (1971:3), social learning implies learning through experience, in other words, by “doing”. The integration of both cognitive and affective domains in social learning is important. Cognitive features of learning focus on understanding, applying and evaluating scientific ideas. Affective features like the fostering of interest, enjoyment and excitement when learning science and gaining a respect for the natural environment, are often neglected (Littledyke, 2008). Social learning helps students/learners to develop thought processes which guide their future actions (Bandura, 1971:3). In the opinion of Wenger (1998a:1), social learning incorporates all groups of people who engage in a process of collective learning in a shared domain of human endeavour, which he refers to as a “community of practice” (COP) (Pahl-Wostl *et al.*, 2007).

Social learning theory embraces the teaching and learning approach which was followed in this research and can be described as a project-based approach. Project-based learning emphasises learning through experience and often focuses on environmental concerns (Solomon, 2003:21). Through project-based learning, core curriculum knowledge is learned and applied when authentic problems are solved (Markham, 2011:39). Project-based learning therefore imparts thinking competencies and creates flexible learning environments (Doppelt, 2003:255).

The NWU (Vaal Campus) dams provide a suitable training ground for monitoring experiments – therefore a laboratory outside lecturing halls and a real-world learning opportunity. Real-world learning opportunities are defined by Brundiers, Wiek, & Redman (2010:312) as learning that helps to increase the understanding of sustainability problems (knowledge) and complements methodological competence in applying problem-solving approaches.

1.3 PROBLEM STATEMENT

In recent times, there has increasingly been a critical need for monitoring water quality in South Africa. Parts of the country are experiencing the worst drought since 1982 and six of South Africa's nine provinces have been declared disaster areas (Du Toit, 2015). Water quality tends to plummet under circumstances of drought (Du Toit, 2015). In 2015, at a time of severe drought, Turton (2015:12,16-17) argued that the water shortage in South Africa was induced by a lack of strategic planning, a loss of strategic skills due to political transformation and the fact that poorly functioning wastewater treatment plants spewed 4 billion litres of untreated or partially treated sewage into the country's dams and rivers every day. It is possible that more frequent water monitoring interventions, conducted with the assistance of citizens, could be a possible solution to the dilemma.

The relevance of researching community-based water monitoring at university level is supported by the view of Waghid (2002:457), who indicated that globally and in South Africa there needs to be a shift towards problem-solving or applied research opposed to disciplinary research. According to Waghid (2002:457), universities are increasingly challenged in terms of how they should respond to societal needs. They are under pressure to bridge the gap between higher education and society at large. Tertiary institutions are expected to excel in community service by providing integrated teaching and research opportunities where knowledge production is grounded in the context of application (Waghid, 2002:458).

Progress in South African schools regarding access to safe water has been slow. As early as 2011 the National Education Infrastructure Management System Report (NEIMS) (Department of Basic Education (DBE), 2011b: Tables 4, 5, 7 & 8) reported that of the 24 793 public schools, as many as 2 402 schools had no water supply, and a further 2 611 schools had an unreliable water supply. In addition, there were 913 schools that had no ablution facilities at all, while 11 450 of the schools were obliged to make use of pit latrine toilets. There were 21 021 schools that did not have any laboratory facilities, and only 1 231 schools had stocked laboratories. The report further highlighted that Gauteng Province, despite being regarded as the healthiest province, has significant infrastructure inadequacies (Equal Education, 2013).

A more recent report, that by the NEIMS in 2014, indicated that of 23 740 public schools, 604 had no water supply and a staggering 4 681 schools had unreliable water supplies. Furthermore, there were as many as 474 schools without ablution facilities, while 11 033 schools still used pit latrine toilets. Some 20 463 schools (82%) had no laboratory facilities (Department of Basic Education, 2014: Tables 4, 5, 8).

It is clear from the above information that while significant progress has been made regarding the supply of water to schools, the number of schools with unreliable water supplies has increased and the lack of laboratories still raises concern. This scenario at public schools makes it clear that there is an urgent need to implement a project to raise awareness on water and water health at schools by using a simple water quality test kit to perform water-monitoring experiments.

The notion to involve educational institutions in water monitoring is supported in a South African study by Otieno and Adeyemo (2012) who indicate that there is a critical need to increase the quantity and improve the quality of drinking water available to rural schools and communities in general. According to these researchers, the national drinking water standards are not supported by the necessary laboratory facilities to monitor compliance and to promote improvement. Furthermore, they indicate that regional and local based systems that link public awareness and implement minimal water quality surveillance are most urgently needed. Higher education institutions are not safeguarded against water-related infrastructure problems. The NWU (Potchefstroom Campus) on 1 March 2013 had to temporarily suspend activities to prevent a possible health risk for students when a municipal water pipeline and storage reservoir crisis affected the campus. Students were sent home so that officials of Tlokwe Local Municipality could fill its reservoirs more rapidly and take the necessary precautions to address the crisis (NWU, 2013).

Methodologically, the proposed project presented a number of problems. The trans-disciplinary nature of the research study meant that the researcher had to rely on more than one specific theory/framework as a guideline to underpin the execution of the research project and assess the outcomes consistently. For the purposes of this study, transdisciplinarity is based on the definition provided by Lang, Wiek, Bergmann, Stauffacher, Martens, Moll, Swilling, & Thomas (2012:26-27) as a “reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating

knowledge from various scientific and societal bodies of knowledge". In this research study the societal problem of poor water quality in communities was addressed by performing water quality measurements on nine variables of water which indicated the water quality status of the NWU (Vaal Campus) and Emfuleni Local Municipality. The relevant bodies of knowledge which were incorporated in the study were chemistry (measurement of water quality variables); environmental management (adaptive management of campus dams); and environmental education, indicated by the social learning of different groups of participants.

This study is, to the knowledge of the researcher, the first of its kind in South Africa, to link a higher institution, the NWU (Vaal Campus), with a community-based monitoring project focusing on the learning experience and acquisition of skills among pre-service teachers and Grade 10 school learners. The research was based mainly on qualitative findings, in contrast to most other water monitoring studies that tend to focus primarily on quantitative findings. The format of the study was motivated by the need to improve environmental learning and awareness at university and school level by establishing the water quality status despite the limited availability of laboratories to test water quality. Awareness in this study is acknowledged as a broad concept, but can be defined as the acquisition of content knowledge as well as appropriate affective responses to foster caring behaviour in the interest of the natural environment (Littledyke, 2008:2). The contribution of this study was to create an opportunity for citizen scientists to participate in a water-monitoring project with the aim to enable social and environmental learning. The research incorporated pre-service students who are destined to become teachers and possibly community leaders, as well as learners. It therefore promoted the idea of making communal schools environmental monitoring centres. Not only was the value of schools as learning institutions accentuated, but environmental health and especially water health were actively encouraged by incorporating citizen science among the youth, the target audience.

Hence, the following problem statement was formulated: To determine to what extent was a learning opportunity such as this, conducted in a real-world context among young people in local communities, able to enhance environmental education and social learning on water quality and related issues.

Because there is limited qualitative research that has been conducted on the experience of participants in a citizen science community-based monitoring project, this

research aims to make a methodological contribution. Theoretically, the study will contribute towards extending the existing knowledge of citizen science projects and the management of water at educational institutes. The NWU (Vaal Campus) citizen science conceptual framework, using the context of educational organisations as the unique departing point, can be used as a guiding instrument or planning tool for citizen science community-based monitoring projects. Furthermore, the conceptual systems framework provides insight into the required system elements by linking various educational institutions and natural resources in a systemic process. The contextual contribution of the study is linked to the social learning and social capital gained by the diverse groups of participants in the study.

1.4 RESEARCH QUESTIONS AND OBJECTIVES

The primary research question is:

How can a citizen science water quality-monitoring project, involving Physical Science pre-service teachers and Grade 10 Physical Science learners, contribute to environmental education, social learning and adaptive management?

Secondary research questions are:

In a scientific report on a project based (as an example) at the NWU (Vaal Campus),

- What do environmental education, social learning, project-based teaching, water quality monitoring, community-based monitoring and adaptive management at educational institutions refer to in the context of a citizen science, community-based water monitoring project at the North-West University (Vaal Campus)?
- How should the relation between the campus community and the environment be understood?
- How could environmental education, in the form of citizen science, be integrated and presented in the teaching and learning processes of pre-service teacher education and Grade 10 Physical Science learners respectively, by using project-based education to advance environmental learning?
- How could participation in a community-based water monitoring project that includes a university campus and a high school science class contribute towards developing and implementing a citizen science framework for education institutions?

- How could participation in a community-based water monitoring project that includes a university campus and a high school science class contribute towards developing and implementing a citizen science management systems framework for education institutions?
- What were the challenges and advantages of conducting a citizen science water-monitoring project to enhance environmental and social learning at education institutions?
- What conclusions can be drawn and recommendations made to promote citizen science water quality monitoring and management at teaching and learning institutions?

Research aim and objectives

The main aim of the study is:

To explore how a citizen science water quality-monitoring project involving Physical Science pre-service teachers and Grade 10 Physical Science learners could contribute to environmental and social learning at educational organisations while also promoting the adaptive management of natural resources that are contextually important to educational organisations.

The main aim is operationalised in the following objectives, namely to:

- Define and clarify the concepts environmental education, social learning, project-based teaching, water quality monitoring, community-based monitoring and adaptive management at educational institutions with reference to the context of a citizen science community-based water monitoring project at the NWU (Vaal Campus).
- Understand the relation between campus community and environment.
- Investigate how environmental education, in the form of citizen science, could be integrated and presented in the teaching and learning of pre-service teacher education and Grade 10 Physical Science using project-based teaching to advance environmental learning.
- Explore how participation in a community-based water-monitoring project could contribute to making proactive suggestions in developing a citizen science framework for education institutions.

- Understand how participation in a community-based water monitoring project that includes a university campus and a high school science class could contribute towards developing and implementing a citizen science management systems framework for education institutions.
- Identify the challenges and advantages of performing a citizen science water-monitoring project to enhance environmental education and social learning at education institutions.
- Draw conclusions and make recommendation to promote citizen science water quality monitoring and management at teaching and learning institutions

1.5 CENTRAL THEORETICAL STATEMENT

Although this research study followed a mixed-method design, the focus of this research was on qualitative findings and therefore a central theoretical statement is posited (rather than a hypothesis, which relates more to quantitative findings):

Social learning through a citizen science community-based water quality monitoring project is beneficial for all participants. The community of practice, consisting of different groups of participants, namely, pre-service teachers, Grade 10 Physical Science learners, Rand Water and campus personnel, were engaged in this research study, contributing their diverse social and scientific knowledge. This research study was transdisciplinary in nature because concurrently it addressed the water quality status of the NWU (Vaal Campus) and also promoted environmental education on the campus and in the relevant school communities. Benefits of the research study therefore accrued to both social and environmental gains.

In the next section the research methodology is discussed.

1.6 RESEARCH METHODOLOGY

With reference to this research project, the researcher acknowledges that science is not only a resource but also an agent of change. Society therefore adopts scientific research to help resolve societal problems and promote innovation (Hirsch Hadorn, Biber-Klemm, Grossenbacher-Mansuy, Hoffman-Riem, Joye, Pohl, Wiesmann. & Zemp, 2008:27). This study was proposed from a social constructivist paradigm where the researcher sought understanding of the world in which she lives and works. All

individuals attach subjective meanings to their experiences. The researcher's aim was to investigate the complexity of views rather than to narrow meanings down to a common denominator (Creswell, 2009:8; Grauer, 2012:71).

1.6.1 Transdisciplinary research

The study adhered to the four core concerns of transdisciplinarity, namely that the process (a) focused on a life-world problem, namely water quality; (b) integrated the disciplinary paradigms of Natural Science, Environmental Management and Education; (c) involved different participants with heterogeneous knowledge; and (d) aimed for a unity of knowledge beyond the confines of a single discipline (Hirsch Hadorn *et al.*, 2008:29).

Research design refers to the plan devised to conduct the research (Creswell, 2009:3). The research design of this particular initiative was based on the conceptual framework devised by Lang *et al.* (2012:28) and a three-phase approach suggested by Hirsch, Hadorn *et al.* (2008:36) which includes: (a) problem identification and structuring or problem framing and team building; (b) problem analysis or co-creation of knowledge where research questions are structured specifically to address diverse aspects and aim for integration of all aspects; and (c) bringing results to fruition or integration and application of created knowledge where the project is embedded in the social and scientific contexts and able to test the expected impact in both contexts.

For this particular study, the following sub-phases, based on the three-phase project, are shown in Figure 1.2.

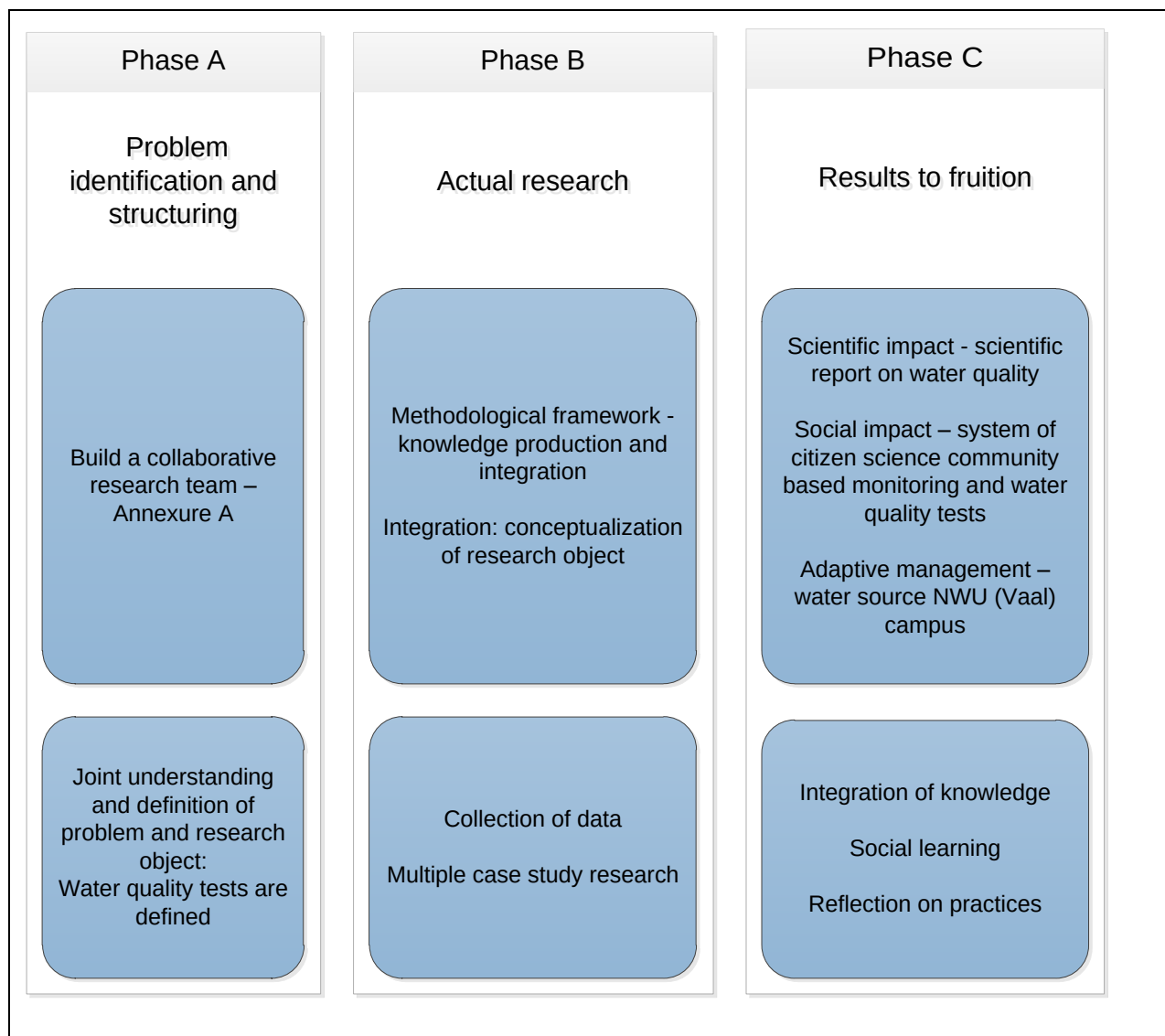


Figure 1.2: Phases of research: NWU (Vaal Campus) community-based water monitoring project

Lang *et al.* (2012:35-40) indicate that transdisciplinary research faces the following challenges, namely: (i) Such a study may be unable to frame the problem or raise sufficient awareness of the problem in participants with diverse backgrounds. (ii) There is unbalanced ownership of the problem when engaging with participants from practice and science. (iii) The legitimacy of the research in general is problematic when there are too few participants and limited resources. (iv) There may be conflicting methodological standards where diverse participants have different expectations and adhere to different quality standards. (v) The lack of integration of knowledge and poor communication may become a problem. (vi) Participants may not continue their involvement in the long run and this might affect results negatively. (vii) There may be vagueness and ambiguity of results. (iix) The fear of failure may mean that some participants do not complete the

study. (ix) There may be limited case-specific solutions to integrate with existing scientific knowledge. (x) The sharing of rights and responsibilities between partners and the tracking of the societal and scientific impacts may lead to inconsistencies.

In this research project, a concurrent embedded strategy as part of a mixed method approach was used. The primary method of qualitative observation guided the project and the secondary quantitative database, the monitoring data of nine parameters, was incorporated. Given less priority, the quantitative part was nested in the qualitative part. The quantitative (nested) part addressed a different question, namely the current status of water quality of the NWU (Vaal Campus) water storage resource (Creswell, 2009:214). Knowing the water quality status provided campus management with valuable information on the upkeep of the dams on campus

Quantitative data collection and analysis were carried out during the monitoring process of the various water resources. The qualitative phase ran concurrently with the monitoring process by asking open-ended questions and conducting interviews with various role players. Data was not compared, but co-existed side-by-side to provide a composite picture of the research study (Creswell, 2009:214). The collection of data by means of monitoring was seen as a scientific experiment because the so-called scientific method was followed. Steps in the scientific method include: statement of the problem; formulation of a hypothesis; conducting an experiment and the collection of data; the interpretation of data; drawing of conclusions and finally, the verification of the hypothesis (Mertler, 2012:6). To examine the experiences of participants while undertaking monitoring activities, participatory action research and a multiple case study methodology were followed.

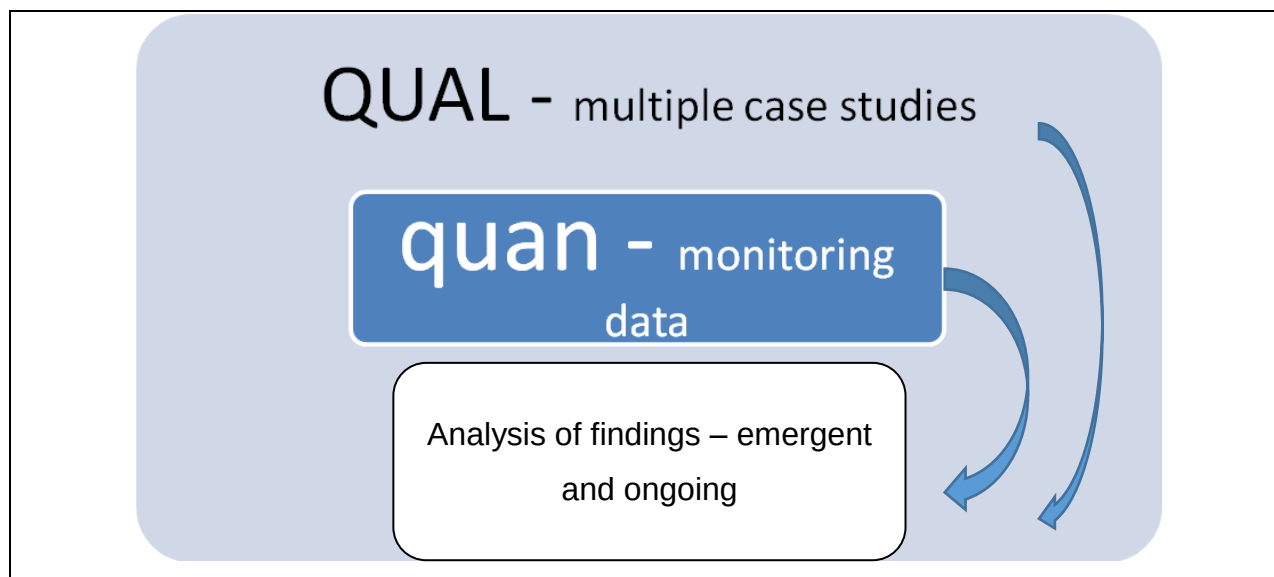


Figure 1.3: Concurrent embedded mixed-method research

1.6.2 Data collection methods

1.6.2.1 Recruitment

The results of this water-monitoring project are relevant for the implementation of environmental education among a range of people in South Africa. Those selected to participate in this study were chosen purposively (Nieuwenhuis, 2007:79).

Eight NWU pre-service teachers majoring in Physical Science as a school subject voluntarily indicated their interest in water monitoring and were selected to take part in the project to be based at the NWU campus. All eight students majoring in Physical Science were in the second year of their B.Ed. course. Incorporating only eight pre-service teachers in the research study enabled the researcher to engage frequently with a group of manageable size. The group was chosen by using the following criteria: They were second year B.Ed pre-service teachers who were studying Physical Science as a major.

The school learners participating in the water-monitoring project at local schools numbered 320 learners. When applying for consent to carry out the research, the researcher specifically selected Gauteng Education Department schools and those which represented the diversity of the local and regional society. Monitoring at schools was done after school hours. The researcher chose schools in close proximity to the university to ensure easy accessibility to the pre-service teachers. The criteria used to

select these learners were: Grade 10 learners at schools in the D 7 and D 8 districts, Gauteng Province who had Physical Science as a subject.

The 320 Grade 10 learners who were to collect the water-monitoring data were divided into eight Physical Science classes, each class comprising 40 to 50 learners. The eight student teachers were then each assigned the task of directing a class of learners. The learners worked in groups of four to six members and answered open-ended questions in groups.

Other participants included members of the technical services division at the NWU (Vaal Campus) responsible for environmental management; scientists employed at Rand Water; and members of the Green Campus Initiative, which included representatives of campus management.

Rand Water is the national leader on water quality monitoring and water purification. Experts of Rand Water monitored the activities of pre-service students to ensure correct practices. Rand Water officials validated the monitoring findings of pre-service students and assisted with proposals to ensure that water in the dams on the premises of NWU (Vaal Campus) remained healthy and sustainable.

The Green Campus Initiative (GCI), of which the researcher is a member, is a committee that meets once a month. Representatives of the campus management's technical division also serve on the committee. At these meetings, the researcher frequently shared her findings on water quality in a transparent manner and made suggestions on possible management actions in respect of the dams on campus. She also reported on her deliberations with senior campus management on matters related to her project that could be of value for the campus. The GCI meetings meant that the researcher cooperated fully with members of the campus' technical management which is responsible for the dams and water-related matters. The formal meetings, for the purposes of this project, served as an information base for the researcher to inform campus management on proposed actions to ensure water quality and safe campus dams. The GCI is a multi-stakeholder committee that engages with students and staff on all matters related to a positive engagement between humankind and the environment.

The participants in each of the different phases and levels are indicated in MPA 1.2: Co-creation of knowledge in a water-monitoring project.

1.6.2.2 Data gathering techniques – methodological steps

In this research study data was collected by means of interviews with participants; open-ended questions to the participants; journal notes; photographs; observations and measurements made while water quality experiments were conducted; and by document reviews. The researcher interacted proactively with all participants in the collection of data. Her role included the examination of related documents on water monitoring of local water storage resources such as documentary material from Rand Water; observing the monitoring practices on campus; questioning the participants on their various roles; and personally performing monitoring tasks. Photographs, which were taken during monitoring, were used to establish the condition of the water in campus dams at different times and seasons for purposes of comparison and to aid with management proposals. The researcher was acknowledged as a fully functioning member of the community and simultaneously as part of the monitoring group. The nature of the monitoring project determined the role and position of the researcher during monitoring. It was foreseen that trust in the validity and objectives of this study were engendered by the researcher and intra-group cooperation was promoted by working with one another (Mertler, 2012:93).

Data gathering techniques that were used are discussed in detail below.

- **Document reviews**

To understand the focal system and the relation between the campus community and the environment, the researcher conducted research for a Master's degree in Environmental Management in 2013/2014 and relied on documents that date back as far as the 1960s when the NWU (Vaal Triangle Campus) was founded in Vanderbijlpark. These documents include information on available land, student numbers, biodiversity and other key events regarding climate and weather. The document review provided rich, descriptive data about the NWU (Vaal Campus). The information was of value for the proposed research project. During her Master's study the researcher noticed that any disturbance in the Vaal River influences the water storage resources on campus (Muller, 2014).

- **Literature**

Literature was also reviewed to explore the concepts of: environmental education, social learning, the project-based teaching approach, monitoring in general and community-

based monitoring. The researcher acknowledges that more than one resource recommended that the project-based teaching approach prefers a transdisciplinary research methodology (Brundiens *et al.*, 2010:321 & Waghid, 2002:457).

The researcher has 30 years Physical Science teaching experience at school and university level. She therefore maintains that a sound subject knowledge of Physical Science as a subject is necessary in the implementation of environmental education.

- **Interviews**

Interviews are seen as a two-way conversation in which the researcher aims to see the world through the eyes of the participant, thereby gleaning rich, descriptive data that helps to understand the participant's construction of knowledge and social reality (Yin, 2009:107). Semi-structured interviews were conducted with different participants involved in the monitoring activities. Those interviewed included the technical staff of the NWU (Vaal Campus), especially Mr Burger Scholtz, to assist with the incorporation of proposals for the adaptive management of water storage resources; experts from Rand Water, notably Mrs Nyree Steenkamp who offered advice on monitoring practices; Mr Francois van Wyk who made adaptive management proposals; other non-participating students who observed the monitoring; members of campus management; and the GCI. The purpose of these interviews was to determine how these role players experienced the project and hear their thoughts on the value of water monitoring.

- **Measurement of water quality variables**

The measurement of nine water quality variables related to water monitoring, namely pH, temperature, the concentration of chloride -, nitrite- and nitrate ions, the bio oxygen and oxygen demand, the hardness of the water, *E. coli* concentration, and the physical appearance of the particular water storage resource was undertaken in this research project. The measurements were recorded by means of specific scientific processes as described in the manual by Somerset Education, the suppliers of the Water Monitoring Test Kits.

To record the measurements, field notes were made by the pre-service teachers and the researcher. These notes included details of the date and time, and readings of variables. Data collected was in quantitative and qualitative format, and was summarised in columns and worksheets prepared and formatted by the researcher. The researcher reflected on practices by noting all relevant details in a journal. Experts from

Rand Water, including Mrs Nyree Steenkamp, acted as co-observers and confirmed measurements during the field trips.

The water quality measurements conducted at the selected schools used the same water test kits and the same procedures were followed. This ensured consistency in the testing and monitoring of water. The water quality measurements focused on the physical parameters of water, namely pH, temperature, dissolved oxygen, dissolved bio-oxygen, turbidity, hardness, and the concentration of chloride-, nitrate and nitrite ions. The only biological parameter that was tested was the *E. coli* level of campus dams and the Vaal River. The measurements are simple and easy to perform with no exposure to dangerous chemicals. The researcher provided the water quality kits for the pre-service teachers to take to schools. The learners took water samples of their domestic water to school in containers provided by the researcher. Tap water available at the schools was also tested to provide information of water health at local schools. The various water samples were tested at the schools under the guidance of the pre-service teachers.

- **Observations**

Observing is a systematic process of recording the behavioural patterns of practices without necessarily questioning them or communicating with participants. Observation helps researchers to gain deeper insight and understanding of the phenomena under scrutiny and is a selective and subjective practice. Observations tend to focus on specific practices, and the researcher had to be conscious of her own biases and find ways to deal with them by being as objective as possible (Yin, 2009:109).

Photographs were taken during the water-monitoring project (MPA 2, 2015 & 2016) as part of the observation process. These photographs not only indicated the change of water storage resources as seasons change and time passes, but were also useful in making adaptive management proposals to campus management. Photographs provided another method of observing the pre-service teachers and learners while they were participating in the project and provided valuable footage on actual monitoring in educational institutes.

- **Open-ended questions**

The researcher asked the pre-service teachers to answer open-ended questions in writing, reflecting on their experience of the monitoring project, asking what they had learnt and how they had learnt it. The questions left room for them to raise any concerns

they might have had and to indicate whether they encountered any difficulties while carrying out the monitoring process. The questions enabled the researcher to determine whether individual pre-service teachers had benefited in terms of knowledge acquisition by their participation in the research project.

Similarly, the researcher asked learners (in groups of four to six learners) to reflect in writing and verbally, on their experience of water monitoring. The questions were set to give learners the opportunity to raise their own voices with regard to the monitoring experience.

- **Journal notes – water monitoring project diary**

From the outset the researcher made journal notes on the water-monitoring project to keep a record of meetings with various participants, the discussions and decisions taken and proposals made. Because the water-monitoring project was still at the emergent stage, it was important for the researcher to note the general flow of the project; her encounters with various role players and potential challenges which needed to be addressed. This journal, more appropriately called the water monitoring project diary, was an important tool used to direct the research and provided valuable information for reflection on the project.

1.6.3 Rigour in transdisciplinary research

The quality of transdisciplinary research depends on its assessment in terms of the following criteria (James, Slater & Bucknam, 2012:222 & Lang *et al.*, 2012:26), namely:

- Salience refers to the practical relevance of the results of the research (Lang *et al.*, 2012:26). The researcher is of the opinion that the results of this water quality project raised awareness of the need for water monitoring and the extent to which community-based monitoring can provoke interest and knowledge regarding environmental concerns among impoverished communities and society at large.
- Legitimacy refers to whether the chosen participants do indeed provide a sound representation of the community that is under scrutiny (Lang *et al.*, 2012:39). In this research study the NWU (Vaal Campus) was represented by the pre-service teachers; the GCI committee; and the NWU management, via the director of the university's technical services division. The local community was represented by the school learners who were studying Physical Science. Also represented were Rand

Water employees, who assisted in the validation of the monitoring practices and water quality measurements. They acted as the experts in the research process. (See Annexure G for detail on participants and the level and extent of participation.)

- Authenticity, as applied to a research study, is explained by James *et al.* (2012:222) as having four primary characteristics, namely: (a) Fairness, which refers to a consideration of all the sides and possible interpretations of the situation. In this particular study, several notions and opinions were weighed up, including those of the researcher and the pre-service teachers and Grade 10 learners (as citizen scientists); the GCI committee (as a concerned partner to environmental management of the NWU's Vaal Campus); and Rand Water (as the organisation with the expertise in water monitoring). (b) Ontological authenticity, which refers to the positive internal and external outcomes of the project. The researcher envisioned that outcomes of this research study had significant positive connotations. (c) Educative authenticity indicates that people with disparate ideas are able to relate to and understand opposing viewpoints. This research study complied with educative authenticity because the researcher and pre-service teachers were cognisant of adhering to prescriptive scientific methods in collecting the data; and importantly, findings were confirmed by experts from Rand Water. This verification of the credibility of data ensured that educative authenticity was achieved. (d) Catalytic authenticity refers to studies where research outcomes stimulate action towards the wellbeing of all – in other words, the wider picture is positive on a larger scale. In this research study the gains included the empowerment of pre-service teachers and the Grade 10 school learners; it was posited that the initiative raised awareness of water quality and indicated that there are relatively simple methods to ensure positive improvement of water quality.

Regarding the multiple case studies and quantitative monitoring data the following criteria were met:

Quantitative findings

- Construct validity was ensured by using multiple sources of evidence during data collection such as documents, interviews and observation techniques – and by reviewing the report in the light of the recommendations of experts from Rand Water and academic study leaders.

- Internal validity was achieved during data analysis by practising explanation building and by using tables and graphs to represent the monitoring data. Regarding the interviews and questionnaires, questions were reviewed by study leaders to ensure that accurate yet rich and descriptive data emerged.
- External validity was achieved by gleaning accurate descriptive data not only of the study field but also of the varied experience of the participants.
- Reliability was achieved by means of scientific data collection techniques. Case study protocol was applied and a case study database was developed with the parameter data in columns and graphs (Yin, 2009:41 and 114). Reliability was also enhanced by maintaining a chain of evidence and by comparing data from different months and seasons. By including experts from Rand Water as co-observers to confirm measurements made by participants and to trace the chain of evidence, reliability was ensured. (Yin, 2009:123).

Qualitative findings

Trustworthiness in qualitative research includes: credibility, transferability, dependability and confirmability (Mills, 2007:85).

- Credibility refers to the degree to which data makes sense and is relevant to readers of the report (James *et al.*, 2012:217). In this research study credibility was by a prolonged engagement and persistent observation efforts in the study field. The researcher, acting as a full participant, working and reporting collaboratively with other role players increased credibility. The reflective action and constant comparison of collected data, as well as member validation of data, also heightened credibility.
- Transferability indicates whether sufficient information is available to judge whether findings are indeed applicable to other settings. In this study, detailed descriptions of settings and processes were provided to assist the researcher in making this judgement call (Ebersöhn, Eloff & Ferreira, 2007:134).
- Dependability refers to the degree to which the readers can be convinced that the findings reached and reported are dependable, i.e. did indeed occur and have been accurately transcribed (Ivankova, Creswell, & Plano Clark, 2007:297). In this research study dependability was achieved by cross checks carried out by pre-service teachers who worked in pairs and confirmed each other's findings. The

researcher and the experts from Rand Water confirmed the pre-service teacher's findings. Furthermore, the researcher discussed salient themes (in the form of open-ended questions) with pre-service teachers to ensure that their findings were accurate and dependable. In addition, the researcher compiled an accurate and detailed report on how the school learners experienced the monitoring experiments and this report was sent to the schools that participated and the Department of Education. Data was triangulated during the research process, i.e. the results from interviews, journal notes, photographs and open-ended questions were integrated to provide reliable findings. Bias was eliminated by constantly reflecting interactively on the research process.

- Confirmability refers to the use of self-critical methods (Ebersöhn *et al.*, 2007:134). In this study, reflective practices were a crucial component of transdisciplinary research. The researcher reflected by using the journal notes to compare monitoring activities. The response of the pre-service teachers to open-ended questions was discussed with them and this reflection on previously answered questions became a tool to confirm that their answers were indicative of their real experience. Interviews with experts from Rand Water and the members of the technical services division of the NWU (Vaal Campus) were used to reflect on the monitoring process.
- Trustworthiness was achieved in this research study by using: (a) multiple collectors of data, namely the pre-service teachers and school learners; (b) using multiple methods of data collection such as observation, interviews, document analysis, journal notes and photographs; and (c) crystallisation which promoted a deeper understanding of a variety of diverse views on water monitoring and citizen science (Nieuwenhuis, 2007:81).

1.6.4 Data analysis

Data analysis was performed from an interpretive paradigm where an inductive data analysis enabled the researcher to identify the multiple realities potentially present in the data (Maree & Van der Westhuizen, 2007:37). The data collected in this research study required continuous review to allow for the development of new techniques and analytical concepts. Multiple cycles of analysis and reflection were proposed. The data from multiple viewpoints was collected and the researcher looked for meaning, context, historical aspects and causal relationships (James *et al.*, 2012:110).

The following analytic techniques were utilised:

- Qualitative: pattern matching using evidence from the open-ended questions and interviews to indicate personal experience of participations (Yin, 2009:136) and data transformation to quantify the qualitative data (Yin, 2009:141).
- Quantitative: explanation building by compiling graphs from the quantitative data and explaining the influence of seasons and campus activities on the dams; and analyses of data were seen as an on-going process in this research study because it assisted in the integration of concepts, knowledge and findings (Bergmann, Jahn, Knobloch, Krohn, Pohl, & Schramm, 2012:40).

1.7 RESEARCH ETHICS

Creswell (2009:88) indicates it is important to identify a problem that will benefit individuals who participate in the research. In other words, the research should be beneficial for others besides the researcher.

The researcher was sensitive to the following ethical guidelines raised by Creswell (2009:89-91) in that she:

- Requested permission from the acting rector (NWU Vaal Campus) for the research study to be conducted on the NWU, Vaal Campus (MPA 14.1) and applied for funding in order to extend the scope of this research study to include international collaboration (MPA 9.1);
- Was trained on ethical issues related to research in a three-hour training session presented at the NWU (Vaal Campus) and attended a workshop on submitting computer-based evidence of ethics (Info Ed) (9 and 10 June 2015);
- Gained access to Info Ed, the ethical website of the NWU, to supply the HHREC ethics committee with all relevant documents and proof of ethical conduct in this research study;
- Applied successfully for consent from the Gauteng Education Department to perform water quality measurements in schools (MPA 10);
- Secured permission to conduct research at schools by compiling consent letters to principals and teachers of participative schools (MPA 13);

- Secured permission from participants to collect and use data by compiling consent letters for learners, parents and pre-service teacher (MPA 12.1, 14.2 - 14.4);
- Identified herself to all participants and respondents, giving them information on the reasons for their selection as participants in the project, the expected benefits of the research, and how and why they were involved; and
- Declared that she has no intention whatsoever to falsify findings or invent findings to suit her own needs.

Furthermore, the researcher also indicated that she plans to release the findings of this research study in detail so that other researchers in the same and allied fields are able to determine the credibility and merit of the study.

1.8 SEQUENCE OF RESEARCH

This research process is organised in 8 chapters. After the introduction, the following summary indicates the heading and content per chapter.

Chapter 2: The link between citizen science, environmental education and water quality management in a water monitoring project

The relevance of citizen science and community-based monitoring to promote learning are discussed in this chapter. Types of community-based monitoring, as well as the advantages and challenges when performing community-based monitoring, are highlighted. The different types of environmental learning and how they were applied in this study are emphasised, with the focus on social learning. The project-based teaching approach, to educate sustainable development at educational institutions, is highlighted.

Chapter 3: Empirical research and the water monitoring project

The empirical research design is discussed in Chapter 3. The level of participation as well as the complex nature of water quality determined the choice in research design, methodology and strategy.

Chapter 4: Interpreting the views of participants in the water monitoring project

This chapter aims to display the qualitative empirical data revealed by the research. The experience of various participants was revealed, specifically that of pre-service teachers

and Grade 10 learners. The focus of Chapter 4 is on the social learning experience of participants.

Chapter 5: Water quality monitoring and adaptive management at the NWU (Vaal Campus)

This chapter elucidates the concepts of water quality monitoring and adaptive management. In the first part, the quantitative findings of the water storage resource are presented in a scientific report, indicating to interested and affected parties the water quality status of NWU (Vaal Campus) dams and the bordering Vaal River.

Proposals are made regarding environmental practices of the dams of the NWU (Vaal Campus) to promote water health. The relevance of the water quality monitoring and adaptive management for a university campus is highlighted.

Chapter 6: A citizen science framework for water quality monitoring

This chapter focuses on the design of a system of citizen science to implement at a tertiary teaching institution and in local high schools. This framework refers to various theories and opinions and includes primary concepts used to promote citizen science, namely community-based monitoring, social and environmental learning, a project-based learning approach and water quality and adaptive management. The framework was implemented at the NWU (Vaal Campus) and at local, secondary schools and assessed accordingly.

Chapter 7: Design of a tiered citizen science project system framework

In this research, a higher education institution (university), a university campus and local schools form a educational system. This chapter focuses on the design of a water quality monitoring and management system to include all three levels. The proposed system includes needed components, part of a monitoring project, and indicates challenges designing a systems framework.

Chapter 8: Operationalising environmental education through citizen science: findings, challenges and recommendations

This final chapter includes possible recommendations when proposing citizen science as part of community-based water monitoring to enhance environmental education. The

conclusion indicates the contribution of this research study regarding the implementation of the citizen science framework which was tested, to water quality monitoring and management at educational institutions in South Africa.

1.9 CHAPTER SUMMARY

Chapter 1 revealed the relevance of proposing a community-based water monitoring project in South Africa as part of pre-service teacher and school curriculum. The outline of the research project as well as the research methodology provided guidance to plan the study and indicates the flow of activities when proposing a community-based water monitoring project. In Chapter 2 the relation between community-based monitoring as part of citizen science, environmental education and adaptive management, as indicated by previous research studies, are discussed.

CHAPTER 2

THE LINK BETWEEN CITIZEN SCIENCE, ENVIRONMENTAL EDUCATION AND WATER QUALITY MANAGEMENT IN A WATER MONITORING PROJECT

2.1 INTRODUCTION

A study in 2010 by the Council of Scientific and Industrial Research (CSIR) indicated that human activities affect water quality. Most of the metropolitan areas of South Africa are located on the watersheds of river catchments. The rivers draining from these watersheds have a dual burden: to supply water and transport waste material. The latter process adds to progressively contaminated water sources downstream that again have implications for water quality (CSIR, 2010:8).

During 2016, the South African media highlighted the critical state of wastewater treatment works in South Africa. South Africa produces 5,4 Megalitres of raw sewage per day. Only 1,4 Megalitres of this is treated correctly and according to legal requirements. The other 4-milliard litre flows as untreated sewage into dams and rivers (Steyn & Cilliers, 2016). The current drought conditions that have prevailed since 2012 have been responsible for making the concentration of untreated sewage in water sources higher than normal (Hartleb, 2016). Monitoring the country's water quality logistically is a difficult task (Hartleb, 2015). The number of monitoring points and the quality of monitoring samples delivered to a single laboratory for testing raises serious concerns. Resolving infrastructural problems regarding water management will require a great deal of political will and money (Hartleb, 2015). A project which supports water monitoring at the community level with the support of volunteers, seems to have the possibility of filling a sorely-needed gap in current practices.

Attempting a water monitoring project to indicate the experience of citizen scientists exposes a variety of new concepts. In order to indicate the sequence of discussions and links between concepts the following conceptual framework is proposed by the researcher.

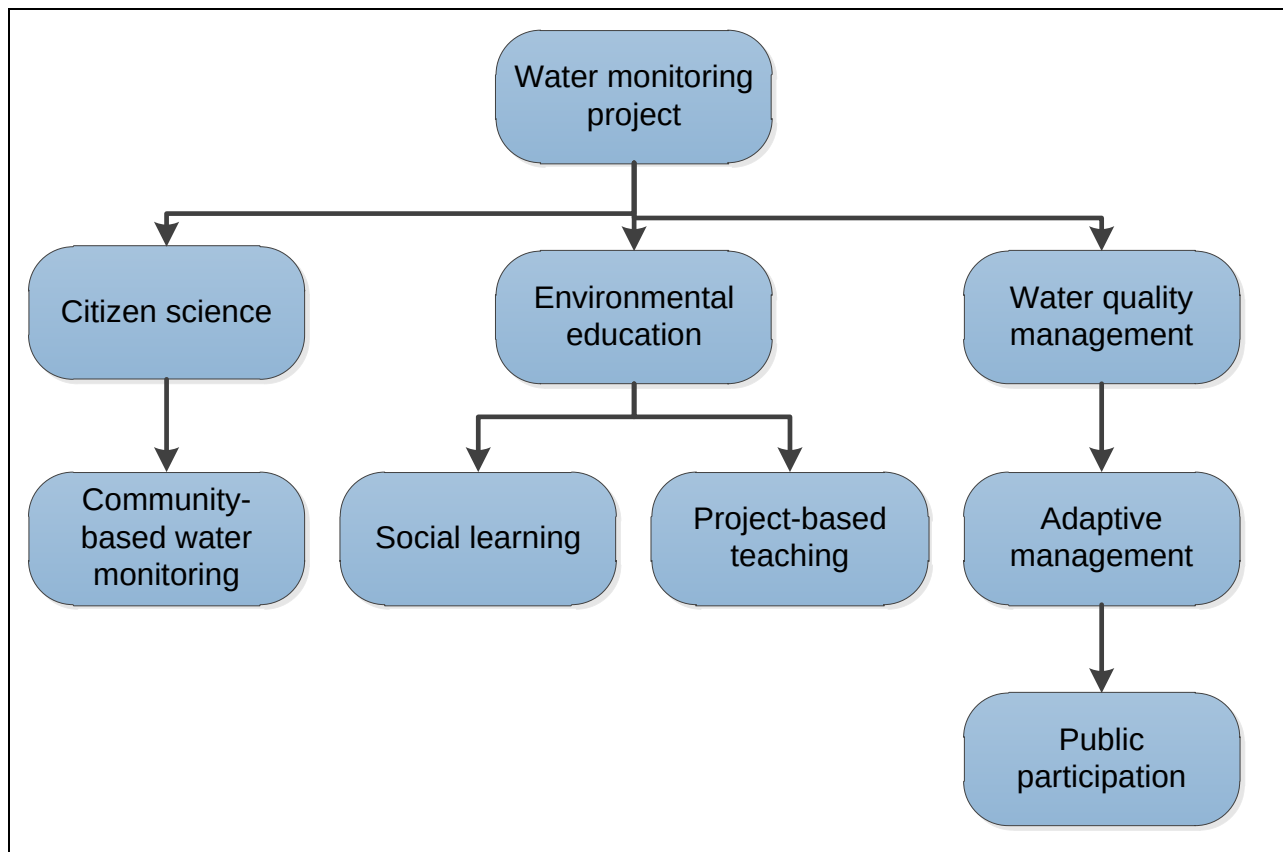


Figure 2.1: Conceptual framework of relevant concepts in a community-based water monitoring project

Firstly, the concept of citizen science is discussed as relevant to community-based water monitoring. Secondly, the concept of environmental education in the South African context with special reference to social learning and project-based teaching is dealt with. Finally, water quality management and the relevance of adaptive management of water sources and public participation are discussed (cf. Figure 2.1).

2.2 CITIZEN SCIENCE

Citizen science is a relatively new subject of interest in the field of environmental management. The work of citizen scientists is seldom published in conventional academic journals. Instead, there are lively research activities on citizen science websites, social media and even a number of non-academic articles (Conrad & Hilchey, 2011:273). Resources of this nature have been referenced in this study. Studies of citizen science in Canada and the USA are well documented (Conrad & Hilchey, 2011:275; Pollock & Whitelaw, 2005:212; Savan *et al.*, 2003:563). An increase in public knowledge about environmental matters as well as concern about the impact of humans

on the natural ecosystem leads to an increased interest in citizen science (Conrad & Hilchey, 2011:274).

In the next sections the following are discussed: the concept citizen science; the relation between citizen, civic and community science; current practice regarding citizen science in relation to the water monitoring project; and the motivation for engaging in a citizen science project.

2.2.1 Citizen science defined

Citizen science is described as a process in which members of civil society (citizens) become actively involved in science as researchers (Buytaert & Zulkafli, 2014:3; Whitelaw *et al.*, 2003:410). These ‘scientists’ are literally novices, but are notable for their keen interest in scientific matters. The data gathering objectives and protocols are established by scientists or science research managers, while citizen scientists who gather data are usually not involved in planning the research or analysing and interpreting the results (Conrad & Hilchey, 2011:274; Fernandez-Gimenez *et al.*, 2008:2). From a scientific perspective, citizen scientists can therefore play a valuable role as ‘unattached’ or ‘independent’ participants in the process of data gathering.

The concept of citizen science originated in the United States of America and refers to the collection of large-scale data in the fields of ecology and conservation. In Europe, the term describes a philosophy of engaging public perspectives and knowledge in a science discourse. Terms like *volunteer biological monitoring* and *participatory monitoring* are relevant in citizen science (Shirk *et al.*, 2012:29).

Citizen science also goes by the name of *community science* and includes *community-based monitoring* as an approach where concerned citizens, industry, academia, community groups and local institutions collaborate to monitor, track and respond to environmental issues (Buytaert & Zulkafli, 2014:3; Kruger & Shannon, 2010:462).

The different terms used in citizen science distinguish the amount of power given to participants. *Civic science* involves citizens who have knowledge that is often inaccessible to scientists using traditional methods (Potschin & Haines-Young, 2006:165). Civic science therefore opts for the infusion of culture in science and the empowerment of society through direct and constructive involvement in science (Savan *et al.*, 2003:563).

Community science is more inclusive than citizen science and more radical than civic science. Carr (2004:841) explains that community issues drive citizen science issues. Community science refers to the interaction between conventional or professional science with community-based or volunteer scientific knowledge. Community science shares features with participatory research, such as including the community to gather data, but it also empowers community members as full partners in all aspects of the research process (Fernandez-Gimenez *et al.*, 2008:3).

For the purposes of this study, citizen science is evident in the involvement of pre-service teachers and Grade 10 Physical Science learners at secondary schools in the water monitoring project. The reason for using citizen science in this research study is motivated as follows: The notion exists that the pre-service teachers and learners will benefit from gathering data on water sources in local communities. Participation in the water monitoring project could enhance their general knowledge of water as a natural resource and provide both pre-service teachers and learners with the skill to perform water quality measurements. The researcher, with the aid of a specialist community-based scientist from Rand Water, a regional bulk water utility operating in five South African provinces, decided on the monitoring method and the specific water test kit to use. The pre-service teachers analysed the data they gathered from campus water sources and presented their analysis at a Teaching Practice Symposium in October 2016 (MPA 7.1 (2015.10.26)). The researcher and the Rand Water specialist checked and validated their findings (MPA 3.1 (2015.05.08)). The pre-service teachers and learners therefore gathered the data, but were not involved in the planning of the research project. The researcher is of the view that involving pre-service teachers and Grade 10 Physical Science learners in the collection of data will inspire participants to become scientific researchers in the future.

An element of civic science, which is acknowledged in this research, is the infusion of culture in science. The researcher accepts that some pre-service teachers and learners were probably exposed to African water mythology narratives at school or home (MPA 1 (2015.02.20)). The relevance of this infusion of culture is discussed in this chapter under social learning and indigenous knowledge (*cf.* 2.3.2.7).

In essence, the researcher is of the opinion that citizen science could be synthesised as the incorporation of ordinary citizens in the collection of data for scientific research.

Their level of involvement determines the impact and experience of participants in citizen science projects.

In the next section, current practice on citizen science is discussed.

2.2.1.1 Current practice of citizen science – globally and nationally

Wikipedia lists 135 active citizen science projects of which the longest running, the National Weather Service, began in 1890 (Wikipedia, 2016). According to this list only one such project had its origin in Africa, namely MammalMAP from the Animal Demography Unit (ADU) at the University of Cape Town. The United States of America (USA) dominates citizen science with the most projects initiated on a national and global level (Wikipedia, 2016). Buytaert & Zulkafli (2014:6) indicate that currently 1 800 volunteer water quality monitoring programmes are running in the USA.

Individuals, universities and global organisations initiate citizen science projects (Buytaert & Zulkafli, 2014:4). New developments such as inexpensive and robust sensors, new information and communication technologies like cellular networks and the internet, all provide for a more dynamic and interactive approach to citizen science (Buytaert & Zulkafli, 2014:3). The organisation Earth Echo serves as an example on how to use the internet in citizen science. Earth Echo is an international, non-profit organisation that aims to inspire young people to act for a sustainable future (Earth Echo, 2016). It promotes interactive technology to log in water quality data via a website in their project called World Water Monitoring Challenge. The researcher has logged data collected during the NWU water monitoring project onto the Earth Echo website. This initiative makes the project part of a global initiative, which involves 142 countries and about 71 000 water bodies (Earth Echo, 2016).

In South Africa most citizen science projects are linked to biodiversity. In 2012 Barnard and De Villiers compiled a guide under the mantle of the Department of Environmental Affairs (DEA), the South African National Biodiversity Institute (SANBI) and the Animal Demography Unit (ADU) of the University of Cape Town. ADU is the driving force behind most of the prominent citizen science initiatives in the country. So-called virtual museums are created where anyone may contribute photographic footage about animals. ADU has its roots in ornithology and bird-related citizen science initiatives. These include the South African Bird Ringing Unit; Coordinated Waterbird Counts;

Coordinated Avifaunal Road Counts; the Southern African Bird Atlas Project; and My Birdpatch. ADU's flagship website is the MammalMap website where photos of mammals, their distribution and habits may be added by members of the public (South African National Biodiversity Institute, 2016).

The Natures Valley Trust (NVT) is an example of a South African regional community supporting national initiatives of citizen science. Projects supported by NVT include the African Raptors Databank (ARDB); the Coordinated Waterbird Counts (CWAC); iSpot, a virtual website aimed at the identification of various life groups, including plants; the ADU Virtual Museum; Birds with Odd Plumage (BOP); the Southern African Frog Atlas Project (SAFAP); and the Southern African Butterfly Conservation Assessment (Lepimap) (NVT, 2016).

The monitoring of physical aspects of natural resources in South Africa is reported in a less significant way. Water monitoring is addressed by MVULA Trust, South Africa's leading rural water and sanitation non-governmental organisation. The MVULA report, *The potential of civil society organisations in monitoring and improving water quality* (Munnik *et al.*, 2011:1) indicates that no large-scale citizen science monitoring on physical aspects exists in South Africa. Examples of citizen participation can be found in catchment management forums and civil society water quality campaigns (Munnik *et al.*, 2011:2). The report points out that citizen science has the ability to contribute to high-quality data and valuable local knowledge as well as raising awareness and therefore promotes public water education (Munnik *et al.*, 2011:10). National programmes that use volunteers are the Adopt-a-River initiative, and the Working for Water and Wetlands projects (CWP) (Munnik *et al.*, 2011:10). The MVULA report indicates that citizen monitoring is an untapped and potentially valuable area in South African water quality monitoring (Munnik *et al.*, 2011:10).

Other South African studies include that by Rivett *et al.* (2012:409) who investigated the use of a cellular phone-based information system in South Africa. Participants, typically borehole operators, submit reports on pH, turbidity and conductivity of groundwater supplies in boreholes (Rivett *et al.*, 2012:413). Tandlich *et al.* (2014:46) reported on the monitoring of rain water quality in the Eastern Cape. In this initiative, eight volunteers used a hydrogen-sulphide test kit to detect microbial contamination in rainwater (Tandlich *et al.*, 2014:48). Mark Graham, a director of Groundtruth, a multidisciplinary environmental company that performs a diverse variety of environmental assessments,

initiated a water monitoring project in Mpophomemi, KwaZulu-Natal. He shows that effluent draining from the settlement causes eutrophication of the Midmar dam. The Mpophomemi Sanitation Education Project (MSEP), which started in 2011 focused on sanitation and toilet etiquette, biodiversity and environmental health as well as the monitoring and reporting of sewage spills. Graham sees education as a force in citizen science that should be harnessed (McLouglin, 2015).

Because of the remarkably lively field of water-related monitoring in South Africa and the number of projects dealing with water-related citizens' science activities, the researcher is of the opinion that the current NWU-based project has substantial prospects. Moreover, involving pre-service teachers in a citizen science project will be a first in South Africa.

Recently some South African school learners were involved in a citizen science mini-stream assessment scoring system (SASS) project. SASS was run in Hilton, KwaZulu-Natal and used the composition of macro-invertebrates as an indication of water quality (Matthews, 2014:13). The latest initiative launched by miniSASS is an app for smartphones which allows volunteers to access and upload data to the miniSASS database to improve the service delivery of water (McLouglin, 2015). It is therefore apparent that a citizen science water monitoring project such as the current study, which focuses on the collection of physical data and the experience of both pre-service teachers and school learners, may close the gap in contemporary citizen science practice in South Africa.

Various researchers provide their motivation on why volunteers are prepared to engage in citizen science projects. Such projects offer opportunities to volunteers to become part of the scientific process (Conrad & Daoust, 2007:359). Volunteers tend to have a broader input in local decision-making (Buytaert & Zulkafli, 2014:4; Conrad & Hilchey, 2011:280). Citizen science projects display the diversity of ecological systems and the practices of local people who depend upon such systems for their livelihood. It is argued that citizen science involvement also helps volunteers to cope with natural crises and phenomena such as climate change (Buytaert & Zulkafli, 2014:4). Involvement in a project such as this also helps volunteers to garner innovative skills and increase their local knowledge (Woolley *et al.*, 2010:686).

Professional scientists and researchers, in turn, engage in citizen science projects to promote education and conservation or to improve societal conditions (Macknick & Enders, 2012:377).

Locally, as an added advantage, the South African Environmental Observation Network (SAEON) (Pauw, 2009) has indicated that the outcomes of citizen science could be used to generate revenue. Apart from the adventure of working as part of a team in a science project, volunteers gain experience and/or knowledge when participating in citizen science initiatives (Pauw, 2009). To the best knowledge of the researcher, the participation of school learners and pre-service teachers in a citizen science project to measure physical water quality variables, is the first to be reported in South Africa. In the next section, important components of a citizen science project are addressed.

2.2.1.2 Aspects of a citizen science project

The intentions of a citizen science project are usually altruistic, but the following aspects need attention to ensure a sustainable project. Volunteers must be trained in the collection of data. Once-off training is often not enough and repeated training improves the quality of the collection of valid data (Whitelaw *et al.*, 2003:412). Volunteer motivation is dynamic and changes over time so it is important for the researcher(s) to communicate regularly and provide feedback on the project to the participants and non-participating community (Rotman *et al.*, 2014:111). The design of any citizen science project must adhere to the objectives of the particular project regarding knowledge and gained benefits (Shirk *et al.*, 2012). Data collection, interpretation, use and integration of findings that influence local decision-making and environmental planning need special attention (Conrad & Daoust, 2007:359). Another aspect to consider is the funding of a citizen science project and this involves close examination of the possible impact and sustainability of the project in a local community (Conrad & Hilchey, 2011:281). The safety, security and health of volunteers are a concern. This implies screening the volunteers for physical fitness purposes and making sure that indemnity forms are duly signed. In other words, planning a citizen science project must include protective and back-up measures (Pauw, 2009). The relevant local authority that stands to benefit from the findings of the project, must of course be included in discussions during the planning phase (Conrad & Hilchey, 2011:283).

Various frameworks such as the scientific consulting research framework; the citizen science framework; and the participatory action framework, indicate the approaches to be followed in citizen science projects (Cooper *et al.*, 2007). The scientific consulting research framework was developed in the Netherlands in the 1970s and sees university researchers as consultants who aid communities with empowerment to answer scientific problems (Cooper *et al.*, 2007). The citizen science framework incorporates volunteers to assist professionals in research to collect data. The researcher and not the volunteers (Cooper *et al.*, 2007) usually raise the problem that needs to be addressed. The participatory action research framework starts with the interests of participants, who work collaboratively with researchers to find answers to communal problems (Cooper *et al.*, 2007).

Buytaert and Zulkafli (2014:6) indicate that the level of engagement, as well as the building of social capital and incorporation of adaptive management principles, determines the choice of framework. It is evident that there are diverse frameworks that can be used. The researcher aimed to design a citizen science system suited to the objectives of this particular water quality monitoring project and therefore incorporated input from various current frameworks. Initiating a framework for a unique context such as a university campus and involving a natural resource like water, called for a creative approach. Most frameworks suggest that the initiating point of citizen science projects should be the purpose or role of the participants.

In the next section the concept of monitoring and how it relates to citizen science are discussed.

2.2.2 Monitoring and community-based monitoring

Monitoring is generally defined as the long-term, standardised measurement and observation of the aquatic environment in order to define status and trends (World Meteorological Organisation (WMO), 2013:9).

Stem *et al.* (2005:297) suggest monitoring has four purposes, namely:

- Basic research, which is the gathering of knowledge to gain better understanding of a specific topic;
- Accounting and certification to indicate whether a project is fulfilling its obligation to different stakeholders;

- Status assessment, which monitors the condition or status of a conservation entity; and
- Effective measurement, which is linked to interventions used by specific actors. Effective measurement is divided into two groups, namely impact assessment and adaptive management. Impact assessment is performed once a project is completed to determine how well it performed. Adaptive management is an interactive process which involves the integration of project design, management and monitoring to examine interventions to adapt and learn in a systematic manner (Salafsky *et al.*, 2001).

In this study, community-based monitoring was used in practice, namely *community-based monitoring* as a process whereby concerned citizens, government agencies, industry, academia and community groups collaborated to monitor, track and respond to common community concerns. Community-based monitoring implies the direct, active involvement of the local community in monitoring, either by participating in monitoring efforts or by training of local workers to carry out the monitoring process (Conrad & Hilchey, 2011:275).

Conrad and Hilchey (2011:275) reported that monitoring intent differs in various parts of the world. In North America, environmental quality monitoring is predominant, whereas in Europe biological species monitoring is more common. Universities have an intricate relationship with community-based monitoring groups due to laboratory facilities, available free space and funding (Conrad & Hilchey, 2011:275).

University-community partnerships are found in the USA and Canada. Savan *et al.* (2003:563-565) reported on the Citizens' Environment Watch of Toronto University in Canada. These researchers concluded that staff resources, stable funding and sound partnerships with other role players contributed to the success of the programme. Conrad and Hilchey (2011:285-288) compared twenty Canadian community-based monitoring initiatives, of which five were linked to universities. The initiatives were compared in respect of monitoring activities, governance structure and influence on conservation. The researchers concluded that community-based monitoring has a positive impact on society. Conrad and Hilchey (2011:288) call for more research on the success of programmes, how obstacles are overcome and how decision-makers use the available data.

Monitoring may differ in terms of focus, approach or technique. Community-based monitoring can be commodity-based or non-commodity based. Commodity-based monitoring deals with economic issues alongside social and environmental issues like resource fishing. In contrast, non-commodity based monitoring focuses on issues that may not seem to be directly of economic importance such as recreational fishing (Conrad & Hilchey, 2011:275). Water quality is the most monitored variable and is defined as non-commodity based monitoring (Conrad & Hilchey, 2011:276).

Both Whitelaw *et al.* (2003:411) and Conrad & Daoust (2007:360) point to four approaches to community-based monitoring:

- Top-down approaches are projects initiated by government. This approach ensures early detection of ecosystem changes. It includes expert investigation as well as long-term database sets with value to both government and citizens.
- Interpretive approaches aim to get citizens involved in environmental problems and educate them about the environment. This approach facilitates effective communication and contributes to conservation, providing personal learning opportunities and helping to promote participants' long-term commitment.
- Advocacy monitoring or bottom-up monitoring occurs when a group concentrates its efforts in an area of concern in the hope to spawn action and affect decision-making. The objective of advocacy monitoring is to move beyond data collection and public education to action and advocacy. This approach is not reliant on government support and focuses on local issues like water and human health.
- Multiparty monitoring, a form of collaborative monitoring, involves all interested stakeholders. It is a multi-tiered approach where a number of citizen groups try to influence decision making. Multiparty monitoring fills gaps in existing monitoring arrangements and aims to increase cooperation. It involves many individuals who have different interests and forms of expertise in the design and implementation of monitoring (Fernandez-Gimenez *et al.*, 2008:2).

Universities can play a collaborative role in community-based monitoring. The contribution of universities can vary from training of volunteers; analysis of samples in laboratories; as well as interpreting and reporting of findings. University personnel serve as expert advisors, facilitators, trainers and encouragers to motivate students to take

part. Aid from universities in the form of available free working space, internet access and funding enhance environmental monitoring (Savan *et al.*, 2003:561, 567).

A synthesis of the theory on monitoring and community-based monitoring reveals that monitoring is a checking activity used to determine the status of natural resources. Involvement of pre-service teachers of the NWU (Vaal Campus) and Grade 10 learners in a multiparty, collaborative monitoring citizen science project was a tangible example of institutional commitment to community service. This approach acknowledges that pre-service teachers and Grade 10 learners have different interests and expertise when participating in the water monitoring project. A multiparty, collaborative monitoring project exposed both pre-service teachers and Grade 10 learners to interaction with other role players such as members of campus management and Rand Water officials. The pre-service teachers and Grade 10 learners were responsible for the measurement of water quality variables, which meant that they gained knowledge and practical skills. The NWU (Vaal Campus) monitoring project also provided the opportunity for generating interpretive information on how participants benefited from personal learning opportunities.

The next section addresses the second part of the conceptual framework, namely environmental education, social learning and a project-based teaching approach.

2.3 ENVIRONMENTAL EDUCATION

Environmental education (EE) is a polysemous term that cannot be reduced to a simple, fixed meaning. Globally, most of the formal development regarding EE has been directed by international agencies like the United Nations Educational, Scientific and Cultural Organisation (UNESCO) and the United Nations Environmental Programme (UNEP) (Reddy, 2011:14). A UNESCO conference on environmental education held in Tbilisi, Georgia, USSR in 1977 laid down principles for EE in general, which are still relevant today (Le Grange, 2002:84).

A more recent concept in EE, education for sustainable development (ESD), received attention in 2002 at the World Summit on Sustainable Development. Delegates called for the UN to convene a deal for environmental academic development by emphasising the key role education has to play in environmental protection and social development. In 1987, the World Commission on Environment and Development (WCED) in its report

Our Common Future focused on sustainable development and the term was coined. The Conference on Environment and Development, held in Rio de Janeiro in 1992, as well as its successor, the World Summit on Sustainable Development, held in Johannesburg in 2002, propelled Education for Sustainable Development forward. In December 2002, the United Nations passed Resolution 57/254 which declared a Decade of Education for Sustainable Development starting in 2005 (Jickling & Wals, 2008:4).

Brundiers *et al.* (2010:310) indicate that Education for Sustainable Development incorporates the following key competency clusters namely: (a) a strategic knowledge cluster that includes content and methodological knowledge about the sustainability problem or challenge; (b) a practical knowledge cluster that indicates the hands-on experience to put knowledge into practice; and (c) a collaborative cluster that involves competencies to work in teams and in different knowledge communities.

A research study by Hungerford (2009:3-4) evaluated the current state of environmental education for the 21st century. Hungerford (2009:2-4) made the following deductions: Environmental education is an interdisciplinary effort aimed at helping participants gain knowledge and skills. Environmental education enables participants to understand complex environmental issues in society as well as being able to deal effectively and responsibly with salient issues on the environment. Responsible behaviour, as taught through environmental education is a complex relationship of attitudes, knowledge, cognitive skills and psychological character. Any world citizen who uses information and educational processes to help other to analyse the merits of many and varied points of view on a given environmental issue, is an environmental educator. Environmental educators are skills developers and information analysts who prepare people to participate in environmental decision-making. Environmental education involves teaching participants about the environment rather than making responsible citizenship decisions concerning the environment. Hungerford supports the notion of this research project where teaching pre-service teachers and Grade 10 Physical Science learners about water quality took preference over the deduction of critical decisions regarding problematic water challenges.

2.3.1.1 Environmental education defined

Sauve (2002:2) defined environmental education as an essential dimension of basic education that lies at the root of personal and social development: the sphere of relationships with our environment, with our “common home of life”. This definition is compatible with the notion of the research study which is to focus on the personal experience of pre-service teachers and Grade 10 Physical Science learners participating in a water monitoring project. The key competencies put forward by Brundiers *et al.* (2010:310) suited the objectives of the NWU (Vaal Campus) monitoring project, namely to promote the content and social knowledge of participants and enhance their practical skills. Given the conceptualisation outlined above, the researcher concludes that environmental education is a complex concept which evolves with the quest for sustainable development and the responsible use of natural resources. This research project provided learning opportunities for pre-service teachers and Grade 10 school learners in this regard. Positive aspects were the collaboration between the various groups of participants, the learning of subject content and the development of practical skills of relevance to environmental education.

2.3.1.2 Development of environmental education in South Africa

Environmental education was initially not part of the formal school curriculum and was largely driven by non-governmental conservation organisations and individual teachers. Organisations like the Environmental Education Association of Southern Africa (EEASA) adopted and advanced the agenda to introduce environmental education into formal education curricula (Reddy, 2011:15). In 1989, the White Paper on environmental education was the first formal attempt to include environmental education in the school curriculum (Le Grange, 2002:84). The Environmental Education Policy Initiative (EEPI) introduced a participatory policy-making process on environmental education just prior the first democratic election (Lotz-Sitsitka, 2002:101). The Education White Paper of 1995 saw this policy process emerge into a curriculum process. The principles of the Tbilisi Declaration of 1977 are regarded as fundamental for environmental education in South Africa. Guiding principles from the Tbilisi Declaration were included in the Government White Paper (March 1995) as follows:

Environmental education, involving an inter-disciplinary, integrated and active approach to learning, must be a vital element of all levels and

programmes of the education and training system, in order to create environmentally literate and active citizens and ensure that all South Africans, present and future, enjoy a decent quality of life through the sustainable use of resources (Principle No. 20:22, RSA, 1995).

The Environmental Education Curriculum Initiative (EECI) lobbied policy makers to give attention to environmental education. The EECI is a state-civil society partnership project, which enables the Department of Environmental Affairs and Tourism (DEAT), provincial government education departments and environmental education practitioners to make inputs into Curriculum 2005 (Lotz-Sitsitka, 2002:99). Environmental education was introduced in 1997 for the first time into the formal school curriculum when the Revised National Curriculum Statement (2002) underpinned the principles of social and environmental justice, human rights and a healthy environment (Reddy, 2011:15).

To infuse environmental education into school curricula has its challenges. Another new curriculum was initiated for South African schools in 2006 with the planning of the Curriculum and Assessment Policy Statements for subjects (Reddy, 2011:16). However, major obstacles encountered include the capacity of teachers to implement environmental education content in the curriculum; the lack of necessary skills and attitudes of teachers; and the challenge of introducing a sustainable discourse into curricula and pedagogical practices (Reddy, 2011:11). According to the researcher, the deliberate inclusion of environmental education in the training of pre-service teachers in Physical Science has the potential to provide these student teachers with the attitude and skills necessary to teach environmental education in their own classes in the future.

The question arises: Why is environmental education so important in teaching and learning?

2.3.1.3 Implementing environmental education

Historically, little or no attention was given to environmental education in teacher education programmes in South Africa (Reddy, 2011:17). According to Reddy even current teachers are in need of professional development regarding environmental education. An initiative to train in-service teachers in environmental education was undertaken by the National Environmental Education Project for General Education and

Training (NEEP-GET) which ran from 2000 to 2002 in all nine provinces (Reddy, 2011:19). This initiative was a top-down approach by policy makers to pay attention to environmental education (Reddy, 2011:21). In contrast to this, Reddy (2011:22-23) promotes a bottom-up approach to the teaching of environmental education, where teachers are seen both as subjects and agents of change in a transformative role.

Waghid (2002:457) maintained in 2002 that South African universities should follow global trends and focus on problem-solving or applied research instead of disciplinary research. In the view of Braskamp & Wergin (1998:65) universities are challenged in their responsiveness and relevance to social needs and need to bridge the gap between higher education and societies by becoming active partners in their communities. By providing integrated teaching and research-based services grounded in knowledge production, universities can assist communities to be jointly responsible for social change (Waghid, 2002:458). Environmental education programmes provide the opportunity for universities to engage collaboratively with society at large on real-world problems (Brundiers *et al.*, 2010:311).

Le Grange (2002:83) suggests that three aspects must be addressed in environmental education – there must be education about, in/through and for the environment. Education about the environment emphasises knowledge about natural systems and processes. Education in/through the environment emphasises learners' experience in the environment as a means of developing learner competencies and values. Education for the environment has an overtly critical agenda of educational values, social change and transformation through action-based exploration and involvement in resolving environmental problems. The more recent discourse on environmental education focuses on education for sustainable development (ESD); education for a sustainable future (ESF); and education for sustainability (EFS) (Le Grange, 2002:84).

The water monitoring project accommodated all these approaches to environmental education. The expectation was that pre-service teachers and learners exposed to water research would gain knowledge about the water cycle and how natural phenomena such as drought conditions and floods, or climate change, could potentially have an impact on water quality. Therefore, the focus was on education about water. Conducting water quality measurements on water samples in nature and in classrooms helped pre-service teachers and learners to develop skills to perform practical work and to value water as a multifaceted form of matter. They were thus being educated

in/through the environment. Education for the environment was addressed when participants engaged with others to share their concerns and their knowledge about water quality. The pre-service teachers had the opportunity to reflect on their concerns and the need for knowledge regarding the campus water resources when they engaged with campus management and other students at the regular GCI meetings.

Campbell *et al.* (2010:25) indicate that school science provides pre-service teachers with opportunities to raise awareness about the impact of socio-economic and political practices on the environment, while Campbell *et al.* (2010:25) suggests that the inclusion of environmental education in the science curriculum would be a practical way of increasing the awareness of the environment among school learners.

This research project aims to use environmental education, and specifically water quality monitoring, as a process to address the gap in problem-solving research and pre-service teacher training at higher education institutions. Involving pre-service teachers and learners in the water monitoring project indicated a bottom-up approach in environmental education. Both pre-service teachers and learners were thereby empowered to act in their communities as agents of change regarding water health.

The water monitoring project is in accordance with the following principles of the Tbilisi Declaration regarding environmental education: (a) It considered the environment in total, focusing on the social-ecological system (human-nature relationships) as a unit; (b) For all participants it formed part of a lifelong process that included formal and informal (social) learning; (c) It was also part of an interdisciplinary study linking the subject fields of Natural Science, Education Science and Environmental Management; (d) It examined local but also national and international points of view regarding water to provide insight into environmental conditions; (e) It focused on the current condition of water sources at the NWU (Vaal Campus) to provide insight into possible conditions in the future; (f) It promoted and valued cooperation between diverse groups of participants; (g) It provided both the pre-service teachers and learners with experience to make decisions and to use problem-solving skills; (h) It promoted the identification of symptoms and causes of water pollution; (i) It emphasised water as a complex chemical compound and used diverse learning environments to learn about the environment with practical activities (Tbilisi Declaration, 1977).

The next section explores the ways in which environmental education is included in the water monitoring project

2.3.1.4 Ways of including environmental education in the water monitoring project

The researcher proposed that service learning would be the vehicle to convey environmental education from lecture room to schools. Service learning is a form of experiential learning through active participation in an issue which meets the needs of a community (Phillipson-Mower & Adams, 2010:66). Characteristics of service learning that apply to the water monitoring project, include: enhancement of the academic curriculum; structured time for reflection on experience; frequent opportunities to use newly acquired skills and knowledge in a real-life scenario (Phillipson-Mower & Adams, 2010:66).

Shephard (2008:91) indicates that community service, service learning and student activity programmes all promote affective learning. Affective learning relates to values, attitudes and behaviours and involves the student emotionally (Shephard, 2008:88). Bloom, cited in Shephard (2008:88) constructs a hierarchy for the affective domain as the ability to: (a) Listen; (b) Respond in interactions with others; (c) Interact with others; (d) Demonstrate attitudes or values appropriate to particular situations; (e) Demonstrate balance and consideration; (f) display a commitment to principled practice on a daily basis, alongside the willingness to revise judgement and change behaviour in the light of new evidence.

It is possible for students to learn about a subject and be able to describe, comprehend, apply, analyse, synthesise and evaluate it without actual change in attitude or behaviour (Shephard, 2008:89). However, Shephard (2008:92) emphasises that intended change in perspective from teacher-centred to student-centeredness in pre-service teacher training is necessary to accommodate affective learning.

To address values, attitudes and behaviour to different extents in a curriculum depends on the stance of the lecturer towards complex issues (Lemkowitz *et al.*, 1996:355). Shephard (2008:93) proposes a transdisciplinary case study approach based on project-based learning that enables students to tackle real-life problems and challenges to attain affective learning. Shephard's notion convinced the researcher that this

research study should include a number of elements which emphasise the relevance of a water monitoring project based at, for example, educational institutions. The student-centred approach of the project allowed for the involvement of both pre-service teachers and learners to promote affective learning and a possible change in behaviour, values and attitude of water as a scarce, valuable, natural resource.

In the next section the concept of social learning, as linked to affective learning, is discussed in detail.

2.3.2 Social learning: Teaching-learning framework for water monitoring project

The water monitoring project was conducted in accordance with the theory of social learning. This theory includes a range of ideas which aim to explain what and how social interaction contributes to individual learning and collective learning (Blackmore, 2007:523). Theorists who have contributed to the scholarship on social learning include Bandura (1971), Freire (2005) and Wenger (1998a).

The motivation for enhancing social learning through the water monitoring project was found in the research of Osborne, Simon and Collins (2003:1060) who report that from the age of 11 years onwards, school learners tend to regard science education as a subject that is difficult to master. Other research shows that the over-emphasis on content inhibits the promotion of science literacy and that in general, science teaching in schools focuses on what is important from a scientist's perspective rather than from the viewpoint of the learner or society at large (Holbrook & Rannikmae, 2007:1349). The water monitoring project based at NWU provided an opportunity to teach scientific content that has relevance for participants and potential to benefit the community concerned.

To define social learning, the views of Bandura (1971) and Wenger (1998a) are discussed in relation to more current views on social learning.

2.3.2.1 Social learning defined

Social learning is rooted in the work of Albert Bandura (1977; 1986). Bandura (1971:1) defines social learning as individual learning that takes place in a social context and is influenced by social norms. For Bandura (1971:3) social learning implies learning

through experience. Individuals respond to experience automatically and unconsciously. Through experience, one develops thoughts which guide one's future actions. These cognitive actions then lead to insightful behaviour (Bandura, 1971:3).

The social learning theory indicates that people learn and imitate behaviours they have observed in others (Bandura, 1986:50). Bandura proposed three basic frameworks of observational learning, namely:

- a live framework, which involves demonstrating or acting out a desirable behaviour;
- a verbal instructional framework involving descriptions and explanations of a desirable behaviour; and
- a symbolic framework involving fictional characters that display behaviours for example in books, online media, films etc. (Bandura, 1986:50).

For Bandura (1971:6-9) certain frameworks aid social learning because they provide individuals (in this project, the learners and students) with symbolic representations of various activities. Four interrelated processes in these frameworks are: (a) *Attention*, which requires of the individual to recognise features of the activity. Each person has his/her own interpersonal attention and will focus on different stages or parts of an activity; (b) *Retention* which indicates how well one is able to remember the activity and reproduce it in the long-term or permanently; (c) *Motoric reproduction* which indicates the response of the individual according to the framework pattern; and (d) *Self-reinforcement and motivation* which urges the person to overt action after being exposed to such a framework.

The community-based water monitoring project supported the idea of a live framework. The aim of frame-working in the water monitoring project was to enable both pre-service teachers and learners to acquire knowledge and thereby assist them to address water quality issues in their communities. The research enabled the pre-service teachers to display all processes that form part of the framework of observational learning. Different responses by pre-service teachers to open-ended questions regarding their experiences during monitoring activities gave evidence of interpersonal interaction. Pre-service teachers repeating the monitoring activities in schools indicated a level of retention. Motoric reproduction was apparent when pre-service teachers displayed the live framework when performing water quality experiments on the university campus and in schools. Pre-service teachers had the opportunity to openly

express their concerns about water quality that indicated self-reinforcement and motivation.

Wenger supported the notion of social learning as coined by Bandura and introduced four related concepts, namely community of practice (COP), identity, learning citizenship and the landscape of practices.

Wenger (1998:1a) indicates that social learning incorporates all groups of people who engage in a process of collective learning in a shared domain of human endeavour. He refers to all these groups as a “community of practice” (COP). A COP is a social learning system. The social partnership anchors learning in a mutual engagement of five domains, namely: (a) The *discipline of domain*, which refers to what we care about; (b) The *discipline of community*, which refers to the effects of participation on the trust and dynamics of the group; (c) The *discipline of practice*, which refers to how our practice becomes visible and acceptable (d) *Discipline of convening* which refers to leadership, sustainability of partnership, the roles of participants etc.; and (e) The *social discipline* referring to the personal responsibility which comes with social participation (Wenger, 1998b:12).

Wenger (1998b:2) sees social learning as a dual, meaningful process. On the one hand, individuals engage directly in activities, thereby participating in social life. On the other hand, they produce physical and conceptual artefacts, such as words, tools, methods, documents, etc., to reflect their shared experience. Through social learning individuals create an identity. An *identity* includes all memories, competencies, events, stories and relationships one person has with other people and places. It includes a nexus of multi-membership because individuals belong to multiple communities at any given time. An identity is multi-faceted due to the sharing of experience with others in the same scenario, in society and in the world at large (Wenger, 1998b:11).

The concept of learning citizenship means the investment of identity in a particular society or community (Wenger, 1998b:14). By learning citizenship people acquire the ability to contribute to their communities and bridge boundaries by using their multi-membership. They have the ability to be involved in more than one group of participants as a trusted member. They are able to identify needs in a community and connect to others, thereby enhancing the learning process (Wenger, 1998b:14).

Knowledge consists of a *landscape of practices*, and is not only curriculum content. This landscape of practice is dynamic because communities emerge, split, compete and complement each other. Between the landscapes of practices there are boundaries. Boundaries may possibly present misunderstandings between commitments, values or perspectives (Wenger, 1998a:5). In a landscape of practice, learning can be positioned in one of three modes: (a) *Engagement* which refers to the doing of things and direct experience in activities; (b) *Imagination* which indicates the construction of an image of the world to aid understanding. These images help to locate and orientate a project; and (c) *Alignment*, which refers to the coordination of activities. Alignment is a two-way process to coordinate perspectives and to interpret actions and contexts (Wenger, 1998a:5).

In accordance with Wenger's theory, the researcher acknowledges that a unique COP was formed which consists of pre-service teachers, school pupils/learners, Rand Water officials and university personnel. Each participant in this research study had his/her own identity, which contributed to diverse and rich responses. One of the aims of the water monitoring project was met when pre-service teachers and school pupils experienced learning citizenship. The landscape of practice comprised pre-service teachers and school learners in a mode of engagement and imagination. Engagement was linked to the water monitoring activities, while imagination was displayed in the measurement of variables and interpretation of collected data. The construction of a scientific report and presentation of measurements called for imagination. The researcher who coordinated monitoring activities on campus and in schools was engaged in a process of alignment.

More recent contributions to social learning

- Keen, Bruck and Dyball (2005:4) define social learning as “collective action and reflection”, which takes place among both individuals and groups when working in social-ecological systems. Social learning must therefore demonstrate a change or understanding beyond the individuals or small groups to become situated within wider social units or communities of practice. The water monitoring project supported the practice of collective action and reflection. Both pre-service teachers and school pupils learnt from one another and reflected on their involvement in water monitoring activities by answering open-ended questions.

- Pahl, Wostl *et al.* (2007) indicate that social learning includes governance. *Governance* refers to the legal and organisational structure as well as the cultural and socio-economic environment. Social learning is impeded by centralised political and economic systems, privatisation, commercialisation of the environment and poor public access to information (Pahl-Wostl *et al.*, 2007). The water monitoring project at the NWU (Vaal Campus) addressed the governance aspect of social learning. Pre-service teachers and the researcher had the opportunity to engage with personnel of technical services and campus management during GCI meetings. These meetings served the purpose of exposing pre-service teachers to the political and economic challenges faced by campus management. The meetings also provided the pre-service teachers the opportunity to voice their concern about campus water resources and gave the campus community access to information about the research project.
- Reed *et al.* (2010) are of the view that social learning is a *process of social change* beyond the individual level in wider social context. Social change occurs when people learn from each other in ways that benefit wider social-ecological systems. The dynamic interaction between people and the environment in the construction of meaning is also emphasised. Reed *et al.* (2010) regard social learning as both a process and an outcome and indicate that social learning can improve management of social-ecological systems. Social learning can also enhance trust between diverse participants and initiate the practice of adaptive management and behavioural change. Through social learning participants are empowered and social networks and sustainable communities are strengthened (Reed *et al.*, 2010).

Social learning is a dynamic, multi-faceted concept and is linked to a changed view by participants on social-ecological systems. Participation in the water monitoring project provided pre-service teachers to engage with their lecturer, the researcher, in a more informal manner. Pre-service teachers would also share and gain knowledge from expertise like Rand Water officials and other academia, when presenting their findings at a symposium. This indicated that social learning is both a process and an outcome of this research. The pre-service teachers would engage with learners and teachers at school, other students on campus when performing water monitoring activities. Learners would engage with the researcher, the pre-service teachers, their teacher as well as their parents and community members during and after monitoring activities.

Exposure to a diverse audience would fulfil the vision of Reed *et al.* (2010) regarding social learning as a vehicle for social change. In the next section related learning types and levels of learning as relevant to social learning are explored.

2.3.2.2 Types and levels of learning as related to social learning

Mezirow (1997:5-12) indicates three types of learning. *Instrumental learning* refers to the acquisition of new knowledge and skills, while *communicative learning* indicates understanding and reinterpretation of knowledge. The third type of learning in Mezirow's theory is *transformative learning* which refers to an examination of underlying assumptions leading to change in attitudes, behaviour and social norms. In the water monitoring project, the aim was to attain all three types of learning discussed above, but especially transformative learning.

According to Pahl-Wostl *et al.* (2007) social learning occurs in three different timescale and agent interaction levels. The timescale levels are: (a) a short to medium timescale when there is interaction between collaborating participants; (b) a medium to long timescale when there is change that depends upon possible outcomes and feedback about processes; and (c) a long-term timescale when the level of change is in governance structures or other formal or informal institutions and there is a shift of cultural values, norms and paradigms.

In respect of agent interaction levels, Pahl-Wostl *et al.* (2007) refer to micro, meso and macro levels, which are interdependent. *Multilevel* change occurs in an iterative and not necessarily sequential fashion. *Single-loop learning* refers to an instrumental change in strategy and means learning about the consequences of specific actions. *Double-loop learning* refers to more radical changes in underlying values and beliefs. Reflecting on assumptions which underlie one's actions, is known as *transformative learning* which is analogous to double-loop learning. *Triple-loop learning* challenges the values, norms and higher order thinking processes which underpin assumptions and actions (Fazey, 2010).

The water monitoring project aimed to include all three types of learning as discussed above in the work of Mezirow (1997). Instrumental learning refers to gaining knowledge and skills, which pre-service teachers and learners did indeed acquire. Communicative learning was evident in the scientific reports compiled by both these groups of

participants. This was ample proof of their understanding and interpretation of the water monitoring data. It is clear that transformative learning had occurred because pre-service teachers and learners gradually changed their opinions, attitude and behaviour towards of water as a vital natural resource that is not only scarce in South Africa but is extremely fragile. Detecting transformative learning is far from easy. However, the researcher posits that open-ended reflective questions after the water monitoring activities, did indeed reveal a change in attitude and behaviour of the participants towards water.

The timescales proposed by Pahl-Wostl *et al.* (2007) are interpreted for this water monitoring project as follows: In the short to medium timescale collaborative interactions were observed between the researcher, pre-service teachers, Rand Water expertise and learners during water monitoring activities. In the medium to long-term timeframe there was a great deal of consultation on outcomes, feedback etc., over a relatively longer period. Change in the management of water resources at the NWU (Vaal Campus), as an outcome of the water monitoring project, would of course be carried through on a far longer timescale.

The agent interaction put forward by Pahl-Wostl *et al.* (2007) and Fazey (2010) when applied to the water monitoring project can be interpreted as follows: The researcher believes that in terms of single loop learning, all those involved were fully aware that their participation will have environmental consequences. The reflective, open-ended questions asked of groups of participants after completion of the project revealed a change in values and attitude regarding water and water quality, therefore double loop learning had taken place. It is suggested that triple loop learning took place when campus management were made aware of the challenges involved and agreed to adhere to adaptive management of the campus' water resources.

Reed *et al.* (2010) concur with Pahl-Wostl *et al.* (2007) and indicate that social learning leads to a positive change, a broader more insightful understanding. In the water project participants reflected on an in-depth, concrete experience. If their mind change occurs on a sufficiently broad scale through social interaction, this can be seen as social learning. Learning may occur through two basic types of social interaction. *Information transmission* is simple learning of new facts through social interaction while *deliberation* refers to the genuine exchange of ideas and arguments. This feature of social learning implies that diverse groups of participants may encourage other groups to support their

broader, more insightful outlook or notion. It also indicates that social learning brings together participants with different views and knowledge systems (Keen *et al.*, 2005:5). In the water monitoring project the expectation was that both information transmission and deliberation would occur between diverse participants. Each participant entered the project with diverse knowledge about water quality. Information transmission included knowledge on variables that relate to water quality and also the testing of these variables and interpretation of the resultant measurements. Deliberation followed when ideas were mooted and discussions, even arguments, about the interpretation of these variables took place.

Reed *et al.* (2010) agree with Wenger (1998 a & b) that learning is situated within social units, or communities of practice. They argue that *collective learning* by members of a group yields more than the sum of individual learning. Good citizenship can be learned, not through a formal curriculum, but through positive experience and active involvement in society.

Holbrook and Rannikmae (2007:1352) propose that learning has three domains, namely: (a) the *science domain*, which includes enquiry and investigative skills; (b) the *society domain*, which is about cooperative learning, social values and socio-scientific decision-making; and (c) the *personal domain*, one's intellectual ability, character, attitude and communication skills. These domains reflect the cognitive, affective and psychomotor domains outlined by Bloom and those by Holbrook & Rannikmae (2007:1352). Bloom's cognitive domain comprises six levels which can be compared with the three domains posited by Holbrook and Rannikmae. Bloom's six categories are knowledge, comprehension, application, analysis, synthesis and evaluation. These categories of learning are arranged from simple to complex. To learn progressively, one must master the lower category before attempting a more complex category (Krathwohl, 2002:213).

Community-based water monitoring in this research project engaged with a complex issue in society – the socio-scientific issue of water quality – that relates directly to health. Pre-service teachers and learners were therefore required to contribute creative and innovative thinking. All the domains of learning are seen as relevant in the water monitoring project (Holbrook & Rannikmae, 2007:1352). The project focused on context-based science teaching and therefore on the realm of science. The cultural and societal knowledge of pre-service teachers and learners was also a contributing factor

in the project. This approach to teaching is known as *education through science* (Holbrook & Rannikmae, 2007:1353), which typically required of pre-service teachers and learners to develop social values and react in a responsible manner within their community, in the school and in smaller groups – therefore the societal domain. They had to be able to function within the world of work with the necessary skills and a sense of responsibility. Pre-service teachers and learners had to learn skills to cope with the public understanding of science and technology in a changing society – the personal domain (Holbrook & Rannikmae, 2007:1353).

In the next section the relation between social learning and other concepts is discussed.

2.3.2.3 Social learning and social capital

Social capital refers to the strength, density and intensity of connections among social actors; it is these connections which increase the capacity of the community for collective actions (Overdevest *et al.*, 2004:178). Pahl-Wostl *et al.* (2007) refer to social capital as social organisation such as networks, norms and social trust that facilitate coordination and cooperation of mutual benefit. Communities with high social capital will know each other, share their experiences and form common bonds of familiarity, which may promote easier coordinated action over time (Pahl-Wostl *et al.*, 2007). Communities with high social capital will outperform other groups in a number of social domains. Social capital is therefore seen as an important public “asset” which is desirable when the need arises to address problems. Dense social networks generate a greater capacity for better community outcomes, including resilience, stability and problem solving (Overdevest *et al.*, 2004:183). The higher the social capital of a community the easier it is to reach environmental quality (Pahl-Wostl *et al.*, 2007).

The student and campus community at NWU (Vaal Campus) provided powerful social capital. Interaction between groups of students, diverse in culture and study fields, as well as campus administration and lecturers, provided for solid social networks in a dedicated environment of intellectual engagement.

Learning formed a unique link for the diverse activities of the water monitoring project. The next sections reflect on the relation between learning and monitoring; and that between learning and data.

2.3.2.4 Social learning and monitoring

Learning by monitoring and through participation is conceptualised as practical learning (Overdevest *et al.*, 2004:179). Proficient learning advances from the mastery of facts to the ability to apply the facts to new situations, to combine parts to a whole and to choose criteria to develop alternatives. Dreyfus and Dreyfus (Overdevest *et al.*, 2004:179) indicate that there are four hierarchical stages when skills are infused in learning. Firstly, *facts acquisition* occurs when individuals make decisions based on external rules. Secondly *contextually based acquisition* is the making of decisions based on a combination of rules and context-specific experience. Thirdly, the hierarchical selection of *context-informed strategies* is built on the ability to choose a course of action to follow. Lastly the *refinement of familiarity* is based on the experience phase when people operate as mature experts and have the capacity to steer a proper course.

The water monitoring project aimed to incorporate all these steps as part of practical learning. When performing monitoring activities, the pre-service teachers and school pupils learnt to advance from fact acquisition (collecting the data), to reporting the facts. The pre-service teachers and learners had to consider where they collected the water samples and how the context influenced their data – therefore they were engaged in contextually based learning. Context-informed strategies were generated when pre-service teachers compared current and previous data from campus water sources to develop adaptive management proposals. Refinement of familiarity was advanced when the pre-service teachers displayed the ability to organise a class of school-going children to perform monitoring activities in the correct manner in order to gather valid data and make the correct interpretation of data.

2.3.2.5 Social learning and data

The type of variable which is monitored determines the learning that takes place (Savan *et al.*, 2003:565). Variables like pH, temperature, turbidity, dissolved oxygen, bio-oxygen demand and concentrations of chloride, nitrate and nitrite taught the pre-service teachers and learners about water chemistry. These variables provide so-called “snapshots” of possible point source water pollution. Biological indicators such as *E coli* measurement provide the bigger picture on water quality (Savan *et al.*, 2003:565).

The inclusion of biological indicators aid community-based monitoring groups to become “environmental watchdogs” and potential “environmental educators” in their communities (Savan *et al.*, 2003:565). In the water monitoring project, pre-service teachers and learners were exposed to both physical and biological indicators of water. Inclusion of both types of indicators ensured complete awareness of the human influence on water.

2.3.2.6 Social learning and values

Social learning is not a neutral activity (Huitema, Mostert, Egas, Moellenkamp, Pahl-Wostl, & Yalcin, 2009). Trust is required because it requires the reliance of others to meet and achieve specific outcomes (Harris & Lyon, 2013:111). Trust is the expectation of others in a relationship (Harris & Lyon, 2013:116) and ensures that although individuals follow different norms regarding the results, different participants understand the incentives and disincentives for collaboration from the perspective of others (Harris & Lyon, 2013:116).

Zucker (1986:60-65) indicates three types of trust, namely: (a) institutional-based trust such as laws and rules laid down in formal structures; (b) process-based trust which links trust to past or expected exchange as in someone’s reputation; and (c) characteristic-based trust where trust is tied to a person such as a particular family or ethnicity. Trust may also emerge from existing measures like a formal contract, or it may begin with a “leap of faith”. Third party or intermediary trust may become evident when individuals bridge different professional cultures and play a key role to mediate language and cultural styles between different groups (Harris & Lyon, 2013:111).

A particular *culture* is a distinct grouping with a collective programming of the mind which distinguishes one group from the next (Harris & Lyon, 2013:110). Harris and Lyon (2013:110) indicate that cultures use different thought styles to make sense of the environment. A good example is the use of indigenous knowledge such as the water snake and mermaid myths to interpret phenomena of nature and water in African culture. To acknowledge the role of divergent cultural beliefs and interpretations of the environment, requires the building of trust between the various groups of participants (Harris & Lyon, 2013:110). To build trust, as a value, has challenges. Trust has a vulnerable element and provides confidence in others even if there is a risk that they may not act as expected (Harris & Lyon, 2013:110).

In the water monitoring project it proved vital to engender trust and accommodate the cultural differences and needs of various participants. These cultural norms had to be incorporated into the planning and execution of the project. Process-based trust, like indigenous knowledge about mystical water figures, as well as third party or intermediary trust were also evident in that mediation and diversity of knowledge were embraced.

Indigenous knowledge emerged as a component of social learning when some of the pre-service teachers asked questions about mythical water figures. The link between indigenous knowledge and social learning will be discussed in the following section.

2.3.2.7 Social learning and indigenous knowledge

Indigenous knowledge is directly linked to mythology (Lombard, 2004a:115). Mokgoatsana (1997:20) refers to mythology as the relationship between body, mind, spirit and world in a holistic attempt to achieve harmonious relationships or peace within the total environment. Myths provide one with the ability to structure and order one's world; they provide an appreciation and understanding of areas outside human control (Mokgoatsana 1997:20).

Alcock (2010) explains in some African cultures water spirits or mermaids are watchful and vengeful creatures if aggravated (Alcock, 2010:174). Mermaids live in rivers, pools and in the sea (Alcock, 2010:175). It is believed that if someone drowns in a river or dam and the body cannot be found, that the victim has joined the mermaids. Relatives do not mourn about the deceased because it is seen as an honour to live with the river people (Alcock, 2010:175). Sacrifices of animals, like cattle or goats, are often made to thank the river people and to seek goodwill and protection (Alcock, 2010:175).

The belief in a giant water serpent is evident in certain African cultures. There is oral evidence that the South African water serpent shares similar features with serpents of Zaire and Angola (Lombard, 2004b:100). The origin of the giant water serpent is directly related to rituals of the Khoisan (Lombard, 2004b:94). According to (Alcock, 2010:365) water serpents are described as powerful creatures, while Lombard (2004b:95) writes that they are able to trigger the forces of nature and synchronise these with human potential, thus rewarding human beings with exceptional power.

Wood (2005:349) distinguishes between different snakes. The snake of the sky or *knanyapa* (Sesotho) or *inkanyamba* (isiXhosa) is associated with violent storms and lives in deep pools (Wood, 2005:351). The second snake, the rain-making snake, can be either a male or female snake. This snake plays a crucial, life-giving role. The she-snake provides soft, gentle rain and the he-snake provides violent and destructive rainstorms (Wood, 2005:349).

Wood (2005:351) indicates that a supernatural snake, the *mamlambo*, has the ability to take on the form of a beautiful woman, the mermaid myth, which incorporates both the woman and snake symbol. This woman-snake has the capacity to bestow great wealth on the people who see it. Wood (2005:355) indicates that the *mamlambo* has an essential modern dimension and that the myth of the *mamlambo* has spread among southern African people because of the migrant labour system.

Maila and Loubser (2003:276) explain that environmental education provides a vehicle to incorporate indigenous knowledge into a curriculum. According to the United Nations Conference on the Environment and Development (UNCED, 1992) society has a great deal to learn from traditional skills and knowledge and that incorporating indigenous knowledge into curricula promotes diversity in general and bio-diversity in particular (Maila & Loubser, 2003:276). According to Masuku-van Damme (Maila & Loubser, 2003:277) indigenous knowledge has evolved over a long period of time and is the product of trial-and-error problem-solving by groups of people trying to meet the challenges they face in local environments by using the available resources at hand. Maila and Loubser (2003:279) maintain that both indigenous and scientific knowledge are crucial when addressing environmental issues and challenges.

The researcher was careful to acknowledge and take heed of indigenous cultural norms and beliefs held by participants when conducting the water monitoring project.

2.3.2.8 Social learning and transdisciplinary co-production

The water monitoring project enabled participants to move into a space which allowed both research and practice through transdisciplinary co-production. Transdisciplinary co-production refers to a “research approach to target real life problem solving where knowledge is co-produced through a combination of scientific perspective and experience from real world practice” (Polk, 2015:111). Therefore, in this water

monitoring project, co-production refers to the science/society interaction and the collaboration of diverse groups of participants. Polk (2015:112) concurs with Wenger (1998a) and refers to a hybrid community of practice that is able to bridge the boundaries between science and practice. The integration of knowledge in transdisciplinary co-production is based on three activities, namely: exchanging knowledge, creating a common understanding base, and engendering a sense of reflexivity in the group (Polk, 2015:113).

To indicate the complex nature of social learning in this study, the researcher constructed the mind map provided below. This illustrates the extent and attributes of social learning as experienced by both pre-service teachers and learners.

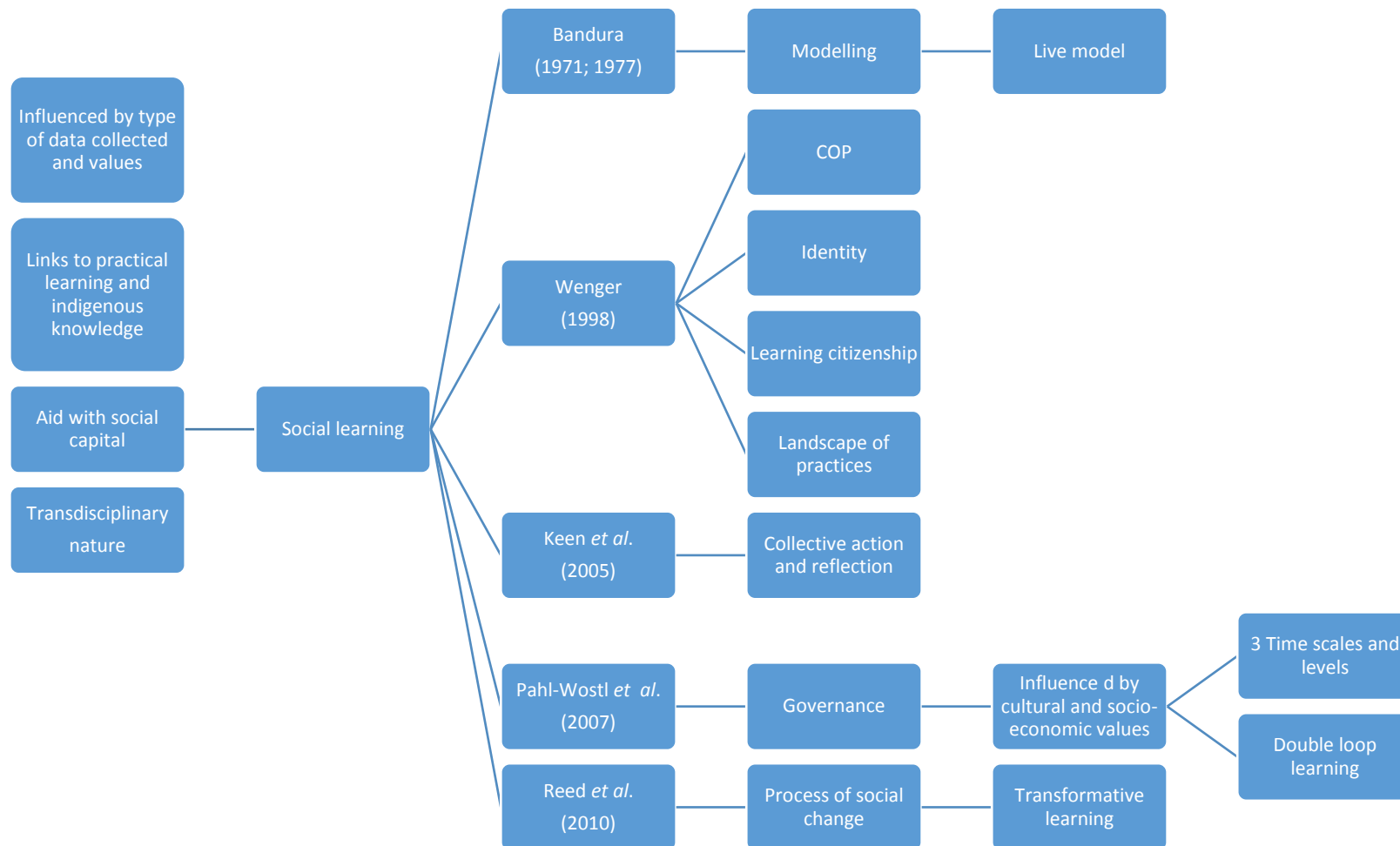


Figure 2.2: Mind map of social learning

In the next section project-based teaching, the teaching strategy used the water monitoring project, is discussed.

2.3.3 Project-based teaching

The teaching approach used in the water-monitoring project to promote learning was a project-based approach, grounded in the principles of social learning.

Project-based teaching that was utilised in the context of the study is classified as a teaching strategy that aids with problem-based or inquiry-based learning as per the South African Institute for Distance Education (SAIDE, 2012:319, 293). There is renewed interest in teaching approaches that link knowledge to the context of application. The word “project” presents a broad class of learning experience, which includes scientific experiments and scientific reporting, writing and the making of artefacts. “Project-based teaching is not an antidote to lecturing or an assessment opportunity, but a challenge to pre-service teachers to solve real-life problems with the world as the classroom” (Solomon, 2003:22). Project-based teaching emphasises learning through experience and often focuses on environmental concerns (Solomon, 2003:21). By means of project-based teaching, core curriculum knowledge is learned and applied when authentic problems are solved (Markham, 2011:39). Project-based teaching therefore imparts thinking competencies and creates flexible learning environments (Doppelt, 2003:255).

Project-based teaching, similar to most concepts applied in this research study, is complex in nature. This type of teaching was particularly appropriate in the water monitoring project because it focused on giving pre-service teachers and learners an opportunity to learn more about water quality, currently a highly relevant environmental concern, by performing scientific experiments on water samples. The following sections discuss important aspects of project-based learning.

2.3.3.1 Project-based learning: a form of active learning

Project-based learning is seen as a form of active learning which places those involved at the centre of the learning process and recognises the variance between different learning styles (Doppelt, 2003:256). *Active learning* transfers the responsibility of learning from the lecturer/teacher/project leader to those who are learning (Doppelt, 2003:256). Project-based learning supports the theories of Piaget, who describes those

who are actively learning as scientists who aim to understand their world by constructing ideas and not merely memorising information (Doppelt, 2003:257).

SAIDE (2012:292) indicates that project-based learning contributes to the acquisition of content and skills; it makes those involved, the participants in the project-learning process, aware of their learning activities. This awareness is known as metacognition (Killen, 2010:251). Metacognition implies that the participants know the goal of learning; have the ability to self-assess how they are progressing towards the goal; use revision as a natural component to achieve the learning goal; and recognise the value of resource and social structures to scaffold their knowledge and support their revision (Killen, 2010:251; SAIDE 2012:292).

The reflective question used to determine the experiences of pre-service teachers and Grade 10 learners focused on metacognition where they had to reflect on the knowledge or value gained through participation in the project.

2.3.3.2 Project-based learning: a real-world learning opportunity

Brundiens *et al.* (2010:311) indicate that project-based learning creates real-world learning opportunities. *Real-world learning* is defined as learning which promotes participants' understanding of sustainability problems. Real-world learning opportunities promote knowledge and methodological competence and are created by applying problem-solving strategies and strategic competence (Brundiens *et al.*, 2010:312).

Rowe (in Brundiens *et al.*, 2010:312) provides criteria to identify real-world learning opportunities which address actual sustainability problems or challenges brought to a higher education institution by the community, business, administration or campus partners. These challenges provide opportunities to apply concepts and methods taught in classrooms; they call upon the learners to use the skills/knowledge acquired to address sustainability problems. Such learning involves academic supervision by lecturers as well as collaboration with the community and others to devise a solution. Ideally it produces a workable plan, a means of addressing challenges, so that those involved, the "learners" begin to understand the positive impact they can have on society at large.

Brundiens *et al.* (2010:312) indicate that the criteria listed above are compatible with transdisciplinary research where students collaborate with non-academic experts and

community partners in all phases of the research project. According to Brundiers *et al.* (2010:312), participants who are diverse regarding expertise and experience, will provide project outcomes that are regarded as scientifically sound and applicable and which respond to the needs and gains of all involved (Brundiers *et al.*, 2010:312).

The researcher argues that the water monitoring project provided a real-world learning opportunity for pre-service teachers and learners with different levels of knowledge. They collaborated in classrooms while performing monitoring activities. Real-world learning fits into the transdisciplinary research paradigm and was observed in this project.

2.3.3.3 Project-based learning as place-based education

Project-based learning is also known as place-based education and is aimed at the growth of partnership between educational institutes and communities. Place-based education puts a high priority on boosting student achievement and the improvement of communal environmental quality and social vitality (Powers, 2004:17). It focuses on the “tear down” of school walls so that the community becomes integrated into all facets of learning. Schools become open and inviting, accessible to the community and in turn the community welcomes student learning in many dimensions (Powers, 2004:17).

The theory of place-based education was certainly relevant in this project on water quality monitoring. It involved learning and gainful interaction with members of the local community via pre-service teachers and Grade 10 Physical Science learners.

In the next section implementation of project-based learning is discussed.

2.3.3.4 Implementation of project-based learning

Killen (2010:249-250) and SAIDE (2012:292-294; 306) provide some direction on conducting project-based learning:

- Projects should be directed by a primary or principal question and care must be taken that “doing with understanding” is the driving force rather than just “doing”.
- Assistance or “scaffolding”, that is, guided aid must be provided to help the novice to carry out the task or achieve the goal.

- Reflection is an appropriate aid to scaffolding. Self-assessment helps project participants to develop the ability to monitor their own understanding and to find new resources to deepen understanding when necessary.
- Participants must gain inquiry skills. They should be given the opportunity to research topics to advance their understanding and communicate and collaborate with others to achieve the main goal.
- Those involved in the project must work in small groups where they are able to contribute as well as peer review their efforts. They should have access to the data of other groups of participants.
- Individuals must be accountable for a specific part of the project.
- Findings must to be presented to outside audiences. This will make the work of participants meaningful and provide new opportunities for learning.
- Connections with other communities are important to provide feedback from audiences with different concerns and to promote effective communication of ideas (Barron, 1998:285).

Challenges will of course be experienced when conducting project-based learning. For example, limited assistance is available for project-based education. Then too, measuring project-based learning remains problematic because it includes value judgements such as personal accomplishment and growth and development of caring relationships, reliable citizenship and a sense of mastery. Because this type of learning is collaborative learning, it is also difficult to distinguish between what the individual knows and what the group knows (Markham, 2011:39). To overcome the problematic scenario of diverse experience of participants in the water monitoring project, the researcher opted for open-ended written responses from participants. Open-ended questions allowed participants to reflect on their own experiences and to communicate their experiences in a way which suited them.

Killen (2010:253) concludes that project-based learning provides opportunities for in-service and pre-service teachers to engage in a type of learning which can be recommended for learners. Real-world learning opportunities as typified in project-based learning allow participants to recognise and engage in different forms of collaboration at different degrees of intensity. By designing and implementing a collaborative process, participants are able build interpersonal skills and reflect on their

experiences (Brundiens *et al.*, 2010:313). Brundiens *et al.* (2010:313) also indicate that participants in real-world learning opportunities become familiar with different, and often conflicting perceptions, values, reasoning and decision-making. They become more aware of institutional scenarios and sustainability challenges and learn how far context can influence solutions proposed by different role players.

The researcher opines that project-based teaching is a sound approach to achieve outcomes beyond the ambit of the classroom – such as water quality monitoring. The intention was to encourage deeper understanding and enable pre-service teachers and learners to transfer this insight and understanding to real-world problems.

In the next section, the third group of concepts relevant in the water monitoring project, namely water quality and adaptive management, are discussed.

2.4 WATER QUALITY AND WATER QUALITY MANAGEMENT (WQM)

This section discusses the concepts of water quality, water quality management, adaptive management and participation. The researcher acknowledges that it is necessary to include this section because the water monitoring project was also geared towards making a positive contribution to adaptive management of the water sources of the NWU (Vaal Campus).

2.4.1 Water quality and water quality management (WQM) defined

According to the Department of Water Affairs, water quality is a measure of the chemical, physical and biological characteristics of water in respect of its suitability for intended purposes (DWS, 2017). Water quality changes due to natural processes and human activities. Water quality varies from place to place due to seasonal and climate changes. Human activities such as agriculture, urban and industrial development, mining and recreation all have significant influences on water quality (DWS, 2017).

Water quality management (WQM) is the maintenance of the fitness of water sources on a sustainable basis. Water quality management aims to achieve a balance between socio-economic development and the protection of water as a scarce natural resource (DWS, 2017). Water quality management is therefore an ongoing process of planning, development, implementation and administration of policy, the authorisation of water use and the monitoring and auditing of water quality (DWS, 2017).

A 2010 report by South Africa's Council for Scientific and Industrial Research (CSIR) on water quality indicates that more than 95% of the country's freshwater resource has already been allocated for use. Inadequate and outdated water treatment and sewage plants and unskilled operators are responsible for declining water quality (CSIR, 2010:9). The executive summary in the National Water Resource Strategy (NWRS) of 2013 as well as Viljoen (2006) support the views expressed by the CSIR and indicate that a lack of understanding of legal requirements and water quality standards and guidelines, as well as poor service delivery of water to smaller towns and communities, have a direct impact on WQM. Inadequate management and monitoring are apparent in the lack of data on drinking water quality and inadequate basic laboratory equipment (NWRS, 2013; Viljoen, 2006). Additional challenges regarding WQM include inadequate budgets for maintenance; outdated and inappropriate technology; the problem of vandalism; lack of institutional capacity regarding staff, funds, expertise and education, as well as a lack of intervention to address poor water quality (NWRS, 2013; Viljoen, 2006).

The water monitoring project conducted on the NWU (Vaal Campus) has the potential to address a few of these obstacles to the prevention and implementation of sound WQM.

In the next section, the structure of WQM in South Africa is discussed.

2.4.1.1 Water Quality Management in South Africa

The responsible cabinet minister and the Department of Water and Sanitation (DWS) are collectively the public trustee of the nation's water resources (Du Plessis, 2010:31). These two entities have the right to manage South Africa's water resource to ensure continuous adequate water supplies of acceptable quality to all consumers. Users of water can be categorised into five sectors, namely domestic, agricultural, industrial, recreational and the water resource base (DWS, 2017).

WQM is governed and influenced by the following legal and ethical obligations:

On the international level, South Africa has agreed to adhere to the following obligations regarding WQM:

Agenda 21; the 1990 New Delhi Principles; the 1992 Dublin Principles and Earth Summit, Rio; the 1997 UN Convention on the Non-navigational Uses of International Watercourses and Earth Summit; the 2000 World Water Vision and Vision to Action

Targets; the 2001 Bonn Ministerial Declaration; the 2002 Johannesburg Plan of Implementation and Abuja Ministerial Declaration on Water and Accra Declaration; as well as the 2003 Third World Water Forum and Ministerial Declaration (CSIR, 2010:20).

At the national level, the Constitution of the Republic of South Africa (Act No. 108 of 1996, section 24) ensures that all South Africans have the right to a safe environment and therefore clean water. The National Environmental Management Act (NEMA), (107 of 1998) promotes environmental rights in section 24. Regarding sectorial legislation, the National Water Act (NWA, No. 36 of 1998) and the Water Services Act (No. 10 of 1997) is supported by the Water Services Regulations; and the National Water Resource Strategy promotes water quality management (CSIR, 2010:18).

South Africa shares six river basins and six aquifer systems with the neighbouring countries of Namibia, Botswana, Zimbabwe, Mozambique, Lesotho and Swaziland. Sharing a critical and strategic resource with other countries requires strong and robust institutions as well as sound legislation to ensure harmony and alignment (CSIR, 2010:18).

At the regional level the Southern African Development Council (SADC) Action Plan for Water and the 2000 SADC revised proposal on Shared Watercourses provide sound legal advice on water management (CSIR, 2010:19).

WQM in South Africa evolved from a pollution control approach to an integrated, remediated and direct management approach (Craigie, Saayman, & Fourie, 2010:61). Water User Associations (WUAs) and Catchment Management Forums (CMFs) are statutory institutions in South African WQM (DWS, 2017). The basic geographical unit of WQM is the catchment. At catchment level the physical characteristics of the catchment determine the use of water and land. The economic status of communities in the catchment is also considered. This integration of diverse factors in a holistic management programme aims to improve WQM over time (Craigie *et al.*, 2010:84; DWS, 2017).

Various stakeholders and institutions in the catchment area are engaged via Catchment Management Forums (CMFs). CMFs are non-statutory institutions, but are included in the National Water Act (NWA) No. 36 of 1998 to provide a formal interface between the water needs of the community and the formal institution that regulates water (DWS, 2017). These forums are the participatory representative bodies that voice the interests

and needs of stakeholders. A framework strategy, known as the Catchment Management Strategy (CMS), considers all matters relevant to the protection, use, development, conservation, management and control of water resources (DWS, 2016).

The researcher is of the opinion that the management of NWU (Vaal Campus) needs to be fully aware of WQM in general. The campus is part of a community situated beside the Vaal River and has access to the water.

Four WQM instruments are used in South Africa, namely:

- *Regulatory management* makes use of instruments such as licenses for water use (National Water Act, No. 36 of 1998, Section 40); the issuing of disposal site permits (Environment Conservation Act, No. 73 of 1998, Section 20); the approval of Environmental Management Programmes (Minerals Act, No. 50 of 1991, Section 39) and impact assessments (Environment Conservation Act, No. 73 of 1998, Sections 21, 26 & 28).
- *Market-based instruments* manage the pricing strategy which make provision for incentives with the aim of introducing new technology or management practices; the conservation and economically efficient allocation of scarce water resources; and the removal of elements from waste streams.
- *Self-regulatory instruments* include the ISO 14000 series which comprises a range of environmental standards which can be utilised by industry to improve environmental performance. Promotion of the ISO 14001 certification by the DWS will extend WQM capacity.
- *Civil management instruments* focus on the decentralisation of decision making and the promotion of water user associations and catchment management agencies. These bodies include public participators and are the ideal mechanism to create stakeholder involvement in water quality. This initiative is supported by the National Water Act (No. 36 of 1998). Bodies such as these carry out the process of co-operative governance where CMF serves as the institutionalised mechanism to involve stakeholders in decision-making (Craigie *et al.*, 2010:61-67; DWS, 2017).

The researcher regards the water monitoring project at the NWU (Vaal Campus) as an initiative which benefits from public participation. Pre-service teachers are involved as an institutional mechanism in decision making.

Rand Water is the largest bulk water utility in Africa and played an important role in the WQM used in this research study. Rand Water is an organ of state in so far that it reports to the Department of Water Affairs, but it is financially self-sustaining. Bulk water is supplied to more than 11 million people in Gauteng, parts of Mpumalanga, the North West and Free State provinces over an area of 18 000 square kilometres by Rand Water (Rand Water, 2016a). Rand Water draws water from the Tugela-Vaal scheme and the Lesotho Highlands Water Project. Water available from these schemes ensures that Rand Water is able to supply enough water even during major droughts such as those suffered by the country in the years 1983 to 1987, 1995, and from 2012 to 2016. Water is purified for human consumption and is supplied and sold to municipalities, mines and industries. In turn, municipalities supply the water, at a cost, to consumers (Rand Water, 2016c).

To ensure water quality Rand Water is obliged to conform to international and national standards, namely ISO 17025 which embraces the standards of the World Health Organisation, the South African National Standards (SANS 2015) and the requirements of South African legislation (Rand Water, 2016 a & b).

One of the main purposes of the water monitoring project, namely adaptive management, is now discussed as a form of WQM of relevance to the NWU (Vaal Campus).

2.4.2 Adaptive management

Holling (1973:23) maintains that adaptive management has the ability to overcome the limitations of command-and-control mechanisms in natural resource management. Adaptive management takes the form of structured experiments such as attempts to document and learn from both planned and unplanned environmental “surprises” (Huitema *et al.*, 2009). Indeed, Lee (1999:3) is of the opinion that adaptive management is more influential than any other method of conservation. In the light of these views the researcher decided that to engage a group of pre-service teachers in adaptive management practices on the NWU (Vaal Campus) would be more effective than to implement a formal conservation project.

Experimentation is seen by Lee (1999:3) in two different ways, namely as a research methodology and as an approach to management. As a research methodology, it tests hypotheses on the ecosystem’s response to different management interventions.

Information is therefore objective and decisions can be made based on the information gleaned. However, when conducting experiments there is limited space available for public participation. Experimentation as part of a management approach supports the notion that information is always incomplete and uncertain. The inclusion of multiple participants in experimentation allows for learning from and with each other when incorporating diverse perspectives of participants.

Lee's work (1999:3) is supported by further research undertaken by Skelcher, Mathur, & Smith (2005:589) who distinguished between two types of adaptive management. Technocratic adaptive management refers to learning through experimentation and focuses only on learning. Non-technocratic adaptive management has components of both learning and co-management.

Multiple centres of power (polycentric) refers to the inclusion of role players on all levels of management, all of whom provide input. Monocentric management refers to control exercised by one group, such as in law enforcement (Skelcher *et al.*, 2005:589). Polycentric power sees local communities as being in the best position to face up to and solve their own problems. Diversity in governance assists communities to become more resilient and makes them better able to cope with change and uncertainty (Huitema *et al.*, 2009; Skelcher *et al.*, 2005:590).

The water monitoring project fits the description of a non-technocratic, adaptive approach to management. Data collected in experiments on water samples can never be absolute or complete. The variety of stakeholders involved represents multiple centres of power, so the project followed a polycentric approach.

In the next section implementation of adaptive management is discussed.

2.4.2.1 Implementing adaptive management

Implementing adaptive management at an institution implies adherence to certain prescriptions. Collaboration between different groups is vital. Another important aspect is that unexpected outcomes are seen as learning opportunities (Lee, 1999:3). Overdevest *et al.* (2004:179) claim that the core purpose of adaptive management is to see ecological systems as highly complex and dynamic and that it therefore benefits from ongoing ecological and social feedback (Overdevest *et al.*, 2004:179). Adaptive

management as a learning opportunity is linked to other relevant concepts as shown below.

2.4.2.2 Adaptive management and sense of place

The word “place” may mean a location, region, space, site, setting, landscape or environment. Place thus refers to an integrated, meaningful phenomenon to which people have attached certain significance (Kruger & Shannon, 2010:463). Place is not an abstraction or concept, but a directly experienced phenomenon of the lived world and is therefore full of meaning (Kruger & Shannon, 2010:463).

In 2013–2014 the researcher conducted an assessment of resilience on the social-ecological system of the NWU (Vaal Campus). It was found that as researchers Tidball and Krasny (2007:154) suggest, that a green space such as the NWU (Vaal) campus has the ability to reduce domestic violence, quicken healing times and reduce stress by improving physical health and bringing cognitive and psychological benefits to those who frequent such places. Tidball and Krasny (2007:154) go on to claim that soothing green spaces are often used to encourage soldiers and victims of war overcome travail and improve personal wellbeing. Green areas foster a sense of safety and belonging; they represent resilience by resisting not only harsh ecological conditions but also troubled social, psychological, political and economic conditions.

In the process of conducting this water research project, the researcher proposed that pre-service teachers should experience the water monitoring project on the campus, because it forms part of the environment where they are currently studying and where, in a very real sense, they belong.

2.4.2.3 Adaptive management and knowledge

Challenges in adaptive management involve developing approaches that take local and scientific knowledge into account. The reality of local and scientific knowledge came to the attention of the researcher when one of the pre-service teachers asked questions whether the mythical water snake and mermaids in water sources had any bearing on the project. These African cultural beliefs should not be rejected or ignored in a project such as this. To accommodate both scientific and indigenous knowledge the following principles need to be taken into account: (a) The scientific knowledge of academic researchers should be integrated with knowledge of non-academic participants; (b)

shared methods and knowledge must be developed to promote common understanding of the environmental problem; (c) participatory research methods which encourage the inclusion of more stakeholders in decision-making are important; and (d) an interactive process of knowledge creation, application, reflection, learning and feedback needs to be followed (Raymond, Fazey, Reed, Stringer, Robinson, & Evely, 2010:1767).

The infusion of knowledge into adaptive management resonates well with principles proposed for transdisciplinary and participatory research. In the next section the link between social learning and adaptive management is discussed.

2.4.2.4 Social learning, adaptive management and transdisciplinarity

The ontological and epistemological perspectives of the participants challenge social learning. *Ontological perspectives* refer to how participants view the definition, types and intricacies of water quality. *Epistemological perspectives* indicate beliefs about the nature of knowledge or how individuals came to know something (Raymond *et al.*, 2010:1767). For this water monitoring project, ontological and epistemological perspectives indicate the prior knowledge and experimental skill involved in water quality experiments; the competencies pre-service teachers and learners bring when they commence their involvement in the project.

Raymond *et al.* (2010:1769) indicate five dimensions of knowledge in adaptive management, namely: (a) local knowledge versus general knowledge; (b) informal as opposed to formal knowledge; (c) novice versus expert knowledge; (d) implicit (tacit) versus explicit knowledge; and (e) traditional/local versus scientific ecological knowledge.

Enengel *et al.* (2012:107) refined the dimensions suggested by Raymond *et al.* and reduced them to three which are:

- *Scale dimension*: (i) context-specific knowledge, which refers to the concrete setting of the individual case versus (ii) generalised knowledge which makes universally valid claims. General knowledge has to be translated and adapted to apply to a specific context.
- *Functional dimension*: (i) phenomenological knowledge which addresses social and environmental elements of the analysed system; and (ii) strategic knowledge which focuses on connections and interrelations of system elements. This type of

knowledge addresses organisational, functional and network issues that change in the system.

- *Epistemic (cognitive) dimension*: (i) experiential knowledge, which is derived from one's own life experience and is often tacit or implicit rather than formalised; and (ii) *scientific knowledge* which is based on empirical evidence or theories that have been scientifically acknowledged, i.e. theories that are systematic, formalised and explicit.

The dimensions indicated by Enengel *et al.* (2012:107) were used to highlight the transdisciplinary nature of the research study as follows:

Scale dimension: Data collected during the project provided valuable information about the NWU (Vaal Campus) water resource, information that can be described as context-specific knowledge. The pre-service teachers and learners gained knowledge that is more generally applicable, notably in the case of other communities where community-based water monitoring could be introduced.

Functional dimension: Phenomenological knowledge highlights the value of this specific water monitoring project to various participants. It can also refer to the involvement of communities in monitoring water quality and management. Strategic knowledge is valuable in the interrelation between different groups of participants such as the pre-service teachers and Rand Water; between pre-service teachers and learners; pre-service teachers and university personnel, as well as pre-service teachers and the immediate environment of the NWU (Vaal Campus). Strategic knowledge can also refer to water resources, like the campus dams and Vaal River, and how they are influenced by climate and the ever-changing seasons.

Cognitive dimension: By participating in the project and performing the prescribed experiments the pre-service teachers and learners gained experiential knowledge. The formal report on the findings of the scientific experiments, the water quality data presented on the conclusion of the water monitoring project constitute scientific knowledge.

In the next section the relation between adaptive management and public participation is indicated.

2.4.3 Public participation

Public participation in the context of this project, refers to the way in which role players from society at large were involved in monitoring. Pollock and Whitelaw (2005:225) maintain that community-based monitoring is best applied when it is locally appropriate and adaptive, strongly coordinated and based on collaborative partnerships. Participants must have meaningful opportunities to take part, fixed information delivery systems must be in place and the major aim must be to support and maintain sustainability.

Participation of members of society comes in variable scales and can be categorised to fit either a top-down or bottom-up governance/management structure (Lawrence, 2006:281). Participation can be:

- Passive, when the public acts as a spectator and does not interfere with actions;
- Through consultation when the public contributes information to a central authority;
- Functional, when the public contributes information and is engaged to implement decisions;
- Collaborative, when the public works with government to decide what is needed and contributes knowledge;
- Transformative, when locals make and implement decisions with expert support if needed; or
- Inter-active whereby people participate by taking initiatives that are independent of institutional actions (Lawrence, 2006:281).

Both consultative and functional participation are identified as top-down approaches. In these approaches, information is collected from the public and the scale of participation is not limited to local scales. Consultative and functional participation are dependent on the governing group/management for funding and cannot continue on their own (Pollock & Whitelaw, 2005:212).

Collaborative participation refers to multi-party, community-based monitoring groups and involves cooperative or adaptive management. Multi-party groups represent many facets of the community including the landowners, the general public, businesses, government, universities etc. This type of participation yields more decision-making

power than other types of monitoring and manages/governs from the 'bottom-up' (Conrad & Hilchey, 2011:277; Lawrence, 2006:281).

Lawrence (2006:282) indicates that site-specific, community based approaches are popular in economically poor countries where the key variable in participation is empowerment. This may take different forms from empowerment through knowledge, to social inclusion and social capital, to political power and decision-making or a more process-based internalisation of experience. Lawrence (2006:292) maintains that it is impossible to leave the personal factor out of participation and that volunteers who undergo training gain experience of a new activity. For example participation in monitoring often exposes volunteers to nature and helps them to escape from family and social demands.

Personal power is also gained through participation in monitoring actions. Internal value is defined as the contribution of the participatory process to personal learning, development and the relationship to nature. Internal value is subjective – therefore specific to each participant. In contrast, external value is defined as the public usefulness of data for decision-making and is objective, insofar as it is shared and accessible although there may be differences in interpretation among different actors (Lawrence, 2006:292).

The water monitoring project at NWU (Vaal Campus) is characterised by collaborative participation. The water monitoring team aims to collect knowledge on the quality of the water source on campus and to aid campus management and technical services by making adaptive management proposals. The main focus of the research is to give an indication of the experience and therefore the internal value gained by both pre-service teachers and learners. To assist technical services and campus management with adaptive management proposals can be regarded as external value.

In the next section, the link between adaptive management and public participation is discussed.

2.4.3.1 Adaptive management and public participation

Adaptive management aims to incorporate public participation and makes room for debate in decision-making. By encouraging monitoring efforts, public participation and community involvement are increased in adaptive management (Overdevest *et al.*,

2004:179 and Huitema *et al.*, 2009). Members of the public who are involved in monitoring learn about the condition and status of water and with this increased understanding are able to form opinions on environmental matters and educate others. In this way, local understanding is increased. Generating such partnerships among groups or individuals provides alternative ways to address problems in communities. In summary, public participation improves the quality of decision-making by opening the decision-making process and making better use of available information and creativity which can then be passed on to others (Huitema *et al.*, 2009).

To implement public participation institutional and/or cultural change are often required Huitema *et al.* (2009). Well-organised public participation processes may increase positive experience for those involved and prepares the ground for institutional and cultural change. Public participation can only be a success if the process is relevant for the participants and reflects the concerns of all the stakeholders. Furthermore, public participation processes should take care to support under-privileged stakeholders.

Huitema *et al.* (2009) describe this community involvement or participation as *co-management* and indicate that it incorporates the sharing of rights, responsibilities and power between different levels and sectors of governance and society.

The participation of pre-service teachers in the water monitoring project gave them a better understanding of water quality, providing them with opportunities to educate others and to form partnerships with schools and other community groups. At the university campus participants in this project were empowered to contribute to decision-making related to the adaptive management of campus water sources.

In the next section the link between public participation, social learning and resilience is made.

2.4.3.2 Public participation, social learning and resilience

Pahl-Wostl *et al.* (2007) claim that water management is intertwined with the overall societal context. Social learning helps to increase the adaptive capacity of a community and influences the governance of water as a resource in a formal and informal way. According to Pahl-Wostl *et al.* (2007) two kinds of interaction are important, in the participatory process, namely the role of social learning and the influence of the governance context. For social learning to increase, adaptive capacity and effective

water management must be in fine balance. Laws and cultural values provide long-term stability while social learning and negotiation provide flexibility and change. Collaborative platforms between different participants that are resilient show a balance between increased governance and the increased ability of participants to achieve social learning, resolve conflict and build social trust (Pahl-Wostl *et al.*, 2007).

Tidball and Krasny (2007:150) suggest that the involvement of diverse groups of participants adds to communal resilience. Social diversity indicates positive feedback loops and can be identified as the strengths, skills and resources that are already in place in a social-ecological system. Skelcher *et al.* (2005:575) agree with Tidball and Krasny and indicate that polycentric governance makes local communities better able to face and solve their own problems. Similarly, according to Fernandez-Gimenez *et al.*, (2008) adaptive management and social learning enhance the flexibility and responsiveness of social-ecological systems, making them more resilient and increasingly adaptable to stress and change without altering their fundamental nature.

Wenger (1998b:13) proposes that learning in social systems requires decisions about different matters. He goes on to explain that public participation in a social system becomes a learning system where learning drives participation.

The researcher postulates that social learning is a process that depends on public participation. The outcomes of social learning, and the knowledge and experience gained during the learning process contribute to the formulation of adaptive management proposals. Once a community participates in a process to contribute to social learning, participants become accountable. In this research study, the objective was to make a positive contribution to the community by providing a learning opportunity to participants. Through their involvement, they in turn gained knowledge on water quality and will in future be in a position to raise awareness of this important issue in the local community.

In the next section, the relation between public participation and accountability is discussed.

2.4.3.3 Public participation and accountability

There are two forms of accountability in public participation. *Vertical accountability* is associated with traditional hierarchies of authority and the management of resource

policies and regulations. This formal governance of resources is known as vertical accountability. In contrast, *horizontal accountability* is associated with the engagement of participants in joint activities. Participants can negotiate mutual relevance, the standards of practice, peer recognition, identity and reputation and the commitment to social learning (Wenger, 1998b:13). Both these forms of accountability are needed to provide balanced public participation (Wenger, 1998b:13).

Regarding the water monitoring project pre-service teachers and learners were horizontally accountable. The NWU (Vaal Campus) management and especially technical services were vertically accountable; they were obliged to be accountable to a formal governance structure.

2.5 CHAPTER SUMMARY

Citizen science, despite years of practice in other countries like the United States of America and Canada, is still an evolving field of endeavour. As indicated in this chapter, citizen-science is a multi-faceted concept in respect of approach, type and participation. The outcome of a citizen science project depends on sound planning, adaptation to challenges and accentuation of the mutual benefits for all participants.

Proposing citizen science at educational institutions links it to EE. To anchor EE in curricula is a work in progress in the context of South African schools (Le Grange, 2002:86). This research study provides an opportunity to use Physical Science as the vehicle to promote EE. The teaching approach used in creating this learning opportunity is project-based learning. Project-based learning ties in well with ESD and transdisciplinary research studies. Involvement of various groups of participants, with different knowledge bases and experience, points to social learning as the main learning approach in this study.

The knowledge generated when social learning opportunities are provided can lead to positive adaptive management practices. Different kinds of knowledge are generated in this water monitoring project although the focus of the research is on the affective or social domain. Adaptive management is an ongoing experiment with an approach to management. The link between social learning, adaptive management and transdisciplinary research is displayed by the co-production of knowledge on three possible scale dimensions. Public participation is the active involvement of community members and in this project, applies to environmental issues. The main objective of

public participation is to empower the community, while this particular water monitoring project aims to provide pre-service teachers and school learners with opportunities to acquire scientific knowledge and experimental skills.

In the next chapter, the research methodology behind the water monitoring project is discussed in detail.

CHAPTER 3

EMPIRICAL RESEARCH AND THE WATER MONITORING PROJECT

3.1 INTRODUCTION

This chapter aims to elucidate the empirical research by explaining the research design as a plan directing the water monitoring project. The chapter indicates the research methodology for the water monitoring project in detail.

3.2 RESEARCH PARADIGM

With reference to this research project, the researcher acknowledges that science is not only a resource but also an agent of change. Society adopts scientific research to help resolve societal problems and promote innovation (Hirsch Hadorn *et al.*, 2008:27). The philosophical worldview proposed for this study was social constructivist in nature. Social constructivists are of the view that individuals seek to understand the world in which they live and work and develop their own subjective meanings of their experiences, which can be varied and multiple (Creswell, 2009:8). This view supports the notion of this research study to look for complexity in the diverse groups of participants. The use of open-ended, reflective questions as the main source of data collection allowed for the researcher to note the experiences of participants as well as the interaction between different groups of participants. The researcher acknowledges that by having a social constructivist worldview, she positioned herself in the research study as a participant with the intention to seek meaning in the experiences of her fellow participants and could generate a theory or patterns of meaning regarding the participants' experiences of the water monitoring project (Grauer, 2012:71; Creswell, 2009:8).

3.3 EMPIRICAL RESEARCH

3.3.1 Literature review

Research on citizen science and community-based monitoring, as well as project-based teaching and social learning provided valuable information on the relationship between the listed concepts and the research findings. According to the available literature, citizen science is a relatively unexplored domain in South Africa and a project on

community-based water monitoring is an innovative example of citizen science. Monitoring data is primarily quantitative in nature and lacks qualitative research which focuses on the experiences of participants in monitoring. Social learning and collaboration between participants meant that this research also contributed to environmental education.

Data bases like Ebsco Host, Eric, JSTOR and Science Direct were used to link with authoritative academic journals to ensure valid and reliable research. Non-academic websites were used to secure data from non-governmental organisations (NGOs) since citizen science initiatives are often promoted by NGOs. Keywords used include citizen science, community-based monitoring, water quality, project-based teaching, social learning and adaptive management.

3.3.2 Research design

3.3.2.1 Transdisciplinary research

This study adhered to the four core foci of transdisciplinary research, namely that the process (a) focuses on a real life problem, water quality; (b) integrates the disciplinary paradigms of natural science, environmental management and education; (c) involves various participants with heterogeneous knowledge backgrounds; and (d) aims for a span of knowledge beyond the confines of a single discipline (Hirsch Hadorn *et al.*, 2008:29).

The research design is based on a selection of transdisciplinary research projects conducted by Bergmann *et al.* (2012:63, 86, 116). By combining the transdisciplinary case study approach, also known as transdisciplinary integrated planning and synthesis (TIPS), with an inter-institutional approach, a specific approach was formulated for the this research project. TIPS proves useful when underlying societal problems are particularly complex and feature many uncertainties. The TIPS approach assumes that case studies are divided into different steps, each producing a specific type of knowledge. In the final step – the evaluation step – all knowledge/information gained is combined (Bergmann *et al.*, 2012:86).

Multiple mini-case studies were proposed as an appropriate strategy of inquiry for this research. The motivation for choosing mini-case studies was the notion that stakeholder participation in the research study could potentially contribute to a variety of different

forms of knowledge. The study of water quality of the water storage resources on the NWU (Vaal Campus) was categorised as an in-depth study of a specific activity. It is water monitoring and may therefore also be categorised as a case study (Mertler, 2012:13).

Bergmann *et al.* (2012:117) explain that an inter-institutional approach is useful when participants are working on sub-projects, i.e. must engage in comprehensive cooperation. This notion resonated well in this research project. The NWU pre-service teachers performed the initial monitoring on the campus water storage resource. They then applied their skills and knowledge in local schools (i.e. in sub-projects) to cooperate in the overarching project by contributing water quality data.

Both Hirsch Hadorn *et al.* (2008:36) and Lang *et al.* (2012:28) propose three phases when attempting transdisciplinary research, namely: (a) problem identification, structuring of research and team building; (b) problem analysis whereby research questions are structured specifically to address diverse aspects and aim for integration of all aspects of solution-oriented transferable knowledge; and (c) bringing results to fruition by integration and application of created knowledge; in this phase the project is embedded in social and scientific contexts and must be able to test the expected impact in both contexts. For the proposed study the following sub-phases, based on the three-phases outlined here, were proposed (Figure 3.1). The design principles proposed by Lang *et al.* (2012:30) were incorporated with the three phases outlined by Hirsch Hadorn *et al.* (2008:36).

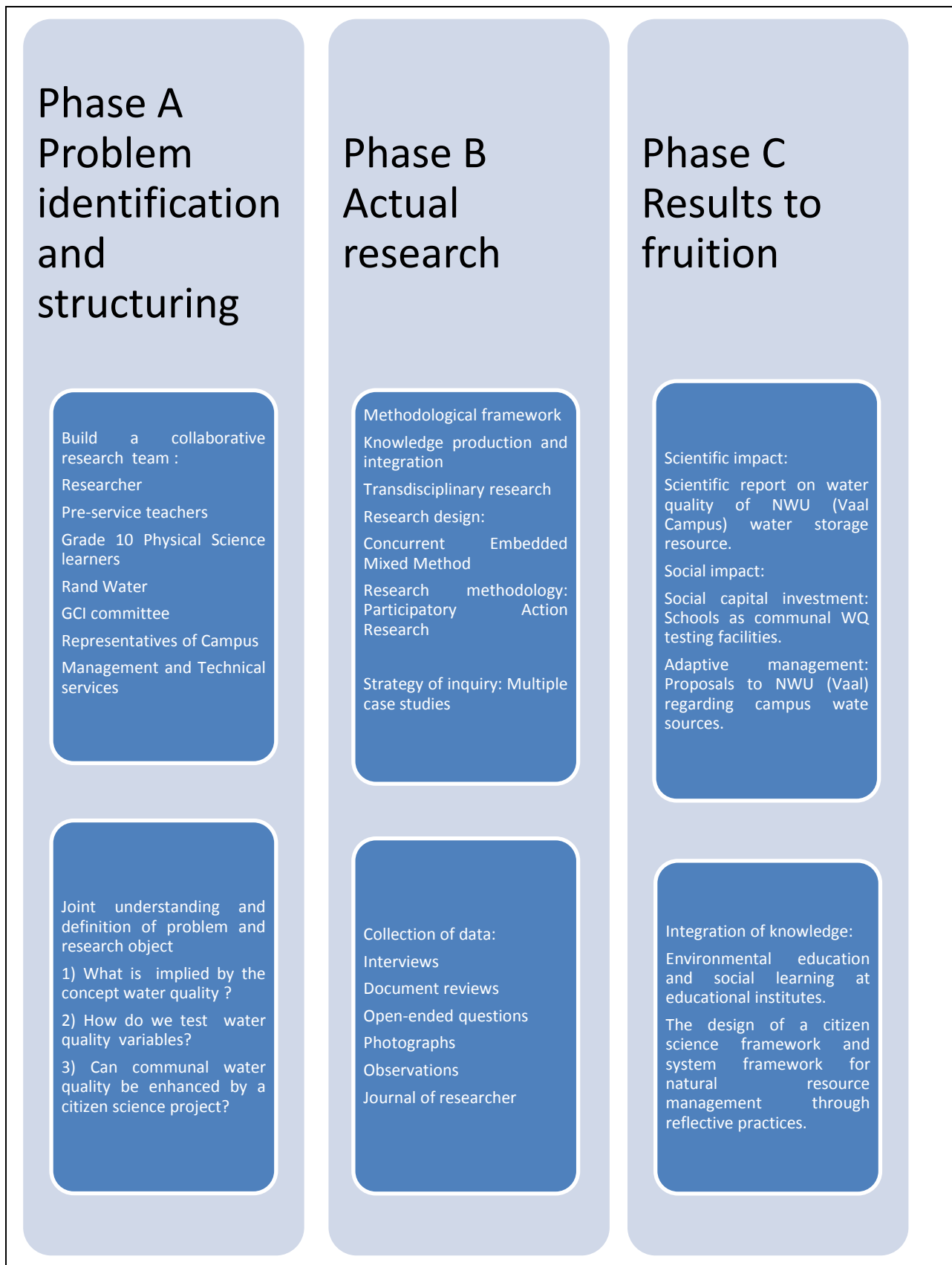


Figure 3.1: Phases of research of community based monitoring at the NWU (Vaal Campus)

This research study and the NWU (Vaal Campus) water monitoring project translate a real-world problem (that of water quality) into a researchable phenomenon to provide insight on how the campus and local community address water quality. The project also provides scientific knowledge on water quality and corresponds with phase one as proposed by Lang *et al.* (2012:28). Phase two of the research, conducting the water monitoring experiments, involved different groups of participants from diverse backgrounds who collaborated in a functional and dynamic way (Lang *et al.*, 2012:28). In the final phase, knowledge was transferred, but not in a classical form; instead the results of the research were integrated as adaptive management proposals on the campus dams. In other words both societal practice and scientific practice were involved in that a relevant citizen science framework and a system framework were developed (Lang *et al.*, 2012:28).

3.3.2.2 Mixed-method research design

The researcher pursued a combination of mixed-method design and participatory action research (PAR) methodologies in the execution of the project (Klein, 2012:9). The reason for inclusion of both was motivated by Mertler (2012:13) who indicates that participatory action research and mixed-method research both utilise qualitative and quantitative data. The main purpose of mixed-method research is to understand and explain a research problem whereas PAR addresses local problems to find solutions. The water monitoring project incorporated both methodologies to understand and explain the experience of pre-service teachers and learners participating in this community-based water monitoring project. Similarly there was a need to understand and explain the current water quality of the campus water storage resource and to aid campus management with possible proposals for adaptive management of this resource.

In this research a concurrent embedded strategy was used as part of the mixed-method research design. The main focus of qualitative observation of participants' experience guided the project. The monitoring data consisted of quantitative measurement of nine water quality variables. Given less priority, the quantitative data was nested in the qualitative data. The quantitative (nested) data addressed a different question, namely the current status of water quality of the NWU (Vaal Campus) water storage resource (Creswell, 2009:214; Ivankova, Creswell & Plano Clark, 2007:267). Quantitative data in the form of measurement of water quality provided additional information to the primary,

qualitative data that focused on the learning experiences of the participants. It was hoped that the personal involvement in collecting measurement data would contribute to learning about the seriousness of water quality. Both sets of data thus contributed to achieving the main aim of the study, namely environmental learning.

Knowledge of the water quality status provided campus management with valuable information to maintain the quality of water storage resource on campus.

Quantitative data collection and analysis were carried out at the time of the water monitoring experiments. The qualitative phase ran concurrently with the monitoring process. The researcher asked open-ended questions and conducted interviews with various role players to determine their experiences while participating in monitoring activity. Data were not compared, but co-existed side-by-side to provide a composite picture of the research study (Creswell, 2009:214).

The collection of quantitative data by means of monitoring was seen as a scientific experiment because the so-called scientific method was followed. Steps in the scientific method include: stating a problem; formulating a hypothesis; performing an experiment and collecting data; interpreting data and drawing a conclusion; and verifying the hypothesis (Mertler, 2012:6). To examine the experience of participants during monitoring activities, a case study methodology was followed.

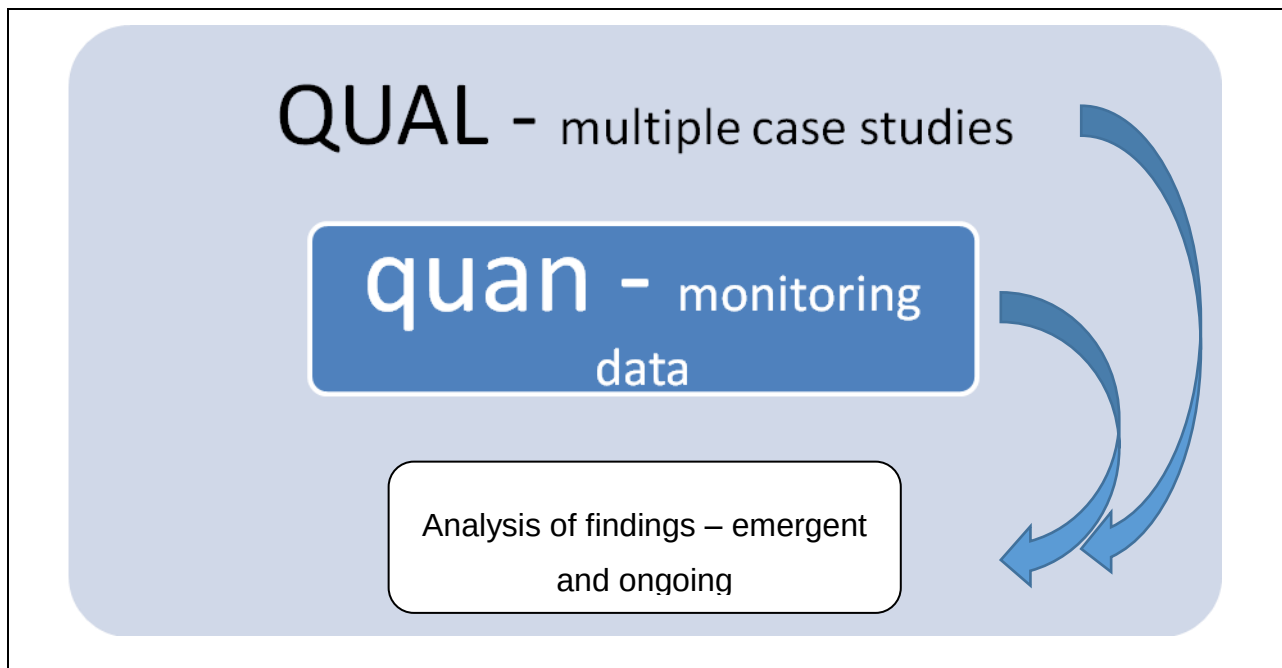


Figure 3.2: Concurrent embedded mixed-method participatory action research design

3.3.2.3 Participatory action research methodology

Participatory action research (PAR) was the research methodology which guided this research study. The researcher associates with the view of Minkler (2000:192) which defines PAR as a research practice that positions the researcher as a co-learner with an accent on community participation and the translation of research findings into action for education and change. Ebersöhn *et al.* (2007:126) maintain that participatory action research is a hybrid of action research. These researchers indicate that issues which constrain human lives are studied. An emphasis on collaboration of participants in the research process and a focus on life-enhancing changes guide this research methodology.

Minkler (2000:192) provides useful parallels between PAR and healthy communities, indicating that both PAR and healthy communities are 'bottom up' approaches which grow out of a recognition of limitations in knowledge to a complex human problem. Both PAR and healthy communities use processes of social learning to promote change, emphasising the strength of people and their capacity to solve their own problems. The researcher is of the opinion that these two approaches are driven by community priorities and cannot merely follow a generic strategy to resolve problems.

Ebersöhn *et al.* (2009:126) and Minkler (2000:192) agree that poor water quality impacts negatively on human lives and this became evident in the NWU (Vaal Campus) monitoring project. The researcher and pre-service teachers and learners collaborated during the research process to collect water quality data and this was a lived experience. The knowledge gained about the negative effects of poor water quality by both pre-service teachers and learners can be regarded as a step towards life-enhancing change.

Rossmann and Rallis (2012:213) indicates that three basic aspects are included in PAR in environmental education, namely *participation* which implies active involvement; *action* which indicates engagement with the experience and history of participants; and *research* which refers to a soundness in thought and growth in knowledge. This view is supported by Baum, MacDougall, & Smith (2006:854) who reason that PAR differs from conventional research in three ways: Firstly, PAR enables action through a reflective cycle which enables participants to collect, analyse and interpret data to determine action. Secondly, PAR deliberately shares power between “the researcher and the researched until the researched become the researchers”. Lastly, PAR posts that these new researchers have an impact on the phenomenon under observation and brings their set of values to the inquiry their set of values, making them actively involved in the process.

The NWU (Vaal Campus) monitoring project adhered to the prescriptions of PAR, namely participation, action and research. Firstly, pre-service teachers and learners live and function, participate, in a community. Secondly, the pre-service teachers and learners engaged actively in monitoring activities (action), bringing to the project their previous knowledge and cultural values, therefore their identity (Wenger 1998b, *cf.* 2.3.2.1). Thirdly, the monitoring activities were representative of the research aspect of PAR.

Strydom (2007:492) indicates that PAR is a research process involving a particular community to encourage the use of knowledge to plan, develop and achieve jointly set objectives. By implication, PAR principles can be used to introduce pre-service teachers and learners to the role of researchers in pre-arranged settings at educational institutions. Babbie (2013:341) agrees with Strydom and suggests that in PAR the researcher serves as a resource for those being studied. The participants are therefore

empowered to define their needs while the researcher brings special skills and insights which the participants need.

Strydom (2007:495-499) outlines the characteristics of participatory action research as a process which: (a) is committed to the development of knowledge as an instrument of power; (b) provides a holistic understanding of the research problem and aids with ways to achieve change in communities; (c) is applied research because it directs practical problem-solving; (d) is collaborative by acknowledging the opinions and thoughts of all participants; (e) regards both the researcher and participants as equal partners to present solutions to problems; (f) is practical and aims to synergize the views of different groups of participants on the particular problem; (g) assists with critical reflection the project; (h) is a planned and systematic approach to the learning process; (i) regards both the intra- and interpersonal perspective of participants on the project; (j) is open-minded and regards the values, culture, experience and potential of participants; (k) enables participants to shape their own lives by improving self-esteem and self-determination; (l) involves a cyclical process of planning, acting, developing and reflection. Collective reflection is the act of making a critical exploration of what you are doing, why you decided to do it and what it effects (Mertler, 2012:14).

Minkler (2000:192) posits that PAR involves a process of reflection, social learning and the development of critical consciousness on the focus of enquiry. There are various theoretical frameworks for conducting participatory action research (Mertler, 2012:14-21; Mills, 2007:16-18). PAR tends to reiterate the four stages of planning, acting, developing and reflecting listed above. Figure 3.3 displays the various steps in PAR that are relevant in this research study.

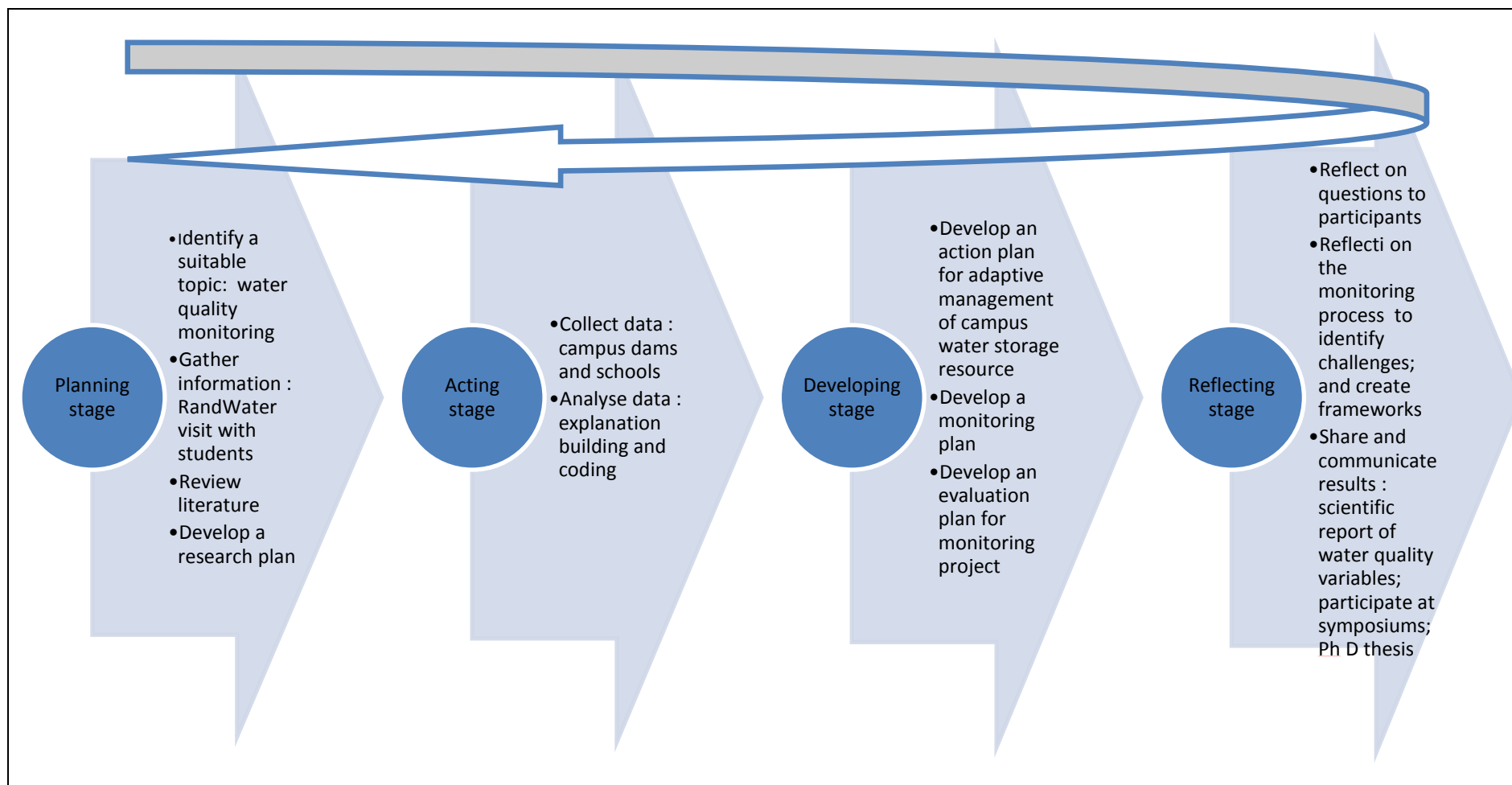


Figure 3.3: Step-by-step process of participatory action research (PAR) in the community-based water monitoring project (Mertler, 2012:37)

Kidd and Kral (2005:187) provide useful guidance on properties that define PAR. It is a dynamic process that develops from unique needs, challenges and learning experience that are specific to given groups. Kidd and Kral (2005:187) reason that PAR is not a method per se, but rather the creation of a *context* in which knowledge development and change may occur. PAR relates well with the constructivist paradigm because it is dialogical and proactive and focuses on the empowerment of participants during the research process (Kidd & Kral, 2005:187).

PAR displays the following properties in the context of the water monitoring project at the NWU (Vaal Campus) (Kidd & Kral, 2005: 189; Mertler, 2012:30):

Repetition of the cycle: PAR consists of a self-reflective spiral composed of multiple sequences of reflecting, planning, acting and observing (Kidd & Kral, 2005:189). The water monitoring activities undertaken by the researcher and pre-service teachers followed this repetitive PAR process on the campus water storage facilities. After each monitoring practice, the researcher and pre-service teachers discussed ways to ensure the accurate collection of data. The open-ended questions to the pre-service teachers also served the purpose of repetitive reflection on experiences during monitoring activities (MPA 4 (2015-2016)).

Prolonged engagement and persistent observation: Stamina and patience are required to deal with the demands of PAR (Strydom, 2007:498). The monitoring activities on campus took place over a period of two years and at schools over a one-year period. This exposure to frequent monitoring activity can be seen as prolonged engagement where the pre-service teachers had to be persistent in the collection of data and transfer of knowledge.

Experience with the process: PAR emphasises the need to go beyond fact gathering. Researchers learn about the lived experience of the participants – how they deal with problems; what they know about each other and their communities; how they experience change – as both active agents and the receivers of positive change (Kidd & Kral, 2005:189). Exposure to many monitoring activities enhances the confidence of the pre-service teachers and contributes to greater performance credibility during the monitoring activities. The monitoring activity was adapted to ensure safety of pre-service teachers during monitoring and valid data collection.

Polyangulation of data: Validity of PAR process also emphasises the importance of polyangulation of data by using multiple perspectives (Kidd & Kral, 2005:191). Multiple sources of data and information were included in this research study. The use of photographs to indicate erosion of dams allowed for cross-check referrals to the proposals of the Rand Water expert groups on how to minimise erosion. Frequent open-ended reflective questions to pre-service teachers are also regarded as multiple sources of data regarding the same activity (Mertler, 2012:30).

Member checking: In October 2016 the researcher provided the pre-service teachers with the opportunity to reveal their findings for the monitoring activities at a teaching and learning symposium. This presentation provided an opportunity to check the quantitative data and its interpretation with the pre-service teachers. Prior to the symposium, the researcher checked whether the pre-service teachers agreed with her findings on their experiences. At schools, the researcher asked the learners verbally, while they were performing the monitoring activity, how they felt about the project; whether they enjoyed the activities; and if they had learned anything new. The responses of the learners corresponded closely with the answers provided by the groups of learners to the open-ended questions, namely that they enjoyed performing the measurement process; found it easy to do and were keen to know more about water quality (Mertler, 2012:30).

Participant debriefing is similar to member checking but focuses on emotions and feelings. The open-ended questions to both pre-service teachers and learners gave them the opportunity to express themselves on their experiences. This supports the requirement of providing opportunities for affective and social learning (Mertler, 2012:30).

As a member of the Green Campus Initiative (GCI), the researcher volunteered to investigate the water storage resource facilities on the campus. After mentioning the GCI's aims and purpose to her students, they volunteered to participate in a visit to the regional water utility, Rand Water, to gain knowledge about water quality and water monitoring in general. This initial visit inspired the group to form a research team to investigate the possibilities of a community-based water monitoring initiative. After monitoring activities on campus and at schools, the researcher asked the pre-service teachers verbally about their experiences, noting their responses in her journal. Furthermore, the pre-service teachers answered open-ended questions after their monitoring activities and the researcher made sure that she understood their responses

by discussing these with them before the next session of monitoring. At the schools, the researcher asked the learners verbally if they were enjoying the monitoring; if they understood what they were testing and why they were testing it; and what their general impressions were. Like the pre-service teachers, the learners reflected on their participation by answering open-ended questions. In this way, the researcher ensured that there had been collaborative communication during the monitoring project.

PAR suited the design principles of transdisciplinary research as indicated by Lang *et al.*, (2012:33). The joint problem framing and collaborative approach of diverse groups of participants supported the implementation of phase one. GCI meetings, monitoring activities on campus and at community schools, as well as engagements with Rand Water officials enabled participation at various levels of expertise and interest of participants. The planning of the water monitoring project was done in accordance with the four step, repetitive PAR process prescribed for phase B of transdisciplinary research. The report on experiences of participants, both social and scientific, as well as the scientific report on the water quality status of campus dams and the design of relevant theoretical frameworks, was compliant with phase three, where results were brought to fruition.

3.3.3 Research strategies

The research strategy followed for the qualitative part of the study is a case study approach. Yin (2009:18) defines a case study as an empirical inquiry which investigates a contemporary phenomenon in a real-life context. Case studies are seen as in-depth examinations of single or multiple investigations that provide a systematic way to: approach problems; collect and analyse data; and report results (Yin, 2009:18). Grauer (2012:70) indicates that the use of multiple data sources enhances the credibility of case study research. This type of research also allows for convergence of quantitative and qualitative data. Collectively, such data provides a rich sense of understanding.

Yin (2009:36) explains that case study design is appropriate when: (a) the focus of the study is to answer 'how' or 'why' questions; (b) the behaviour of those involved cannot be manipulated; (c) contextual conditions are relevant to the phenomenon under study; and (d) boundaries between the phenomenon and the context are unclear.

The notion of Yin is recognised in this research study. The researcher wanted to: (a) find out how the participants (pre-service teachers and Grade 10 learners) experienced

the water monitoring project; (b) know more about the honest learning experiences of the participants; (c) explore the prior knowledge or lack of participants' knowledge in respect of water and water quality and how it could be accommodated in the research process; (d) learn more about water health and water quality, from the viewpoint of participants and how it is generally accepted in the context of their real-life world.

For the quantitative part of the study, observational research was applied. The focus of observational studies is broader (more than one type of educational institution) than that of observational case studies which focus only on a particular physical location, for example, only the NWU (Vaal) campus (Mertler, 2012:91).

The collection of quantitative data also became part of the case study approach because the research involved an in-depth study of water quality of the NWU (Vaal) campus – a contemporary phenomenon in a real-world context. The scientific method was used as a specific component of the case study strategy to answer questions and resolve problems on the water quality of the campus' water storage facilities (Mertler, 2012:6, 13).

3.3.4 Data collection methods

3.3.4.1 Position of the researcher in the research study

In an observational study the researcher becomes an integral part of the research and gains the trust of participants (Mertler, 2012:91). In this study the researcher was acknowledged as an active member of the community and simultaneously also part of the monitoring group. The nature of the project determined the role and position of the researcher. Rossman and Rallis (2012:148) regard this degree of involvement as *co-participation*. As a co-participant, the researcher was able to yield a deep understanding of the setting and other participants. Co-participation is extraordinarily time-intensive and relies heavily on the trust of other participants in the project to share their knowledge and experience with the researcher. (Rossman & Rallis, 2012:149).

Being a part of the group, the researcher collected data by studying the context of the research and the nature of the participants (Mertler, 2012:93). The researcher interacted proactively with all participants during the process of data collection. Her role included the examination of related documents on water monitoring of local water storage facilities, for example material from Rand Water; observing the monitoring

practices on campus; asking questions of participants; personally performing monitoring tasks; reflecting on monitoring activities with the aim of ensuring safety of pre-service teachers; and contemplating the collection of useful data. The researcher spent an extended period of time, from February 2015 to November 2016, with various participants on different aspects of the monitoring project. Co-participation and co-production of knowledge are regarded as important aspects of transdisciplinary research (*cf.* 2.3.2.8).

3.3.4.2 Recruitment

The research results of the water-monitoring project are relevant for the introduction of environmental education into various subjects in South Africa. The quality of water is a changing variable and the interest and value of participants to whom this is relevant must be taken into account (Bergmann *et al.*, 2012:36). The participants in this study were chosen purposively (Nieuwenhuis, 2007:79).

Eight NWU pre-service teachers, majoring in Physical Science in the second year B.Ed. programme voluntarily indicated that they wanted to participate in the water monitoring project to be held on the campus. They will be teaching Physical Science at schools once they graduate. Incorporating only eight pre-service teachers in the project enabled the researcher to engage frequently with a group of manageable size. The group was chosen by using the following criteria: The pre-service teachers were second year B.Ed. pre-service teachers who started studying Physical Science at first-year level in 2015 and continued at second-year level in 2016, as third year students.

The learners participating in the project at local schools numbered between 240 and 320. The researcher identified schools of the Gauteng Education Department and applied in advance for consent from the Gauteng Department of Education (GDE). Schools included in the research were chosen to represent the diversity of the local and regional community, irrespective of race and class. Monitoring at schools was done after school hours. The researcher therefore chose schools in close proximity to the university to provide accessibility to the pre-service teachers. The criteria used to choose these learners were: Grade 10 learners; at schools in the D 7 and D 8 districts of Gauteng Province; and those who had Physical Science as a subject.

Each of the eight student teachers took responsibility for conducting the experiments with a group of 30 to 40 Grade 10 learners in a Physical Science class. The learners

worked in groups of four to six members and answered open-ended questions in groups about their experiences during monitoring activities once the practical was done.

Other participants included: four members of the technical services division at the NWU (Vaal Campus) who are responsible for environmental management; 6 scientists employed at Rand Water; and 20 members of the Green Campus Initiative (GCI), which included members of campus management.

Rand Water is an acknowledged national industry leader in the field of water quality monitoring and water purification. Rand Water experts attended the monitoring activities of pre-service students to ensure correct practices. Rand Water officials validated the students' findings and helped to formulate proposals to ensure that the water storage resource on the NWU (Vaal Campus) remains healthy.

3.3.4.3 Data gathering techniques – methodological steps

In this research study data was collected by means of: i) interviews with participants; ii) open-ended questions to the participants; iii) journal notes; iv) photographs; v) observations and measurements made while water quality experiments were being conducted; and vi) document reviews. Photographs, which were taken during monitoring, were used to indicate the state of water storage resource at different times and seasons – to aid with management proposals and not for analysis. Below, different data gathering techniques are discussed in detail.

- **Document reviews**

To understand the focal system and the relation between the campus community and the environment, the researcher conducted research for a Master's degree in Environmental Management in 2013/2014 and relied largely on documents that date back as far as the 1960s, when the NWU (Vaal Triangle Campus) was founded in Vanderbijlpark. These documents covered a very wide range of information on available land; student numbers; biodiversity, and other key events regarding climate and weather. The document review provided rich, descriptive data about the NWU (Vaal Campus). This information was of great value for the purposes of this research study on water monitoring.

- **Literature review**

Literature was also reviewed to explore the concepts of environmental education, social learning, a project-based teaching approach, monitoring in general and community-based monitoring. The researcher acknowledges that more than one resource recommended that the project-based teaching approach prefers a transdisciplinary research methodology (Brundiers *et al.*, 2010:321 & Waghid, 2002:457).

The researcher has 30 years of Physical Science teaching experience at secondary schools and at a university campus. She therefore maintains that wide-ranging subject knowledge of Physical Science as a discipline makes her well-suited to implement environmental education in subject curricula.

Rand Water releases information on water quality of the Vaal River on its website on a weekly basis. In addition, Mrs Nyree Steenkamp, the Rand Water expert with an interest in the NWU (Vaal Campus) water monitoring project, provided the researcher with suitable materials for the adaptive management of water bodies. The information proved to be very useful for the purposes of comparing measurements of the water from the Vaal River with those of Rand Water and gaining insight on adaptive management strategies for dams.

- **Interviews**

Interviews were seen as a two-way conversation in which the researcher aimed to see the world through the eyes of the participant, thereby gleaning rich, descriptive data that helped to understand the participant's construction of knowledge and social reality (Yin, 2009:107). Semi-structured interviews were conducted with the various participants involved in the monitoring process once they gave the necessary consent. Participants included: members of the technical staff of the NWU (Vaal Campus) especially Mr Burger Scholtz who assisted with the incorporation of proposals for adaptive management of the water storage resource; experts from Rand Water, particularly Mrs Nyree Steenkamp who helped with advice on monitoring practices; Mr Francois van Wyk, a Rand Water catchment manager, who provided adaptive management proposals; and members of campus management and the GCI. The purpose of these interviews was to determine how these role players regard monitoring of water and their thoughts on the value of water monitoring at the NWU (Vaal).

- **Observation**

Observing is a systematic process of recording behavioural patterns and events without necessarily questioning participants or communicating with them. Observation helps researchers to gain deeper insight and understanding of the phenomena under scrutiny and is a selective and subjective means of research. Observations tend to focus on specific practices and the researcher needs to be conscious of his or her own biases and find ways to deal with them by being as objective as possible (Yin, 2009:109).

In this research study the condition of campus dams and the Vaal River were observed for evidence of litter, change in colour, algae growth and measurement of water quality variables. To record the observations, field notes were made by the pre-service teachers and the researcher. These qualitative notes included details of the date and time, situation and actions observed. Quantitative data, in numerical form was summarised in columns on worksheets prepared and formatted by the researcher. The researcher also reflected on monitoring events by noting all relevant details in a journal. Rand Water officials, including Mrs Nyree Steenkamp, acted as co-observers and confirmed observations during field trips.

- **Observations by means of photographs**

Photographs were taken during the water-monitoring project (2015 and 2016) as part of observation. These photographs indicated the changes that occurred in water storage resources as seasons change and time passes and assisted in the compilation of adaptive management proposals to campus management. Photographs also indicated the progress and practice of pre-service teachers and learners during monitoring and provided valuable footage of actual monitoring in educational institutes. The photographs were used in the water monitoring project to indicate areas of focus which required specific attention for adaptive management (Mills, 2007:71).

- **Measurement**

Measurement in this research initiative was used to gain insight into water quality as a complex phenomenon. The nine variables related to water quality monitoring were: pH value, temperature, concentration of chloride-, nitrite- and nitrate ions, bio oxygen and oxygen demand, hardness of water, *E. coli* concentration, and the physical appearance of the water storage resource. The measurements were recorded by means of specific

scientific processes as described in the manual by Somerset Education, the suppliers of the water monitoring test kits.

- **Open-ended questions**

The researcher asked the pre-service teachers to answer open-ended questions in writing, reflecting on their experience of the monitoring project. These questions indicated the pre-service teachers' experience of monitoring, what they learned and how they learned it. The questions also left room for pre-service teachers to raise any concerns they might have and to indicate if they encountered any difficulties while carrying out the monitoring process. The questions enabled the researcher to determine if individual pre-service teachers benefited in terms of knowledge acquisition by their participation in the research project.

Similarly, the researcher asked learners (in groups of four to six learners) to reflect in writing on their experience of water monitoring. Learners answered open-ended questions in writing on their experience after performing monitoring measurements. The questions were set to give learners the opportunity to raise their own voices regarding the monitoring experience.

- **Journal notes – water monitoring project diary**

From the outset the researcher wrote journal notes on the water-monitoring project to document meetings with various participants, the outcomes of these meetings, decisions taken and reflections on monitoring activities and proposals. As the water-monitoring project was emergent and adaptive rather than fixed, it was important for the researcher to note the general flow of the project, encounters with various role players and possible challenges which had to be addressed. The journal, also called the water monitoring project diary, helped to direct the research and provided valuable information for reflection on the project.

3.4 RIGOUR IN TRANSDISCIPLINARY RESEARCH

The quality of trans-disciplinary research depends on its assessment in terms of the following criteria:

Salience refers to the practical relevance of the results of the research (Lang *et al.*, 2012:26). The researcher is of the opinion that the results of this water quality project

raised awareness of the possibilities of and extent to which community-based monitoring is able to provoke interest and knowledge regarding environmental matters in communities.

Legitimacy refers to whether the chosen participants do indeed provide a sound representation of the community that is under scrutiny (Lang *et al.*, 2012:39). In this research study the NWU (Vaal Campus) was represented by the pre-service teachers; the GCI committee; and the NWU management, via the director of the technical services division. The local community was represented by the school learners who are studying Physical Science. Also represented were Rand Water employees, who assisted in the validation of the monitoring practices and water quality measurements. They acted as the experts in the research.

Authenticity, as applied to a research study, is explained by James & Card (2012:222) as having four characteristics, namely: (a) Fairness, which refers to a consideration of all the sides and possible interpretations of the situation. In this particular study, several notions and opinions were weighed up, including those of the researcher, the pre-service teachers and Grade 10 learners (as citizen scientists); the GCI committee (as a concerned partner to environmental management of the NWU's Vaal Campus); and Rand Water (as the expert in water monitoring). (b) Ontological authenticity, which refers to the positive internal and external outcomes of the project. The researcher envisions that the outcomes of this research study have significant positive connotations such as enjoyment, enhanced subject knowledge and practical skill for both pre-service teachers and learners. (c) Educative authenticity, suggesting that people with disparate ideas are able to relate to and understand opposing viewpoints. This research study complied with educative authenticity because the researcher and pre-service teachers were cognisant of adhering to prescriptive scientific methods in collecting the data; and findings were confirmed by experts from Rand Water. This verification of the credibility of data ensured that educative authenticity was achieved. (d) Catalytic authenticity that refers to studies where research outcomes stimulate action towards the well-being of all – in other words, the wider picture is positive on a larger scale. In this research study the gains could include the empowerment of pre-service teachers and the Grade 10 school learners. The initiative might raise awareness of water quality and could indicate that there are relatively simple methods to ensure positive improvement of water quality.

Regarding the multiple case studies and quantitative monitoring data the following criteria were met to uphold rigour (Mertler, 2012:28):

Quantitative findings

Construct validity was ensured by using multiple sources of evidence during data collection such as documents, interviews and observation techniques – and by reviewing the report in the light of the recommendations of experts from Rand Water and academic study leaders.

Internal validity was achieved during data analysis by practising explanation building and by using tables and graphs to represent the monitoring data. Regarding the interviews and questionnaires, questions were reviewed by study leaders to ensure that accurate yet rich and descriptive data emerged. The variables of the water storage resource and data collected from the water storage resource were objective readings which could not be controlled by the water monitoring team.

External validity was achieved by gleaning accurate descriptive data not only of the study field but also of the varied experience of the participants. The citizen science framework and system for environmental education designed by the researcher can be used by other researchers working in the field of citizen science and are therefore transferable findings of this research study.

Reliability was achieved by means of scientific data collection techniques. Case study protocol applied and a case study database was developed with the variable data in columns and graphs (Yin, 2009:41, 114). Reliability was also enhanced by maintaining a chain of evidence and by comparing data from different months and seasons. By including experts from Rand Water as co-observers to confirm measurements made by participants and to trace the chain of evidence, reliability was ensured. (Yin, 2009:123).

Qualitative findings

Curtin and Fossey (2007:89) indicate that **trustworthiness** is an indication of whether the research findings provide an authentic reflection of the personal or lived experience of the phenomenon under investigation. Strategies that were used in this research to enhance trustworthiness include: (a) providing a transparent, clear description of strategies used to collect data of both participants and the phenomenon water; and (b) providing a *thick* description of the research settings and participants.

A thick description is defined as a detailed description of the context and circumstances of the phenomenon as well as a rationale for the chosen method. The researcher is of the opinion that the research proposal included in Chapter 1, as well as the empirical research displayed in this chapter provided a thick description.

The following themes and concepts all contributed to trustworthiness in this study:

Triangulation indicates a method used to determine the position of a single point using observations from two additional points (Curtin & Fossey, 2007:90). Triangulation has two purposes, namely confirmation and completeness.

Confirmation/Confirmability refers to the use of self-critical methods (Ebersöhn *et al.*, 2007:134) to overcome bias and increase the credibility and validity of findings (Curtin & Fossey, 2007:90). In this research study, reflective practices were a crucial component of trans-disciplinary research. The researcher reflected by using the journal notes to compare monitoring activities. The responses of the pre-service teachers to open-ended questions were discussed with them and this reflection on previously answered questions became a tool to confirm that their answers were indicative of their real experience. Interviews with experts from Rand Water and the members of technical services of the NWU (Vaal Campus) were used to reflect on the monitoring process. Learners worked in classrooms in groups and had to discuss and reflect on their answers by providing a single answer per group of four learners.

Completeness indicates the holistic view of the phenomenon being studied. Completeness provided depth and breadth to the research study and enhanced insight and understanding. In essence, to achieve completeness means that a range of results enrich explanation (Curtin & Fossey, 2007:90). In qualitative research completeness ties in with the notion of finding rich descriptive data and not to generalise unduly (*cf.* 3.3.4).

Types of triangulation

Curtin & Fossey (2007:90-91) report that there are three types of triangulation that contribute to trustworthiness. *Data triangulation* refers to the use of a variety of sampling strategies and sources to obtain a diverse view of the specific phenomenon. The use of data triangulation maximises the range of data and provides a more comprehensive understanding of the phenomenon under study. Comparing and cross-checking the data collected at different times and by different means provides for three categories of data

triangulation, namely: (a) time triangulation which refers to the collection of data at different intervals; (b) space triangulation that is the collection of data about the same phenomenon in a different setting to investigate the consistency of data across sites; and (c) person triangulation which refers to the collection of information from more than one group or level of people Curtin & Fossey, 2007:91).

In the water monitoring project data triangulation was achieved when the research team collected water quality data from different campus water storage resources over an extended period from 2015 to 2016 (MPA 8 (2015-2016)). Time triangulation was practised by collecting data in different months and seasons over a two-year period. The collection of data from different campus water storage resources and/or different dams and from the Vaal River was evidence of space triangulation. Collecting water quality data from samples taken by the learners from a communal water storage source in the local informal settlement was also space triangulation. These water samples differed from those the pre-service students worked on. Pre-service teachers and learners answered reflective questions after monitoring activities and person triangulation was thus achieved. The pre-service teachers shared individual, personal experiences when answering open-ended, reflective questions on a variety of activities. The learners also reflected on their experiences, providing responses in groups after performing the water experiments at schools. The personal triangulation of data provided both depth and breadth to the perspectives of participants in the NWU (Vaal Campus) monitoring project.

Methodological triangulation

The use of two or more research methods in one study is regarded as methodological triangulation. Curtin and Fossey (2007:91) distinguish between two types of methodological triangulation, namely across-method and within-method. Across-method triangulation makes use of both qualitative and quantitative approaches to investigate the same phenomenon. An example is the use of focus groups and a survey to test the views and perceptions of participants. Within-method triangulation is the use of two or more different methods in a methodological approach to measure the same phenomenon. The water measuring project applied within-method triangulation because the researcher used an observational method to investigate the experiences of participants and a scientific method to research the water quality status of campus water storage resources (*cf.* 3.3.4).

Collaboration was evident in the water quality project at the NWU (Vaal Campus). The pre-service teachers and school learners cooperated as co-researchers (*cf.* 3.3.2.3). All these participants contributed to the collection and interpretation of data, and the trustworthiness of this study.

Credibility refers to the degree to which data makes sense and is relevant to readers of the report (James *et al.*, 2012:217). In this research study credibility was ensured by a prolonged engagement and persistent observation efforts in the study field. The researcher acted as a full participant, working and reporting collaboratively with other role players, thereby increasing credibility. Training in the use of the Atlas coding programme also enhanced credibility. Ongoing reflection and comparison of the data and member validation of data, also heightened credibility.

Transferability indicates whether sufficient information is available to judge whether findings are indeed applicable to other settings. In this study, detailed descriptions of settings and processes are provided to enable the duplication of the study in other contexts (Ebersöhn *et al.*, 2007:134; Curtin & Fossey, 2007:92).

Dependability refers to the degree to which findings reached and reported stand up to scrutiny and have been accurately transcribed (Hinckley, 2005:297). In this research study dependability was achieved by cross checks carried out by pre-service teachers who worked in pairs and confirmed each other's findings. The researcher and the experts from Rand Water confirmed these findings. Furthermore, the researcher discussed salient themes (in the form of open-ended questions) with pre-service teachers to maintain accuracy. In addition, the researcher compiled a detailed report on how the school learners experienced the monitoring experiments and this will be sent to the schools that participated and to the Department of Education once the thesis is finalised. Data were triangulated during the research process, i.e. the results from interviews, journal notes, photographs and open-ended questions were integrated to provide reliable findings. Bias was eliminated by constantly reflecting interactively on the research process.

Reflexivity is the direct acknowledgment by the researcher that she was an active participant throughout the research process and therefore had significant influence on the process and the engagement of participants. By keeping a journal on the water monitoring project the researcher has access to a wide range of detail on the interaction

and experiences of pre-service teachers and the learners. By planning the water monitoring project and the evaluation programme the researcher has explicit evidence of her influence in the research study (*cf.* 3.9).

Trustworthiness was further achieved in this research study by using: (a) multiple collectors of data; (b) multiple methods of data collection such as observation, interviews, document analysis, journal notes and (c) crystallisation, which promotes deeper understanding of a variety of diverse views on water monitoring and citizen science (Nieuwenhuis, 2007:81).

3.5 DATA ANALYSIS

Data analysis was performed from an interpretive paradigm. An inductive data analysis enabled the researcher to identify the multiple realities present in the data (Maree & Van der Westhuizen, 2007:37). The data required continuous reviewing to allow for the development of new techniques and analytical concepts. Multiple cycles of analysis and reflection were undertaken in accordance with the PAR approach. The researcher asked the pre-service teachers open-ended questions after each monitoring session, allowing them enough time to report on their experiences (MPA 4 (2015–2016)). The data from these multiple viewpoints was collated and was studied for meaning, context, historical viewpoints and causal relationships (James *et al.*, 2012:110).

The researcher reviewed documents to familiarise herself with the concepts of citizen science, environmental education and water quality monitoring; relevant information was summarised and the researcher built a comprehensive picture of secondary source material as indicated in Chapter 2. The agendas and minutes of GCI meetings also provided relevant information and were used to comment on water monitoring activities.

The researcher interviewed the following participants in person: Mrs Nyree Steenkamp and the Rand Water expert group, Professor Johann Tempelhoff and Mr Burger Scholtz. Mrs Nyree Steenkamp accompanied the monitoring group on two occasions to observe the water monitoring process on the campus. Mrs Steenkamp's remarks were noted as observations on the water monitoring worksheets and then communicated via e-mail correspondence. The findings of the Rand Water expert groups were written down by the researcher and confirmed by the expert group via e-mail. The interviews with Mr Scholtz and Prof. Tempelhoff were noted in the researcher's journal on the day

of the discussion. The researcher used the participants' verbatim transcriptions to indicate their views on the water quality project.

Both observations and photographs, discussed in the next sections, are regarded as visual data. *Visual data* is defined as two or three dimensional images or computerised representations for better understanding of the phenomenon being studied (Klein & Agostinone-Wilson, 2012:82). Typical of participatory action research studies, visual data provides a snapshot (one-time event) or a time series collected over a short period (Klein & Agostinone-Wilson, 2012:85) and was used to good effect in this project. The collection of variable data on the campus water storage resources at specific times provides a snapshot of the variables present at that specific time. Combining of data readings for the period 2015 to 2016 in graphic form provided a time series of variables at campus dams.

Semiotic analysis of visual data was used in this research study (Klein and Agostinone-Wilson, 2012:90). Semiotic analysis allows for the interpretation and interrogation of visual images within research contexts for personal, visual and social meanings. Three questions guide semiotic analysis, namely: (a) what does the visual data mean?; (b) how does the data represent what it means?; and (c) why does the data mean what it means? These three guided questions indicate how the researcher analysed the data collected via observation, measurement and photographs. Chapter 5 deals with the meaning of each variable; the meaning of the values of the variable in campus dams; and then interprets why the variables have specific values. Data from the experiments on water quality of the campus water storage resources were made on a specially designed worksheet to indicate the objective readings of all variables. The researcher used Excel worksheets to summarise the collected data and then drew Excel graphs to indicate the relation between the readings. Data was summarised electronically as soon as possible after monitoring activities to ensure that the data was safely stored and available. Data was not analysed by using statistical techniques. Explanation building was used to compile graphs and represent quantitative data. The influence of change in seasons and campus activities on the water storage resource was explained by analysing the tabled data and graphs.

Photographs were taken during monitoring events at the campus dams and in the schools. At dams the photographs were taken with the purpose of displaying the care taken to support adaptive management proposals. Photographs were not compared

from 2015 to 2016 because the researcher was informed by campus management of the serious economic demand on campus funds due to the “fees must fall” protest action and resultant curbs on adaptive management proposals.

The pre-service teachers and learners provided information by answering open-ended questions. Pattern matching via the computerised Atlas ti program was used as an analytical technique to indicate the personal experiences of participations (Yin, 2009:136). The researcher was trained to use the Atlas ti coding programme at a workshop in April 2016 under the guidance of Dr Lize van der Merwe of the Potchefstroom Campus. The Atlas ti coding programme was valuable when data was coded and analysed. New data that emerged were added to the similar data pool, codes were revisited and reviewed and new, emergent codes were added. This also served the purpose of reflecting on existing data and comparing existing codes with new ones.

In summary: the quantitative data was analysed, while the qualitative data was interpreted (Bergmann *et al.*, 2012:40). The integration of quantitative and qualitative data adhered to the final design principle in transdisciplinary research (Lang *et al.*, 2012:34) to deliver products which have both a scientific and societal impact. Analysis of quantitative data produced a scientific report which revealed the water quality status of campus dams at the NWU (Vaal Campus) in comparison to the water quality of the Vaal Barrage catchment – thereby providing evidence of a scientific impact. Analysis of qualitative data revealed the nature of social and environmental learning by participants and was used to throw light on theoretical frameworks and social gains in the community.

3.6 COMPLYING WITH ETHICAL PRINCIPLES

Creswell (2009:88) maintains that before undertaking research it is important to identify a problem that will benefit individuals who participate in the research and others across a wider spectrum.

The researcher was sensitive to the following ethical guidelines by Creswell (2009:89-91) in that she:

- Requested permission from the campus rector for the research study to be conducted on the NWU, Vaal Campus and applied for funding to extend the scope of the research project to include international collaboration. The researcher wishes to

present the findings of the water monitoring project in the near future at an international symposium (MPA 14.1).

- Was trained on ethical issues related to research in a three-hour training session presented at the NWU (Vaal Campus) (22 March 2016). The researcher also attended a workshop on the ethical implications of submitting computer-based evidence (Info Ed) (9 and 10 June 2015).
- Gained access to Info Ed, the ethical website of the NWU, so as to supply the Humanities and Health Research Ethics Committee (HHREC) and later the Basic and Social Science Research Ethics Committee (BaSSREC) with all relevant documents and proof of ethical conduct in this research study (MPA 14.5 & 14.6).
- Applied successfully for consent from the Gauteng Education Department to perform water quality measurements in schools (October 2015) (MPA 10.1–10.3);
- Secured permission to conduct research at schools by compiling consent letters to principals and teachers of participative schools (during 2016) (MPA 12.1)
- Secured permission from participants to collect and use data by compiling assent letters for learners and for pre-service teachers. Consent letters were distributed to be signed by parents (MPA 13.1, 14.2-14.4).
- Identified herself to all participants and respondents, giving them information on the reasons for their selection as participants in the project, the expected benefits of the research, and how and why they were involved.
- Declared that she has no intention to falsify findings or invent findings to suit her own needs.

The researcher also indicated that she plans to release the findings of this research study in detail so that other researchers in the same and allied fields will be able to determine the credibility and merit of the study.

In the next part the water monitoring project programme is discussed in detail.

3.7 THE WATER MONITORING PROJECT PROGRAMME

Chapter 2, the literature review, indicated that community-based biological monitoring of water is preferred in South Africa above physical and chemical monitoring of water (*cf.* 2.2.1.3). Before embarking on a community-based water monitoring project at the NWU

(Vaal Campus) the researcher looked for examples of similar initiatives in other skilled countries. The United States of America (USA) has the longest running community-based water monitoring project which began in 1890 and the researcher used information from the USA to guide the NWU water monitoring project. The US Department of Agriculture (USDA) facilitates volunteer water quality monitoring and indicates on its website that the type of monitoring activity and the data objectives determine the frequency of monitoring. It also indicates that physical data like pH, temperature etc. for educational purposes needs to be collected at least once a month (USDA, 2016). The researcher acknowledged the academic schedule of the NWU as well as Gauteng schools when she set monitoring dates. The USDA website indicates that the following basic components must guide the programme, namely: (a) the question which needs to be answered; (b) the use of data and (c) the resources available to accomplish goals.

Guidelines provided by the USDA assisted the researcher in designing the following water monitoring project programme.

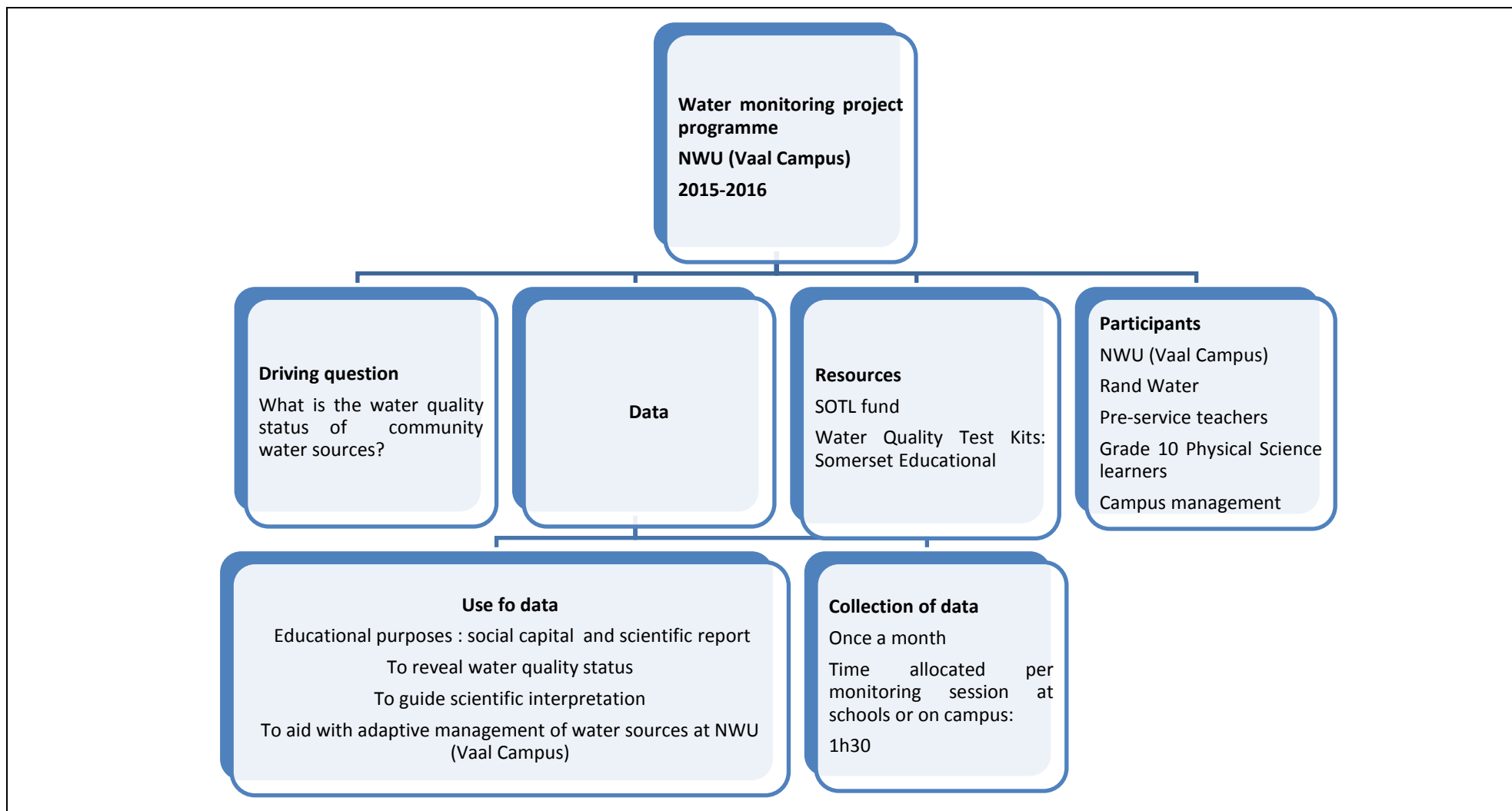


Figure 3.4: The water monitoring project programme (USDA, 2010 (IV):1-2)

3.7.1 Volunteers – the heart of the monitoring project

The USDA (2012 (V):1-3) suggests that active and committed volunteers are the heart of any water quality monitoring project. To ensure that the water monitoring project was a successful, well-run and positive experience for those involved, something they could be proud of being involved in and could prove gainful for their community, the researcher adhered to typical volunteer rights such as: (a) providing orientation and training for all participants; (b) giving clear, appropriate instructions for monitoring and collection of data; (c) ensuring that participation was fulfilling by monitoring relevant variables which met programme goals; (d) recognising the contribution of volunteers by, for example, giving pre-service teachers frequent exposure to opportunities to apply their skills and show their knowledge; (e) respecting all participants as individuals who were giving of their valuable time and making allowances for their own academic schedules in planning the project; (f) ensuring that time was best used by keeping to the allocated monitoring time of an hour and a half; (g) providing safe and healthy working conditions by using the Somerset Water Quality Kit which has no dangerous chemicals and is easy to handle; also redesigning apparatus to ensure safe collection of data on campus; (h) redesigning the monitoring activities at schools to ensure the collection of all monitoring data in ordinary classrooms if laboratories were unavailable; (i) considering experienced volunteers for leadership and giving the pre-service teachers opportunities to collect monitoring data in classrooms without intervention of the researcher; (j) providing honest feedback after monitoring activities through reflective questions which could be answered at a suitable time and place for the volunteer.

3.7.1.1 The training of volunteers in the NWU (Vaal Campus) water monitoring project

In the implementation of a community-based water monitoring programme involving civil society, this research study used pre-service teachers and Grade 10 Physical Science learners as data collectors (*cf.* 3.3.4.2). It was important to ensure that the collected data could be used for the designated purpose so the training of participants was a necessity. Training can either be carried out one-on-one or in a group (USDA, 2012 (V):2). In this water monitoring project both methods were used.

The researcher provided orientation for the pre-service teachers and learners in a group with a power point presentation focusing on reasons why water status is important and

the effects of unhealthy water. She then turned to explaining relevant concepts like citizen science, community-based monitoring, and monitoring of the physical and chemical variables of water. The researcher emphasised that they would be part of a project-based teaching approach and outlined the possible gains of participating in a water monitoring project.

The water quality test kit and content was shown to the participants and the test kit manual was used to explain the how and why of monitoring. Participants were free to ask questions if they were unsure of anything.

Once monitoring activities began, the researcher and on occasion Rand Water experts were available to work one-on-one with any participants who were uncertain about methods and measurement. The researcher prepared data sheets to collect the data and provided these to both pre-service teachers and learners. Participants were permitted to repeat the monitoring until they were skilled and had the necessary knowledge to perform data collection activity with confidence. The role of the participants in the collection of data was clearly explained and they were free to leave at any time if they didn't want to continue their participation.

Pre-service teachers received field training on the water storage facilities of NWU (Vaal Campus). This training took place once a month on a Friday when the pre-service teachers had no classes, tests, examinations or holidays. The monitoring of the water storage resources on campus took about an hour and a half. The researcher often treated the pre-service teachers to a picnic or snack after monitoring activities. The researcher accompanied the pre-service teachers on all monitoring activities on campus to ensure their safety at water storage resources and to allow for social learning opportunities if the student teachers were still unsure about monitoring. After the first session of monitoring the researcher held a picnic for the project team. An informal meeting followed and the team discussed any problems that had arisen.

Mrs Nyree Steenkamp participated in the monitoring activities after the first two sessions. She advised the pre-service teachers to collect data at the same location each time. All data was collected in sun exposed spaces at the dams. Mrs Steenkamp was instrumental in identifying suitable sites for multiple data-collection events. The pre-service teachers worked in groups of two. In this way, they soon became experts on testing the variables and their technique of data collection. Mrs Steenkamp and the

researcher agreed to redesign the apparatus to ensure the safety of pre-service teachers during data collection. The researcher's husband redesigned the apparatus slightly to make it more user-friendly for the monitoring team.

The researcher indicated to both pre-service teachers and Grade 10 Physical Science learners that her intent with the project was research related and the participants were in fact citizen scientists. The pre-service teachers and learners were allowed adequate time to complete their scientific reports and were requested to answer open-ended questions so that their experience of the project could be assessed as part of the research study. The researcher returned to the schools to collect data if learners needed more time to rethink and reflect on monitoring practices.

3.7.2 Evaluating the water monitoring project

The USDA (2012 (XVI):1) reports that there are three purposes for evaluation of a monitoring project, namely (a) to inform on the state and effectiveness of the programme; (b) to provide information that can be used to refine or improve results; and (c) to collect evidence on the progress of the project to meet the intended outcomes and communicate the impact of the project.

Regarding the effectiveness of a programme the following guiding questions are posited: (a) Is the programme serving its objectives?; (b) What aspects of training are most engaging or disengaging?; (c) Is the programme being run in a cost effective and sustainable way? and (d) To what degree is the programme achieving its goals? (USDA, 2012 (XVI):1).

The USDA (2012 (XVI):4) proposes five steps when evaluating a water monitoring programme, namely to (a) engage stakeholders; (b) develop questions; (c) define indicators of success; (d) collect data and (e) summarise findings.

These directions proposed by the USDA helped the researcher to design the following evaluation programme for the water monitoring project at the NWU (Vaal Campus).

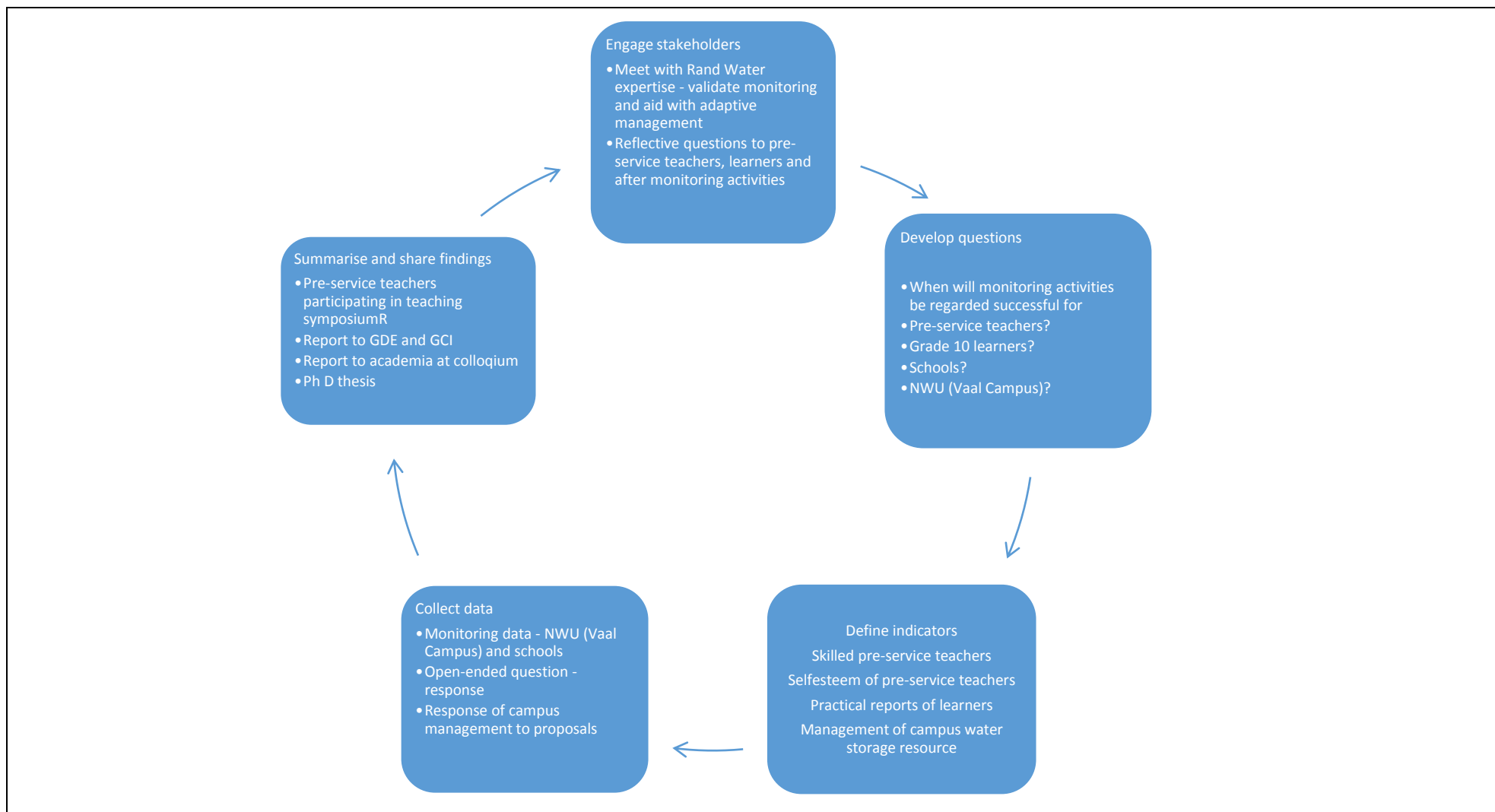


Figure 3.5: Evaluation programme for the water monitoring project NWU (Vaal Campus) (USDA, 2012 (XVI):4)

USDA (2012 (XVI):2) indicates that a water monitoring project that promotes learning calls for an evaluation of changes in awareness, knowledge or understanding. Accordingly an attempt was made to evaluate both the change in awareness and knowledge. Change in awareness was evaluated by coding of the reflective responses of pre-service teachers and Grade 10 Physical Science learners to open-ended questions. Change in knowledge and understanding was informally evaluated when pre-service teachers performed monitoring activities at schools and presented their findings at a teaching symposium. Grade 10 learners in groups were evaluated when the researcher assessed the acquisition of knowledge in their practical reports on monitoring. The researcher used a rubric to mark the reports and handed the material back to the responsible teacher. The educators had permission to use the researcher's marks for the purposes of the learner's Physical Science "practical work" if they wanted to do so.

Regarding environmental outcomes, the researcher presented the monitoring data to a group of experts from Rand Water, including the catchment manager, Mr Francois van Wyk. These experts accompanied the researcher to all the water storage resources and proposed relevant management proposals for each source (MPA 1 (2015.11.10)).

3.8 CHAPTER SUMMARY

Chapter 3 indicated that the research process began with the researcher's social constructivist paradigm from which the research process emerged (*cf.* 3.2). Social constructivists aim to show their understanding of the world and its phenomena, by means of a theory of patterns. The literature review was used to gain insight into the research initiative and assisted in identifying gaps in current research in this particular field of water studies (*cf.* 3.3.1). An embedded mixed-method research approach, which included the core concerns and phases of transdisciplinary research, was proposed (*cf.* 3.3.2.1).

The research methodology followed was PAR (*cf.* 3.3.3). The researcher is of the opinion that trans-disciplinary research and PAR complemented each other in this research study. The first phase of transdisciplinary research, namely problem identification and structuring, concurs with the planning stage of PAR. The second phase of transdisciplinary research, namely the research process, is in accordance with

the acting and developing stages of PAR while the final phase, namely bringing results to fruition agrees with the reflection stage of PAR.

The research strategy employed was a multiple case study because there were different groups of participants and a variety of variables. The specific type of case study used was an observational study because of the incorporation of more than one type of educational institution (*cf.* 3.4). In planning and execution of the project the researcher aimed to ensure rigour (*cf.* 3.6). Participants were purposively chosen (*cf.* 3.3.5.2) and data gathering techniques included document reviews, interviews, observations, measurements, photographs, journal notes, and open-ended reflective questions asked of the participants (*cf.* 3.3.5.3). Pattern matching for qualitative data using the Atlas coding programme; and explanation building for quantitative data, was used as data analysis (*cf.* 3.7). Qualitative data was thereby interpreted while quantitative data was analysed.

The findings of the monitoring project are revealed in the next two chapters. First, the qualitative findings of the different case studies with different participants are interpreted. Using the Atlas ti programme the responses of the pre-service teachers and learners are then coded. The input of other participants, including the Green Campus Initiative, the campus management, technical services and Rand Water are also discussed. The quantitative data on the water storage resource is analysed in graphs and interpretations and displayed in scientific report format in Chapter 5.

CHAPTER 4

INTERPRETING THE VIEWS OF PARTICIPANTS IN THE WATER MONITORING PROJECT

4.1 INTRODUCTION

In this research study reflective, open-ended questions were posed to the two main groups of participants, namely the pre-service teachers and the Grade 10 Physical Science learners. Each of these two groups is regarded as a case study group and the data analysis and interpretation of each was carried out separately. In the interpretation of data, the researcher distinguished between the cognitive domain (social learning) and the affective domain (experience) of participants and dealt with each accordingly.

4.2 DATA ANALYSIS AND INTERPRETATION OF PRE-SERVICE TEACHER EXPERIENCE AND SOCIAL LEARNING

On Fridays, the researcher and the eight pre-service teachers monitored water quality in the five dams on the campus and in the Vaal River that borders the campus. In all, the pre-service teachers completed 10 sessions of water monitoring activity. Five of these sessions were done in 2015 and another 5 in 2016. The pre-service teachers did not have academic classes on Fridays and the monitoring activity took about two hours to complete. In 2016, the same pre-service teachers who had been trained in water monitoring techniques in 2015, performed monitoring activities in local school, together with and overseeing groups of Grade 10 Physical Science learners. The eight pre-service teachers also responded to four sets of reflective questions during their 2015 training. In 2016, the pre-service teachers responded to one set of questions after performing the monitoring activities with Grade 10 Physical Science learners at schools. These responses are shown in the data analysis and interpretation below.

4.2.1 Activity 1: The initial stages of the project with pre-service teachers (before commencing with the monitoring activities)

Background

In the very early stages of the project the researcher asked the participants questions about water quality and monitoring activity to ensure that they knew what they were

going to do and why. The pre-service teachers were given basic information and asked to do research on the concepts of project-based teaching approach; water monitoring and environmental stewardship. In the analysis of this activity the researcher relied on scientific definitions of the concepts to determine whether pre-service teachers were ready and able to interpret the process per se and the data they collected from water sampling.

The following questions were asked:

1. What is meant by a project-based teaching approach?
2. Indicate your current understanding of water monitoring.
3. What is the value of water monitoring for the community?
4. Why is environmental stewardship important?
5. Can teachers assist with environmental stewardship through subject education?
6. What is your expectation of this project?
7. What scares you/makes you feel insecure regarding the project?

The researcher collected related data in a personal archive (See Annexure A for the archive document list). In this chapter, reference is made to the pre-service teachers as participant 4.1 to 4.8 to indicate the responses of each of the eight pre-service teachers. The abbreviation MPA refers to Muller Personal Archive and the numbering of the documents used is according to the archive document list. Participants were allowed to answer the questions individually at a time that suited them (this had to be within a week after the four training activities and school visit). The researcher coded their answers by using the ATLAS.ti qualitative data software programme.

QUESTION 1

What is meant by a project-based teaching approach?

The main theme extracted from the direct responses of the pre-service teachers to question 1, is:

A teaching approach which responds to complex questions, over an extended period, whereby knowledge and skills are gained.

The theme is motivated as follows by quoting some of the verbatim evidence obtained from the open responses:

- Pre-service teacher 1 wrote: “It is a personal experience over an extended period” (MPA 4.1).
- Pre-service teachers 3, 4 and 5 explained that project-based teaching refers to a teaching method in which students gain knowledge and skills by working for extended periods of time to investigate and respond to complex questions and problems (MPA 4.3, 4.4 & 4.5).
- Pre-service teacher 6 wrote: “seek[ing] knowledge, investigations taking place” (MPA 4.6).

The researcher found that the pre-service teachers had a sound idea of what a project-based teaching approach entailed because the responses aligned to varying extent with literature in the field. Solomon (2003:21) suggests that project-based teaching emphasises learning through experience and often focuses on environmental concerns (Solomon, 2003:21) (*cf.* 2.3.3). Brundiers *et al.* (2010:311) write that project-based teaching creates real-world learning opportunities (*cf.* 2.3.3.2). Real-world learning responds to complex questions, as indicated by the pre-service teachers, and often takes an extended time to be resolved.

QUESTION 2

Indicate your current understanding of water monitoring.

The main theme extracted from the direct responses of the pre-service teachers to question 2, is:

Checking activity that is related to quality

The theme is motivated by the following verbatim evidence taken from the open responses:

- Pre-service teacher 1 wrote: “to determine the conditions and quality of water” (MPA 4.1).

- Pre-service teachers 3 and 4 wrote that water monitoring is a checking activity to inspect the purification of water (MPA 4.3 & 4.4).
- Pre-service teacher 5 wrote: “aims at protecting water quality” (MPA 4.5).
- Pre-service teacher 8 wrote: “helps regulating our water for different uses (MPA 4.8).

The researcher concluded that the pre-service teachers used ordinary, but correct terms to describe the scientific definition of water monitoring. Monitoring is a long-term, standardised process of measuring and observing the aquatic environment in order to define status and trends (World Meteorological Organisation, 2013:9) (*cf.* 2.3.1).

QUESTION 3

What is the value of water monitoring for the community?

The main theme extracted from the direct answers of pre-service teachers to question 3, is:

To educate [people] and protect water health

The theme is motivated by quoting the following verbatim evidence from the open responses:

- Pre-service teacher 1 wrote: “to understand the human impact on water and find ways to resolve noticeable problems” (MPA 4.1).
- Pre-service teachers 3 and 4 realised that knowing water quality and quantity is a critical aspect of life (MPA 4.3 & 4.4).
- Pre-service teacher 6 indicates that water monitoring enables participants to take precautions and be aware of unsuitable water (MPA 4.3 & 4.4).
- Pre-service teacher 8 wrote: “to teach people how to save water and re-use them” (MPA 4.8).

The pre-service students all reacted to this question with resource protection in mind. By referring to understanding and educating people regarding water health the pre-service teachers reflected on their role as teachers. Researchers like Overdevest *et al.* (2004:183); Stem *et al.* (2005:296); and Yarnell & Gayton (2003:11) all suggest that monitoring can provide an indication of whether water quality is in a desirable state or not. It helps in the process of making decisions about water management. It is inspiring

that the pre-service teachers regarded water quality as critical to preserve and maintain life although they had not performed any monitoring experiments at this stage of the water monitoring project. The pre-service teachers also realised that monitoring can improve natural resource management and promote learning – thereby providing social capital in communities (*cf.* 2.3.2.3). The responses of the pre-service teachers therefore agreed with the notion of value added by research monitoring.

QUESTION 4

Why is environmental stewardship important?

The main theme extracted from the direct answers of the pre-service teachers to question 4, is:

Protection, responsibility and impact

The themes are motivated as follows through examples of verbatim responses:

- Pre-service teacher 1 wrote: “it helps protecting and conserving the environment; would benefit the economy” (MPA 4.1).
- Pre-service teachers 3 and 4 suggest that environmental stewardship enable us to take responsibility for our environment and to protect it (MPA 4.3 & 4.4).
- Pre-service teacher 5 wrote: “to conserve scarce resource for upcoming generations” (MPA 4.5).
- Pre-service teacher 6 wrote: “to conserve the natural environment” (MPA 4.6).
- Pre-service teacher 7 wrote: “to take action and financially help the cause” (MPA 4.7).

The concept of environmental stewardship was raised by the researcher in the initial stage of the water monitoring project. She wanted pre-service teachers to think about the implications of current actions and project these into the future. The responses from the pre-service teachers made it clear that they had given these issues some thought and had not only focused on the preservation of the environment but also on the financial implications when the environment is soundly managed (*cf.* 2.4.1). The pre-service teachers thus gave an indication of an awareness of environmental stewardship. Committing to the water monitoring project, the pre-service teachers took responsibility

for the aquatic environment of their campus. Acknowledging water as a scarce resource, they showed a sense of conservation (Pahl-Wostl *et al.*, 2007) (*cf.* 2.3.2.1).

QUESTION 5

Can teachers promote environmental stewardship through subject education?

The main theme extracted from the direct answers of the pre-service teachers to question 5, is:

To teach, to engage and to raise awareness (not only of learners, but also the community)

The themes are motivated as follows by verbatim examples from the responses:

- Pre-service teacher 1 wrote: “yes, teachers have the opportunity to raise awareness and teach” (MPA 4.1).
- Pre-service teacher 3 and 4 wrote: “yes, by teaching the community” (MPA 4.3 and 4.4).
- Pre-service teacher 5 wrote: “Yes! They can teach the learners how to conserve natural resources and engage them in project of conservation” (MPA 4.5).
- Pre-service teacher 6 wrote: “yes because teachers are part of the community” (MPA 4.6).
- Pre-service teacher 7 wrote: “trained to be aware and knowledgeable” (MPA 4.7).
- Pre-service teacher 8 wrote: “to engage learners to certain activities to have more information about their environment” (MPA 4.8).

The incorporation of environmental education (EE) into a subject should be considered seriously at university level (Reddy, 2011:15) (*cf.* 2.3.1.1). By asking the pre-service students question 5, the researcher encouraged them to think about the possibility of linking Physical Science to EE. A study by Reddy (2011:16) (*cf.* 2.3.1.1) maintains the major obstacles to EE are the capacity of teachers to implement EE content in the curriculum; the necessary skills and attitudes of teachers and the inclusion of sustainable discourse into curriculum and pedagogical practices. The pre-service teacher responses to this question showed that they realised the importance of having an opportunity not only to teach their learners but also educate the community. Wenger

(1998b:14) (*cf.* 2.3.2.1) points out that the identification of need in a community indicates that the pre-service teachers acted as conveners who connect to others to enhance learning possibilities and therefore promote social learning.

QUESTION 6

What is your expectation of this project?

The main theme extracted from the direct answers of the pre-service teachers to question 6, is:

To learn

Examples of verbatim responses motivate the theme as follows:

- Pre-service teacher 1 wrote: “to learn about the importance of water and the impact we have on our water resource” (MPA 4.1).
- Pre-service teachers 3 and 4 wrote: “to learn from the project how water is monitored” (MPA 4.3 & 4.4).
- Pre-service teacher 6 wrote: “to learn more about different aspects of water and to learn to monitor water” (MPA 4.5).
- Pre-service teacher 8 wrote: “to improve my chemistry knowledge; learn more about water monitoring” (MPA 4.8).

A study done by Savan *et al.* (2003:561 & 567) (*cf.* 2.2.2) maintains that monitoring data can be used for education, problem identification and the provision of background information to aid with local decision making. Pre-service teachers indicated in their responses to questions that they expected to gain knowledge about monitoring as an activity, but also about water related issues and subject knowledge. This aligns well with the findings made by Savan *et al.* (2003:567) (*cf.* 2.2.2).

QUESTION 7

What scares you/makes you feel insecure regarding the project?

The main theme extracted from the direct answers of the pre-service teachers to question 6, is:

Concern/s – own and other

The theme is motivated with the following examples of verbatim responses:

- Pre-service teacher 1 wrote: “that the project will not have a lasting positive effect on campus” (MPA 4.1).
- Pre-service teachers 3 and 4 indicated that the possibility of making mistakes and working with chemicals scares them (MPA 4.3 & 4.4).
- Pre-service teacher 5 wrote: “the possibility of pollution in streams and river” (MPA 4.5).
- Pre-service teacher 6 wrote: “to make mistakes and ended up falling in the water” (MPA 4.6).
- Pre-service teacher 7 wrote: “kids going nearby the river and chemicals that can burst in the laboratory” (MPA 4.6).
- Pre-service teacher 8 wrote: “going nearby the river; what will happen with the results?” (MPA 4.8).

The responses to this question were diverse. The research design allows for inductive data analysis of multiple realities which emerged from the data (*cf.* 1.8.4). Pre-service teachers 1, 5 and 8 thought further than their own fears and were concerned about the findings (polluted river) and purpose of the monitoring project. Pre-service teachers 3, 4, 6 and 7 were concerned about safety while performing the water monitoring activities themselves or with learners. The lack of practical exposure and skill are evident as factors that contributed to a sense of apprehension. Participants were worried about making mistakes in the process and concerned about working with chemicals. The fear of falling into the water could perhaps be put down to not being able to swim. At this stage of the water monitoring project, no monitoring activities were performed and the pre-service teachers saw monitoring as a laboratory experiment which might include harmful chemicals. The responses also reflected the belief that at schools practical work is often neglected in favour of theoretical work.

The fear of falling into the water could be linked to indigenous knowledge such as the belief that the water snake and mermaids are sacred water spirits in African culture (*cf.* 2.3.2.7). During monitoring sessions, the researcher had the opportunity to discuss their fear of water with individual pre-service teachers. Pre-service teachers often came back

after a few sessions of monitoring and to explain that they understood the link between scientific and indigenous knowledge better. After informal discussions on indigenous water knowledge one of the pre-service teachers remarked that her family often took part in water sport, like skiing and canoeing, on the Vaal River and not even once had her family witnessed the water snake or mermaid. This remark by a fellow classmate reassured the other on the safety of water sources.

Reflection by the researcher: At this early stage, the pre-service teachers indicated some subject knowledge related to water monitoring. However, it is clear that initially they had latent fears about water and about conducting experiments with chemicals. They were unaware that they would be working in groups and have support in what they did and what they learned. At this stage there was no link between the cognitive and affective domains of learning because they had not yet been exposed to the monitoring process.

4.2.2 Activity 2: The pre-service teachers' visit to Rand Water

Background: Once the pre-service teachers had indicated voluntarily that they wanted to become part of the monitoring project, the researcher arranged a visit to Rand Water. The visit took place on a Friday when they did not have any classes. University transport was provided to the Rand Water headquarters in Vereeniging. The visit lasted three hours. The students participated in a water quiz; they purified water in groups; and visited the water purifying works at Rand Water with the so-called “water train”. In an informal discussion the researcher disclosed her intention to monitor the water quality in the campus dams and the bordering Vaal River. A Rand Water official, Mr Victor Hlongwe, was most cooperative; he provided the researcher with a Somerset Water Quality Test Kit and undertook to provide support from Rand Water once the water quality monitoring project was under way (MPA 1 (2015.02.13)).

Each of the pre-service teachers was asked the following questions after the Rand Water visit. They responded by writing reflective answers.

1. Describe your experience of the Rand Water visit.
2. What did you learn during the Rand Water visit?
3. Which of the information that was shared during the Rand Water visit was familiar to you?

4. Were the activities that we performed at Rand Water relevant? Why were they relevant?

QUESTION 1

Describe your experience of the Rand Water visit.

The main themes extracted from the direct responses of the pre-service teachers to question 1, were:

Enjoyment and learning

These themes were motivated as follows by examples of verbatim responses:

- Pre-service teacher 1 wrote: “The experience was very interesting. I enjoyed it a lot and learned from it” (MPA 4.1).
- Pre-service teacher 2 wrote: “I had a great experience. I like how they involved us. We don’t get bored” (MPA 4.2).
- Pre-service teacher 3 wrote: “I enjoy it. I believe that dirty water can be cleaned” (MPA 4.3).
- Pre-service teacher 4 wrote: “I definitely enjoyed it without a doubt. It was a good experience for me” (MPA 4.4).
- Pre-service teacher 5 wrote: “The visit was good. I learned important principles on how to use water wisely” (MPA 4.5).

All the students expressed enjoyment and said they learned new things.

QUESTION 2

What did you learn during the Rand Water visit?

The main theme extracted from the direct responses of the pre-service teachers to question 2, is

Water purification

The theme is motivated as follows by citing relevant examples of verbatim responses:

- Pre-service teacher 1 wrote: “I learned about how water is being cleaned” (MPA 4.1).
- Pre-service teacher 2 wrote: “I learned about different substances they removed before cleaning water” (MPA 4.2).
- Pre-service teacher 3 wrote: “Rand Water cleans and treats water” (MPA 4.3).
- Pre-service teacher 6 wrote: “I learned that the white substance in water is not chemicals but air that came through the pipes when they were fixing it” (MPA 4.6).
- Pre-service teacher 8 wrote: “I learn more on how to clean and re-use water” (MPA 4.8).

The varied responses were evidence of the pre-service teachers gaining a sense of personal identity, a process that involves an awareness of their own relationship with people and places and determines what they learn (Wenger, 1998a) (*cf.* 2.3.2.2). In general, the responses indicated Rand Water’s primary concern was to ensure the provision of purified, safe water supplies.

QUESTION 3

Which of the information that was shared during the Rand Water visit was familiar to you?

One of the themes extracted from the direct responses of the pre-service teachers to question 3, is:

Water purification

The following examples of verbatim responses motivate the theme as follows:

- Pre-service teacher 1 wrote: “I learned about how water is being cleaned” (MPA 4.1).
- Pre-service teacher 2 wrote: “Rand Water is a company that cleans dirty water” (MPA 4.2).
- Pre-service teacher 7 wrote: “the water cycle, water purification and filtration” (MPA 4.7).

The pre-service teachers understood the main function of Rand Water as an organisation that purifies and supplies water for human use (*cf.* 2.2.1).

The rest of the pre-service teachers' responses indicated their diverse pre-knowledge backgrounds. A second theme that emerged is:

Diverse knowledge

This theme is motivated as follows:

- Pre-service teacher 3 wrote: “wasting of water” (MPA 4.3).
- Pre-service teacher 4 wrote: “using water wisely” (MPA 4.4).
- Pre-service teacher 5 wrote: “South Africa does not have enough water and get their water from Lesotho; man-made operations are the main source of water pollution” (MPA 4.5).
- Pre-service teacher 6 wrote: “the population is big and we need more water as it increases; we buy water from Lesotho” (MPA 4.6).
- Pre-service teacher 8 wrote: “the water cycle and most of our water comes from underground and the mountains” (MPA 4.8).

The responses to question 3 reflect that other concepts related to water were more of a concern to some members of the group than the actual purification process. Their responses indicated to the researcher that when attempting a project-based teaching approach where learning opportunities are informal, students responded with honesty about their pre-knowledge. The responses from the pre-service teachers supported the notion of “education through science” (Holbrook & Rannikmae, 2007:1353) (*cf.* 2.3.2.2) which is motivated as follows:

The pre-service teachers functioned in a small group during the Rand Water visit, but later, in the schools they took on the role as teachers and then, in their communities, they became educators. By learning practical skills while performing water monitoring experiments, they were exposed to and had to cope with the public understanding of water monitoring.

QUESTION 4

Were the activities that we performed at Rand Water relevant? Why were they relevant?

The main theme extracted from the direct responses of the pre-service teachers to question 4, is:

Relevance and real-life practice

The theme is motivated as follows with examples of some verbatim responses:

- Pre-service teacher 2 wrote: “every step we did regarding cleaning water were the exact steps Rand Water use to clean dirty water” (MPA 4.2).
- Pre-service teacher 3 wrote: “yes, we did an activity on how to purify water, a process that Rand Water does in order to clean and treat water for humans to drink” (MPA 4.3).
- Pre-service teacher 4 wrote: “how the company [Rand Water] cleans water in the very manner that we did” (MPA 4.4).
- Pre-service teacher 5 wrote: “the activities were relevant; integrated our background knowledge and taught us things we were not aware of” (MPA 4.5).
- Pre-service teacher 7 wrote: “we engage ourselves in the way to clean polluted water” (MPA 4.7).

These responses confirm the research carried out by Reed *et al.* (2010) (*cf.* 2.3.2.2) who indicate that social learning is a process of social change where people learn from one another in ways that benefit wider social-ecological systems. During the Rand Water visit, the students learned from officials and had the opportunity to verify their own pre-knowledge on water related concepts. Being actively involved in water purification and then seeing for themselves that the same experiment was being performed on a far bigger scale in a real-life scenario, ties in with the view expressed by Doppelt (2003:256) (*cf.* 2.3.3.1) that project-based learning is active learning. The Rand Water visit, which formed part of the training for the water monitoring project, supported the view of Brundiers *et al.* (2010:311) (*cf.* 2.3.3.2) that learning is linked to a real-life learning opportunity.

4.2.3 Activity 3: Reflection of pre-service teachers after three monitoring sessions on campus in 2015

Background: The actual water monitoring project at the NWU (Vaal Campus) began in February 2015 and ended in September 2016. The researcher and the eight pre-service

teachers, met on Fridays once a month to monitor the water quality in the five dams on the campus and in the Vaal River on one perimeter of the campus. Due to the other demands on the time of the pre-service teachers, notably the academic programme, recesses and work integrated learning, five monitoring sessions were conducted in 2015 and five in 2016 (a total of 10 sessions).

The initial monitoring activities were notable for trial and error. The researcher realised that most of the pre-service teachers could not swim and were therefore afraid of water. The relevance of African water mythology also needed consideration. The water monitoring kit was simple to use, but the location of water in the shallow campus dams made it difficult to access. The researcher asked her husband to help re-design the basic tool to ensure the safety of pre-service teachers when they collected water samples. The attachment of the measuring instruments to sticks ensured that the pre-service teachers did not need to touch the water. The researcher provided gloves for those who preferred to work with them and they were also given data collection worksheets in a scientific report format suitable for recording the different variables (pH, temperature, dissolved oxygen (DO), bio-oxygen dissolved (BOD), concentration of chloride-, nitrate- and nitrite ions, hardness, turbidity and *E. coli*).

After three monitoring sessions the researcher asked the pre-service teachers about their experience as members of the monitoring project. These reflections at an early stage gave the researcher feedback on problems experienced by the pre-service teachers. Early detection of these challenges served as a checking device for the researcher, ensuring success of the monitoring project in the long run. The pre-service teachers collaborated by providing input on more than just the monitoring activity – there was complete collaboration on all relevant issues.

The following photographs indicate the method used to collect water samples before and after redesigning of the testing apparatus.

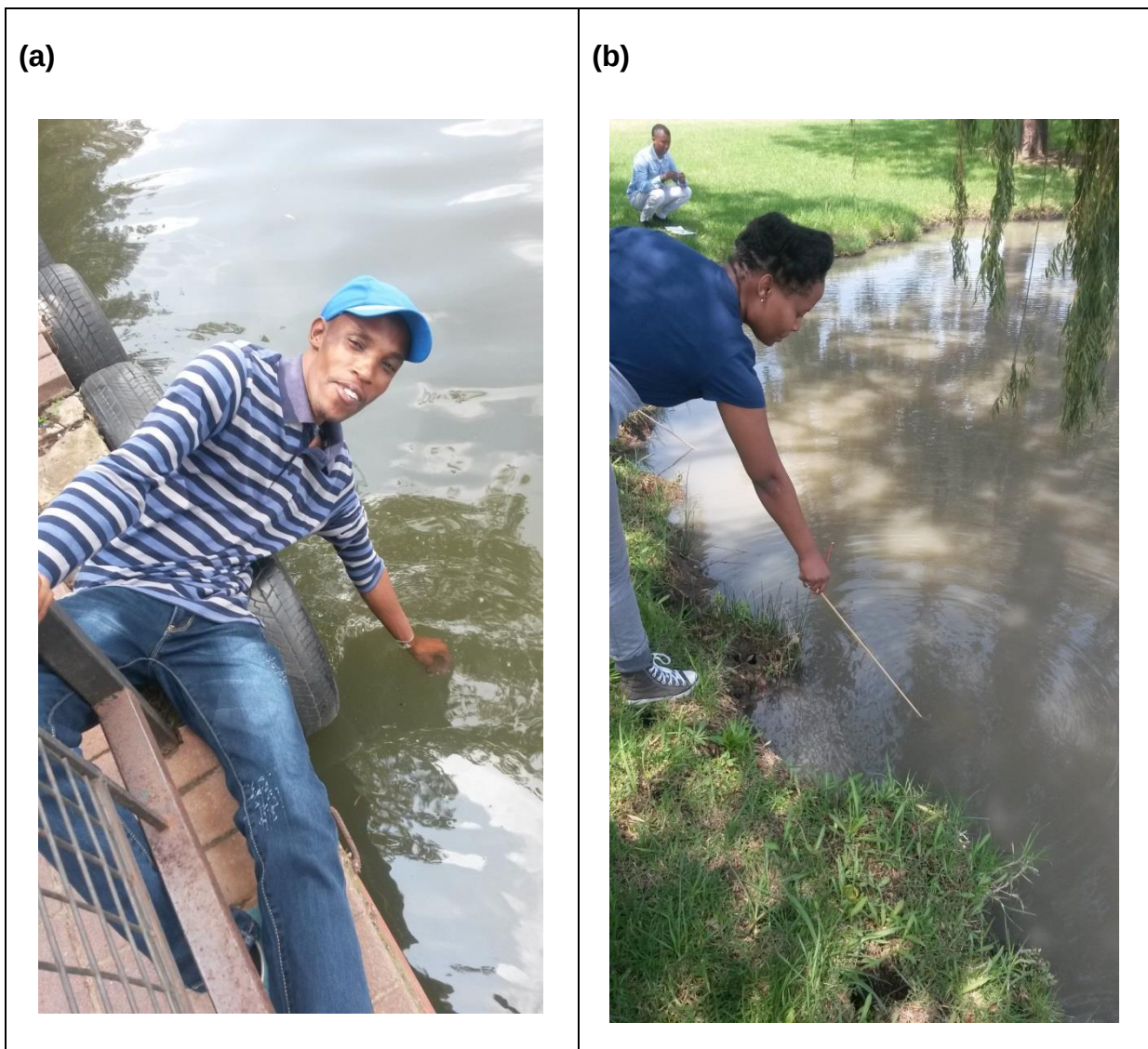


Photo 4.1: The use of tools during monitoring activities: (a) initially and (b) after re-design (MPA, 2 (20/02/2015 & 08/05/2015))

During our second monitoring session, Mrs Nyree Steenkamp, a Rand Water expert, visited the campus to attend proceedings. She validated the monitoring practices and the equipment used. She found that the pre-service teachers were performing the water monitoring correctly and were able to interpret the data accurately. She provided the group with valuable advice on the campus dams in general and how best to conduct the monitoring practices. The photograph in figure 3.7 shows Mrs Steenkamp providing assistance (MPA 2, (20/02/2015; 13/03/2015 & 08/05/2015)).



Photo 4.2: Mrs Nyree Steenkamp, a Rand Water monitoring expert (MPA, 2 (20/07/2015))

The pre-service teachers were asked the following questions after three monitoring attempts:

1. What is the main purpose or aim of our project?
2. Can you formulate other related purposes for our project?
3. How can we improve our observations, measurements or the design of our project?
4. What are your feelings regarding the project? Are you excited or not? What are your expectations for our project?
5. Is it an easy or difficult project? Explain.

6. Did you learn any new concepts? If so, mention them and explain the meaning of any new concepts.
7. What are the advantages of participating in our project?
8. What are the challenges when participating in our project?
9. What value has participation in the project meant for you?
10. Can you formulate your role in environmental matters on campus?

QUESTION 1

What is the main purpose or aim of our project?

The main theme extracted from the direct responses provided by the pre-service teachers to question 1, is

Monitoring of campus dams, Vaal River and pollution

The following examples of verbatim responses motivate the theme as follows:

- Pre-service teacher 1 wrote: “the condition and quality of water resource of our campus; and the impact of people and other factors on the dams” (MPA 4.1).
- Pre-service teacher 2 wrote: “to monitor the water’s safety and cleanliness; we are minimising the negative impacts on the environment” (MPA 4.2).
- Pre-service teacher 4 wrote: “to show other students how imperative it is to look after these dams and not to pollute them; to show students the process of cleaning water” (MPA 4.4).
- Pre-service teacher 7 wrote: “to monitor water on the campus; taking into account all those aspects that can pollute our campus dams” (MPA 4.7).

Their responses indicated that pre-service teachers grasped the intent of the water monitoring project, namely the acquisition of knowledge about the water quality status of campus dams and the Vaal River. These responses concur with the opinions expressed by Conrad and Hilchey (2011:280), Whitelaw *et al.* (2003:410) and Conrad and Daoust (2007:359) who indicate that participation in citizen science benefits scientific literacy and promotes the environmental education in the wider community (*cf.* 2.2.1.1 & 2.2.1.2).

QUESTION 2

Can you formulate other related purposes for our project?

The main theme extracted from the direct responses of the pre-service teachers to question 2, is:

Taking action

The theme is motivated by the following examples of verbatim responses:

- Pre-service teacher 1 wrote: “to see how efficient actions can improve quality; to create better strategies to creating a healthier environment” (MPA 4.1).
- Pre-service teacher 2 wrote: “to monitor the water’s safety and cleanliness; we are minimising the negative impacts on the environment” (MPA 4.2).
- Pre-service teacher 4 wrote: “to monitor and check the pollution within the lakes and flowing river on our campus” (MPA 4.4).
- Pre-service teacher 6 wrote: “to characterise the water and also [identify] changes in the water; to be able to prevent pollution” (MPA 4.6).
- Pre-service teacher 7 wrote: “to monitor water on the campus; taking into account all those [these] aspects that can pollute our campus dams” (MPA 4.7).

These responses accentuated another benefit of citizen science, namely the building of leadership, enhancing problem-solving ability and identification of resources in local communities (Conrad & Hilchey, 2011:280; Whitelaw *et al.*, 2003:410; Conrad & Daoust, 2007:359); *cf.* 2.2.4).

QUESTION 3

How can we improve our observations, measurements or the design of our project?

The main themes extracted from the direct responses of the pre-service teachers to question 3, are:

Comparing results

The theme is motivated with the following verbatim examples:

- Pre-service teacher 1 wrote: “by comparing the quality of our water resource to the quality of water at other campuses” (MPA 4.1).
- Pre-service teacher 7 wrote: “taking the temperature [sic] at the edge of the dam and also in the middle will validate results” (MPA 4.7).

Involving other people

- Pre-service teacher 2 wrote: “We could make posters or have a specific day where we educate students and lecturers about the water monitoring project; our observation is getting better and better because we are getting assistance from Rand Water” (MPA 4.2).
- Pre-service teacher 4 wrote: “by engaging more students in this project” (MPA 4.4).

The responses by pre-service teachers contributed substantially to making observations more relevant in a wider context and promoting participation in community-based monitoring and other citizen science activity. To compare findings of our water monitoring project with other projects pointed to a growth and maturation in scientific literacy on the part of the students. It also reflected how they responded to steps in scientific research method. To include other people in our project meant that we were being inclusive and in the process were gaining social capital and knowledge (Conrad & Hilchey, 2011:280; Whitelaw *et al.*, 2003:410; Conrad & Daoust, 2007:359) (*cf.* 2.2.1.2).

QUESTION 4

What are your feelings regarding the project? Are you excited or not? What are your expectations for our project?

The main themes extracted from the direct responses of the pre-service teachers to question 4, are:

Excitement

The following examples of verbatim responses motivated the theme:

- Pre-service teacher 1 wrote: “I feel excited because it’s a new learning experience” (MPA 4.1).
- Pre-service teacher 2 wrote: “I am excited about the project” (MPA 4.2).

- Pre-service teacher 4 wrote: “excited – my expectation for this project is to see every student in the campus taking part in this” (MPA 4.4).
- Pre-service teacher 7 wrote: “makes me to feel good” (MPA 4.7).

Expanding the project

The theme is motivated as follows:

- Pre-service teacher 1 wrote: “I expect to learn of our water quality and convey what I learned to others” (MPA 4.1).
- Pre-service teacher 2 wrote: “we are growing; we are not only looking at the quality of water around our campus but trying to find a way to keep it clean” (MPA 4.2).
- Pre-service teacher 4 wrote: “my expectation for this project is to see every student in the campus taking part in this” (MPA 4.4).
- Pre-service teacher 7 wrote: “To me as a student the project is an educational project; water monitoring to be run not only from the campus but involved in every day and around the Vaal as a whole” (MPA 4.7).

The pre-service teachers indicated that they were excited about the project and wanted to expand it to include others, such as their fellow students. This notion relates well to the findings by Conrad and Hilchey (2011:280), Whitelaw *et al.* (2003:410), and Conrad and Daoust (2007:359) (*cf.* 2.2.1.2) who indicate that participating in citizen science initiatives such as this contributes to social capital and increased trust, harmony and cooperation in communities.

QUESTION 5

Is it an easy or a difficult project? Explain.

The main theme extracted from the direct responses of the pre-service teachers to question 5, is:

Challenging project

To motivate the theme, the following examples of verbatim responses are cited:

- Pre-service teacher 1 wrote: “requires a lot of persistence and responsibility, because you need to make sure you get the correct reading” (MPA 4.1).

- Pre-service teacher 2 wrote: “most students are not fully informed about our project, so they turn to contribute to water and land pollution” (MPA 4.2).
- Pre-service teacher 7 wrote: “at first step it was a difficult project not knowing exactly what to do” (MPA 4.7).

These responses accord with the work done by Conrad and Daoust (2007:360) who suggest that one of the challenges of citizen science is the gathering of data and volunteer confidence in their training to collect data (*cf.* 2.2.2). The pre-service teachers clearly took the project seriously because they mentioned various responsibilities they had assumed.

QUESTION 6

Did you learn any new concepts? Mention them and explain the meaning of any new concepts.

The main theme extracted from the direct response of pre-service teachers to question 6, is:

Diverse knowledge

The theme is motivated as follows:

- Pre-service teacher 1 wrote: “Dissolved oxygen, biochemical oxygen and coliform bacteria” (MPA 4.1).
- Pre-service teacher 2 wrote: “turbidity” (MPA 4.2).
- Pre-service teacher 4 wrote: “to check pH of the water; to check hardness” (MPA 4.4).
- Pre-service teacher 7 wrote: “Dissolved oxygen, biochemical oxygen and coliform bacteria” (MPA 4.7).

The diverse responses from the pre-service teachers in as far as learning new concepts/gaining knowledge is concerned, show that different individuals will focus on different aspects of an activity (Bandura, 1971:6) (*cf.* 2.3.2.1). All of the pre-service teachers indicated that knowledge of the particular variable/s they were testing (pH, temperature, dissolved oxygen (DO), bio-oxygen dissolved (BOD), concentration of chloride-, nitrate and nitrite ions, hardness, turbidity and *E. coli*) was new to them. This

indicated that the activity each specific individual focused upon became the new knowledge and skill in his/her repertoire. In their discussion with fellow group members they learned other skills and acquired new knowledge, implying that they also learned in a social context.

QUESTION 7

What are the advantages of participating in our project?

The main theme extracted from the direct responses made by pre-service teachers to question 7, is:

Knowledge can be used

The theme is motivated as follows:

- Pre-service teacher 1 wrote: “to gain knowledge; as a future teacher I can use this knowledge to teach students and use it in my lessons” (MPA 4.1).
- Pre-service teacher 2 wrote: “I can educate learners about water pollution and how it can affect us in future” (MPA 4.2).
- Pre-service teacher 4 wrote: “to know more about water” (MPA 4.4).
- Pre-service teacher 7 wrote: “gain knowledge on how waste pollutes our water system; have an overview [on] how to clean water and how to use water wisely” (MPA 4.7).

The responses of the pre-service teachers indicate that the primary advantage of participation in the project was that participants gained useful knowledge, thus supporting the learning theories put forward in the literature. Conrad and Hilchey (2011:276) (*cf.* 2.2.1.1) maintain that the advantages of participating in community-based monitoring can be internal or external. The indication that knowledge is acquired is a personal benefit and an *internal* gain. The indication that the gained knowledge can be used, not only for individual benefit, but also for the benefit of others, shows the development of a stewardship ethic which helps to promote social networking and healthy communities, bringing *external* gain. This notion therefore supports the pro-stewardship approach which was noted as early as in activity 1 of the monitoring project. It is also in accordance with one of the properties of so-called “service learning” which indicates learning through active participation and which meets the needs of (or

serves) a community (Phillipson-Mower & Adams, 2010:66) (*cf.* 2.3.1.4). By participating in the water monitoring project the pre-service teachers gained skill and knowledge by active participation, skills that could be used to determine water quality in their communities. Wenger's (1998a:2) community of practice (COP) concept also features in this theme. The pre-service teachers indicated that they understood the purpose of the project and developed a perspective about the effect of their participation on wider society. They indicated their ability to develop an identity through the relationships established and the roles they played in the group. (*cf.* 2.3.2.2). Furthermore, they claimed to have benefited from social learning by connecting with others.

QUESTION 8

What are the challenges when participating in our project?

The main theme extracted from the direct responses of the pre-service teachers to question 8, refers to diverse challenges.

Diverse challenges

The following examples of verbatim responses motivate the theme:

- Pre-service teacher 1 wrote: "getting relevant and correct readings and interpreting the data correctly" (MPA 4.1).
- Pre-service teacher 2 wrote: "as a small group we are short of funding" (MPA 4.2).
- Pre-service teacher 4 wrote: "rain [weather]" (MPA 4.4).
- Pre-service teacher 7 wrote: "to take water out of the Vaal River" (MPA 4.7).

The responses of the pre-service teachers to challenges encountered in the project again refer to their personal experience. In comparing these responses to their initial insecurities (Activity 1 Question 7) at the beginning of the project, the researcher deducted that there was evidence of personal growth. Initially they were concerned for their own safety and that of others (such as the learners) in collecting water samples from dams and the Vaal River.

At that stage, the pre-service teachers projected a more holistic view of the project. They want to collect data correctly and interpret it; they were concerned about funding

of the project and the weather which might disrupt data collection. Only one student still has to overcome her internal fear of water. These findings provide evidence of an increase in scientific literacy and social capital as reported by Conrad and Hilchey (2011:280), Whitelaw *et al.* (2003:410) and Conrad and Daoust (2007:359) (*cf.* 2.2.1.1)

The pre-service teachers grasped that the knowledge and skills gained would not only benefit them, but could assist them with problem-solving and be an asset in their communities regarding water health.

QUESTION 9

What value has participation in the project meant for you?

The main theme extracted from the direct responses of the pre-service teachers to question 9, is

Environmental awareness

The theme is motivated as follows with examples of verbatim responses:

- Pre-service teacher 1 wrote: “it makes me aware about the environment and think about my actions. It creates a bigger and better perspective of the world for me” (MPA 4.1).
- Pre-service teacher 2 wrote: “I understand our streams and their role in the watershed; I can identify specific water quality problems; I can take a wise action to improve or protect the water quality of our rivers and streams around the campus” (MPA 4.2).
- Pre-service teacher 4 wrote: “respecting the dams/rivers and not polluting them” (MPA 4.4).
- Pre-service teacher 7 wrote: “responsibility” (MPA 4.7).

These responses are indicative of the value pre-service teachers attach to their participation in the project and they resonate with the work of Phillipson-Mower and Adams (2010:66) (*cf.* 2.3.1.4) who indicate that service-learning promotes civic responsibility and caring. The responses also relate to the findings by Conrad & Hilchey (2011:280), Whitelaw *et al.* (2003:410) and Conrad & Daoust, (2007:359) (*cf.* 2.2.1.2)

who suggest that a stewardship ethic on environmental issues and the encouragement of sustainable communities are promoted when partaking in citizen science projects.

QUESTION 10

Can you formulate your role in environmental matters on campus?

The main theme extracted from the direct responses of the pre-service teachers to question 7, refers to healthy water status.

Healthy water status

The following examples of verbatim responses motivate the theme as follows:

- Pre-service teacher 1 wrote: “we need to research and monitor the water on our campus to ensure that all life on campus stays healthy and balanced” (MPA 4.1).
- Pre-service teacher 2 wrote: “we are trying to ensure the safety of our water in the future and also make our environment habitable” (MPA 4.2).
- Pre-service teacher 4 wrote: “this project plays a huge role regarding environmental matters on campus” (MPA 4.4).
- Pre-service teacher 7 wrote: “to keep our campus clean in terms of water at our campus dams, to symbol[ise] good health care” (MPA 4.7).

The pre-service teachers agreed that the main focus of the water monitoring project was to ensure that water quality is healthy. By knowing the status of the water in the dams on campus, the pre-service teachers are able to influence the campus community and management about adaptive management of the dams. This issue is discussed in detail in Chapter 5. The theme is one of the advantages of community-based monitoring as indicated by Conrad and Hilchey (2011:276) (*cf.* 2.2.1.2).

4.2.4 Activity 4: Pre-service teacher reflections after monitoring activities on campus and the presentation at the NWU (Vaal Campus) Teaching and Learning Symposium

Background: The water monitoring group had its last monitoring session for 2015 at the NWU (Vaal Campus) dams and the Vaal River on 23 September 2015. On 26 October 2016, the researcher took the team to the NWU (Vaal Campus) Teaching and Learning Symposium to report on their findings to an academic audience (MPA1). The pre-

service teachers spoke on the respective tasks they were responsible for in the project. The researcher then asked them to write a reflective essay on the monitoring experience as a whole, including the training provided and their participation in the symposium in the year ending 2016. She gave no indication of any expectations for this final reflection, but encouraged the pre-service teachers to write honestly about their experience. The following themes were dominant in the essays.

The ability to test water/practical skill gained

The theme is motivated as follows from the essays:

- Pre-service teacher 1 wrote: “I learned to test water quality myself; to attempt a practical research project” (MPA 4.1).
- Pre-service teacher 2 wrote: “we check if there is life for aquatic (marine) organisms” (MPA 4.2).
- Pre-service teacher 3 wrote: “I learned how [drinking] water is made” (MPA 4.3).
- Pre-service teacher 4 wrote: “I also manage to learn how to purify water” (MPA 4.4).
- Pre-service teacher 6 wrote: “I learned how to check for the quality of water” (MPA 4.6).
- Pre-service teacher 7 wrote: “doing [monitoring] activities is one of the challenges” (MPA 4.5).
- Pre-service teacher 8 wrote: “scientific skills I already gained” (MPA 4.8).

This theme on the acquisition of practical skills corresponds to the notion suggested by Phillipson-Mower and Adams (2010:66) (*cf.* 2.3.1.4) who indicate that pre-service learning is a form of experiential learning which consists of planning, action and reflection. The pre-service teachers put their newly gained skills into practice when they went to the schools and performed water monitoring measurements with Grade 10 school learners. The student teachers had gained personal knowledge and skills as well as the confidence to display what they had learned.

Learning/gaining of knowledge

The theme is underscored by the points made in the essays:

- Pre-service teacher 3 wrote: “I learned very important things about water” (MPA 4.3).

- Pre-service teacher 6 wrote: “We accomplished so many things especially knowledge” (MPA 4.4).
- Pre-service teacher 6 wrote: “I learned new skills” (MPA 4.6).
- Pre-service teacher 7 wrote: “to know beyond the content of subject; I learned scientific skills to [communicate to] learners and the community” (MPA 4.7).
- Pre-service teacher 8 wrote: “it exposed me to get certain knowledge; I learned more about water as I kept on monitoring” (MPA 4.8).

The pre-service teachers not only gained personal knowledge and self-confidence by participating in the water monitoring project; this was also an indication of personal learning and development as put forward by Conrad and Hilchey (2011:276) (*cf.* 2.2.1.1) when participating in a community-based monitoring project.

A benefit for the community/wider influence

This issue is motivated as follows from the essays:

- Pre-service teacher 1 wrote: “a small impact on the environment can be a huge gain for our country and future generations” (MPA 4.1).
- Pre-service teacher 3 wrote: “It will be a good idea to present at the community and schools so that they have an idea and knowledge about water” (MPA 4.3).
- Pre-service teacher 4 wrote: “awareness to the community about the safety of water” (MPA 4.4).
- Pre-service teacher 5 wrote: “it is possible to develop uneducated communities in saving and purifying water” (MPA 4.5).
- Pre-service teacher 8 wrote: “I educate some of my family members as how to clean water before using it” (MPA 4.8).

These responses by the pre-service teachers indicated the value of a community of practice (COP), (Wenger, 1998b:12) (*cf.* 2.3.2.2), where the pre-service teachers were anchored in a mutual engagement of social discipline. Their participation in the water monitoring project provided them with personal responsibility which develops along with social participation and they realised that their gains in skills and knowledge can also be beneficial for others and their communities. The pre-service teachers displayed the competencies as noted by Wenger (1998a:2) (*cf.* 2.3.2.2), namely understanding water

monitoring and how it fits into the demands of wider society, enabling them to engage with others on water health.

The responses of pre-service teachers has resonance with the research by Keen *et al.* (2005:4) and Reed *et al.* (2010) (*cf.* 2.3.2.1) who indicate that the pre-service teachers' understanding is enhanced beyond their small group and becomes relevant in a wider social unit or COP.

Responsibility towards the environment

The theme is motivated as follows from the essays:

- Pre-service teacher 1 wrote: “a small impact on the environment can be a huge gain for our country and future generations” (MPA 4.1).
- Pre-service teacher 3 wrote: “we should respect water by not putting plastic, paper or tins in water” (MPA 4.3).
- Pre-service teacher 4 wrote: “we can engage with learners to be aware of water” (MPA 4.4).
- Pre-service teacher 5 wrote: “teaches us about the importance and need to save our scarce resource” (MPA 4.5).
- Pre-service teacher 6 wrote: “I did not care about the environment but after being part of the project I now care about the environment” (MPA 4.6).

These responses relate to the research findings by Hungerford (2009:3-4) (*cf.* 2.3) who indicates that environmental education enables participants to understand complex environmental issues in society and makes it possible for them to deal effectively and responsibly with environmental issues. The pre-service teachers demonstrated that responsible behaviour towards the environment is a complex combination of attitudes and knowledge.

Enjoyment – (monitoring and presentation at teaching symposium)

This is motivated as follows from the essays:

- Pre-service teacher 1 wrote: “it will be a nice lesson to do with learners in January” (MPA 4.1).
- Pre-service teacher 3 wrote: “it will be a good thing to go and present” (MPA 4.3).

- Pre-service teacher 4 wrote: “it was a wonderful opportunity” (MPA 4.4).
- Pre-service teacher 5 wrote: “the presentation on water monitoring was good” (MPA 4.5).
- Pre-service teacher 6 wrote: “My experience of the project was mostly positive; I enjoyed being part of the project; it was a great experience; overall it was a good presentation” (MPA 4.6).

It is clear from these comments that the pre-service teachers enjoyed participating in the monitoring project and presenting their findings at a teaching symposium. This ties in with personal gains such as newfound self-confidence after taking part in community-based monitoring (Conrad & Hilchey, 2011:276) (*cf.* 2.2.1.1). The psychological safety awareness training provided and the collaborative learning opportunity also highlighted the advantages of participating as a group.

Group work

The advantages of group work are evident in the following excerpts from the essays:

- Pre-service teacher 1 wrote: “I got to know the rest of the group better by working together on the project” (MPA 4.1).
- Pre-service teacher 4 wrote: “to see how we accomplished so many things” (MPA 4.4).
- Pre-service teacher 5 wrote: “the advantages of being part of this group” (MPA 4.5).
- Pre-service teacher 6 wrote: “it brought a bond between me and my fellow colleagues and my lecturer” (MPA 4.6).
- Pre-service teacher 7 wrote: “being part of a group, speaking and sharing some of ideas” (MPA 4.7).

These responses relate to the notion propounded by Bandura (1971:1) (*cf.* 2.3.2.1) that learning takes place in a social context and is influenced by social norms. Wenger’s idea of a community of practice (COP) (1998a:1) (*cf.* 2.3.2.1) is evident in responses which show that social learning incorporates all groups of people who engage in a process of collective learning in a shared domain. The engagement of pre-service teachers in the water monitoring project as well as the production of physical evidence such as reporting findings at a teaching symposium indicate their shared experience.

They made mention of their identity, being part of the monitoring group, which, according to Wenger (1998a) (*cf.* 2.3.2.1), is a prerequisite for social learning. An identity includes all memories, competencies, events, stories and relationships an individual has with other people and places. For the pre-service teachers, their identity indicates a multi-membership because they belong to multiple communities such as the campus and school communities, at a given time. This identity is multi-scaled because they shared their experience with others like the academics at the Teaching and Learning Symposium and the learners at schools (Wenger, 1998b:11) (*cf.* 2.3.2.1).

The benefit of being part of the group is discussed by Reed *et al.* (2010) (*cf.* 2.3.2.2), who indicated that social learning implies active social participation in a community of practice as well as the importance of dynamic interaction between people and the environment in the construction of meaning. Photo 4.3 was taken after the monitoring group had presented their findings and told of their experience as participants in the project at the NWU (Vaal Campus) Teaching and Learning symposium held in October 2016 (MPA 2).



Photo 4.3: The monitoring group presenting at the Teaching and Learning symposium at the Riverside Hotel, Vanderbijlpark in October 2016 (MPA, 2 (26.10.2016))

4.2.5 Activity 5 Pre-service teachers' reflection on their classroom practices and experience when performing monitoring activities with Grade 10 Physical Science learners in local schools in 2016

After completing the monitoring training, the pre-service teachers went to schools to perform the monitoring activities with learners. The researcher secured consent from the Gauteng Department of Education to run the project at eight local schools. The researcher visited the schools in advance to arrange with the responsible teachers for a suitable time after/during school hours to do the testing. A week before the project was due to begin she networked with the responsible Grade 10 Physical Science teachers and supplied about 320 learners with assent forms; they were also given consent forms for their parents to sign. Headmasters and responsible teachers decided on the best time slots to perform the monitoring. The researcher provided the learners with sample bottles to fill at home and bring to school on the specific day. Learners were encouraged to note the exact position of the water source in their community by indicating the street name and the suburb.

The pre-service teachers facilitated the learners during the monitoring process. The researcher visited classrooms while the testing was underway to provide guidance and information if required by either the pre-service teachers or learners. The learners were provided with a worksheet in scientific report format, similar to those the pre-service teachers used (*cf.* 4.2.3) The worksheets have clear instructions on how to perform the monitoring activities, as well as suitable tables for measurements and interpretations. Monitoring activities were performed by the learners in groups of 4. The names of learners were not noted and groups were numbered to ease the process. Learners were allowed to take photographs if they wished to do so and the researcher took photographs of the activities after asking the participants for their verbal assent; she also assured them that their names would not be used when reporting results. The teachers were told they could decide if they wanted to use the monitoring experiment as a Physical Science practical mark. Photo 4.4 shows the pre-service teachers and the Grade 10 Physical Science learners in action during monitoring activities (MPA 2 – 2016).

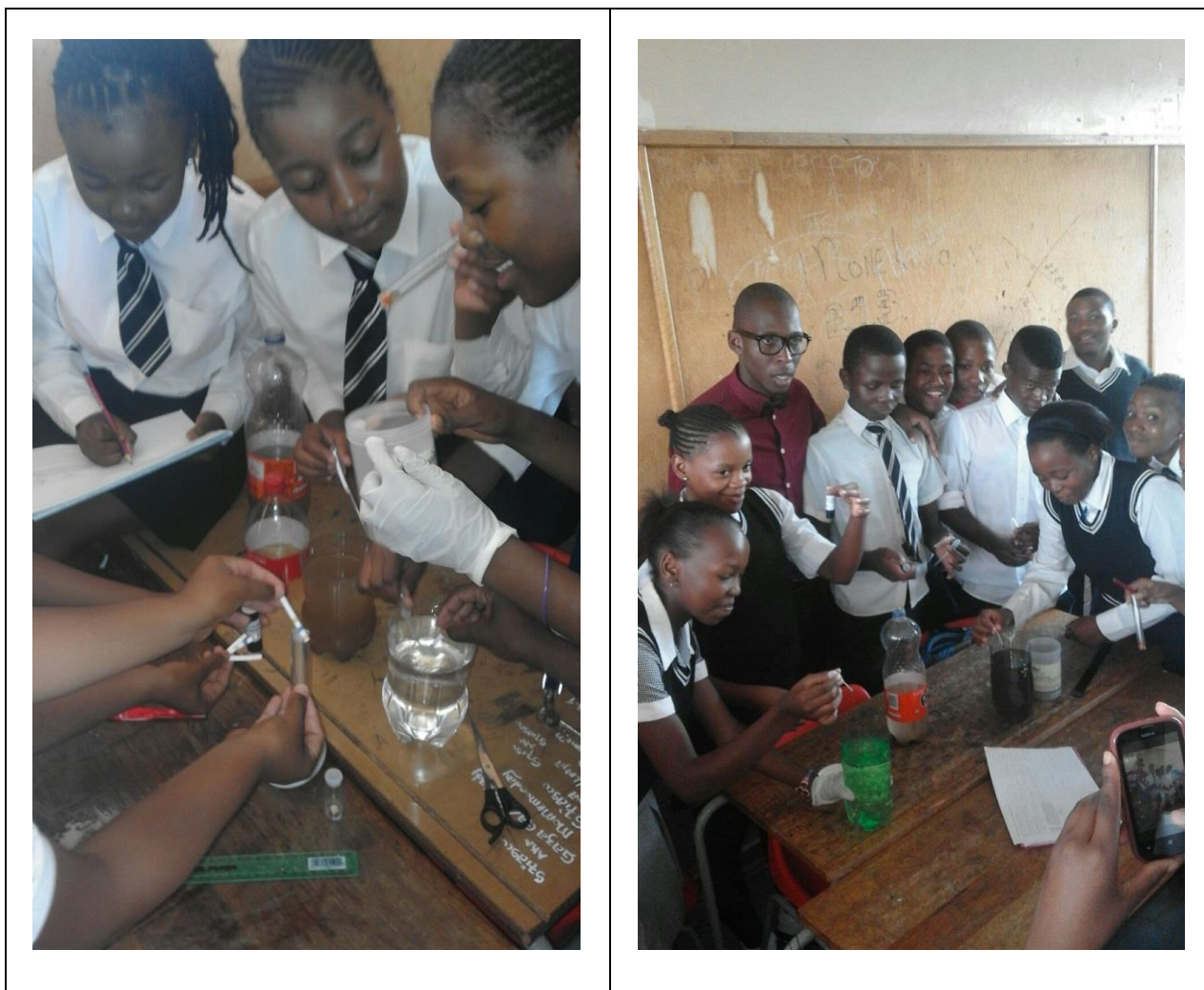


Photo 4.4: Monitoring activities at schools

After performing classroom-based monitoring with Grade 10 Physical Science learners the researcher asked the pre-service teachers to reflect on their classroom practice and experience while interacting with learners. The student teachers were asked the following reflective questions:

1. Indicate how the monitoring project on campus aided you to perform the activities with learners.
2. Did you enjoy applying your knowledge in the classroom? Why/why not?
3. Mention problems/challenges and advantages of this classroom practical on water quality.
4. Discuss how participation in the water monitoring project and its application in the classroom aided you as a pre-service teacher.

The pre-service teachers' responses to the questions follow below.

QUESTION 1

Indicate how the monitoring project on campus aids you to perform the activities with learners.

The main themes extracted from the verbatim responses of the pre-service teachers to question 1, are

Good exposure

The theme is motivated as follows:

- Pre-service teacher 4 wrote: “enabled us to clearly explain and demonstrate how each parameter is tested” (MPA 4.4).
- Pre-service teacher 6 wrote: “the monitoring project on campus gives me experience and makes me aware of possible mistakes I make” (MPA 4.6).
- Pre-service teacher 7 wrote: “very good exposure in the field” (MPA 4.7).
- Pre-service teacher 8 wrote: “monitoring at the campus taught me some skill of what I can do with my learners” (MPA 4.8).

Know how to conduct the experiment

The theme is motivated as follows:

- Pre-service teacher 4 wrote: “demonstrate how each parameter is tested” (MPA 4.4).
- Pre-service teacher 6 wrote: “makes it easy for me to help learners with the activities” (MPA 4.6).
- Pre-service teacher 7 wrote: “helps me to know how to conduct the experiment in the classroom” (MPA 4.7).
- Pre-service teacher 8 wrote: “made me aware of how to engage in practical work” (MPA 4.8).

The responses from pre-service teacher responses indicate that they recognised the value of the exposure they had in performing water monitoring. This resonates with Killen’s findings (2010:251) (*cf.* 2.3.3.1) which show that project-based learning raises metacognition and the ability of students to value resource and scaffold knowledge.

QUESTION 2

Did you enjoy applying your knowledge in the classroom? Why or why not?

The main themes extracted from the verbatim responses of the pre-service teachers to question 2, are

Enjoyment

This is motivated as follows:

- Pre-service teacher 4 wrote: “yes” (MPA 4.4).
- Pre-service teacher 6 wrote: “as a student teacher I enjoy working with learners” (MPA 4.6).
- Pre-service teacher 7 wrote: “yes ... it was very productive to give a learner new information” (MPA 4.7).
- Pre-service teacher 8 wrote: “Yes, I did enjoy it; my learners were willing to learn” (MPA 4.8).

Applying knowledge

The theme is indicated with examples of verbatim responses:

- Pre-service teacher 4 wrote: “we are easily applying our knowledge” (MPA 4.4).
- Pre-service teacher 6 wrote: “applying the knowledge I have and having learners to follow my instructions” (MPA 4.6).
- Pre-service teacher 7 wrote: “it was very productive to give a learner new information” (MPA 4.7).
- Pre-service teacher 8 wrote: “I was able to help a few to know what are clean water” (MPA 4.8).

The responses to question 2 indicate that project-based teaching provides students with opportunities to apply concepts and methods learned to address sustainability problems. By applying their knowledge on water monitoring, they were provided with a real-world learning opportunity in a classroom (Brundiens *et al.*, 2010:312) (*cf.* 2.3.3.2).

QUESTION 3

Mention problems/challenges and advantages of this classroom practical on water quality.

The main theme extracted from the verbatim responses of the pre-service teachers to question 3, is

Classroom management

The theme is motivated as follows:

- Pre-service teacher 6 wrote: “learners easily make mistakes and may need more [equipment]” (MPA 4.6).
- Pre-service teacher 7 wrote: “learners do not follow instructions properly and [were] lazy to write” (MPA 4.7).
- Pre-service teacher 8 wrote: “it was difficult to manage a large group and [perform] so many activities” (MPA 4.8).

Brundiers *et al* (2010:312) (*cf.* 2.3.3.2) indicate that real-world learning opportunities, like facilitating water monitoring in classrooms, typically challenge pre-service teachers. Markham (2011:39) (*cf.* 2.3.3.4) agrees and indicates that there is limited assistance available for teachers to organise and sustain a student-centred classroom. In a classroom with Grade 10 Physical Science learners, the pre-service teachers were challenged to manage learners and the available resources (the water testing kits) in the limited classroom space. They became aware of how real-life issues inform the context of teaching; they had to address these challenges to complete the water monitoring activities.

QUESTION 4

Discuss how participation in the water monitoring project and its application in the classroom aided you as a pre-service teacher.

The main theme extracted from the responses to question 4, is

Teach with confidence

The theme is motivated with examples of verbatim responses:

- Pre-service teacher 4 wrote: “learners enjoyed the project and [could] easily recall what [had] been done” (MPA 4.4).
- Pre-service teacher 6 wrote: “it enables me to interact and gives me experience with different learners” (MPA 4.6).
- Pre-service teacher 7 wrote: “to teach learners through practical [learning activities]” (MPA 4.7).
- Pre-service teacher 8 wrote: “being a good example to the learners and having the [necessary] subject knowledge” (MPA 4.8).

Responses to question 4 indicated that project-based teaching opportunities provided psychological safety; the pre-service teachers managed the demands of the project with confidence (Ayas & Zeniuk, 2001: 65; Brundiers *et al.*, 2010:311; Doppelt, 2003:259; Markham, 2011:39; Solomon, 2003:21) (*cf.* 2.3.3.1). Project-based teaching is place-based education which opens schools to the community and emphasises the growth of partnerships between educational institutions. The water monitoring project therefore supported the notion put forward by Powers (2004:17) (*cf.* 2.3.3.3) in that it placed high priority on the empowerment of pre-service teachers to involve learners in local schools in water monitoring.

4.2.5.1 Reflections by the researcher after monitoring activities performed by pre-service teachers with Grade 10 Physical Science learners

Witnessing the practice of pre-service teachers in Grade 10 classrooms emphasised the value of social learning and a project-based teaching approach. The pre-service teachers were self-assured and were able to manage the practical activities with skill. They were self-assured in conducting and managing all aspects of their task. The researcher made a point of praising them and the permanent staff in all the schools acknowledged that the student teachers had acquitted themselves well (MPA 1).

4.2.6 Data analysis and interpretation of Grade 10 Physical Science learners’ experience

The learners were provided with a worksheet in scientific report format to guide their data collection and to help them with interpretation of their results. After the monitoring, the learners were asked to answer four open ended questions in groups. A number was

allocated to each group to ease the coding process (MPA 5). The groups were asked the following questions:

1. Did your group enjoy the activities? Give reasons why or why not.
2. Was it easy or difficult to perform the monitoring? What was easy or difficult?
3. Did you learn something new while performing the water testing? Explain the new concepts learned.
4. What is meant by water quality? Why is it important to have knowledge about water quality?

QUESTION 1

Did your group enjoy the activities? Give reasons why or why not.

The main themes are motivated with examples of verbatim responses by the Grade 10 learners to question 1:

Interesting, enjoyment and learning

The theme is motivated as follows:

School 1 group 1: “yes, we enjoyed the experiment”

School 1 group 2A: “yes the experiment was interesting”

School 1 group 2B: “my team mates and I had a good time”

School 1group 4: “we enjoy science and testing water was interesting”

School 1group 5: “yes, we learned about water”

School 1group 7: “yes, it was fun, educational and interesting”

School 2 group 2: “we got to understand the changes and how they are similar”

School 2 group 4: “we were learning; it was fun”

School 3 group 1: “we learn about water”

School 3 group 2: “yes we enjoyed it; it is something we know more about”

School 4 group 1: “we learned to test water”

School 4 group 2: “it was interesting”

School 4 group 3: “it was interactive”

School 5 group 1: “we enjoyed it, we learned new things”

School 5 group 2: “the experiment was fun and informative”

School 5 group 3: “yes, it taught me a lot about water”

School 5 group 5: “yes, we learned things we never knew”

School 5 group 6: “yes we gained knowledge about water”

School 5 group 8: “it gave us knowledge on things we don’t know”

School 5 group 10: “yes, it shows us the kind of water we have”

School 5 group 12: “yes, we learned to check the water, if it is clean or dirty”

School 5 group 13: “we now know water has *E coli* bacteria”

School 6 group 1: “we learned a lot”

School 6 group 3: “yes it was fun and we experience a lot about the water we drink everyday”

School 6 group 4: “yes it was interesting and we learned a lot from it. We understood the experiment”

School 6 group 7: “we were never aware that the water we drink had bacteria in it”

School 6 group 9: “we learned new things through the whole experiment” (MPA 5).

Opportunity

School 2 group 1: “It was the first time for individuals to participate in such experiment”

School 2 group 3: “it is good to experiment new things”

School 5 group 9: “we did the experiment on our own, which makes the experience more enjoyable”

School 5 group 11: “we learned how to test water and the quality of water”

School 5 group 14: “yes, because we did the activities ourselves”

School 5 group 15: “yes, it was very good to find out what our water quality is”

School 5 group 17: “we can take this knowledge and use it in our community to better ourselves and future generations”

School 6 group 2: “I can build a better water purifying device”

School 6 group 4: “we enjoyed because we got a chance to experience solutions on cleaning the water”

School 6 group 5: “yes because we were not aware of the importance of testing water”

School 6 group 8: “we become more water aware; we got to do a practical instead of just reading” (MPA 5).

All the groups of school learners enjoyed being part of the project. The researcher noted that they enjoyed working in groups rather than individually. These social units or COPs tie in with the research of Reed *et al.*, (2010) and Wenger (1998a) (*cf.* 2.3.2.2). In groups, *collective learning* occurs which implies that learning by members in a group is better than the sum of individual learning. Performing monitoring activities with the learners supports the notion that good citizenship can be learned. The enjoyment of the learners suggests that they had a positive experience and gained knowledge, not by a formal curriculum, but by means of active involvement with monitoring activities related to the local community’s water resource supply (Reed *et al.* 2010; Wenger, 1998a; *cf.* 2.3.2.2).

QUESTION 2

Was it easy or difficult to perform the monitoring? What was easy or difficult?

The main theme extracted from the verbatim responses of Grade 10 learners to question 2, is

Easy with clear instructions and necessary apparatus

The themes are motivated as follows:

School 1 group 3: “it was easy, we followed instructions”

School 1 group 7: “easy – there were methods; we cooperated with the methods”

School 1 group hendo: “it was easy we got help from the student teachers”

School 1 group CFK: “it was easy, it was never challenging”

School 1 group ultramel: “easy testing”

School 1 group KRK: “it was easy because all the instructions were clear”

School 2 group 1: “it was easy because we were instructed”

School 2 group 2: “it was very easy we had all the instruments to use”

School 2 group 3: “it is easy because we have the apparatus”

School 2 group 4: “it was easy because we understood the instructions”

School 3 group 2: “it was easy”

School 4 group 1: “it was easy and simple; instructions were given”

School 4 group 2: “easy – we followed the steps”

School 4 group 3: “it was easy to perform it”

School 4 group 4: “the methods were expertly indicated; it was easy to perform the experiment”

School 5 group 2: “it was easy, we had a good assistant”

School 5 group 3: “easy, all the steps was explained”

School 5 group 5: “it was easy, the tutor explained very well, everything was clear”

School 5 group 6: “it was easy, everything was explained in a way we all could understand”

School 5 group 8: “it was easy – instructions were clear and the equipment needed to perform was clearly marked”

School 5 group 11: “it was easy, the method was easily understood and explained in a simple way”

School 5 group 12: “it was easy, the instructions were pretty straight forward”

School 5 group 13: “it was easy, we followed the description”

School 5 group 14: “it was easy, we had instructions to follow”

School 5 group 15: “it was easy we had guidelines”

School 5 group 17: “it was easy, we followed the instructions”

School 5 group 18: “it was easy, most of the activities were logical”

School 6 group 1: “it was easy, the teachers took us through each step”

School 6 group 2: “it was very, very easy – following quick and easy steps”

School 6 group 3: “easy, we got instructions to do the activities”

School 6 group 5: “it as easy; the lecturer and students were there to help throughout the experiment”

School 6 group 6: “it as easy the instructions given were clear”

School 6 group 7: “it was easy, we had guidance and instructions to follow”

School 6 group 8: “easy, there was assistance and the lecturer explained everything step by step”

School 6 group 9: “it was easy, we had someone who was guiding us” (MPA 5).

Osborne *et al.* (2003:1060) (*cf.* 2.3.2) indicate that from the age of 11 onwards Natural Science is often seen as difficult. The learner groups at participating schools felt that the monitoring was easy and that the instructions were clear. The researcher concluded that frequent exposure of pre-service teachers to monitoring meant that they were able to manage the school project at schools with confidence and skill. This concurs with the

live framework described by Bandura (1986:50) (*cf.* 2.3.2.1) which allows for the demonstration of desired behaviour. Furthermore, the student teachers showed self-reinforcement and motivation by overtly expressing their skills (Bandura, 1971:6-9; *cf.* 2.3.2.1). While performing water monitoring at schools they displayed *education through science* (Holbrook & Rannikmae, 2007:1353; *cf.* 2.3.2.2); and developed social values. They reacted in a responsible manner in the schools and in their community, thereby extending their societal domain (*cf.* 2.3.2.2).

QUESTION 3

Did you learn something new while performing the water testing? Explain the new concepts learned.

This theme is motivated as follows with examples of verbatim responses:

New knowledge is diverse

School 1 group CFK: “we never knew polluted water is acidic or basic”

School 1 group hendo: “we did not know water does not have chloride”

School 1 group I love u: “chloride and nitrate levels affect the health state of water”

School 1 group KRK: “water has many chemicals”

School 1 group 6: “we did not know there was oxygen in water”

School 2 group 1: “Yes, the pH scale, how to test chloride, temperature, turbidity”

School 2 group 2: “we learned a couple of things – chloride, pH, water hardness and temperature”

School 2 group 3: “we learn the difference between tap and [bore] hole water”

School 2 group 4: “we learn the difference between clean and dirty water; hardness, chloride, turbidity”

School 3 group 1: “learn to be water wise”

School 3 group 2: “we did not know water from the river is different from tap water”

School 4 group 1: “how to test water”

School 4 group 2: “There are a lot of ingredients in water”

School 4 group 3: “how to test water”

School 4 group 4: “pH and the dissolved oxygen; how to test for it”

School 5 group 1: “water can be dirty if it looks clear and transparent”

School 5 group 2, 3, 4, 6, 8: “the difference between hard and soft water”

School 5 group 6, 7: “dissolved oxygen and coliform bacteria”

School 5 group 9: “the pH value, as well as the change in water colour if it contains chlorides, nitrates/nitrites and oxygen”

School 5 group 10: “the difference in temperature and pH of the two samples”

School 5 group 11: “that water has chloride, nitrates and these stuff”

School 5 group 12: “how to test water quality and the importance of clean water in the environment”

School 5 group 13: “that water contains parts of magnesium and chlorides”

School 5 group 14: “how to clean water and more about Cl, Mg and O”

School 5 group 15: “chloride cleans water and is needed”

School 5 group 16: “now we can test our water if we are unsure about the drinking quality”

School 5 group 17: “we never knew there was oxygen in water; we never knew we drink dirty water”

School 5 group 18: “we did not know how to test water at first; now we can use this knowledge to help better ourselves”

School 5 group 19: “we learned chloride is a substance which cleanses water”

School 6 group 1: “water quality is hardness made by how much magnesium and calcium there is”

School 6 group 2: “what is water quality and how to test for it”

School 6 group 3: “we learned to clean water”

School 6 group 4: “we learned about the hardness and softness of water. Hard water has high concentrations of calcium and magnesium”

School 6 group 5: “the tap water that we drink contains *E coli*”

School 6 group 6: “the difference between hard and soft water”

School 6 group 7: “the hardness and softness of water”

School 6 group 8: “water with dissolved oxygen is the safest to drink”

School 6 group 9: “soft and water and water contaminated by sewage is not safe to drink even from the tap”

School 6 group 10: “hardness indicates the concentration calcium and magnesium ions” (MPA 5).

The variety of responses from the learner groups pointed to practical learning which is defined as learning by monitoring and through participation (Overdevest *et al.*, 2004:179; *cf.* 2.3.2.4). The learners had to make decisions based on the methods and observation guide for each parameter. This practical learning is known as *contextually-based acquisition*. Learners then made the hierarchical selection of *context-informed strategies* built on their past experience to choose a course of action. All the learners have a unique past experience therefore the course of action depended on their previous experiences, which were indicated by a variety of diverse responses (*cf.* 2.3.2.4). The responses from learner groups can also be linked to metacognition. Question 3 can be seen as a self-assessment question which allows learner groups an opportunity to reflect on the monitoring process. Through their own revision in groups the learners supplied a range of responses on what they learned (Killen, 2010:251; SAIDE 2012:292; *cf.* 2.3.3.1). The use of reflective questions on teaching practice is also a characteristic of project-based teaching (*cf.* 2.3.3.4).

QUESTION 4

What is meant by water quality? Why is it important to have knowledge about water quality?

The main theme extracted from the verbatim responses of Grade 10 learners to question 4, is

Safe water is healthy water

The theme is motivated as follows:

School 1 group 1: “how healthy is the water and is it good for drinking”

School 1 group 2: “is the water suitable for drinking or not?”

School 1 group 3: “water quality is the cleanness of water”

School 1 group 4: “the cleanness and safeness of water”

School 1 group 5: “it is important to know how clean is the water or else we will fall ill”

School 1 group 7: “is it safe to drink”

School 2 group 1: “we were able to know what type of water we can drink”

School 2 group 2: “so that we can differentiate between healthy and unhealthy water”

School 2 group 3: “so that we know how clean or dirty the water is”

School 2 group 4: “water quality shows how pure water is”

School 3 group 1: “unpolluted water”

School 3 group 2: “water quality it is important to know what chemicals are used in water”

School 4 group 1: “water is valuable and scarce”

School 4 group 2: “good quality water is important for good health”

School 4 group 4: “poor water quality influence human health”

School 5 group 1: “to know water quality before drinking is to be beneficial for the health of our country”

School 5 group 4: “to know whether we drink clean or dirty water”

School 5 group 5: “quality water is healthy”

School 5 group 7: “to know what is safe to drink”

School 5 group 8: “how good or bad the water; for safety of our environment”

School 5 group 9: “water quality is sustainability + particles, whether it is healthy or unhealthy”

School 5 group 8: “water quality: clean water; it is important to sustain health”

School 5 group 9: “how the water is for consuming; know that the water you drink is not harmful”

School 5 group 10: “how clean or dirty water is; prevent yourself from drinking harmful water”

School 5 group 11: “empowerment to a person to know the quality of your water”

School 5 group 12: “clean and healthy for our health”

School 5 group 13: “to know the type of water we are drinking”

School 5 group 15: “it is important to know you can have clean water”

School 5 group 16: “how safe the water is to consume”

School 5 group 17: “it will help to prevent diseases”

School 5 group 18: “if the water is clean to drink or use”

School 6 group 1: “how healthy water is”

School 6 group 2: “is it drinkable or usable; it is important to know about quality if it is safe to drink”

School 6 group 3: “is it purified or not”

School 6 group 4: “it is good quality and bad quality; good quality is safe to drink”

School 6 group 5: “how healthy the water is; it is important to know the quality of water because it might have elements that are harmful to your body or immune system.

School 6 group 6: “clean, healthy and safe water”

School 6 group 7: “water quality depends on how purify the water is”

School 6 group 8: “water quality is simply clean water”

School 6 group 9: “water quality is how dirty the water is”

School 6 group 10: “clean water is healthy water; we need to know the quality of water that we drink” (MPA 5).

The responses of learner groups to this question show they had gained useful information about water that is safe and suitable for consumption. Most of the groups indicated that it is vitally important to know about water quality. None of the learner groups appeared to think of water as a natural commodity or a scarce resource; their major concern was their personal use of water. These responses could perhaps be because of limited exposure to environmental education (Reddy, 2011:16; *cf.* 2.3.1). The researcher was thus encouraged to support Reddy’s view (2011:11) (*cf.* 2.3.1) that environmental education must become part of the academic curriculum at schools. The groups of learners had the opportunity to indicate their practical skill with monitoring equipment and observed water as a multifaceted form of matter, therefore *education in and through the environment* (*cf.* 2.3.1.1) was apparent.

In the next section, the input of other role players in the water monitoring project is discussed.

4.3 RESEARCHER’S REFLECTIONS ON ROLE PLAYER INPUT IN THE WATER MONITORING PROJECT

The NWU (Vaal Campus) monitoring project focused on the experience of pre-service teachers when performing monitoring activities on campus and in community schools. The once-off experience of learners, facilitated by pre-service teachers has also been discussed above. Other participants include the Green Campus Initiative, campus management, NWU technical services and Rand Water. Nearby school, as has been

shown, also contributed to the project. In the next section, the contributions of other participants are discussed.

4.3.1 Green Campus Initiative (GCI) meetings

This research study was initiated after a GCI meeting in response to a request that the water quality of campus dams be established (MPA 6.1 (2015.05.11)). The GCI meetings served as a platform for the researcher to communicate the findings of the monitoring team with campus representatives, other students and management. Prof Johann Tempelhoff, the GCI coordinator and Madeline Evert, the GCI project manager at the NWU (Vaal Campus) provided support. Prof Tempelhoff responded quickly and arranged a meeting with technical services after the researcher had indicated the findings of the Rand Water expert team. The GCI also provided pre-service teachers with support and motivation. In October 2016, the student teachers presented their findings (based on the quantitative data) at a Teaching Practice Symposium held at the NWU (Vaal Campus). Prof Tempelhoff attended this presentation and acknowledged the sterling efforts of the monitoring team by providing certificates to those who participated in the project. The GCI meetings provided the researcher with an opportunity to share the outcomes of the project in a safe and understanding environment as suggested by the research of Harris and Lyon (2013:111; *cf.* 2.3.2.6) who called this *third party or intermediary trust*, the trust that is found when individuals bridge different professional cultures to share and mediate language and cultural styles between different groups.

4.3.2 Campus management

Campus management is the formal management structure of the NWU (Vaal Campus). As such it was a vital partner in the monitoring project because management has the authority to permit and support environmental decisions, as well as to supply money for implementing its decisions (Muller, 2014:73, 75). Mr Jacob Simango, director of Student Engagement and Leadership (SEAL) at the NWU (Vaal Campus) attended the GCI meetings. Any water management issue that was raised at the regular GCI meetings was noted by Mr Simango and discussed with peers when the campus management met. He was able to provide feedback from management at consecutive GCI meetings and his involvement at GCI provided the researcher with a sound channel of

communication to senior management without having to confront senior management directly (MPA 1 (2016)).

4.3.3 Technical services

Campus management is the entity that directs technical services to maintain and improve the campus environment (Muller, 2014:75). The food service manager, Mr Burger Scholtz has sound insight into the environmental problems on the campus and has been a member of technical services since 1983 when the campus began its operations on the banks of the Vaal River in Vanderbijlpark. He was willing to share his knowledge about the dams and to listen to other environmental concerns raised by the researcher. Mr Scholtz also attended GCI meetings and he and the researcher often shared ideas at the meetings; he also contacted the researcher when technical services had problems with water quality. The irrigation system at the NWU (Vaal Campus) is connected to campus dams and therefore the Vaal River. Members of the academic and administrative staff of NWU often complained that after gardens were watered, the water droplets from the irrigation system made stains on their vehicles. At Mr Scholtz's request the researcher tested the water from the irrigation system and testing revealed that the pH of the water was neutral with limited evidence of nitrate-, nitrite- and chloride ions. The only possible explanation for the stains on vehicles was the high turbidity of water, that is water which has a high concentration of particles such as animal manure (MPA 1 (2015-2016)). The researcher tested the water again when new boreholes were drilled on campus grounds. One of the newly drilled boreholes produced water with a distinct smell. Concerns were raised that the drilling had possibly severed a sewage pipeline. Measurements confirmed that the borehole water was not contaminated with sewage (*E. coli*). (MPA 1 (2015-2016)).

4.3.4 Rand Water

The cooperation of members of staff from Rand Water, the acknowledged experts on measuring water quality, was particularly significant from the outset of the project. These professional scientists provided valuable guidance (MPA 1 2015.02.13). Mrs Nyree Steenkamp of Rand Water took responsibility for the NWU's (Vaal Campus) water monitoring project and performed the following duties: She visited the monitoring team once to check on the pre-service teachers' monitoring skills and she also provided valuable information on the protocol to be followed to ensure valid and reliable data.

Mrs Steenkamp advised the researcher to make adjustments to the tools used for collecting water samples to ensure the safety of the collection process. The researcher and Mrs Steenkamp also engaged on the issue traditional African beliefs such as the mythical water snake and mermaid (MPA 1 (2015.05.15)). She and the researcher tested a monitoring session on 20 July 2015 to validate the use of the Somerset Education Water Test Kit for reliable data (MPA 1 (2015.07.15)). In October 2016 Mrs Steenkamp attended the Teaching Practice Symposium held at the Riverside Hotel, Vanderbijlpark where pre-service teachers presented their monitoring findings for 2016. Mrs Steenkamp expressed her enjoyment and praised the work of the pre-service teachers (MPA 1 (2015.10.26)). On 24 November 2016 Mrs Steenkamp arranged a meeting on the Vaal campus with five Rand Water representatives, including Mr Francois van Wyk the catchment manager for the Vaal River Barrage. After visiting the dams and Vaal River the Rand Water expert team agreed to send their findings in writing to the researcher.

The researcher wishes to acknowledge Mrs Nyree Steenkamp's sterling contribution to the water monitoring project. Through its interaction with Rand Water's expert group, and particularly with regard to Mrs Steenkamp's role as a committed contact person, the credibility of the project increased significantly.

4.3.5 Schools

The inclusion of schools and the school community in the water monitoring project provided pre-service teachers with the opportunity to display the knowledge and skills they had learned. The researcher phoned schools to initiate contact, but none of the responsible teachers responded. She then visited each school personally and after securing the permission from the principal, made arrangements with the Grade 10 Physical Science teachers. Some schools chose to embark on the water monitoring process later in the year when that specific curriculum content was being taught. The researcher accommodated the schools accordingly. Some teachers preferred to do the water testing after school hours, while others wanted it held during school hours. Again these preferences were followed.

The researcher provided the schools with the necessary water quality test kits, as well as printed scientific material for guidance, informing the learners what they had to test and how. The teacher at each school could decide whether from the school's point of

view, participation by the learners and the findings of the tests were used in a scientific report as proof of a practical activity on water quality (MPA 1 (2015-2016)).

The researcher visited each of the schools with her pre-service teachers. Although they handled the monitoring activities without her direct assistance, the researcher was available to provide guidance and aid with practical skills and questions if necessary. Because the pre-service teachers have a tight academic schedule and their own practical teaching commitments the researcher personally performed monitoring at two of the six schools (MPA 1 (2016.07.20 & 2016.08.02)). At all the schools, the researcher asked the responsible Grade 10 class teacher what they thought of the monitoring project and the pre-service teachers' performance. All the school teachers regarded the monitoring project as a valuable learning experience; that it contributed to a better understanding of water as a complex and scarce natural resource (MPA 1 (2015-2016)).

The researcher concluded that the school visits resembled *real citizen science*. The learners were literally novices, but were notable for their keen interest in scientific matters. The researcher established data gathering objectives and protocols. Citizen scientists, like school learners who gather data, are seldom involved in planning the research or analysing and interpreting results (Conrad & Hilchey, 2011:274; Fernandez-Gimenez *et al.*, 2008:2; *cf.* 2.2.1). The school visits complied with the three clusters of education for sustainable development (ESD), namely the strategic knowledge cluster, which includes content and methodological knowledge about water quality; the practical knowledge cluster, which indicates the hands-on experience of testing water quality themselves; and the collaborative cluster, which involves competencies for learners to work in teams and interact in different knowledge communities with their peers and pre-service teachers (Brundiers *et al.*, 2010:310; *cf.* 2.3.3.1).

4.3.6 Final reflections by the researcher on participation in the NWU (Vaal Campus) water monitoring project

The water monitoring project at the Vaal campus was a learning experience for both the researcher and the participants. The researcher had to be aware that indigenous knowledge such as the water snake and mermaid mythology in African culture is relevant not only in South Africa but throughout the continent (Alcock, 2010:175) (*cf.* 2.3.2.7). Embracing this indigenous knowledge proved to be valuable in creating a sense of trust between the researcher and pre-service teachers. In the opinion of the

researcher, the personal growth of the student teachers, not only in gaining subject knowledge and practical skills, but also as far as promoting their self-esteem is concerned, is a major accomplishment of the project. The pre-service teachers had confidence and were eager to display their subject knowledge and practical skills in the classrooms. Their commitment to being part of the project for a two-year period is commendable. They overcame challenges like fear of water, fear of the unknown practical work, and the fear that they might be unable to collect the data correctly (*cf.* 4.2.1 Activity 1).

The researcher incorporated different partners like Rand Water and community schools. The value of engaging in a project beyond the boundaries of the campus provided fruitful results as far as social learning in diverse groups of participants was concerned. In the monitoring project, all activities were initiated from a bottom-up, collaborative approach. Diverse groups of participants, despite their difference in knowledge, evidenced the same high level of accountability when engaging in water quality monitoring (*cf.* 2.4.3.4). All learners enjoyed the monitoring activities, especially when they performed the practical work themselves. Working in groups allowed the researcher and pre-service teachers to provide answers to learner questions in an informal manner which was conducive to constructive dialogue. The researcher realises that a single visit to schools does not mean that classrooms can be seen as community laboratories to address water quality and improve water health ... but the notion that this possibility may exist in the future is an exciting one. The water monitoring project indicated that the NWU (Vaal Campus) is able to support environmental education in the community schools.

4.4 CHAPTER SUMMARY

In Chapter 4 the researcher reported on the responses of different groups of participants in the water monitoring project, thereby taking a multiple case study approach. The focus was on the main group, the pre-service teachers, who indicated their experience by answering multiple reflective open-ended questions.

The researcher concluded that the pre-service teachers (a) understood water as a resource; (b) had the ability to form opinions regarding water as an environmental matter; (c) had the ability to educate others; (d) could influence local understanding of dams by engaging in GCI meetings; (e) generated various partnerships with teachers,

learners and campus management as well as academic staff and Rand Water officials; (e) regarded the water monitoring project as a positive experience; (f) became a voice for the student community in GCI meetings; (g) were able to combine learning and co-management and (h) helped to make the social-ecological system of the NWU (Vaal Campus) more resilient (*cf.* 4.2.1). The water monitoring project provided both internal and external value to the pre-service teachers. All pre-service teachers indicated that they gained knowledge and acquired the necessary skill to perform monitoring activities (*cf.* 4.2.1). The external value of the water monitoring project at the NWU (Vaal Campus) is the use of data on the water in the dams and the Vaal River to compile a scientific report on the water status of the campus dams (*cf.* 5).

Learners answered open-ended questions in groups and indicated that they enjoyed the water monitoring project. They found the activities easy to perform because of they were given clear written and verbal instructions and competent assistance from the pre-service teachers. All the groups learned new concepts about water quality, which indicates that they gained unique prior or base knowledge. All the learners became aware that monitoring water quality is the first step in making water safe to drink (*cf.* 4.2.2).

The GCI meetings provided a platform to connect with campus management and technical services. In each of the groups, GCI, campus management and technical services there were so-called “connectors” who were contacted frequently and engaged with the researcher on water management issues. The same was true for the expert group from Rand Water. Mrs Nyree Steenkamp fulfilled the role of “connecting” the water monitoring project with Rand Water officials and expertise.

To open up schools to a water monitoring project required commitment and school visits from the researcher. By involving school learners in the NWU (Vaal Campus) monitoring project the “heart of citizen science” was exposed.

In the next section, the quantitative data gleaned from samples of water taken from campus dams and the Vaal River are analysed and interpreted. Adaptive management proposals from the Rand Water expert group are revealed and adaptive management practices at the NWU (Vaal Campus) are discussed.

CHAPTER 5

WATER QUALITY MONITORING DATA ANALYSIS AND ADAPTIVE MANAGEMENT AT THE NWU (VAAL CAMPUS)

5.1 INTRODUCTION

The water monitoring project focused in particular on the collection of quantitative data on a variety of variables by the researcher and pre-service teachers. The use of the NWU (Vaal Campus) as the training ground for this community-based project to monitor the water in the dams and the Vaal River, was a fruitful activity in more than one way. The campus became a real-world context in which to promote community-based monitoring and citizen science in general and the initiative produced scientific, workable data. The project also raised an awareness of possible involvement in community affairs among the pre-service teachers.

The results of the water monitoring tests, the quantitative findings on the quality of the water samples taken from the storage resources of the university campus are presented in this chapter in the form of a scientific report.

To promote water health proposals are then made regarding appropriate adaptive management of the campus dams.

The aim of the chapter is to report on the water quality status of the NWU (Vaal Campus) dams and bordering Vaal River for the period 2015–2016 so that the following research question can be answered:

What is the health quality status of the water in the dams and Vaal River at the NWU (Vaal Campus) over a two-year period?

The qualitative focus of this research study allowed for an authentic theoretical statement, rather than a hypothesis, on the health quality status of the water in the campus dams and the Vaal River.

Authentic theoretical statement on the health quality status of the NWU (Vaal Campus) dams and the Vaal River

To a certain extent, anthropogenic interventions have played a role in the quality of the surface water resources on the university campus, but the problem can be resolved if the social-ecological system is managed in an adaptive manner.

A social-ecological system in the context of this research study is the integrated system prevalent at the NWU (Vaal Campus) incorporating human, social and cultural phenomena. The Vaal campus system is unique in respect of boundaries and relationships and there are cross-scale linkages in its social-ecological system between the various participants in the project, including fellow students, personnel (administrative, management and teaching/research) and an expert group like Rand Water (Du Plessis, 2008:66). A social-ecological system differs from a purely ecological system in the introduction of abstract thought and symbolic construction as drivers of change processes and as governors of behaviour (Du Plessis, 2008:70).

In the next section, the quantitative materials and methods of the water monitoring project are discussed and interpreted to reveal the water quality status of water storage resources at the Vaal campus).

5.2 QUANTITATIVE DATA COLLECTION MATERIALS AND METHODS USED: WATER MONITORING PROJECT AT THE NWU (VAAL CAMPUS) (2015–2016)

5.2.1 Site description of the water monitoring project

The water storage resource of the NWU (Vaal Campus) was created in the early 1980s when the campus was built at the current location (De Klerk & Moller, 2005: 478). Being part of the Vaal Barrage Catchment has advantages in the form of scenic recreational facilities next to the river, and quiet spots where students can relax and participate in water sporting activities such as like canoeing. Potential disadvantages include raw sewage and industrial release which is spilled into the river upstream, causing bad smelling water, pollution and fish deaths. In such cases the water has a high count of bacteria growth and algae blooms flourish (Yende, 2016).

The campus map indicates the position of the campus dams and Vaal River and is presented below (*cf.* Figure 5.1). The dams were created as part of a landscape design initiative by the Vaal campus management to beautify the environment. The buildings on the campus were built in 1884 and are located above the 100-year flood line on the

banks of the Vaal River (De Klerk & Moller, 2005:478). The campus dams were not designed by engineers, nor were they placed according to the natural flow of the catchment features of the local environment (MPA 3.3 (2015.07.22)). The dams are therefore not sustainable from an environmental perspective, although from a landscaping point of view their placement promotes a pleasing sense of aesthetics in the local environment of the Vaal campus, which is conducive to a cultivated nature reserve. The average depth of all the campus dams is ~1.5m (MPA 3.2 (2015.02.20)).

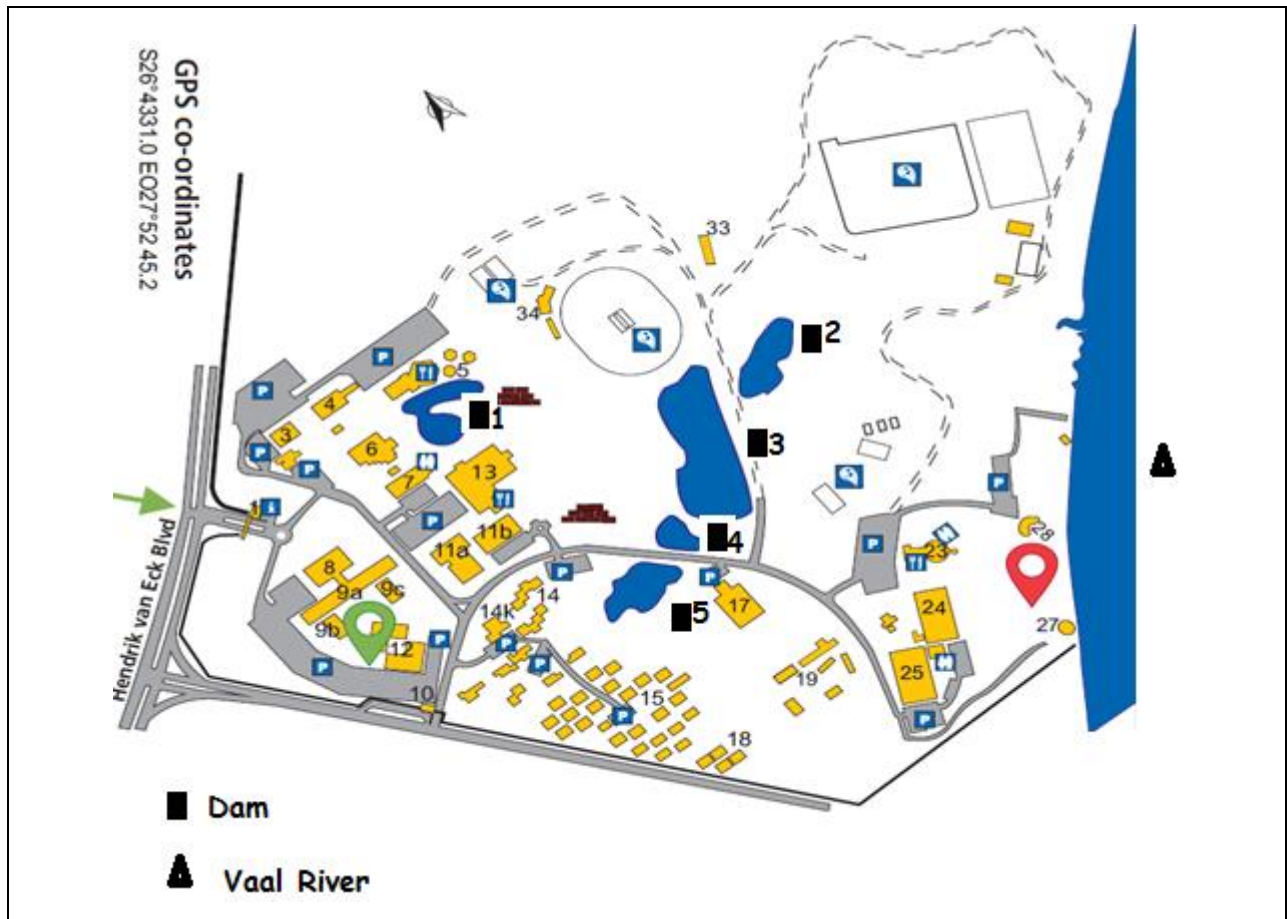


Figure 5.1 Campus plan of the NWU (Vaal Campus) 2010–2020 indicating the position of dams and the Vaal River (NWU, 2012)

The researcher aims to give an indication of the siting of the dams in the campus environment by using photographs and descriptions. It is important to note that being part of an industrial town and region, the campus is in the vicinity of the nearby steel company, Arcelor Mittal. Across the river is the SASOL plant (South African Synthetic Oil Liquid), as well as the Lethabo power station owned by ESCOM (Electricity Supply Commission).

The South African Water Quality Guidelines dating back to 1996 provide criteria to ensure the validity of measurements of water variables (DWAF, 1996a & b). These guidelines provide four broad categories for water use, namely for domestic, industrial, agricultural and recreational purposes (Department of Water Affairs and Forestry, [DWAF] 1996a:3). The water resources of the NWU (Vaal Campus) dams fit the description of domestic water use because they are also used for gardening purposes and include water supplies to the local fish ponds (DWAF, 1996:10). Domestic water can experience any of the following impacts: i) health impacts; ii) aesthetic impacts such as change in odour or colour; and ii) economic impacts such as the cost of treatment or maintenance (DWAF, 1996:10).

The Vaal River's uses include all four categories of impact, but in the vicinity of the NWU (Vaal Campus) the recreational use of river water is an outstanding feature. The water quality guideline for the Barrage Reservoir Catchment of which the Vaal campus forms part, is also provided on the Barrage Reservoir's website, as well as on Rand Water's website. The Reservoir's website provides valuable information on the Vaal Barrage and Vaal Dam Catchment forums (The Reservoir, 2017; Rand Water, 2017b).

Adherence to the South African Water Quality Guidelines as well as the indicated Rand Water guidelines will certainly ensure safe, healthy water at the NWU (Vaal Campus) dams. The researcher therefore compared measurements taken in the monitoring project with these two water quality guidelines when discussing the measured variables (pH, temperature, dissolved oxygen (DO), bio-oxygen-dissolved (BOD), concentration of nitrate-, nitrate- and chloride ions, turbidity, hardness and *E. coli*) in samples from campus dams and the bordering Vaal River.

5.2.1.1 Dam 1

The first of the NWU (Vaal Campus) dams, Dam 1, is situated between the Library (Building 13) and the student centre. Dam 1 is located in the heart of the campus buzz and scores of students pass the dams daily *en route* to and from the student centre and other campus buildings. The student centre provides food and drink, as well as entertainment in the form of television, to students during breaks from their lectures. Because of its locality, Dam 1, which has two inlets, is more exposed to anthropogenic influences. Dam 1's data was collected at two different points, namely on the side of the library (south) (D1 A), and on the side of the student centre (north) (D1B).

5.2.1.2 Dam 2

Dam 2 is situated above the level of the rugby fields and below the cricket fields. A man-made wetland is the best description for the status of Dam 2. Wetlands are natural water purifiers because they have the ability to filter and degrade toxic waste and pollutants; to reduce flooding and erosion by absorbing storm water before releasing it slowly; to help to replenish stream flow during dry periods; to recharge groundwater aquifers; to maintain biodiversity by providing habitats to a variety of species; and to provide observational and recreational opportunities for bird watchers, anglers and photographers (Miller & Spoolman, 2012:183). The huge overgrowth of reeds in Dam 2 creates a sanctuary for birds like the South African national bird, the blue crane (*Grus paradise*), and other species like frogs (*Xenopus laevis*), beavers (*Castor*) and insects (Phylum: *Arthropoda*). Dam 2 is of vital importance to campus management because it is the main provider of water for irrigation of the various sports fields. Photo 5.1 illustrates Dam 2 with its thick growth of reeds.



Photo 5.1: Dam 2 overgrown with reeds (MPA 2 (11/03/2016))

5.2.1.3 Dam 3

Dam 3 is the largest of the dams on the Vaal campus and is situated at the southern edge of the campus cricket pitch. Dam 3 is connected to Dam 4 via a very small, overgrown connection. Both Dams 3 and 4 have a tranquil setting beside the student walkway to building 25.

5.2.1.4 Dam 4

Dam 4 is situated next to the road which connects the buildings on the higher elevation to the administrative building 25 and the lecture rooms on the river front. Although a student walkway was built between Dam 3 and Dam 4, students have since created their own walkway between the tarred road and Dam 4. Dam 4 also has a natural storm water channel which leads into the dam at the western end (Photo 5.2).



Photo 5.2: Students created their own walkway beside Dam 4's storm water channel (MPA 2 (18/09/2015))

5.2.1.5 Dam 5

Dam 5 is situated opposite Dam 4 and is also next to the road that leads to building 25. Dam 5 has a unique man-made decorative weir. Dam 5 is situated beside the road-

bridge and pedestrian sidewalk which link the administrative and technical complex to the academic and residential buildings at a higher elevation (Photo 5.3).

Apart from natural rainfall and limited storm water inflows, the dams on the campus are filled by means of pumping water supplies from the Vaal River. Dam 5 is the first of the campus dams to be fed with Vaal River water. It is located on the side of the student residences below a natural slope and therefore a great deal of storm water flows into the dam in the summer months when there are frequent thunderstorms in Gauteng (SAWS, 2017b).



A



B

Photo 5.3A: Dam 5 with student residences in the background (MPA 2 (18/09/2015))

Photo 5.3B: The decorative weir of Dam 5 and the bridge over the tarred road to building 25 (MPA 2 (11/09/2015))

5.2.1.6 The Vaal River

The last monitoring point was at the Vaal River on the eastern perimeter of the campus. The dams are filled from the Vaal River and in times of flooding the dam water flows back into the Vaal River. The quality of the water in the river directly influences the water quality of the Vaal campus dams because water is circulated between the campus dams and the river. The water storage resources are therefore interlinked.

5.3 WATER QUALITY DATA FROM NWU (VAAL CAMPUS) DAMS AND BORDERING VAAL RIVER

Water quality is a complex concept with multiple variables (DWAF, 1996a:3). For the purposes of this research the focus was to measure nine variables and to indicate how the measurement of these variables can provide a picture on water quality status.

Monitoring was conducted on five different occasions during 2015; and five times during 2016. Water samples were taken from the five dams described above and from the Vaal River which borders the NWU (Vaal Campus). A total of 10 water monitoring sessions took place over a two-year period. These sessions were carried out in the months of February, March, May, July (in 2015 and again in the same months, in 2016) and in September (2015) and October (2016). The chosen months allowed for data collection throughout the year and provided a comprehensive examination of the water quality in the dams and in the Vaal River on the campus boundary. Monitoring in the same months in two consecutive years provided water quality variables over a two-year period.

Pre-service teachers were divided into groups of two members per group. A total of four such groups (pairs) collected data on 10 variables on five pre-determined dates during 2015. This meant that two groups collected data on two variables and the two groups collected data on three variables. Group one collected data on pH and temperature. Group two collected data on dissolved oxygen (DO) and bio-oxygen-dissolved (BOD). Group three collected data on the concentration of nitrate-, nitrite- and chloride ions. Group four collected data on turbidity, hardness and *E coli*.

On advice from Mrs Nyree Steenkamp, the Rand Water expert who attended campus monitoring activities in 2015, the pre-service teachers monitored the same two variables in all the 2015 sessions. In this way expert groups with sound knowledge and skill on

specific variables were created. In 2016 the groups swapped variables and monitored different variables at subsequent monitoring sessions. By following this procedure all pre-service teachers eventually gained experience in monitoring all the given variables and were equipped to teach school learners. Importantly the student teachers also had the opportunity to learn from experts such as the Rand Water staff members and ask any questions they had about the variables in water quality. Each variable (pH, temperature, dissolved oxygen (DO), bio-oxygen-dissolved (BOD), concentration of nitrate-, nitrite- and chloride ions, turbidity, hardness and *E.coli*) was tested in triplicate by the same group on the monitoring days and the average of the three readings was recorded. This standard practice of taking readings in triplicate is in accordance with the required standards of water monitoring (DWS, 2017).

The apparatus of the Somerset Educational Microlife Water Quality Test Kit Code E was used (see Photo 5.3). The focus of the monitoring was on physical and chemical variables, including pH, temperature, dissolved oxygen (DO) and percentage saturation with oxygen, bio oxygen dissolved (BOD), chloride, nitrite and nitrate concentration, hardness and turbidity. The biological variable monitored was the coliform bacteria test. The Somerset test kit is a simple, affordable and safe method to perform basic water quality measurements on samples (Somerset Microlife Water Quality Test Manual, 2016:4) and is designed to test surface water from rivers and dams, making it suitable for this water monitoring project.

The researcher became familiar with the use of the Somerset test kit when visiting Rand Water's headquarters in Vereeniging in February 2015. At the time she was making investigative enquiries on starting a water monitoring project on the Vaal campus. The Rand Water officials who ran the workshop with the pre-service teachers, provided the researcher and the monitoring group with the initial test kits and because Rand Water is the acknowledged expert in this field its advice on the use of the Somerset test kit was followed. The manual (2016:4) indicates that results generated with this kit can be used as a quantitative guide.

To ensure that this particular test kit was suitable, in 2015 the researcher arranged with Mrs Nyree Steenkamp to visit the campus more than once while monitoring was under way. For example she visited the campus on 8 May 2015 to observe and validate the monitoring process being carried out by the pre-service teachers. She confirmed that they were performing the water testing and data collection correctly. On 20 July 2015

she visited the campus once again to observe the monitoring activity. On this occasion the pre-service teachers were at the schools busy with work-integrated learning (WIL) and the researcher carried out the monitoring and data collection herself using the same Somerset Microlife Water Quality Test Kit. Mrs Steenkamp brought along more advance apparatus from the Rand Water laboratory and took water samples from all the campus dams and from the Vaal River; the idea was that she would test these in in the Rand Water laboratory. She later confirmed that the Somerset test kit provided the same results as the more expensive Rand Water laboratory apparatus. This indicated to the researcher that the Somerset test kit was able to provide reliable quantitative data on water quality variables.

Furthermore, the Somerset manual provides safety instructions to ensure that water samples are not contaminated and that the people who do the monitoring are safe (Somerset Microlife Water Quality Test Manual, 2015:5).

The Somerset test kit includes a small thermometer to measure temperature in degrees Celsius (°C). Test strips, which must be dipped into the water for a various number of seconds (depending on the variable being monitored) help to test pH (no unit); nitrite, nitrate and chloride ion concentration (in ppm); and hardness (in ppm). Dissolved oxygen (DO) and biochemical oxygen demand (BOD) are tested with dissolved oxygen tablets in small tubes with props and foil is provided to cover the tubes when testing BOD (in ppm). Percentage saturation is determined by a table (provided) which compares temperature and dissolved oxygen (in %). Coliform bacteria are tested with a tablet in a closed tube. If coliform bacteria are present (a positive test) there is a yellow colour indication showing that there are more than 200 faecal colonies per 100 ml of water. A negative coliform bacteria test is indicated by a pink colour for below 200 faecal colonies per 100 ml water. Turbidity is tested when the lid of the Somerset test kit is attached to a ruler or stick and dipped into water at least 20 cm below the surface of the water. The visible numbers on the disk is linked to Nephelometric Turbidity Units (NTUs) where the number 5,4,3,2 indicates estimated turbidity of less than 10 NTU; 4,3,2 indicates estimated turbidity between 10–20 NTU; 3,2 indicates estimated turbidity between 20–30 NTU and 2 or none indicates estimated turbidity of more than 30 NTU (Somerset Microlife Water Quality Test Manual, 2015:1-37).

The kit was originally designed to be used on field trips to dams and rivers, but based on experience it is evident it can be used easily in school classrooms. Samples of water

tested in school classrooms or laboratories need to be collected in sterile, wide mouthed containers and closed with a lid to prevent the loss of dissolved gases. Learners were urged to wash their hands after the collection of water samples and were told to test the samples as soon as possible to prevent the loss of gas or the accumulation of coliform bacteria (Somerset Microlife Water Quality Test Manual, 2015:6).

Water quality data collected at the NWU (Vaal Campus) dams and the bordering Vaal River are discussed per variable in the following sections.



Photo 5.4: The Somerset Educational Microlife Water Quality Test Kit with contents (MPA 2 (12/02/2017))

5.3.1 Results of the chemical variables

The discussion of results of chemical variables is divided into three main parts. (i) The variables of temperature, dissolved oxygen, percentage saturation and biochemical oxygen demand are discussed in relation to each other. (ii) The conventional variable (pH) and nutrients related to the variables of hardness, concentration of nitrite, nitrate and chloride ions as well as turbidity are then discussed and (iii) Finally, coliform bacteria as a biological indicator of water health is discussed separately.

All data were collected as whole numbers. The measurement of data in whole numbers reflects the simplicity of the apparatus used to collect water quality data and was a

factor that determined the statistical analysis of data. Descriptive statistical analysis of collected data complemented the water monitoring project. The aim was to find the health status of water quality at the NWU (Vaal Campus) dams and the bordering Vaal River and not to compare collected data with other water resources.

The collected data are displayed either in figures or in suitable tables for interpretation purposes. Data were compared in terms of descriptive statistics such as average, standard deviation, median, confidence interval as well as the lowest and highest level of the confidence interval. The standard deviation aims to compare individual data readings with those of different groups (Pietersen & Maree, 2007a:189). Lower standard deviation indicates more clustered data around a single point, while higher standard deviation indicates spread out data. Confidence intervals are estimations with a certain level of confidence that the true value of the variable lies within limits. A higher level of confidence indicates a wide interval, while a lower level indicates a narrow interval. Accuracy is linked to narrower confidence intervals. All confidence data are reported for the difference width of 95% (Pietersen & Maree, 2007b:201).

Measurement of relevant variables on water quality taken at the Suikerbosrand River weir at Three Rivers, Vereeniging, was added in the displayed data (Rand Water, 2017a). The Suikerbosrand River weir is situated upstream and presents a collective point of data before water reaches the NWU (Vaal Campus). These measurements, taken by Rand Water, allowed the researcher to compare the measurements on the Vaal campus water with a controlled standard. In the quarterly reports of Rand Water four measurements per variable are displayed. The researcher used the average of these four measurements in the data analysis and interpretation. The Suikerbosrand River weir measurement is indicated as Vaal River - RW.

5.3.1.1 Discussion of the temperature, dissolved oxygen, percentage saturation and biochemical oxygen demand

The variables of temperature, dissolved oxygen, percentage saturation and biochemical oxygen demand are displayed in the following tables and figures. These variables are discussed together because temperature influences the amount of oxygen which dissolves in water; percentage saturation expresses the relationship between temperature and oxygen levels; and bio-oxygen-dissolved indicates the oxygen level in water samples after a 48-hour period.

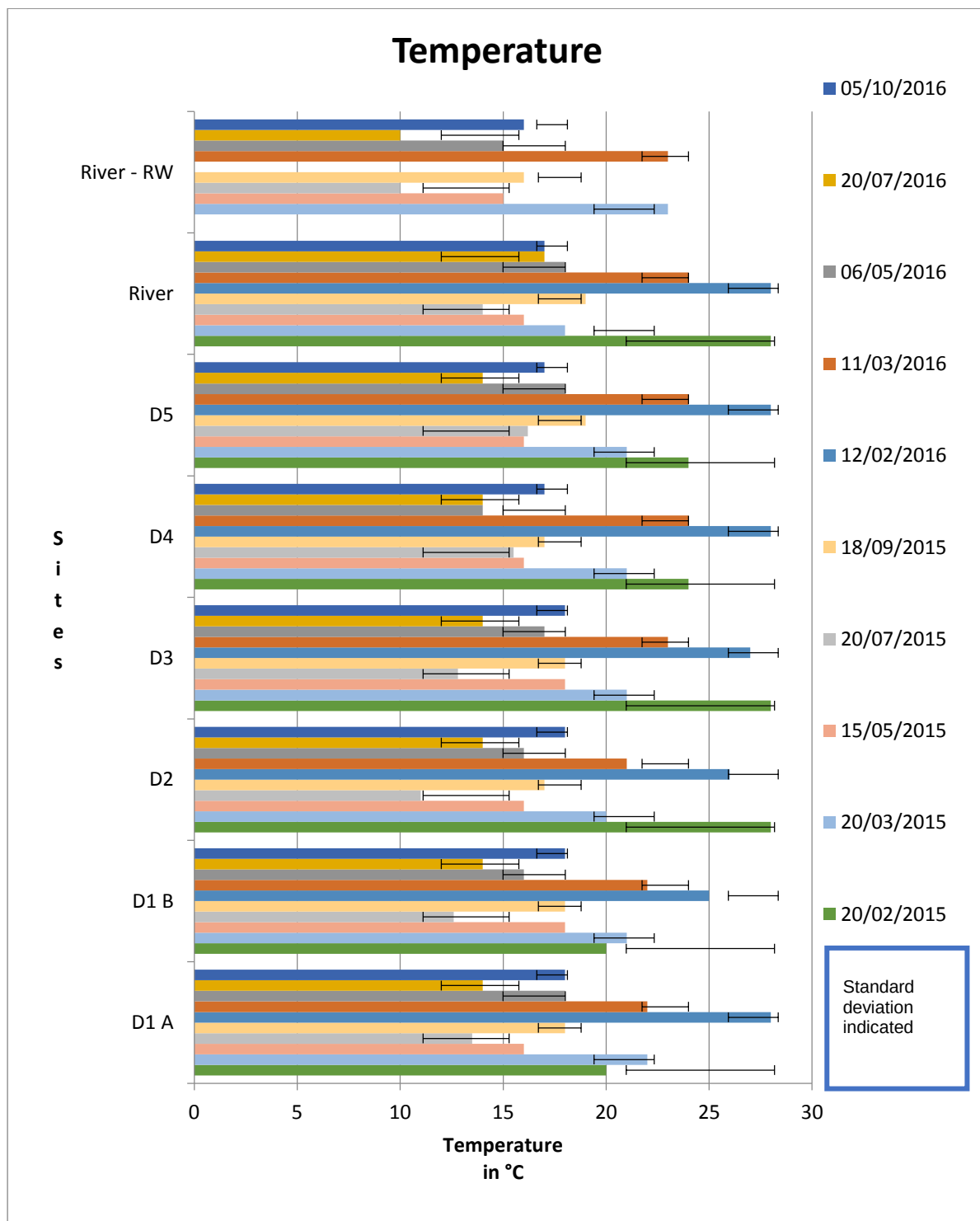


Figure 5.2: The average temperature from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016

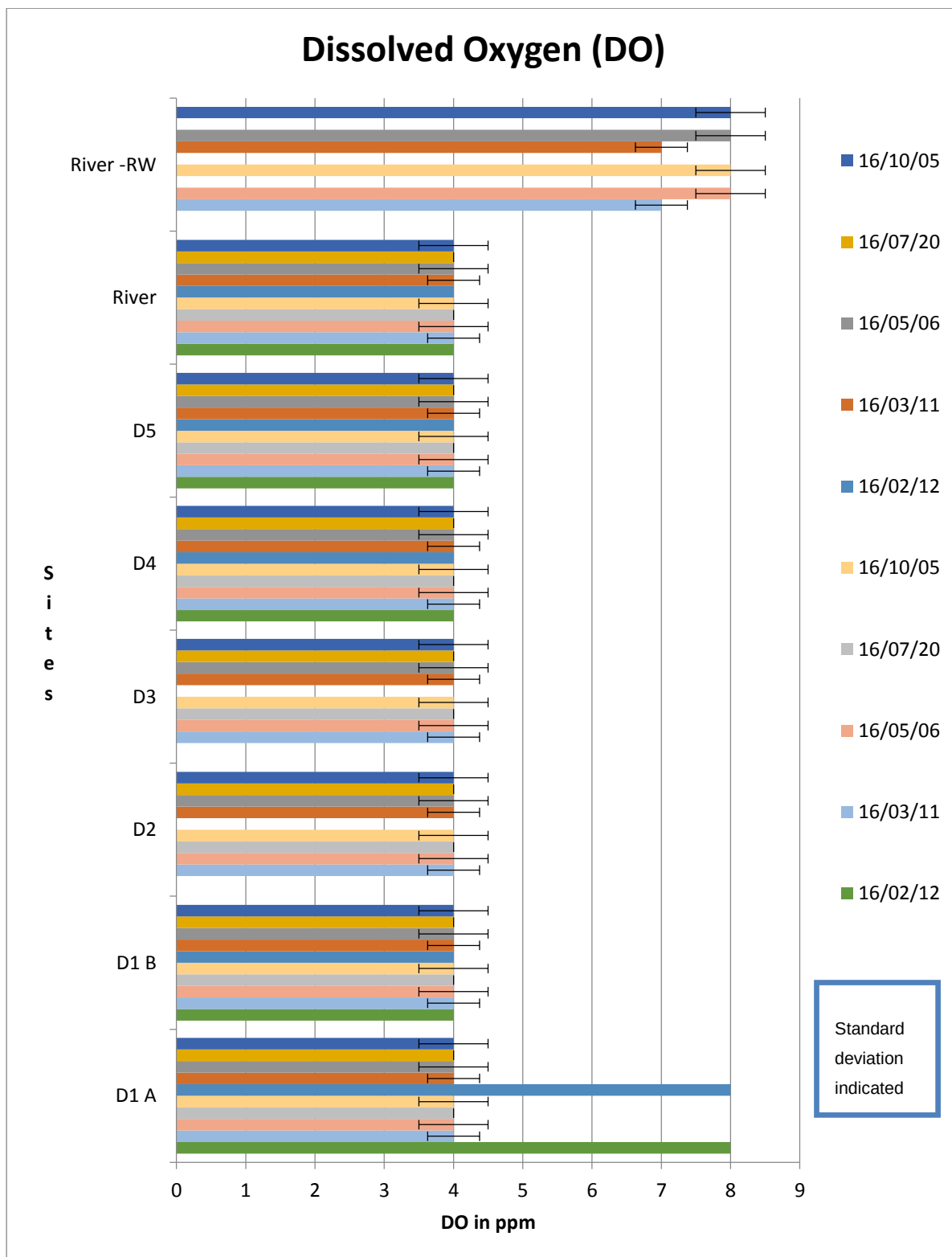


Figure 5.3: The average dissolved oxygen (DO) from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016

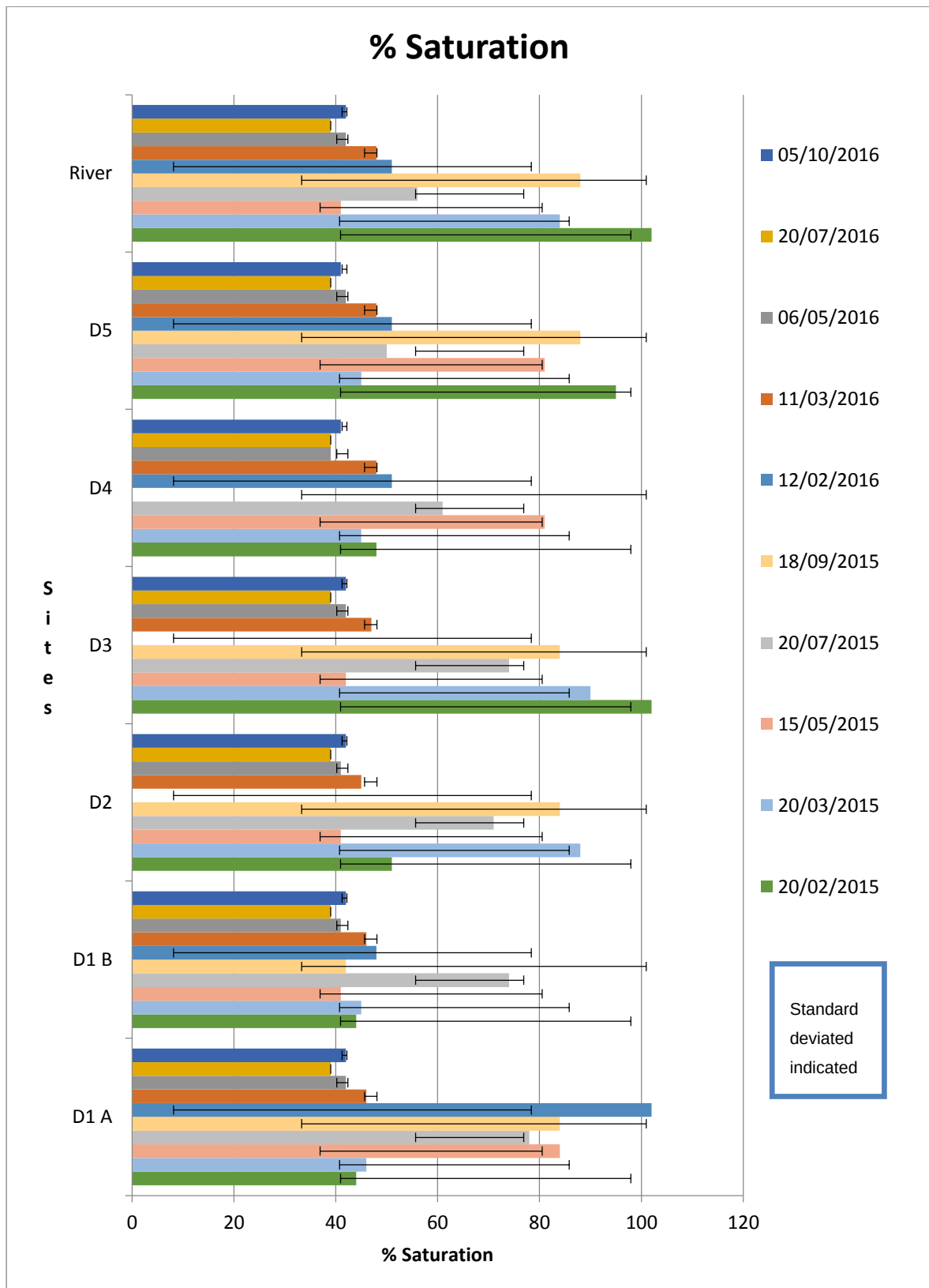


Figure 5.4: The average percentage saturation from six sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016

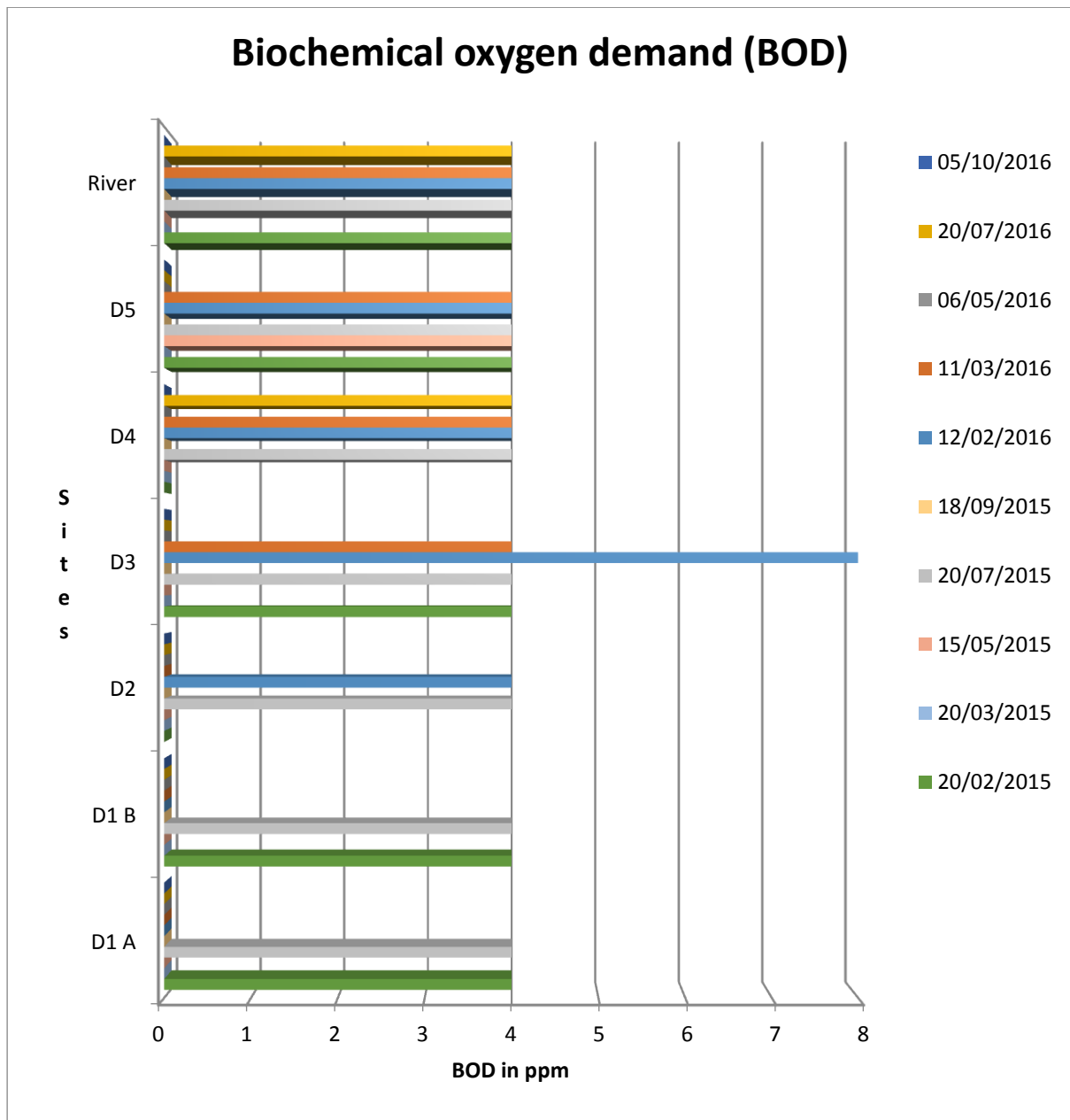


Figure 5.5: The average biochemical oxygen demand (BOD) from six sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016

The highest temperature, of 28°C, was reached in all the campus dams and the river in February of both years. The lowest temperature over the two-year monitoring period was 11°C which was reported for Dam 2 on 20/07/2015. The lowest temperature recorded in 2016 on 20/07/2016 was 14°C in all campus dams. The standard deviation for temperature is large due to seasonal changes. For the variable temperature, the median, which is 18°C, presents temperature of water bodies at the Vaal campus more comprehensively (Fig. 5.2). The temperature of the water at the Suikerbosrand River weir is more or less two to three degrees lower than the average temperature of the

campus dams which have smaller volumes of water than the Vaal River and should therefore gain heat far quicker than the river.

The measurement of temperature is fundamental to report pollution spills in water bodies (Porteous, 2008:666). The ongoing drought (2014-2017), as well as the higher pollution levels of campus dams are possible reasons for the increase in temperature from 2015 to 2016. Water has a high heat capacity, which means that 4184 joules of energy is required to increase the temperature of 1kg of water with one degree Celsius (Porteous, 2008:334). The high heat capacity of water explains why the lowest temperature of campus Dam 2 was 11⁰C during winter (20/07/2016) despite night temperatures of below zero degrees Celsius. Despite average high daytime air temperatures in January and February (about 32⁰ C) the highest temperature for campus water storage resources was reported as 28⁰ C.

The highest dissolved oxygen (DO) level of 10 ppm was recorded in Dam 1A (20/07/2015) (Fig. 5.3). The high DO level corresponded with the lowest recorded temperature in the campus water storage resources for the period 2015 to 2016. In general, higher DO levels were recorded in 2015 in comparison to 2016. The standard deviation for campus water storage resources was between one and three during 2015 and between zero and two in 2016. The lower standard deviation in 2016 confirmed that DO levels were more consistent, although low in value, during 2016 in comparison to 2015. Miller & Spoolman (2012:520) indicate that DO levels of 8 indicates slightly polluted water, and DO levels of four indicate heavily polluted water. Rand Water indicated that readings less than five were unacceptable (Rand Water, 2017b). Again, the median DO value provided a better picture on DO levels at the NWU Vaal for 2015–2016. The median DO value of six ppm in 2015 and four ppm in 2016 confirm polluted water in the Vaal campus dams and the bordering Vaal River. The confidence interval of the DO levels during 2015–2016 ranged between zero and two and this is a high degree of accuracy for DO level collected data. The measurements for dissolved oxygen in the NWU Vaal dams corresponded with the Rand Water measurement of the Vaal River. This means that polluted water in the Vaal River flows into the campus dams.

The lowest percentage saturation reading of 0% was obtained in Dam 4 on 18/09/2015 and in Dams 2 and 3 on 12/02/16 (Fig. 5.4). The highest percentage saturation of 102% was measured on 20/02/2015 (Dam 3 and Vaal River) and 12/02/2016 (Dam 1 A). The higher the temperature, the less the water storage resource will be saturated with

oxygen. The higher the concentration of dissolved salts, the less oxygen is available. Sea water therefore has lower levels of oxygen than fresh water (Porteous, 2008:194). The standard deviation for percentage saturation ranges from four to 30 and cannot provide a comprehensive picture on the data. The median (70 in 2015 and 42 in 2016) provided a better indication of the decrease in percentage saturation in the monitoring period. The decrease in percentage saturation indicates that the water quality of campus dams and the adjacent Vaal River is decreasing. However, the Rand Water quarterly report does not provide data on percentage saturation.

The highest biochemical oxygen demand (BOD) of 8 ppm was reported in 12/02/2016 for Dam 3 (Fig. 5.5). On 18/09/2015 as well as on 06/05/2016 and 05/10/2016, all the dams and the Vaal River had BOD readings of zero ppm. The BOD in the beginning of 2016 exceeded the demand at the end of 2015. The standard deviation is not indicated for BOD due to negative indication when displayed in a figure. A negative standard deviation cannot be interpreted and indicates that the collection of BOD data with the Somerset Water Quality Test Kit is not comprehensive enough to allow for wider statistical analysis. The BOD data gleaned indicate active organisms in campus water bodies and that the BOD of the campus water storage resources lowers significantly during the cooler months. Cooler temperatures make water denser and this results in less dissolved oxygen (DO) and less oxygen available to support water life (Porteous, 2008:194). The median of one (1) in both 2015 and 2016 indicates frequent low levels of BOD in campus dams and the Vaal River. The Rand Water Quality Guidelines reports on chemical oxygen demand and not bio-chemical oxygen demand (Rand Water, 2017b), therefore bio-chemical oxygen demand could not be compared with a controlled variable.

The theory of “static water” in the campus dams is confirmed with the BOD data. In the latter part of 2016 the campus water storage resources were entering the anaerobic phase of the septic zone. During this phase the water on the campus often had a bad smell due to bacterial activity (MPA 1 & 6.1 (23/05/2016)). The fish in the campus dams are mainly barbel (*Clarias gariepinus*) and largemouth yellow fish (*Labeobarbus kimberleyensis*). These indigenous species can enter dams from the Vaal River as fish eggs via the water pipes. Some fish were stocked in the dams by Mr Scholtz as part of a breeding programme to create a natural, lively environment (MPA 3.3 (22/07/2015)).

Limited fish activity was observed in the dams during monitoring activities in 2016 (MPA 1 (12/02/2016 & 11/03/2016)).

Circulating water has more kinetic energy and the possibility increases for oxygen to dissolve in water. Water samples taken for monitoring purposes when the pumps at dams were running, provided for higher kinetic energy, and therefore higher levels of dissolved oxygen (Porteous, 2008:194). Circulation of water in storage facilities may increase the kinetic energy and thereby the temperature of the water. Due to high electricity costs, the pumps in the campus dams seldom run over weekends. Periodic limited circulation of this water can result in lower temperature readings in all seasons. By limiting the running time of pumps the amount of dissolved oxygen was also reduced. Dead fish are often seen in various campus dams and this is the result of depleted oxygen levels which leads to the death of higher life forms (Photo 5.5 A). Less circulation of the water in campus dams decreases the average water temperature and results in poorer water quality.

Lower rainfall in times of drought (notably in the summer seasons in 2015 and 2016) had a marked effect on the water quality of the campus dams and the adjacent Vaal River. Seasonal rainfall below normal leads to a drop in both ground-surface and dam water levels (SAWS, 2017c). The dissolved oxygen readings taken in 2016 suggest that the status of campus dams was static with limited support for living animals and plants. Run-off of water, which enters the dams via slopes and storm water channels, carries with it huge amounts of organic waste originating from the geese and the small antelopes on the campus. This animal waste contributes to the low levels of dissolved oxygen. Huge amounts of algae blooms were reported in the first semester of 2016, prompted by the increase in summer temperature and the demand on oxygen in the water (Photo 5.5 B). The oxidation of organic waste in water consumes oxygen rapidly, which results in depleted oxygen levels and leads to the death of higher life forms (Porteous, 2008:194). The amount of oxygen in the water can also decrease when heated water is released into the storage reservoirs. The water storage facilities will recover from the heated water if the flow rate increases and enough time passes before the next inflow of heated water (Miller & Spoolman, 2012:521).



Photo 5.5 A: Dead fish found at Dam 3 in February 2016 (MPA 2 (12/02/2016))

Photo 5.5 B: Algae bloom at Dam 3 in February 2016 (MPA 2 (12/02/2016))

Data collected and interpreted on the variables of temperature, DO, percentage saturation and biochemical oxygen demand confirmed that the water quality status of NWU (Vaal Campus) dams were poor and posed a threat to human health during the monitoring period of 2015 to 2016. In the next section below, pH, nutrient concentrations and turbidity are discussed.

5.3.1.2 Discussion of conventional variable (pH), nutrients and turbidity

The variables pH, nutrients such as chloride (Cl^-), nitrite (NO_2^-), nitrate (NO_3^-), magnesium ion (Mg^{2+}) and calcium ion (Ca^{2+}) concentration and turbidity are displayed in the following tables and figures and then discussed.

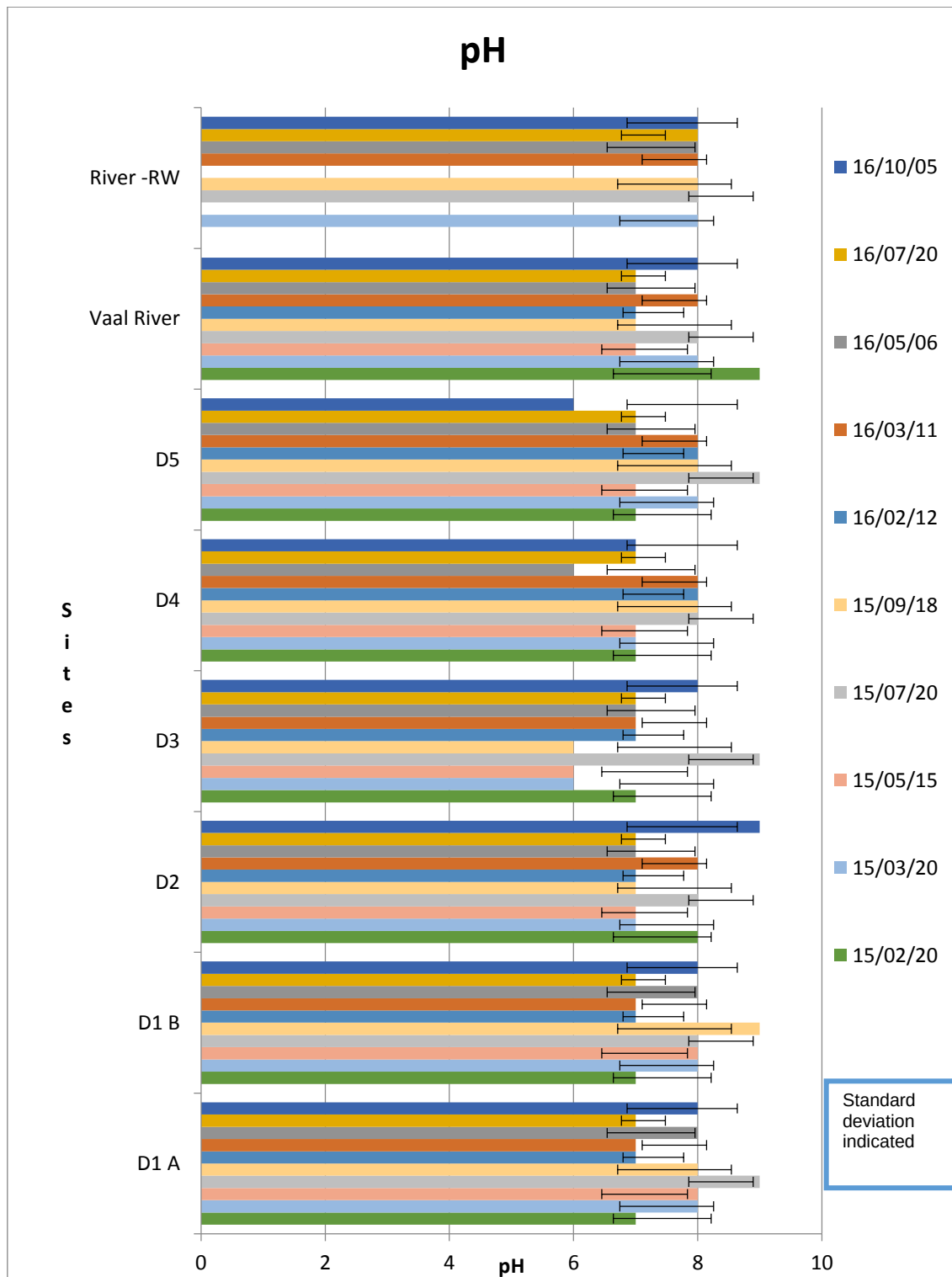


Figure 5.6: The average pH from six sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016

The pH of water samples taken at the NWU (Vaal Campus) ranged from 6 to 9. The standard deviation for pH is one (1). To determine a direct relationship between water health and pH is impossible. The corrosion and solubility of metal water pipes, which carry water to campus dams, can influence pH readings. The pH range between 6 and

9, as measured in campus dams and the bordering Vaal River have no significant effect on human health (DWAF, 1996:118). Any pH measurements higher than 8,4 can lead to the encrustation of irrigation equipment which can influence irrigation from campus dams (DWAF, 1996:116).

In the next section the concentration of other nutrients is discussed.

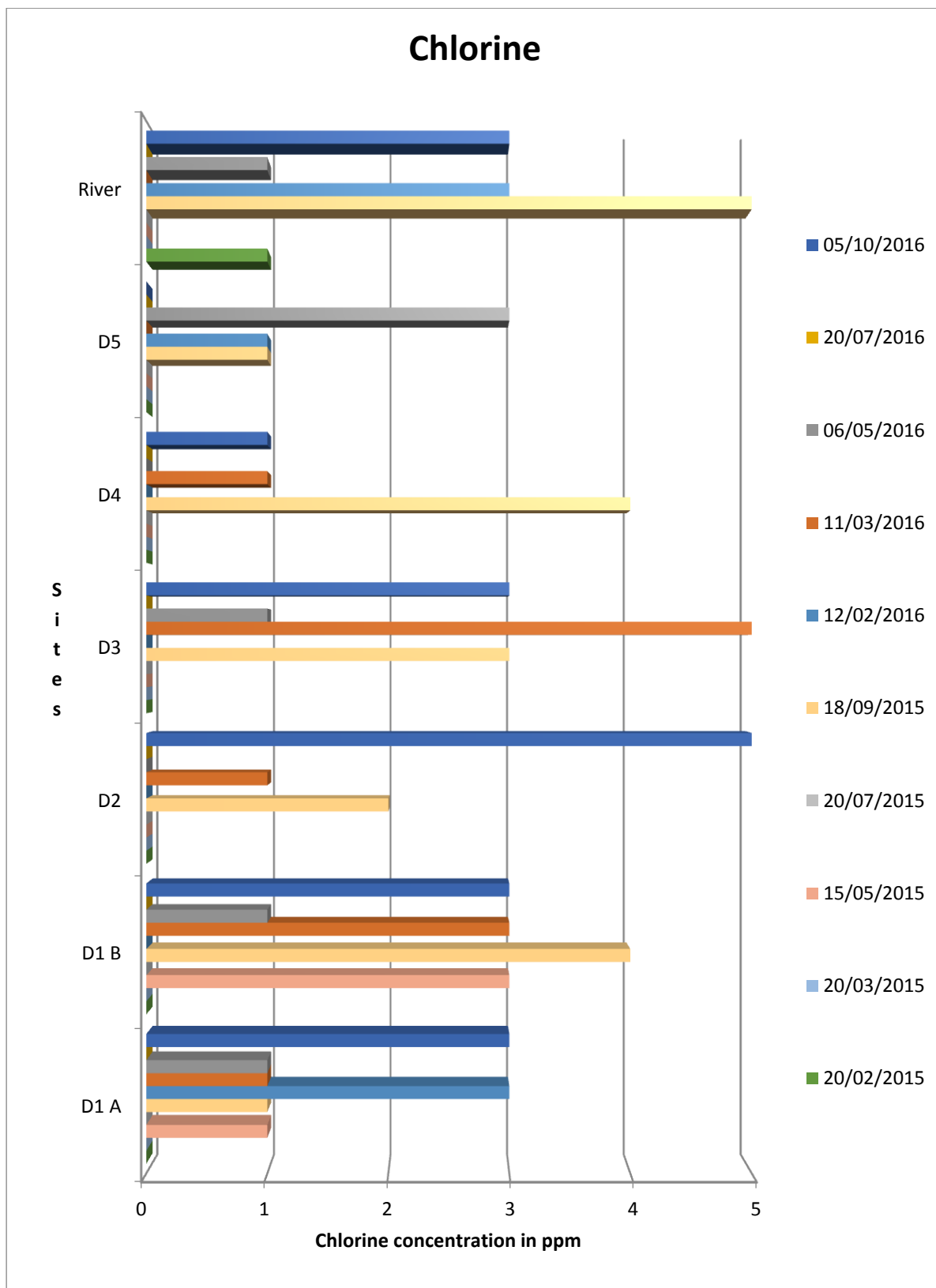


Figure 5.7: The average chloride ion concentration from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016

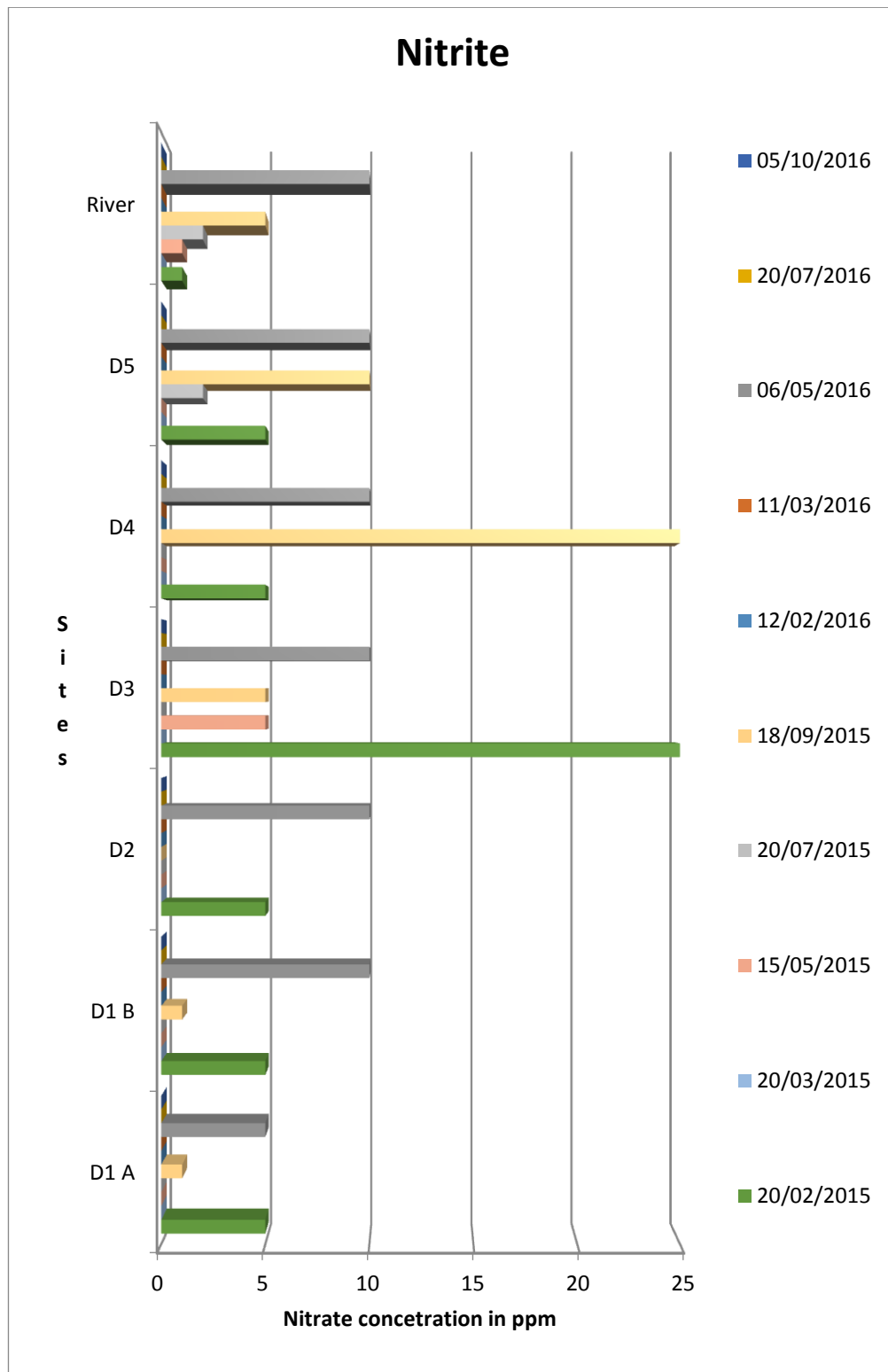


Figure 5.8: The average nitrite concentration of water from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016

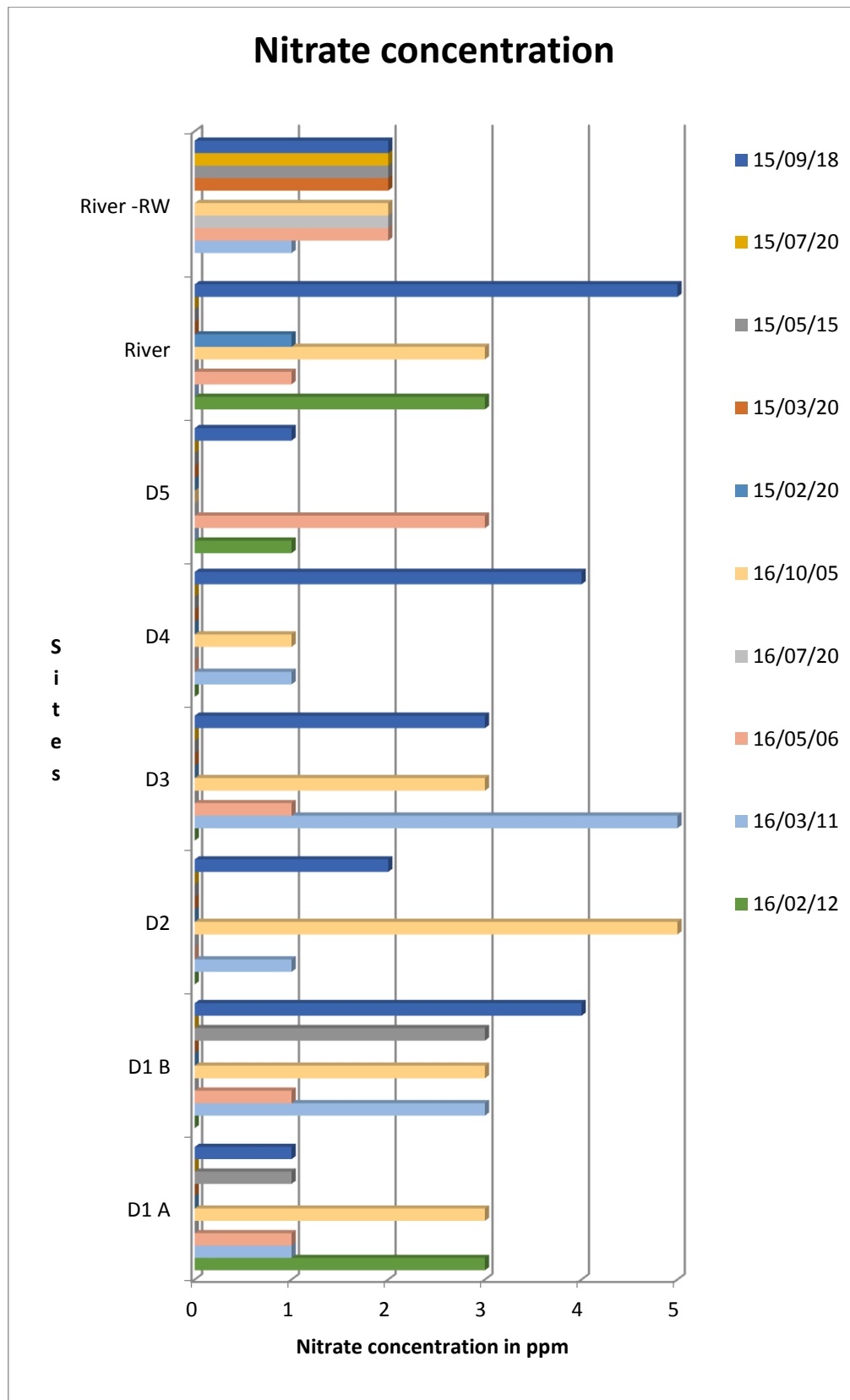


Figure 5.9: The average nitrate concentration of water from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016

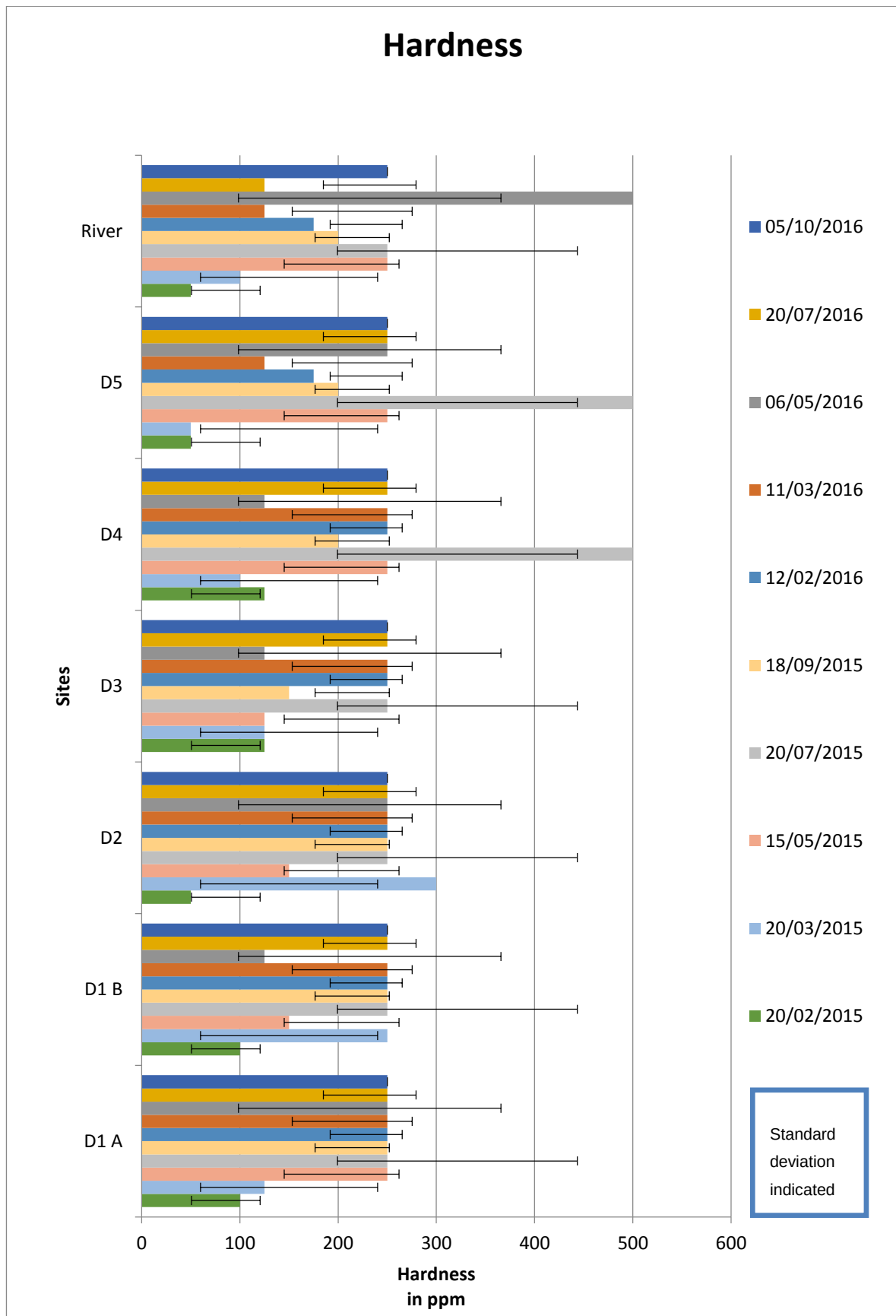


Figure 5.10: The average hardness of water from sampling sites at the NWU (Vaal Campus) dams and Vaal River in 2015-2016

The standard deviation of chloride ion concentration is not displayed due to negative values that could not be statistically interpreted. The highest chloride ion concentration of 5 ppm was observed in the Vaal River on 18/09/15, and in Dam 2 (05/10/2016) and Dam 3 (11/03/2016) (Fig. 5.7). Zero chloride levels were often a general trend in campus dams. The median for chloride was 0 in 2015 and 1 in 2016. The chloride concentration thus increased from 2015 to 2016. The Rand Water Quality Guidelines indicate that chloride concentrations higher than 75 ppm are unacceptable (Rand Water, 2017b). Because the Zuikerbosch pump station is in the vicinity of the Suikerbosrand River weir the chloride measurements of the Vaal River water cannot be compared with the chloride concentration of samples from the campus dams (Rand Water, 2017c). Low chloride concentrations pose no threat to campus water resources. The South African Water Quality Guidelines state that chloride levels higher than 700 ppm will affect crops negatively during irrigation (DWAF, 1996a:48). Low chloride concentrations indicated no threat to the use of campus water resources for irrigating gardens and sports fields.

The standard deviation of both nitrite and nitrate concentrations are not displayed due to negative values that cannot be statistically interpreted (Fig. 5.8 & 5.9). The highest nitrite concentration of 25 ppm was reported for Dam 3 (20/2/2015) and for Dam 4 (18/09/15). Nitrite levels were often 10 ppm and less.

The highest nitrate concentration of 500 ppm was recorded in three instances, namely in the Vaal River (18/09/15) and in Dam 3 (11/03/2016) and Dam 2 (05/10/2016) (Fig. 5.9). The confidence interval of the nitrite concentration (4) indicated more clustered data and therefore more accurate data than the nitrate concentration. The Rand Water Quality Guidelines suggest that a nitrate concentration higher than 6 is unacceptable in the Vaal River (Rand Water, 2017b). Therefore according to these guidelines there is an unduly high concentration of nitrate ions in the campus dams at times and this often had a marked effect on the spread of algal blooms on the dams.

The highest hardness reading of 500 ppm was noted in Dams 4 and 5 on 20/07/2015 (Fig. 5.10). The drought influenced hardness as indicated in the increased concentration of Mg^{2+} and Ca^{2+} ions in water bodies. The large variance in standard deviation for hardness (105 in 2015 and 55 in 2016) cannot be used to interpret data, but the median (211 in 2015 and 239 in 2016) indicates in general that campus dams and the Vaal River have very hard water.

Chloride is often used as disinfectant in water to promote public health (Porteous, 2008:119). The researcher is of view that campus management in the summer months of 2016 disinfects the dams to eliminate poor smelling water. This was confirmed by the data collected on chloride concentration in campus dams during 2016. The addition of chloride to water can harm other organisms and is therefore a possible answer for the limited evidence of fish activity and other water life in campus dams.

High concentrations of chloride in the Vaal River – a severely polluted water course – can be linked to the measures taken by Rand Water to ensure quality water. In 2016, Emfuleni Local Municipality's sewage pump station No. 10 located on Mario Milano Drive, which links NWU's Vaal campus with Vereeniging, was out of order. As a result, raw sewage was decanted into the Vaal River and due to the drought the spilt sewage hardened in the sun and caused an extremely unpleasant smell. In November 2016 it was reported that the Vaal River System had an average dam level of 27% capacity. At that stage, water restrictions were implemented for the Integrated Vaal River System which affected all water users in Gauteng. The restrictions meant a 15% reduction in supplies for domestic users and a 20% reduction for irrigation users. In January, the restrictions in the Emfuleni District, which includes the NWU (Vaal Campus), were increased when water supply to all residences was cut at night between 20h00 and 06h00 (Emfuleni Local Municipality, 2017). The combination of weather patterns, insufficient rainfall and irresponsible water usage were said to be responsible for the water shortage (Petterson, 2016).

There was an ongoing strike outside the Bushkoppies waste water treatment works (WWTW) near Soweto in December 2016. This plant processes between 200 and 250Mℓ of effluent which, once treated, finishes up in the Vaal River. Protestors blocked the entrance to the Bushkoppies WWTW and prohibited treatment operations (Watson, 2016). When the riot came to an end the spill of sewage into the Vaal River required disinfectant and the water was dosed with chloride by the responsible authorities (My Vaal River, 2016).

The lower levels of nitrate (NO_3^-) and nitrite (NO_2^-) ions in campus water storage resource indicated that these ions were taken up by the roots of water plants. Low rainfall during the summer season of 2015/2016 could contribute to low nitrogen compounds in water. Because of the low rainfall and escalating drought, there was little run-off of fertilizers and animal manure seeped into the campus water storage resource.

The animal manure is mainly that of the well-known campus geese and buck species like the springbok (*Antidorcas marsupialis*) and blesbok (*Damaliscus pygargus*).

For nitrites to be available in water there must be a stable nitrate ion (NO_3^-) which is produced by cyanobacteria. These blue-green algae, are frequently found in freshwater and may cause odour problems and oxygen depletion. The monitoring team reported foul smelling water during monitoring on 12 February 2016 (MPA 1 (12/02/2016)). It is therefore concluded that cyanotoxins are produced in the algae cells (Harding, 2006:23). At the time of an algal bloom, these toxins are released into water during cell death and cell rupture, causing foul water odour and possibly death of aquatic life such as fish. Cyanotoxins are reported to affect humans externally with skin, ear and eye irritations, as well as gastro-enteric symptoms if the polluted water is consumed (Harding, 2006:23). Despite low readings for nitrite and nitrate ions, it is concluded that the foul-smelling water in campus dams during summer months indicated poor water quality which posed a threat to human health.

The water in the dams at the NWU (Vaal Campus) is very hard and had values of 150–250 ppm. Various factors may be responsible for the hard water in the campus water storage resource. One possible explanation is acid mine drainage, a result of open coal mines in the Vaal River Catchment. McCarthy and Pretorius (2009:58) predicted that if all the coal resources of the upper Vaal River Basin were exploited, the entire basin would suffer the same problems as the Olifant's River system. According to them the water quality in the upstream Grootdraai and Vaal Dams would, in time to come, resemble that of the Middelburg and Witbank dams and thus be unsuitable for human consumption. At the time of conducting WQM measurements with the pre-service teachers for the purposes of this research project, there were levels of total dissolved solids (TDS), reading higher than 250 ppm which suggested that conditions of hardness and high turbidity were present in the campus dams.

Building projects on campus also contributed to the hardness of water in the campus dams. Plaster cement used in building construction contains limestone and has the same consistency as calcium carbonate (CaCO_3). On windy days, especially in winter and spring, winds carried dust and limestone which settled on the campus dams. Hardness of the campus water for gardening has no negative, but if the water is used in cooking pots, for example, scale forms on these utensils. Using hard water with soap will form scum, which is evidence of insoluble salts due to the formation of long-chain

fatty acids (DWAF, 1996:156). In Table 5.1, turbidity data in NTUs are displayed and then interpreted.

Table 5.1: Turbidity readings in NTUs for 2015–2016 in NWU (Vaal Campus) dams and Vaal River

2015

Source	20/02/2015	20/03/2015	15/05/2015	20/07/2015	18/09/2015
D1A	> 30	>30	>30	<10	>30
D1B	> 30	>30	< 10	<10	>30
D2	>30	>30	>30	>30	>30
D3	>30	>30	>30	>30	>30
D4	>30	>30	>30	>30	>30
D5	20-30	>30	>30	>30	>30
Vaal River	< 10	10 to 20	< 10	>30	10 to 20
Vaal River RW		10 to 20	10 to 20		10 to 20

2016

Source	12/02/2016	13/03/2016	06/05/2016	20/07/2016	05/10/2016
D1A	> 30	>30	>30	>30	>30
D1B	> 30	>30	>30	>30	>30
D2	10 to 20	>30	>30	>30	>30
D3	>30	>30	20 to 30	>30	>30
D4	>30	>30	20 to 30	>30	>30
D5	>30	>30	20 to 30	>30	>30
Vaal River	< 10	10 to 20	< 10	<10	<10
Vaal River RW		10 to 20	10 to 20	10 to 20	20 to 30

The turbidity data indicated higher readings in campus dams than in the Vaal River. The river flows persistently and the motion of the water contributes to lower turbidity

readings. Turbidity refers to the amount of particles that scatter light in water bodies. The turbidity of NWU (Vaal Campus) dams in general increased in 2016. The drought in 2015/16, which resulted in more dust, carried by wind, contributed to the increase in turbidity. The Department of Water Affairs and Forestry (DWAF) in (1996:160) stated that turbidity readings higher than 10 NTU have severe aesthetic implications for the appearance, taste and odour of water. There is always the risk of water carrying infectious diseases and chemicals also increase along with increased turbidity levels. As the DWAF (1996:160) points out, there is a notable change in the potential of disease transmission (even of epidemic proportions) when turbidity levels are high. The Rand Water guidelines for the Barrage Reservoir Catchment suggest that turbidity measurements of more than 55 ppm are unacceptable (Rand Water, 2017b). Turbidity data confirmed that the campus dams do indeed have poor quality water and that this has the potential to lead to health-threatening conditions.

5.3.1.3 Discussion of the total coliform bacteria

The data on variable total coliform bacteria are displayed in the following table and then discussed.

Table 5.2: Total coliform bacteria indications for 2015–2016 in NWU (Vaal Campus) dams and Vaal River

2015

Source	20/02/2015	20/03/2015	15/05/2015	20/07/2015	18/09/2015
D1A				+	+
D1B	+	+	+	+	+
D2	+	+	+	+	+
D3	+	+	-	+	+
D4	+	+	+	+	+
D5	+	+	+	+	+
Vaal River	-	+	+	+	+
Vaal River – RW	+	+	+	+	+

2016

Source	12/02/2016	13/03/2016	06/05/2016	20/07/2016	05/10/2016
D1A	+	+	+	+	+
D1B	+	+	+	+	+
D2	+	+	+	+	+
D3	+	+	-	+	+
D4	+	+	+	+	+
D5	+	+	+	+	+
Vaal River	+	+	+	+	+
Vaal River - RW	+	+	+	+	+

The Somerset Education test kit provides for a positive coliform bacteria test if more than 200 coliform colonies per 100 ml water are present. Data collected in 2015 and 2016 indicated that most campus dams tested positive for the presence of coliform bacteria on monitoring days. The water from the Vaal River only indicated a negative coliform bacteria test on 20/02/2015. The repeated positive coliform bacteria tests over the 2015 and 2016 confirmed that the campus dams are indeed contaminated with bacteria, mainly due to run-off water which contains animal manure. The positive results for coliform bacteria in the Vaal River, which is a flowing water body, indicate possible contamination due to upstream sewage discharge. The conclusion reached is that using water from the Vaal River and campus dams to irrigate sports fields may expose students who are participating in sporting activities close to the banks of the river, to contamination with coliform bacteria. Furthermore, people who use the Vaal River for recreational activities such as canoeing, water-skiing and fishing must give serious consideration to the possibility of detrimental effects that exposure to polluted water may have on their health.

Kings (2015) reported that many of the residents living in the vicinity of the Vaal Dam near Deneysville suffer from frequent attacks of diarrhoea. More serious ailments attributed to contaminated water include cancer, birth defects, brain damage, respiratory problems and skin complaints. The Vaal Dam fills up with water from neighbouring

Lesotho and has an inlet pipe for Rand Water. This inlet supplies drinking water to 10 million people in Gauteng. Rand Water noted a number of serious issues of concern in its 2015 annual report, such as an increase in salinity, sulphates, microbiological pollutants and dissolved solids, all of which impacted on the water quality in the Vaal River system (Kings, 2015). In its 2015 quarterly report Rand Water stated that the most significant challenges were faecal matter and chemical pollution due to mining and industrial activities (Rand Water, 2015b). The utility's water quality guidelines for the Barrage Catchment therefore regard an *E. coli* measurement of higher than 400 to be unacceptable (Rand Water, 2017b). The South African Water Quality Guidelines state that *E. coli* measurements lower than 1000 are safe for irrigation, but measurements higher than 50 000 might well cause irrigation equipment to become clogged (DWAF, 1996a:66).

The conclusion can therefore be made that the multiple positive coliform bacteria measurements show that the water quality status in the NWU (Vaal Campus) dams and adjoining Vaal River is unhealthy and poses a potential threat to human health. Furthermore, there may be financial implications to the university if the high *E. coli* measurements deteriorate even more in the long run and water supply equipment has to be maintained or replaced.

5.3.2 Conclusion

The dams of the NWU (Vaal Campus) are polluted and have poor water quality. The proposed theoretical statement of an agency role for anthropogenic activities affecting the quality of water is therefore correct. The level of pollution has increased over the 2015 to 2016 period and this is due to: (a) less circulation of water in dams and limiting the use of pumps in an effort to save electricity; (b) the current drought conditions due to ENSO, which is severe in most parts of the country; (c) frequent winds which carry dust and pollutants to water bodies; (d) the visible increase in pollution of campus dams with cool drink cans, glass bottles and empty fast food containers indicates that the increase in student numbers means more people on the campus and increased waste pollution; (e) the ongoing construction of new buildings on the campus; (f) more students with cars increase road usage on campus which adds to pollution of the dams with dust and rubber particles; and finally (g) there appears to be limited awareness on the part of students and campus staff in respect of the environment, a tendency that is evident in

the poor attendance of students and staff in the Green Campus Initiative (GCI) meetings and the GCI awareness campaigns.

Water pollution is defined by Miller & Spoolman (2012:516) as any change in water quality that harms living organisms or makes the water body unfit for irrigation and recreational use. Water pollution can occur from point sources or non-point sources. Point sources refer to the discharge of pollutants at a specific location (Miller & Spoolman, 2012:516). In the case of the NWU (Vaal Campus) point source pollution can occur when sewage and heat, and polluted water from industries are discharged into the Vaal River. Point source pollution is easy to identify, monitor and regulate (Miller & Spoolman, 2012:517). Pollution that occurs at a non-point source comes from broad and diffused areas (Miller & Spoolman, 2012:516). An example of non-point pollution of water bodies is the circulation of polluted water from a source such as the Vaal River via a pumping system to the water supply system of a community. To detect non-point pollution, which affects more widely than point pollution, is extremely problematic because the initial starting point in the polluted sequence is difficult to find. With reference to the NWU (Vaal Campus), the non-point pollution of the campus dams is caused by: (a) the construction of new buildings on campus; (b) mining dust from nearby coal mines via the atmospheric wind (MPA 1 (08/05/2015)); (c) run-off of animal manure, soil sediments and chemicals into campus dams; (d) run-off from tarred roads and eroding dirt roads, as well as parking lots and lawns in the vicinity of campus dams; and (e) the evidence of plastic and tin cans, as well as glassware in campus dams. Miller and Spoolman (2012:518) maintain that polymers used for the manufacture of plastic, break down very slowly and are extremely harmful to various life forms. They go on to claim (2012:517) that it is difficult to control discharges from diffuse sources.

In order to address the pollution of the NWU Vaal Campus dams, the researcher, with due recognition of the assistance of Rand Water experts, now proposes the following adaptive management practices. In so doing, the emphasis of the discussion below falls on one of the main objectives of this water monitoring project, namely adaptive management as a form of WQM.

5.3.3 Adaptive management and the water monitoring project at the NWU (Vaal Campus)

Lee (1999:3) and Skelcher (2005:573) indicate that adaptive management needs to take into account both learning and cooperative management of a natural resource (*cf.* 2.4.2). The researcher therefore acknowledges that learning was not the only notion behind undertaking the water monitoring project and thus proposed that a non-technocratic, polycentric adaptive management approach be taken on management of the water storage resources on campus. Although campus management and technical services are responsible for the maintenance of water resource storage facilities (Muller, 2014:75), the pre-service teachers as registered students (and thereby part of the NWU Vaal community) have the right to articulate their views and report on their findings. They expressed their concerns about the water status of the campus dams by participating in the Green Campus Initiative (GCI) meetings and together with the researcher found themselves in a unique position that there was no hierarchical order or power structure where they were able to register their findings, views and proposals for the adaptive management of the water resources on campus (Muller, 2014:75).

One of the notions of adaptive management according to Lee (1999:3) is what is described as “institutional prescription”, that is, the collaboration of diverse groups of participants that aims at social diversity. This resonates with the water monitoring project (*cf.* 2.4.2.1). The pre-service teachers displayed a sense of place when they indicated that they cared about the campus environment, wanted to take some responsibility for its betterment and were concerned when other students did not display the same sentiments towards the campus environment (*cf.* 2.4.2.2).

5.3.4 Public participation in the water monitoring project at the NWU (Vaal Campus)

The public participation process while implementing the water monitoring project at NWU (Vaal) was functional, collaborative and transformative. Functional public participation relates to where this participation contributes its information and is engaged in the implementation of decisions. Collaborative public participation is concerned with how the public engages with government/officials to decide on what is needed and what constitutes relevant knowledge. Transformative public participation

includes the local community when making and implementing decisions with expert support if needed (*cf.* 2.4.3).

The researcher interpreted the participation during the water monitoring project at the NWU (Vaal Campus) as follows: Functional public participation refers to the researcher and pre-service teachers who contributed information in the form of scientific data on the status of water storage resource on the campus. Functional public participation is seen in a top-down approach to adaptive management and in this research study it was regarded as true, because the researcher and her team depended on the NWU for funding the project (*cf.* 2.4.3). Funding was provided through a Scholarship of Teaching and Learning (SOTL) bursary in 2015 (MPA 9.3 2015)).

Collaborative public participation emanated from the collaboration of the researcher and pre-service teachers with campus management to maintain healthy water storage resource on campus (MPA 6.1 (2016.05.23 & 2015.07.22)).

Transformative public participation, the bottom-up form of public participation, was evident when pre-service teachers and the Rand Water officials monitored the campus water storage resource. The researcher, pre-service students and Rand Water represented different stakeholder groups of the campus community with the aim of initiating action to improve the water quality on the campus (MPA 1 2015.02.15)).

5.3.5 Proposed adaptive management practices

On 24 November 2015, a team of Rand Water experts, which included Rand Water's catchment manager Mr Francois van Wyk, and a Rand Water education expert Mrs Nyree Steenkamp visited the NWU (Vaal Campus) (MPA 1 (2015.11.24)). The concept of adaptive management and its role in water quality as outlined above in Chapter 2 (*cf.* 2.4.2) was under discussion. The researcher concluded that a non-technocratic, polycentric adaptive management approach is followed at the NWU (Vaal Campus). Non-technocratic adaptive management is sensitive to learning and co-management opportunities that are key properties in the management process. Polycentricity suggests that multiple stakeholder groups provide inputs on proposals to management (*cf.* 2.4.2). Adaptive management is never a completed action; instead it is an ongoing effort to manage the natural environment (*cf.* 2.4.2).

The following proposals regarding campus dams were made by the Rand Water expert group:

- There must be circulation of water in the dams. The pumps must run for longer times each day.
- The grass close to the dams (about one metre around them) should be left to grow longer. This will ensure that storm water *en route* to the dams will slow down the erosion process.
- Dam 4 next to the tarred road leading to building 25 is severely eroded. The bridge is in danger of collapse, and might have considerable economic consequences for the university. The campus management should consider building gabions in the form of rocks or stones and wire mesh, to support the tar road and halt the erosion of the dam.
- The fish in the dam should be caught (the suggestion was to hold an angling competition). The expert group was of the opinion that indigenous fish would be more appropriate to preserve a uniquely South African nature reserve environment. All carp (*Cypinus carpio*) and barbel (*Clarias gariepinus*) should be removed and replaced with indigenous species like yellow fish (*Labeobarbus kimberleyensis*).
- The dam beside to the cricket pitch (Dam 3) needs structural support in the form of gabions (stone and wire structures) to ensure that the cricket pitch remains intact.
- The reeds in dam 2 must be reduced and then kept under control i.e. cut manually at regular intervals.
- Storm water canal inlets into dams can be covered with stones to prevent a rapid flow and support the maintenance of water.
- Purifying the water in campus dams must become a priority. The circulation of water from and to the Vaal River from the campus dams is the responsibility of the NWU (Vaal Campus) management. Water entering the Vaal River from campus dams must be purified to indicate the university's full commitment to water quality and communal health.
- Rand Water experts indicated that university facilities could serve the community. They foresee the possibility of using campus facilities to promote *Water Wise*, a community initiative to enhance the knowledge about water quality.

- Barley batches placed in the dams could possibly support aquatic life in the water. These barley batches of fodder have the ability to sprout within 6 days and barley grass provides vitamin rich, protein food to herbivores as well as shelter and breeding places for fish in the dams (Fodder solutions, 2017).
- Students must be informed and reminded on a regular basis about the importance of water quality and aquatic life by putting up poster boards beside the dams.
- The focus of water management at the NWU (Vaal Campus) needs to change. The Vaal River is used as a source to irrigate sports fields and gardens. The management of the campus water storage facilities must support the natural water cycle and ensure that the water returned into the Vaal River meets the required standards.

5.3.6 Response to Rand Water's proposals

5.3.6.1 Campus management and technical services

Prof Johann Tempelhoff, GCI co-ordinator, arranged a special meeting early in 2016 (MPA 6.1 (2016.02.16)) to provide the researcher with an opportunity to share the suggestions made by the Rand Water expert group with the NWU (Vaal) campus management and technical services. The following responses were expressed and noted by the researcher:

- The campus dams are circulated according to a schedule. The dam in the vicinity of the student centre (Dam 1) is circulated more often than the other dams. The water circulation in Dam 1 is problematic because it is the last dam to receive water from the Vaal River.
- A note was made to ask garden services to keep the grass longer in the immediate surrounds of the dams.
- Technical services are aware of the erosion of dams. According to technical services erosion increases during winter and periods of drought, but the erosion patches are covered with grass during summer – therefore the erosion patches do not increase in size. Mr Jacob Simanga reported in May 2016 (MPA, 6.1 (2016.05.23)) that campus management arranged with a consulting civil engineer to investigate the position of the tarred road between dams 4 and 5. The engineer concluded that the road might collapse within the next 4 to 6 years.

- Yellow fish (*Labeobarbus kimberleyensis*) flourish in streams and need high flowing water. The barbel (*Clarias gariepinus*) and carp (*Cypinus carpio*) species are more resilient and flourish in water with poor circulation. The proposal made by the Rand Water expert team to arrange a fishing competition to catch the barbel and carp and replace them yellow fish was therefore rejected.
- No attempt has yet made to halt the erosion of Dam 3 (by building gabions) to ensure that the cricket pitch remains intact.
- The reeds in dam 2 create multiple problems. One is that Dam 2 is the main irrigation dam for the sports field, but the pump does not function efficiently because of the low water level. The size of the dam has decreased by half due to overgrown reeds and it is extremely difficult to remove the reeds by cutting them. To arrange for their removal by mechanical machines is deemed too expensive. To this day Dam 2 is still overgrown with reeds and is not reaching its potential as a water resource.
- The technical team agrees that the securing of storm water canal inlets into dams with stones or cement will be advantageous. According to Mr Burger Scholtz, plans are in place to do this in the near future (MPA 6.1 (2016.02.16)).
- No attempt has yet been made to purify water before pumping it back into the Vaal River.
- A collaborative attempt between Rand Water and the NWU (Vaal Campus) water management group to cooperate in water management of the Vaal Barrage Catchment, of which the NWU (Vaal Campus) is part, is planned for 2017.
- The drought of 2016 raised the price of barley. Available funds for water-related matters were exhausted by purchasing the Somerset Educational test kits for the water monitoring initiative held at schools.
- The GCI agreed that in 2017 it would put up posters next to the campus dams and the Vaal River to raise awareness and importance of water quality.
- The researcher intends to indicate the value of this research study to the NWU (Vaal) campus management by sharing the findings with the vice-rector (Academic) for special attention during a management meeting.

5.3.6.2 Reflections by the researcher on adaptive management of campus dams

In the aftermath of conducting the water monitoring project the researcher is aware that the management of campus water storage resources calls for the collaboration of a variety of role players. The main focus of university campuses is academic teaching research. Transdisciplinary research requires turning results into fruition, exemplified by the analysis of quantitative data as a scientific report and the concomitant adaptive management responses. The researcher has noticed that the quality of water in dams is poor after weekends and tends to improve on week days, leading to the conclusion that pumps are only set to operate during the week and not over weekends (MPA 1 (2015-2016)).

A pre-service teacher in the technical BEd. programme who is also a keen fisherman, was involved in the monitoring project in March 2016 (MPA 1 (2016.03.11)). He was interested in the layout of the dams and pumping system and arranged on his own initiative to meet with technical services. His aim was to persuade the Mechanical Engineering subject group to engage in designing a water purification system for the campus dams. Technical services were uncooperative and said the proposals were “impossible to implement”. On the basis of this negative outcome the researcher maintains that the collaboration of academic groups, technical services and campus management needs attention; surely the campus environment should become an integral part of teaching and learning initiatives.

A project-based teaching approach such as this water monitoring project requires a great deal of planning and reflection (*cf.* 2.3.3.4 & 3.7). Reflecting on the adaptive management proposals, the researcher suggests that although her focus was on the teaching and learning of pre-service teachers and learners, a great deal more could be achieved by innovative use of the findings. Creating a new position of an environmental manager on the campus would be a good start. The incumbent of this position, with specific focus on environmental matters, would be able to monitor natural resources as part of his/her job description, particularly in the light of the fact that the NWU (Vaal Campus) is a renowned nature reserve. The researcher made several such proposals to technical services and campus management regarding the adaptive management of dams, but she is far from convinced that the proposals will be turned into action.

Reflecting on the literature review and the dimensions of Enengel *et al.* (2012:107; *cf.* 2.4.2.4) the researcher regards the adaptive management at the NWU Vaal campus as context specific for the scale dimension. All data collected at dams were specific and unique to the campus environment. Strategic knowledge was gained in the functional dimension. The water monitoring project indicated the connections and interrelations between different groups of participants with an interest in water storage resource (*cf.* 2.4.2.4). The scientific knowledge gained was made explicit by the scientific report and represents an epistemic dimension. The input of different groups of participants in the project is indicative of collaborative participation. External value was gained and useful, objective data was produced (*cf.* 2.4.3). The polycentric adaptive management approach, which included not only the researcher and pre-service teachers, but also representatives of Rand Water, campus and the Green Campus Initiative management, promoted social learning (*cf.* 2.4.3.2) between all groups of participants. Horizontal accountability was reached when the researcher, pre-service students and learners produced useful data on communal water which could then be analysed and interpreted. Vertical accountability will be reached if and when campus management and technical services respond to the proposals made to ensure a high level of water quality in campus water storage resource (*cf.* 2.4.3.3).

The researcher noted that the pre-service teachers tended to become bored testing the same variables repeatedly. In 2016, she proposed that they collect data on different variables during at each monitoring session. This decision sparked new energy into the project and provided a comprehensive picture on the collection of data of all variables. The approach used in the 2016 data collection provided sound knowledge and practical skill to the student teachers on all variables and they were better prepared to teach the monitoring process on the full range of various variables at schools.

It proved impossible to introduce an adaptive management strategy at the NWU (Vaal Campus) dams and adjoining Vaal River despite the best efforts of the monitoring team. The negative influence of the harsh economic climate on university campuses in South Africa due to unrest such as the 'Fees must fall', protest action increased costs for electricity and water, and there is now an increasing demand for facilities to accommodate more students. All this leaves university campuses in a dilemma regarding environmental resource management. 'Fees must fall' was a countrywide

protest action and the demand for free higher education in South Africa was the root cause of the protest action (Gasa & Dougan, 2016).

However, to the delight of the researcher in June 2017, the road leading to administrative building 25 (between Dams 4 and 5) was strengthened with gabions (VAAL eNUUS, 2017). The proposal made by the monitoring team that the erosion of the dams be halted and the safety of pedestrians and motorists travelling to the river front on the campus be made more secure, was at last implemented. Photo 5.6 indicates that gabions have been built on the fringe of the road to next to Dam 4 to limit the effects of erosion.



Photo 5.6: The construction of gabions at Dam 4 to limit erosion (VAAL eNUUS, 2017)

5.4 CHAPTER SUMMARY

Chapter 5 discusses the quantitative data collected from water storage resources on the NWU (Vaal Campus) and the Vaal River. The results and discussion of quantitative data indicate that the status of water storage resources on the campus is deteriorating. The current drought and the economic constraints at NWU (Vaal Campus) placed limits on the sound management of campus dams. The evidence that the pollution of campus dams is increasing on a number of crucial variables, was discussed. Adaptive management proposals that were made to improve the status of the campus water storage resource, as proposed by an expert Rand Water group, were discussed. The responses offered by technical services and campus management were also given

attention. The researcher believes that appointing an environmental manager will be a positive move. The natural environment is ever changing and monitoring water quality of campus dams and management of campus water storage resource must become a fulltime commitment.

In Chapter 6, the researcher discusses current frameworks to direct environmental education at educational institutions. The aim of Chapter 6 is to reflect on the NWU's (Vaal Campus) monitoring project and use the knowledge gained by using a project-based teaching approach to design a framework to direct environmental education in specific contexts at educational institutions.

CHAPTER 6

A CITIZEN SCIENCE FRAMEWORK FOR WATER QUALITY MONITORING

6.1 INTRODUCTION

The water monitoring project conducted on the NWU (Vaal Campus) provided for unique participation of different groups of citizen scientists. The participants differed on level of engagement; time spent on the project and their ability to influence the management of the water resource. In this chapter, the researcher will first discuss current citizen science frameworks in chronological sequence. These were developed with knowledge creation, data collection and public participation in mind. The researcher will develop, with the necessary motivation, a citizen science framework unique to the research context and applicable to possible future community-based monitoring projects.

In this research a framework is regarded as an approximate representation of an object which cannot be seen (Miller & Spoolman, 2012:34). A framework is a basic conceptual structure which aligns the understanding of the researcher with existing knowledge (Nieuwenhuis, 2007:111). The design of a framework is relevant in this research because the researcher takes careful note of the contributions of other researchers and combines existing knowledge in a new understanding of citizen science frameworks.

6.2 FRAMEWORKS OF CITIZEN SCIENCE PROJECTS

Buytaert *et al.* (2014:6) suggest that the extent of participant collaboration in a citizen science project determines the choice of framework. There is an extensive range of frameworks in the literature, some of which will be discussed in more detail below. Newman, Graham, Crall, & Laituri (2011:218) maintain that the purpose and objectives, the management of data and number of participants of a citizen science project determine the choice of framework. The transdisciplinary nature of this study motivated the discussion of various frameworks with different intent in citizen science. In the discussion that follows the researcher aims to clarify the position of the NWU (Vaal Campus) water monitoring project in the different available frameworks. The first framework type under discussion is Danielsen *et al.*'s monitoring schemes.

6.2.1 Danielsen *et al.* monitoring scheme

Danielsen *et al.* (2008:32) indicate that monitoring as a citizen science project has received low priority due to difficulties in the process of execution and the high expense involved. However, the claim is that by linking monitoring to local decision making such schemes becomes relevant and sustainable (Danielsen *et al.*, 2008:32). Danielsen *et al.* (2008:33-34) classify monitoring schemes into five categories, namely:

- *Externally driven, professionally executed monitoring* which does not involve local stakeholders. Government agencies and global schemes often use this type of scheme.
- *Externally driven monitoring with local data collectors* use local stakeholders only in data collection. In this type of monitoring the design, analysis and interpretation are done by off-site professional researchers.
- *Collaborative monitoring with external data interpretation* involves local stakeholders in data collection and management-oriented decision making. The design of the scheme and data analysis is undertaken by external scientists.
- *Collaborative monitoring with local data interpretation* involves local stakeholders in data collection, interpretation/analysis of data and management decision making. Scientists may provide advice and training. This type of monitoring scheme creates an enabling environment for local ownership of the data and the research findings.
- *Autonomous monitoring* involves local stakeholders in all steps of the monitoring process. There is no involvement by external agencies except to advocate the continued relevance of the scheme.

The monitoring scheme most applicable to the water monitoring project at the NWU (Vaal Campus) is the collaborative monitoring scheme with local data interpretation. This choice is motivated as follows: Pre-service teachers and Grade 10 Physical Science learners are primary participants who collected and interpreted the data. The researcher and scientists from Rand Water, the expert group, trained the pre-service teachers and learners to perform the monitoring. One of the notions of the NWU research study is to raise awareness of water status and water quality – therefore there is local ownership. The emphasis on local ownership of community water quality

corresponds with the participatory action research principles as discussed in Chapter 3 (cf. 3.3.2.3).

In the next section the three frameworks suggested by Pouliot are discussed.

6.2.2 The three Pouliot (2009) frameworks

Pouliot performed a citizen science study in 2009 on cellular telephone controversies. Pouliot (2009:62) reported on her findings by indicating three possible frameworks namely:

The *deficit of public education framework* implies that scientific researchers inform the public about scientific issues. This framework accentuates the dual divide between citizens and scientists' ability to express their views (Pouliot, 2009:63).

The *public debate framework* allows scientists and citizens to interact in spaces of public discussion. Pouliot (2009:63) indicates that referendums, surveys, focus groups and symposia act are public discussion spaces. Although citizens' knowledge was conceived as different from that of scientists, the experience provides enriched and more complex discussion of sociotechnical issues.

The *co-production of knowledge framework* is characterised by the integration of scientific knowledge with decision-making processes. The co-production of knowledge framework regards citizens as having cognitive and discursive competencies which can be used for the creation of useful knowledge. In the framework scientific knowledge represents the product or outcome of processes in which scientists and citizens collaborate closely (Pouliot, 2009:64). The co-production of knowledge framework is applicable in environmental research and is based on the idea that citizen scientists have experience and can contribute competently to research problems in their contexts (Pouliot, 2009:64).

The co-production of knowledge framework links well with the intent of the water monitoring project at the NWU (Vaal Campus). Participants collaborate at different levels and with a diverse impact on the project, but all contribute towards the social knowledge gained in the project (cf. 2.3.2.1 & 4.2.1).

6.2.3 Frameworks by Bonney *et al.* (2009a & b) on public participation in scientific research

Bonney *et al.* (2009a:11) distinguished between three major categories of public participation frameworks namely:

- *Contributory projects* designed by scientists to which community members may contribute data.
- *Collaborative projects* designed by scientists to which members of the community may contribute data and may also help to refine the project design, analyse the data and disseminate findings.
- *Co-created projects* designed by both scientists and community members. The community members are actively involved in most of not all of the steps of the research process.

Bonney *et al.* (2009b:12) provide valuable information on the assessment of a citizen science project suggesting that all citizen science projects contribute to:

Awareness, knowledge and/or understanding: Understanding ranges from pure scientific information to environmental issues and regulations. Participants gain knowledge of the process of science, community structure and environmental regulation.

Engagement or interest: Citizen science projects are a sound method of informal science education in a fun and meaningful way. Participants develop an interest and are engaged by exploring new or expanding on existing interests.

Skills: Data collected during citizen science projects can be of sufficient quality to allow scientific analysis. Participants may also increase their ability to distinguish between study sites and weigh the pros and cons of the data collection methods. The communication of findings to the public increases communication skills.

Attitudes and behaviours: Positive attitudes increase when individuals learn to function as scientists or at least learn to understand how scientists work. Projects that involve communities draw concerned citizens into the scientific process and may also change behaviours. Participants are likely to indicate their responsibility to the environment and are able to make confident decisions regarding natural resources in their communities.

Bonney *et al.* (2009b:20) explain that the outcomes of citizen science projects are the *describing impacts* of public participation and that there is room for new citizen science projects in three areas namely: projects which study new scientific questions; projects which engage new audiences; and projects designed to test new or enhanced frameworks (Bonney *et al.* (2009b:13).

Also in accordance with the contribution of Bonney *et al.* (2009b:12) is the Tbilisi Declaration which provides a framework, objectives and principles for environmental education (EE) at local, national, regional, and international level and includes all citizens both within and outside the formal school system. The objectives of EE as summarised in the Tbilisi Declaration assist social groups and individuals to:

- acquire an awareness of and sensitivity to the total environment and its related problems;
- gain knowledge and experience in, and an understanding of, the environment and all its related problems;
- acquire an attitude founded on a set of values with feelings of concern for the environment, thus motivating active participation in environmental improvement and protection;
- acquire the skills to identify and solve environmental problems; and
- participate actively at all levels to work towards resolving environmental problems.

The conclusion is therefore that objectives for EE are incorporated in Bonney *et al.*'s (2009b:17) public participation framework and that using elements of this framework can contribute to the objectives set in the Tbilisi Declaration for EE (*cf.* 2.3.1.3)

Bonney *et al.* (2009b:17) also provide a framework for public participation that is based on the steps taken in the scientific process which are:

- Choose or define question(s) for study
- Gather information and resource
- Develop explanations (hypotheses)
- Design data collection methodologies
- Collect samples and/or record data

- Analyse samples
- Analyse data
- Interpret data and draw conclusions
- Disseminate conclusions/translate results into action
- Discuss results and ask new questions

According to Bonney *et al.* (2009b:17), this is the only framework which incorporates participants in all the steps of the scientific method and such projects are known as co-created projects.

The *co-created framework* devised by Bonney *et al.* (2009b:11) is particularly applicable to the water monitoring project conducted at the NWU (Vaal Campus) and the participatory action research methodology followed in this research study (*cf.* 3.3.2.3). The researcher and experts from Rand Water decided on the choice of scientific equipment and the parameters to be monitored. The pre-service teachers developed workable procedures to collect the necessary data in less than 1½ hours at seven monitoring points. They also acquired knowledge and skills and were able to teach Grade 10 learners to complete the monitoring in classrooms. The researcher, Rand Water scientists, pre-service teachers and Grade 10 Physical Science learners all played a part in analysing and interpreting data. All participants were able to disseminate and communicate findings.

The researcher is of the opinion that the engagement of pre-service teachers on the campus and in schools (two levels of participation) in community-based monitoring can be seen as a project with a new audience. The review and application of frameworks and the aim of creating a framework for citizen science projects, as attempted in this chapter, can also be classified as new citizen science projects.

The steps of the scientific process guided the NWU (Vaal Campus) water monitoring project. The prescribed steps were followed, that is to plan, execute and interpret findings, and these steps were a guiding tool in the research study.

Bonney *et al.* (2009b:21-22) designed an assessment rubric to determine the extent of impacts such as awareness, knowledge, engagement, skills, attitudes, behaviours

among others. The researcher used this rubric to assess and reflect on the NWU (Vaal) water monitoring project and is discussed in section 6.3.

6.2.4 The Citizen Science Programme Framework by Bonney *et al.* (2009a)

In another publication, Bonney *et al.* (2009a:979) indicate that a citizen science programme framework should comprise the following nine steps, namely:

- Choose a scientific question
- Form scientist/educator teams
- Develop, test and refine protocols, data forms and educational support materials
- Recruit participants
- Train participants
- Accept, edit and display data
- Analyse and interpret data
- Disseminate results
- Measure outcomes

It can be seen that the main difference here is the inclusion of the recruitment and training of participants (Bonney *et al.* 2009a:979).

The researcher considered both these works by Bonney *et al.* (2009a:979 & 2009b:11) as sufficiently comprehensive to provide guidance for the construction of a citizen science framework for the water monitoring project at the NWU (Vaal Campus).

6.2.5 The Newman *et al.* (2011) framework for a multi-scale citizen science project

Newman *et al.* (2011:218) claim that citizen science projects are designed for multiple purposes and can include scientific research, social empowerment, environmental education and youth career development. In their view the objectives of projects vary from data contribution, the answering of questions, informing local decision making processes, and the opportunities of being in nature. The level of participation of citizen scientists determines to what extent the project will be contributory, collaborative or co-

created (Newman *et al.*, 2011:218). The number of participants in projects as well as the data management, also determine the structure of the project.

All citizen science projects determine their own scope, scale, activities and level of support which is known as the *intra-project* dimension. Newman *et al.* (2011:220) state that effective projects include the following in their intra-project dimension:

- Define/choose a research question
- Gather information and resources
- Design data collection methods
- Collect data
- Analyse data
- Interpret data and draw conclusions
- Disseminate results
- Discuss results

These steps of the intra-project dimension concur with the steps laid down by Bonney *et al.* (2009b:17). The inter-project dimension indicates the degree to which projects coordinate with other programmes and may include: data sharing through collaborative meetings; how data meet standards; methods to address data sensitivity; and the extent to which data is used to address problems.

Newman *et al.* (2011:220) developed a framework which includes the scope, scale and activities of citizen science projects. Each aspect of a multi-scale citizen science project has associated continuums and tensions. These tensions compare the relations between top-down and bottom-up approaches. A second framework developed by Newman *et al.* (2011:226) can aid in determining the exact position of a project regarding social, spatial and temporal scales. The main purpose of this second framework is to position a project in relation to other projects which share the same data and methods. Both frameworks provided by Newman *et al.* (2011:220) were used as steps in the development of the citizen science framework applicable to the NWU (Vaal Campus).

In the next section the typology of Wiggins and Crowston (2011) is discussed.

6.2.6 Typology of citizen science by Wiggins and Crowston (2011)

Wiggins and Crowston (2011) indicate that all citizen science projects are concerned with scientific, organisational and technology issues. These researchers distinguish between five types of citizen science projects, namely:

- *Action-oriented* citizen science projects which encourage participants to intervene in local concerns. These bottom-up projects involve participants for longer terms and aim to solve scientific, technological and organisational issues in communities. Scientists act as consultants or collaborators and provide training and intervention support to participants.
- *Conservation* projects support environmental stewardship and natural resource management. Citizen scientists are incorporated in conservation as a matter of practicality and outreach. All conservation projects are associated with complex collaborative partnerships and have affiliations with larger state or regional agencies.
- *Investigation* projects focus on scientific research where data is collected from the physical environment. Education is not always an explicit goal of investigations, although educational material is provided and structures might exist which support ongoing learning. Investigations have a top-down structure in which academics or non-profit conservation agencies are the primary organisers. Investigations rely on financial sustainability to conclude the research.
- *Virtual* projects are all computer-based and are mediated with no physical elements. Tasks are performed through a web portal where participants answer related questions. Quality is ensured by the project leaders through the multiple volunteers who respond. The validity of virtual projects is often an issue. This top-down approach to research is often purely academic in nature.
- *Education* projects put the emphasis on outreach, learning and developing of scientific skills rather than gathering scientifically valid results. They aim to provide informal learning opportunities to all participants through formal curriculum material. Education projects are organised top-down and must involve multiple types of participants. Substantial funding is required and the intended duration and sustainability of projects can be problematic. The variety of participants from youth to adults may provide a constraint for technology design.

The NWU (Vaal Campus) water monitoring project has much in common with suggested components of both the action-orientated and education projects devised by Wiggins and Crowston (2011). The informal learning opportunities between the pre-service teachers and various other participants such as school learners, Rand Water experts and campus management representatives, provided for mutual learning between different groups of participants. The researcher initially organised the project, which was therefore a top-down approach. Once the pre-service teachers became involved in the project, they realised its potential to impact water quality in communities and a bottom-up approach emerged which enabled the pre-service teachers to solve water quality concerns in their own communities. The researcher agrees that the duration and sustainability of a water monitoring project such as this was a challenge. The challenges of the project will be addressed in the final chapter.

6.2.7 Public participation frameworks suggested by Shirk *et al.* (2012)

Shirk *et al.* (2012) indicate that the degree of public participation in citizen science projects can be quantified, compared and standardised. These researchers define the *degree of participation* as the extent to which individuals are involved in the process of scientific research. Alender (2016:2) indicates that the level of participation reflects the number of participants and how much time they spend participating. To Shirk *et al.* (2012) the *quality of participation* is described as the extent to which a project's goals and activities align with, respond to and are relevant to the needs and interests of public participants. High quality participation is therefore supported by credibility, trust, fairness, responsiveness and relevance. The degree and quality of participation encouraged Shirk *et al.* (2012) to suggest the following categories for projects namely:

- *Contractual projects*: communities ask professional researchers to conduct a scientific investigation and report on the results.
- *Contributory projects*: scientists design projects and members of the public contribute data.
- *Collaborative projects*: scientists design projects, community members contribute data and help to refine the project design, analyse the data and disseminate findings.

- *Co-created projects*: scientists and members of the public work together and design the project. The public participants are actively involved in most, or all aspects of the research process.
- *Collegial contributions*: non-credentialed individuals conduct the research independently with varying degrees of expected recognition by institutionalised science or professionals.

The public participation frameworks by Shirk *et al.* (2012) correlate with the monitoring scheme categories by Danielsen *et al.* (2008). The water monitoring project at the NWU (Vaal Campus) can be categorised as a co-created project where the researcher designed the project, but the pre-service teachers and Rand Water officials, as monitoring experts, gave assistance to refine the design. The pre-service teachers and the learners collected, analysed and interpreted data. Although the pre-service teachers were less in number (8 individuals), they spent more time performing monitoring activities (10 sessions on the campus (1hour 30 minutes per activity) and 6 activities (1 hour 30 minutes per activity) at schools. The learners were larger in number (320) and spent less time monitoring (1hour 30 minutes for one activity).

6.2.8 Other aspects to take into account when designing a citizen science framework

Cooper *et al.* (2007) indicate that consideration should be given to the interaction between adaptive management and change in participation behaviour, attitudes and knowledge. They reason that citizen science has the ability to become a new conservation strategy due to the dual goals of promoting learning and social change.

The 1995 White Paper on Education and Training paves the way for new development in environmental education (EE) in South Africa by emphasising an active approach in learning as a vital element to create environmentally literate citizens (*cf.* 2.3). The White Paper also indicates that environmental educators, as official stakeholders in the curriculum development process, must address community issues. Curriculum developers therefore need to focus on engagement of learners in decision making, in dialogue about and action in environmental issues in local contexts (Ramsarup, 2013:56).

The South African Constitution, chapter 2, section 24 of 1996 indicates that all citizens have the right to an environment that is not detrimental to their health or well-being. An initiative to promote Education for Sustainable Development (ESD) in the South African school curriculum, namely the Curriculum Assessment Policy Statement (CAPS), was implemented in South African schools in 2012. CAPS, as a content and assessment framework, guides and support teachers but it also integrates contemporary environmental and sustainability content into all subjects from Grade R to Grade 12. CAPS principles, like human rights, inclusivity, environmental and social justice infuse the principles and practices of social and environmental justice and human rights defined by the Constitution into the curriculum. Social transformation, active and critical learning, high-level of knowledge and skills, valuing indigenous knowledge systems, credibility, quality and efficiency are also addressed by CAPS (Ramsarup, 2013:62-63).

There is growing interest on how South African higher education responds to sustainability issues (Ramsarup, 2013:69). The Green Campus Initiative (GCI), which is implemented on various campuses of the NWU (NWU), can be regarded as a response to the call for universities to cooperate in ESD. The development of a citizen science framework, as it was applied in the water monitoring project at the NWU (Vaal Campus), is therefore a concerted attempt to promote ESD, critical thinking and social change in a community.

Cooper *et al.* (2007) list seven steps in their *Citizen Science Tool* namely: procedure to establish goals; recruitment and marketing; training of participants; retention of participants; data collection and organisation; feedback of results and management recommendations. Cooper *et al.* (2007) concur with Bonney *et al.* (2009a:979) that the retention and training of volunteers' adaptive management recommendations are acceptable as new criteria for a framework.

Dickenson *et al.* (2012:292) indicate that the use of affected populations in citizen science research is a way to generate ecological knowledge, inquiry, and place-based nature experience in the public domain. The use of participants from different backgrounds and abilities increases the likelihood of innovation. Dickenson *et al.* (2012:297) suggest that all citizen science projects provide educational benefits such as skills to collect data; critical scientific thinking and inquiry; and the ability to generate questions and design or develop frameworks. In Chapter 4 the experience of different participant groups and the gains of the water monitoring project were discussed.

Alender (2016:1) indicates that the motivation of citizen scientists is crucial. Motivation is categorised as developing social values such as concern for others, understanding, personal growth and self-esteem (Alender, 2016:1). Alender (2016:7-14) performed an online quantitative study to determine what motivated volunteers to participate in citizen science projects. She reported that the main reason is to enhance the environment (Alender, 2016:7) and that volunteers are motivated if their collected data are used; they are able to present their findings; are able to interact socially with others. It is also important to participants that they acquire informal learning, and volunteers are recognised and receive rewards (Alender, 2016:13-16). The researcher agrees that the research findings indicated by Alender (2016) are valuable for this study and correlate well with the experience of participants in the NWU (Vaal) project. Chapter 4 revealed that both pre-service teachers and learners enjoyed monitoring activities and the social interaction between participants. The pre-service teachers considered the presentation of their collected and interpreted data on different variables at the 2015 Teaching and Learning Symposium as the highlight of their participation in the monitoring project (*cf.* 4.2).

In the next section, the development of a citizen science framework is discussed. In the framework the researcher will combine the relevant elements of previous research as discussed above that are applicable to the NWU (Vaal Campus) monitoring project.

6.3 DEVELOPMENT OF A CITIZEN SCIENCE FRAMEWORK FOR A WATER MONITORING PROJECT AT THE NWU (VAAL CAMPUS)

In order to develop a citizen science framework for the NWU (Vaal Campus) project, the researcher proposed a set of steps. These steps act as reflective questions on the water monitoring project which contributed to understanding the project and associated concepts.

Step 1: Indicate project objectives in relation to ESD on the template devised by Bonney *et al.* (2009b: 42).

Step 2: Use the steps of the scientific method in the citizen science programme framework suggested by Bonney *et al.* (2009a:979) to indicate the intra-project dimension.

Step 3: Use the framework for multi-scale citizen science support as proposed by Newman *et al.* (2011:220) to determine the scope, scale, activities and system approach. The position of the NWU (Vaal Campus) in relation to the focus of the project (weight of the project) is indicated with an X.

Step 4: Use the second framework by Newman *et al.* (2011:226) to determine the inter-project dimension of the water monitoring project at the NWU (Vaal Campus) in relation to other citizen science projects in South Africa.

Step 5: Use all available information to create prototypes of a framework for citizen science.

Step 6: Test the created prototype framework for citizen science by reflecting on the water monitoring project of the NWU (Vaal Campus) and refine the prototype frameworks.

Step 7: Construct a unique framework from various prototype frameworks.

Table 6.1: Step 1: Project goals and outcomes (Bonney *et al.*, 2009b:43).

Project: Background	Informal Science Education and EE objectives	Training	Measures/Outcomes
Pre-service teachers in Physical Science (BEd programme) as well as Grade 10 Physical Science learners from community schools who volunteered to monitor the local water storage resource. Water storage resources include, NWU dams and Vaal River water and community taps.	1) Participant science content knowledge of physical parameters indicating water health and water status. 2) Participant understanding of data collection from water samples. 3) Participant knowledge of the scientific method. 4) Participant knowledge of process skills. 6) Participant and community water health education. 6) Participation in management action of community water storage resource. 7) Participation in and enjoyment of water science. 8) Social and environmental responsibility 9) Knowledge, attitudes, skills, participation, awareness.	Pre-service teachers: 1) A one day visit to Rand Water for... 2) Protocol training to ensure accurate data collection with water monitoring kits at NWU (Vaal Campus) water storage resource. 3) 10 Opportunities to participate in monitoring activities at NWU (Vaal Campus) during 2015-2016. 4) An opportunity to validate monitoring practice in May 2015 by a Rand Water expert who visited the water monitoring group on campus. Learners: 1) Demonstration in class during school visit. 2) In-person training for unsure learners. 3) Materials provided that explain the method of data collection.	Pre-service teachers: 1) A series of open-ended questions after monitoring activities to indicate: concepts they do not understand; how they experienced the monitoring activities; which changes are needed during monitoring practices to increase their knowledge or experience. 2) In pairs, pre-service teachers analysed and interpreted data of specific parameters. They presented their findings at a Teaching and Learning Symposium in October 2016. A study leader, other academics and Rand Water experts attended the presentation to determine the increase in content knowledge and potential of pre-service teachers. Learners: Learners submitted a practical report in groups to indicate their ability to collect data, interpret data and communicate their findings. Open ended questions were asked of learners in groups to indicate their experience regarding the monitoring activities.

Reflection of researcher: This first step gave the researcher a bigger picture of the monitoring project. It also aligned the EE objectives with measurable outcomes and aided the researcher in confirming that planned outcomes of the project were met.

Table 6.2: Step 2: Framework for developing a citizen science project to indicate the intra-project dimension suggested by Bonney *et al.* (2009a: 979)

Steps	Response from water monitoring project of NWU (Vaal Campus)
1) Choose a scientific question	How do Physical Science pre-service teachers and Grade 10 Physical Science learners experience environmental learning through monitoring water samples in a community-based water monitoring citizen science project within a transdisciplinary case study format?
2) Form a scientist/educator team	The team consists of: Researcher – initiate and design of project, coordination of project and full participant Rand Water – experts on monitoring practices; to validate data collected and findings of data on campus Pre-service teachers – primary collectors of data on campus and assist with data collection in schools Learners – suppliers of community water samples and data collectors in local schools Members of the Green Campus Initiative – accept frequent feedback of project progress and act as link between research team and campus management Technical services and representatives of campus management – to implement possible adaptive management practices to maintain healthy water storage resource on campus
3) Develop, test and refine protocols, data forms and educational support material	The researcher with the aid of Rand Water decides on the apparatus to be used. The Somerset Water Quality test kit allows for the testing of the nine parameters the team decided upon namely: pH, temperature, turbidity, dissolved oxygen, bio-oxygen dissolved, concentration of nitrate-, nitrite- and chloride ions, hardness and coliform bacteria. The researcher designed data forms for both pre-service teachers and school learners. The researcher contacted Somerset Educational and arranged for funding of the test kits.

4) Recruit participants	The researcher proposed to her second-year B Ed Physical Science students (pre-service teachers) the possibility of a water monitoring project. The pre-service teachers agreed to participate in the project.
6) Train participants	The researcher contacted Rand Water and arranged for a visit to expose the pre-service teachers to water monitoring activities. During the visit, the researcher and Rand Water officials agreed on the apparatus and a shared responsibility to train the students. The researcher trained the pre-service teachers at the campus water storage resource. Rand Water visited the training and confirmed that the pre-service teachers were well trained. Trained pre-service teachers went with the researcher to schools to aid with training of school learners in monitoring activities.
6) Accept, edit and display data	The researcher provided report sheets for both pre-service teachers (on campus) and learners (at schools) to report and display data.
7) Analyse and interpret data	Collected data was analysed and interpreted by both pre-service teachers and learners on the report sheets provided.
8) Disseminate results	Results were disseminated: At the Teaching and Learning Symposium held at the NWU (Vaal Campus) by the pre-service teachers in October 2016. At schools by learners who displayed and interpreted data in scientific reports. By the researcher in this PhD thesis By the researcher in a report to the Gauteng Department of Education By the researcher in academic journals
9) Measures outcomes	The project scope, scale, activities and systems approach will be assessed by using the multi-scale framework provided by Newman <i>et al.</i> (2011:220).

Reflection of researcher: Step two reflected upon more information than step one. In this step, the researcher reflected on detail about the participants and the monitoring team. The collection of data and how results of the project were communicated were

revisited. In the next step the NWU (Vaal Campus) monitoring project is measured according to Newman *et al.*'s framework (2011:220).

Table 6.3: Step 3: The framework for multi-scale citizen science support as relevant to the NWU (Vaal Campus) water monitoring project (Newman *et al.*, 2011:220)

	Aspect		Weight of aspect (to the left or right)			
Scope	Purpose	Experience of participants	Perform services	X		Influence policy
	Domain	Communal (local campus and schools)	Focused	X		Broad
	Objective	Learn/change	Create/Act		X	Learn/Change
	Audience	Both	Local public	X	X	Scientists
	Accessibility	Both	Marginalised	X	X	Elite
	Data quality	High – validated by experts	Low		X	High
Scale	Spatial	Local	Local	X		Global
	Temporal	Short – 2 years	Short	x		Long
	Social	Both	Individual	X	X	Community
Activities	Research question	Bottom up	Bottom up	X		Top down
	Protocol	Both	Pre-existing	X	X	Newly created
	Recruitment	Targeted	Targeted	X		Non-targeted

	Training	Pragmatic	Pragmatic	X		Conceptual
	Volunteer Management	Intensive	Cursory		X	Intensive
	Data Management	Restricted	Loose		X	Restricted
	Data Dissemination	Both	Local	X	X	Global
	Program Evaluation	Both	Formative	X	X	Summative
System Approach	Level of Engagement	Collaborative	Category I		X	Category V
	Service Provided	Experimental	Production		X	Experimental
	Funding mode	Innovation	Maintenance		X	Innovation
	Developer Motivations	Design intents	User requirements		X	Design intents
	Research Framework	Research	Development	x	x	Research

Reflection by researcher: Step three provided a unique reflection on the monitoring project by positioning it according to four aspects on the priority or weight that the project displayed. In step four the NWU (Vaal) water monitoring project was compared to other citizen science projects in South Africa. The aim was to indicate the relation between the NWU (Vaal Campus) project and other citizen science projects.

Table 6.4: Step 4a: An inter-project dimension comparison of the position of the NWU (Vaal Campus) water monitor project with similar projects in South Africa

	Aspect	Different projects (<i>cf.</i> 2.2.1)			
	Criteria	NWU (Vaal Campus) project	Local – Mini SASS with school learners	National – ADU bird projects	Andrich study (2014) rainwater – Eastern Cape
	Purpose	Experience of participants	Biological data of river life	Biological data of indigenous birds	Physical data of rain water
	Domain	Community (local campus and schools)	Community rivers in KwaZulu Natal	Country wide	Regional – Eastern Cape
	Objective	Learn/change	Learn/change	Research	Research
	Audience	Both – public and scientific audience	Both – public and scientific audience	Both – public and scientific audience	Both – public and scientific audience
	Accessibility	Both – for marginalised and elite	Both – for marginalised and elite	Both – for marginalised and elite	Both – for marginalised and elite
	Data quality	High – validated by experts	Low – primary school learners	High – trained volunteers	High – trained volunteers
Scale	Spatial	Local	Local	National	Regional
	Temporal	Short – 2 years	Long	Long	Short
	Social	Both – for individuals and community	Both – for individuals and community	Both – for individuals and community	Both – for individuals and community
Activities	Research question	Bottom up	Top down	Top down	Top down
	Protocol	Both – used pre-existing and create new	Pre-existing	Pre-existing	Pre-existing

	Recruitment	Targeted	Targeted	Targeted	Targeted
	Training	Pragmatic	Conceptual	Conceptual	Conceptual
	Volunteer Management	Intensive	Cursory	Cursory	Intensive
	Data Management	Restricted	Loose	Loose	Restricted
	Data Dissemination	Both – local and global (Earth Echo see <i>cf.</i> 2.2.1)	Local	Both – local and global	Both – local and global
	Program Evaluation	Both formative – during program and summative – reflective like this comparison	Formative	Both	Both
System Approach	Level of Engagement	Collaborative	Supportive	Supportive	Supportive
	Service Provided	Experimental	Experimental	Experimental	Experimental
	Funding mode	Innovation	Innovative	Innovative	Innovative
	Developer Motivations	Design intents	User requirements	User requirements	User requirements
	Research Framework	Research and development	Development	Research	Research

Reflection by the researcher: This framework assured the researcher that the two years spent on the monitoring project was worth the time and energy because the project corresponds well on aspects proposed by other highly rated researchers and similar citizen science projects. In Step 4 b the position of the NWU (Vaal Campus) water monitoring project in three-dimensional relation to other South African projects was indicated.

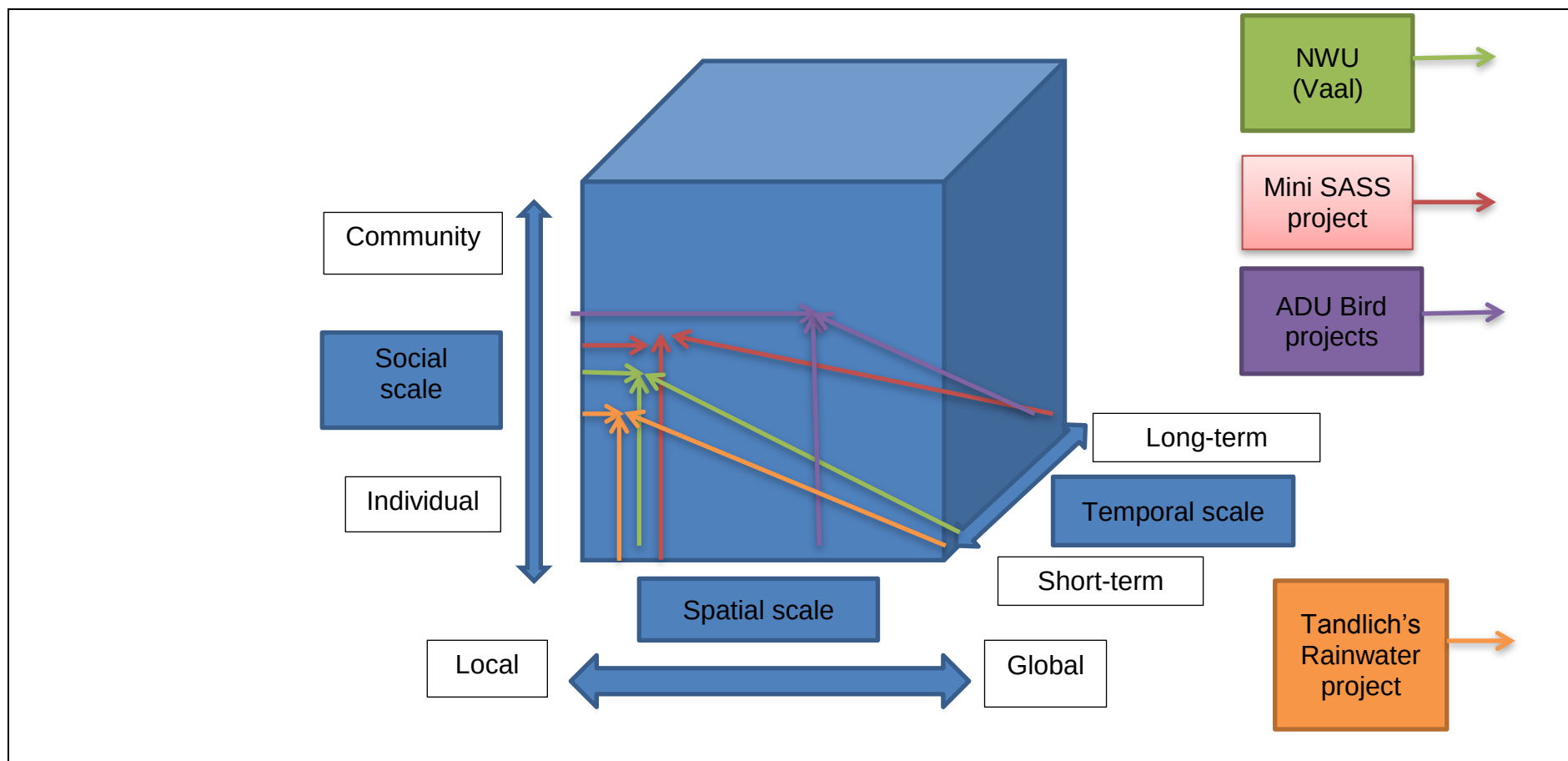


Figure 6.1: Step 4 b: The inter-project dimension of the water monitoring project (NWU Vaal Campus) in comparison to other citizen science projects in South Africa (Newman *et al.*, 2011:226)

Researcher's reflection: The inter-project dimension of the water monitoring project at the NWU (Vaal Campus) corresponds well with projects such as the Mini SASS and Tandlich's (2014) rain water project. The "sweet spot" is where the lines of the social, spatial and temporal scale of these three projects meet. Th "sweet spot" points to the potential for projects to share data and use similar data collection and data management systems.

In the next section the researcher creates various conceptual frameworks from the available frameworks and information.

Maxwell (2013:72) indicated that to be able to construct a framework, four sources are needed namely: experimental knowledge, theory, exploratory research and thought experiments. The researcher argues that these sources were present in this research study which enabled her to construct a framework. The researcher performed monitoring activities with pre-service teachers at the NWU (Vaal Campus) water storage resource and in community school classrooms, thereby gaining experimental knowledge. She used the frameworks or constructions devised by other researchers to develop an appropriate citizen science project; she performed a concurrent, embedded mixed method research design and allowed the research study to reveal rich, descriptive data. The initial project journal and reflective notes were useful in the write-up of the qualitative data and quantitative data enabled the researcher to gain a comprehensive picture of the monitoring project.

In step 5, the researcher proposed two possible prototypes for a citizen science framework. By reflecting on the monitoring project, she applied the knowledge gained on citizen science to design a framework. The suitability of the designed framework is assessed by indicating how well the information of the monitoring project is displayed by a prototype. The researcher motivates her choice of prototype after the assessment of both prototypes.

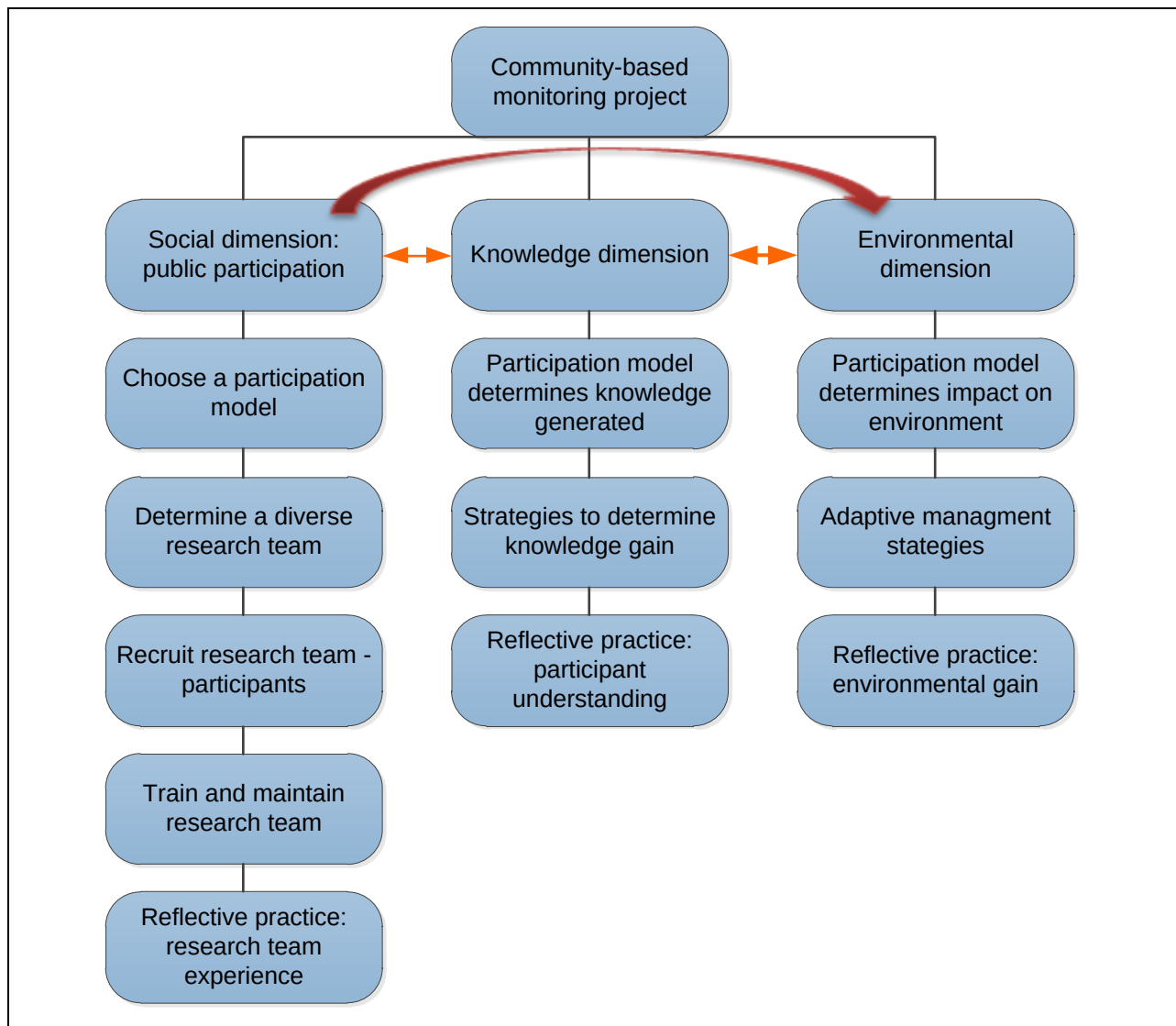


Figure 6.2: Step 5: Create a citizen science framework from available information: Prototype 1a: The dimension framework

Reflection by the researcher: Prototype 1a focused mainly on participants and adaptive management of the natural resource. Both social and knowledge dimensions are concerned with participant experience and understanding.

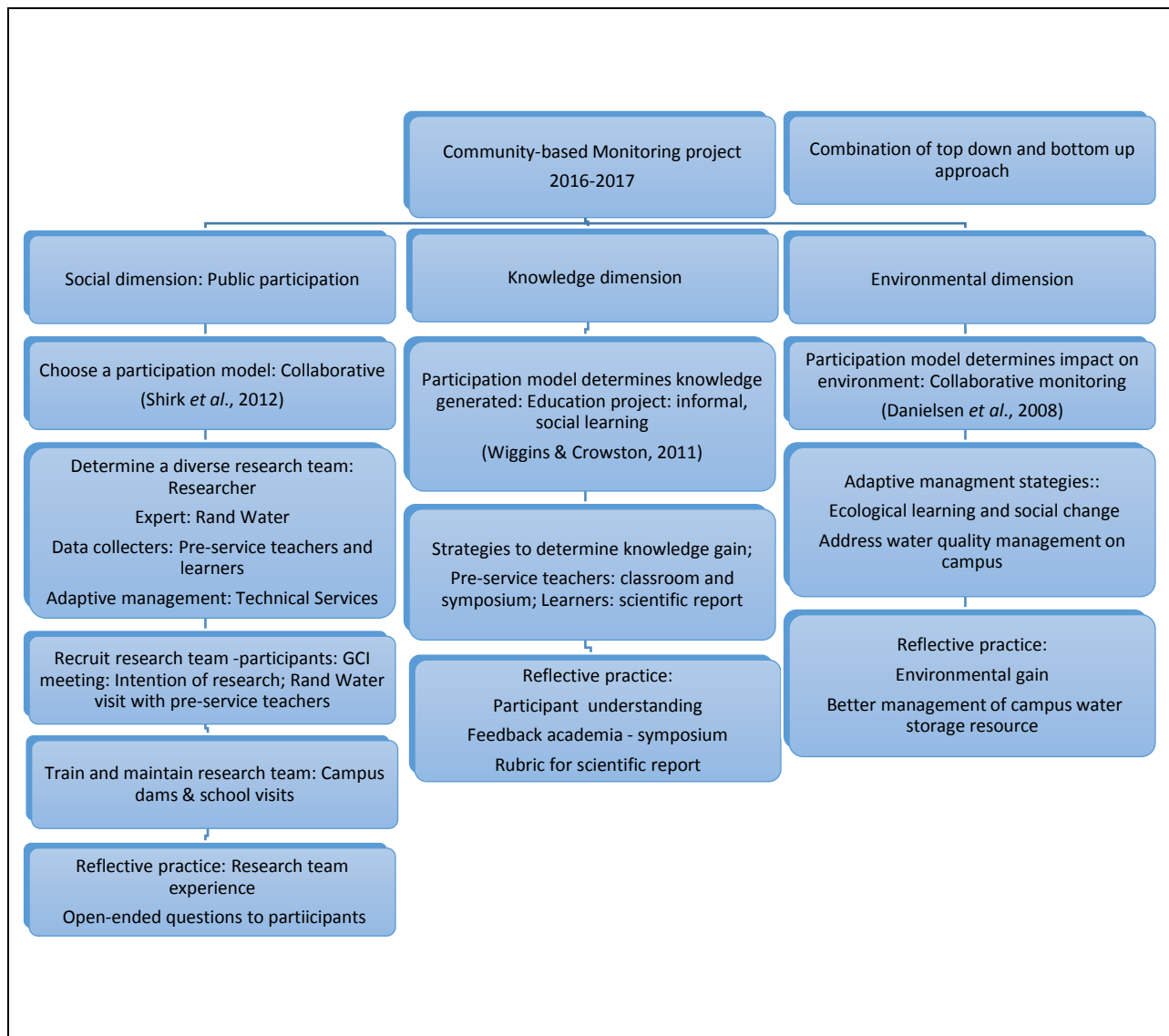


Figure 6.3: Step 6: Application Prototype 1b: Dimension framework with information on the NWU (Vaal Campus) monitoring project

Researcher's reflection: Addition of the NWU (Vaal Campus) water monitoring project information to prototype 1b indicated to the researcher the usability of the prototype. This prototype displays the role and experience of participants clearly.

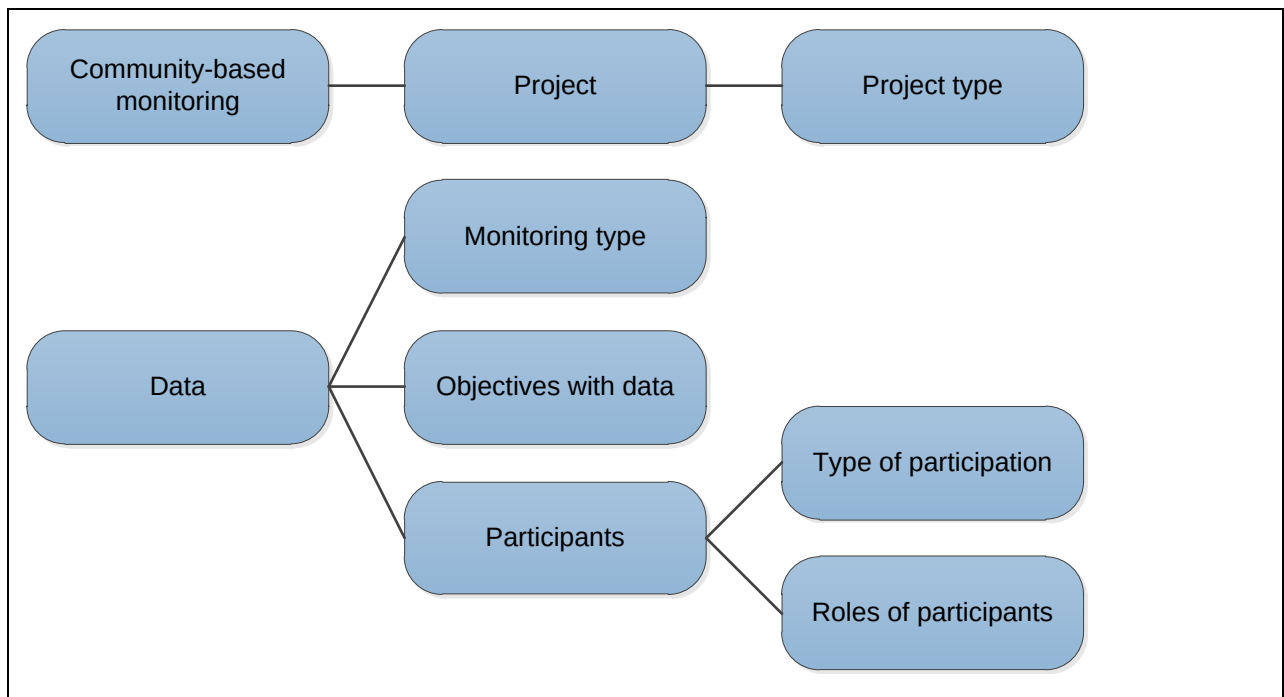


Figure 6.4: Step 5 (repeat): Create a citizen science framework from available information: Prototype 2a: The activity-based framework

Reflection by the researcher: The activity-based framework focuses on how data is collected and the type and role of participation. This simplistic framework makes it straightforward to implement, but it lacks the real-life relevance associated with monitoring projects.

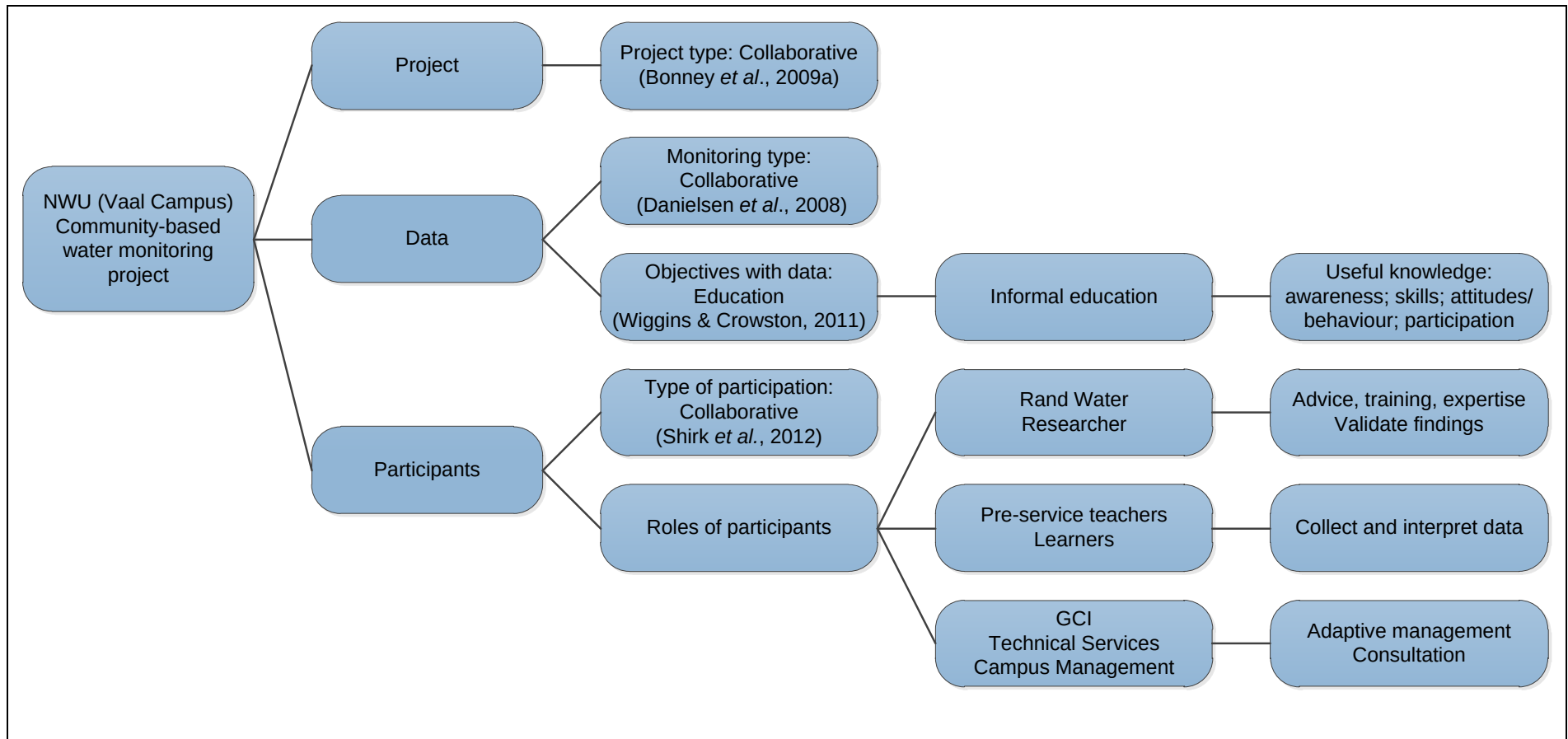


Figure 6.5: Step 6 (repeat): Application prototype 2b: Activity-based framework with information of the NWU (Vaal Campus) monitoring project

Researcher's reflection: Prototype 2 presents a more balanced display of currently available citizen science frameworks. The activity-based prototype provides a better view of the different components of the NWU (Vaal Campus) project.

6.3.1 Reflection on both prototype frameworks

As shown above both the prototype frameworks are based on current citizen science frameworks, most of which use the role of participants or the type of monitoring as the starting point. The researcher aimed to design a unique citizen science framework that has education as an objective and concurs with the view of Lewenstein (2016:4) who posits that running projects only for educational purposes does not lead to the long-term commitment and participation which infuses actual learning. To overcome this problem, the researcher focused on the context and real-life learning opportunities in designing the citizen science framework. The notion behind this focus is that educators or personnel of teaching and learning institutions should decide on a natural resource in their immediate environment (context) which can be monitored. The position of the NWU (Vaal Campus) and its multiple water storage resources on the campus provided a sound point of departure for community-based monitoring.

Other contextual factors which influenced the decision to conduct a water monitoring project were:

- The availability and support of Rand Water experts (*cf.* 4).
- The relatively low cost and simplicity of the Somerset Water Quality test kits (*cf.* 5).
- The ease with which monitoring could be done at an outside water storage resource and inside an ordinary classroom (*cf.* 5).
- The availability of water quality as a topic in the university B Ed programme and the school curriculum (*cf.* 2).
- The funding support from the NWU through the Scholarship of Teaching and Learning (SOTL) programme (*cf.* 1).

The researcher is therefore of opinion that for a citizen science framework to succeed at an education institution, whether a school or university campus, the starting point of the framework should relate to the context of the institution (what is available, what the objective is in addition to gaining knowledge/subject content) and the real-life relevance of the monitored indicator to the audience of the institution.

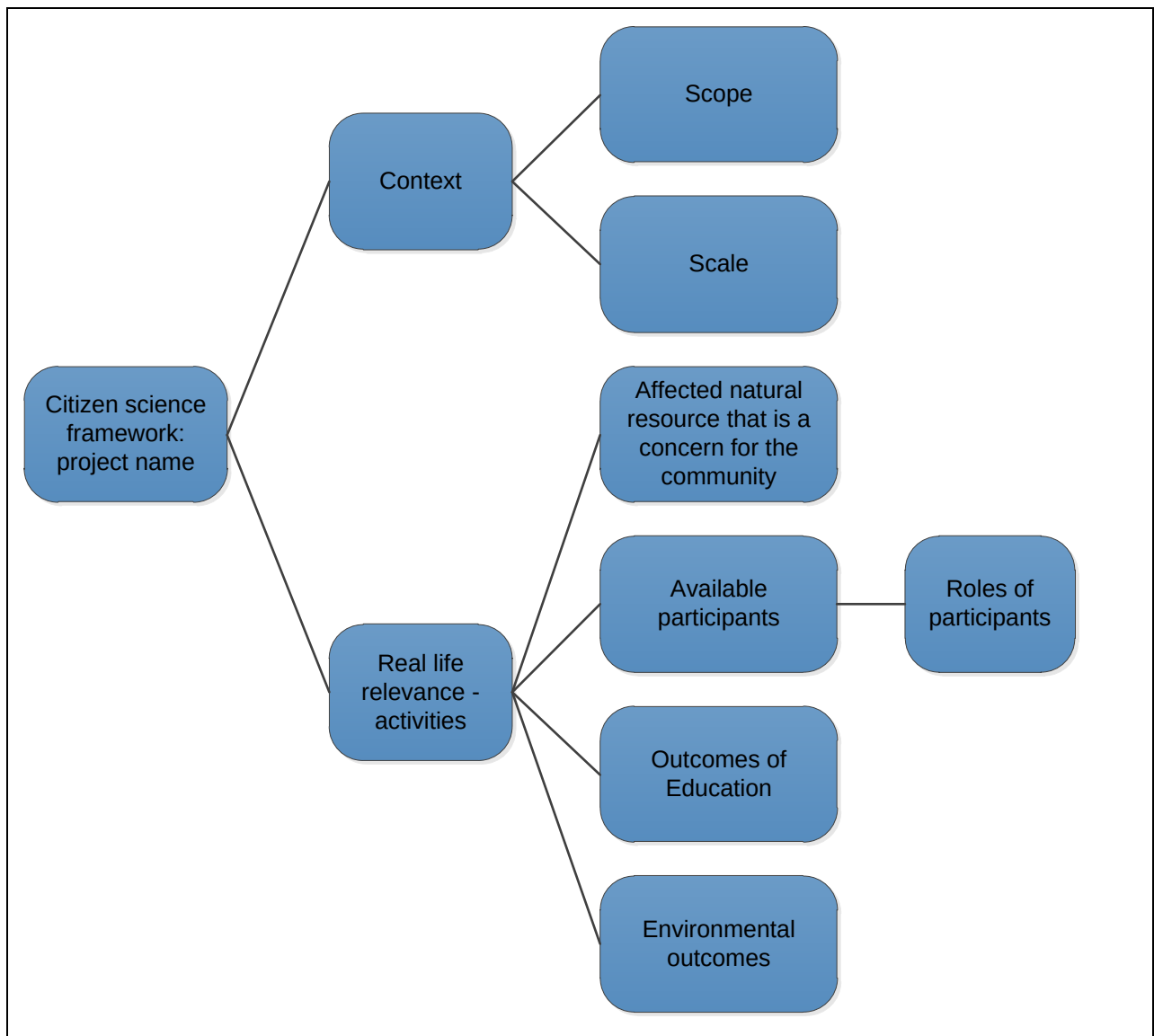


Figure 6.6: Step 7a: Create a citizen science framework from available information: The generic citizen science framework designed for the NWU (Vaal Campus) project indicating contextual and real-life relevance

Reflection by the researcher: This framework approaches a project from two relevant angles namely context and real-life relevance which allows for the role of participants, environmental education and communal concern.

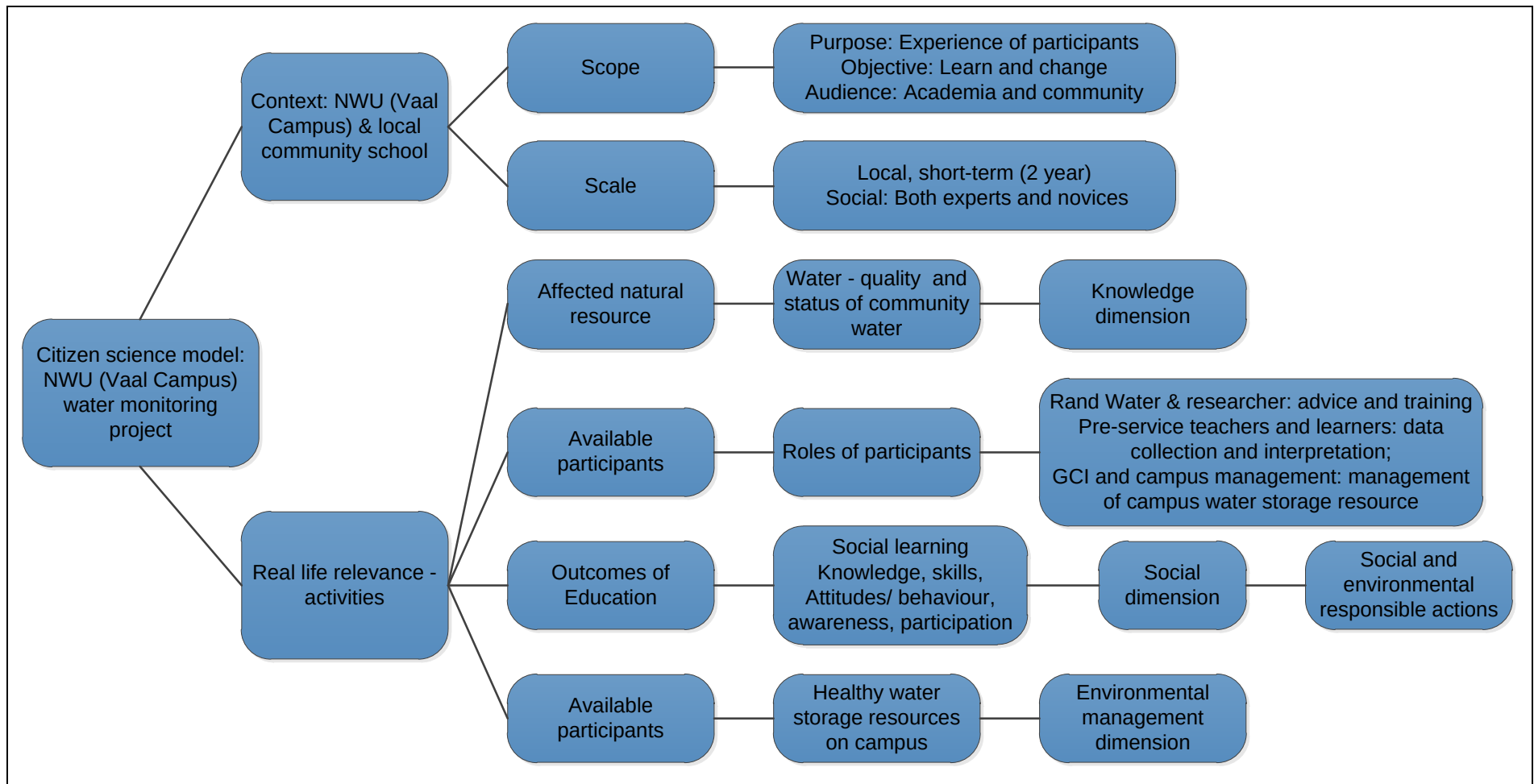


Figure 6.7: Step 7b: Apply information to the framework designed for the NWU (Vaal Campus) citizen science project: contextual and real life relevance

6.3.2 Reflection on the design of the NWU (Vaal) citizen science framework

The framework designed by the researcher provides a comprehensive view of all elements of the water monitoring project. The transdisciplinary nature of the research study is creatively displayed by incorporation of context, participants and adaptive management.

6.4 CHAPTER SUMMARY

The creation of a citizen science framework is a complex process. It is true to say that different researchers would quite possibly design different frameworks for the same research study based on their individual approach to the research topic under investigation. The researcher found that the steps followed in designing the framework served as a reflective practice in the development of the water monitoring project. Each step taken addresses different perspectives of the project. The scientific method proved to be a sound departure point and the transdisciplinary nature of the water monitoring project determined the dimensions of the framework. Many of the frameworks discussed in this chapter refer to similar properties, but researchers chose to name them differently.

The notion behind the design of this framework was to initiate a citizen science project with the focus on context and real-life relevance to the institution. Contextual issues that had to be considered included the availability of a natural resource and problems that could arise, the age of citizen scientists, the availability and cost of monitoring apparatus, available funding etc. In general, the researcher believes that this framework is applicable to most citizen science projects at educational institutions. The initiation of a citizen science project by incorporating context makes it widely applicable. It remains the choice of the individual researcher to add more or less information in allocated spaces and the researcher acknowledges that a simpler framework displaying the basic components of a citizen science project is more user friendly than an intricate framework which requires excessive information. The main idea behind this citizen science framework was to provide an overview or big picture of the water monitoring project at the NWU (Vaal Campus). The framework also indicates the outcomes of the project in a simplified way. The seven steps followed were crucial to provide a comprehensive picture of the project.

In the next chapter a citizen science systems framework incorporating education institutions and local communities, will be designed. The aim with this design is to indicate that the systems approach, as the final aspect in the framework of Newman *et al.* (2011), is also applicable to this NWU (Vaal) citizen science project.

CHAPTER 7

DESIGN OF A TIERED CITIZEN SCIENCE PROJECT SYSTEM

7.1 INTRODUCTION

Chapter 6 focused on the water monitoring project framework unique to and for use in the NWU (Vaal Campus) project. In this research a university (higher education institution), a university campus and community schools formed a educational system. To ensure success when implementing a citizen science project across different tiers of the educational system a great deal of planning and assessment is required. This chapter focuses on the design of an environmental monitoring and management system to include all three levels. To enable the researcher to construct a educational system she reflected on the water monitoring project which was conducted over a period of two years. By this time she had learnt from her own research and mistakes possibly made and had also presented her findings on two occasions (1 November 2016 and 1 February 2017) at colloquiums. Furthermore, the researcher had gained valuable input from academics and colleagues. In the view of the researcher the system proposed includes all the necessary components as part of the monitoring project, and indicates future components required when designing a system of this nature. The researcher first defined the required system elements. The system elements were then related to the scenario of the NWU (Vaal Campus) water monitoring project. Finally, a system that includes the technology and connections required for future use, is discussed.

7.2 SYSTEMS AND SYSTEM ELEMENTS

Tyler Miller and Spoolman (2012:48) indicate that a system is a set of components which function and interact in a regular way. Most systems have the following key components: inputs, flows (or throughputs) and outputs. According to Tyler Miller and Spoolman (2012:48) systems are affected by feedbacks which include any processes that increase (positive) or decrease (negative) change to a system. A feedback loop occurs in a system when an output (matter/information/energy) is fed back into the system as an input and thereby changes the system. Feedbacks can therefore change systems. A positive feedback loop causes a system to change further in the same direction. A good example of a positive feedback loop is the melting of polar ice due to climate change. If polar ice melts it accelerates in a positive feedback loop. The rising of

water levels in arctic areas making less land available land for polar animals, is supporting evidence of a positive feedback loop. Positive feedback loops can reach a tipping point which may destroy a system if irreversible change starts taking place (Tyler Miller & Spoolman, 2012:49). A negative or corrective feedback loop causes a system to change in the opposite direction from which it is moving. The re-use and recycling of materials can be regarded as a negative feedback loop. Recycling cool drink cans is a good example of a negative feedback loop where harmful environmental impact and pollution are minimised (Tyler Miller & Spoolman, 2012:50).

Systems are influenced by time. According to Tyler Miller and Spoolman (2012:50) the lack of response from systems is known as time delay. Time delay or lack of response allows for environmental problems to build slowly till they reach a threshold level or tipping point. A tipping point is therefore the point at which a fundamental shift in the behaviour of the system occurs (Tyler Miller & Spoolman, 2012:50). Synergy occurs in systems when two or more processes interact so that the combined effect is greater than the sum of the separate effects. Synergy can therefore increase risk or be helpful (Tyler Miller & Spoolman, 2012:51).

The researcher interprets the water monitoring project at the NWU (Vaal Campus) and the campus dams as being part of the greater Vaal Barrage and the Vaal River. In other words, the interconnected water storage resource forms part of the bigger ecological picture. Water from the Vaal River is used to supply the campus dams – and is therefore the input.

Pollution of the dams, whether it be dust pollution due to building activities on campus, or the nearby mining activity, or pollution from food containers, cans and bottles thrown into the water, can all be seen as part of the throughput. Throughput can also include corrective methods to increase the water quality of the dams by letting the pumps circulate water on a daily basis. The water from campus dams runs back to the Vaal River therefore there is an output from the campus dams, but an input into the Vaal River. It is important to accentuate the connection of the campus dam system with the bigger Vaal Barrage system. If polluted water from campus water storage resources is released into the Vaal River it increases the pollution of the river with an effect on water quality and ecological life. The adaptive management practices proposed in Chapter 5 help to increase a negative feedback loop, and therefore the water quality of campus water storage resource. The researcher acknowledges that in the past two years she

and the monitoring team often witnessed how time delays influenced the water quality of the campus dams. Pumps that do not run and circulate water, lead to lower levels of oxygen and higher accumulation of particles. This in turn meant that dead fish, crabs and insects were often found in dams. Another example of a possible tipping point was evident when the researcher informed campus management about the high levels of erosion beside the road between Dams 4 and 5 on the way to the administrative building (Building 25). Campus management consulted with an engineer in May 2016 who indicated that the road might collapse within four years due to erosion (MPA 6.1 (2016.05.23)). The researcher is of the opinion that the efforts of the water monitoring team and its involvement of the GCI and campus management in the project, helped to synergise efforts to mitigate potential disaster conditions and also contributed to ensuring the safety of the campus water storage resource. Ultimately the measure corresponds with the idea of synergy, where added attempts by different participant groups went some way to improving the water quality on campus.

Citizen science projects can be seen as systems which comprise interrelated functional components and activities (Prestopnik & Crowston, 2012). According to Prestopnik & Crowston (2012) each system is unique, but key requirements ensure successful citizen science projects, notably high levels of participation with rapid data collection, better public exposure, increased project resource and enhanced scientific goals.

Prestopnik & Crowston (2012) focus on the use of technology in citizen science projects and accentuate the importance of organisational, social and human elements. These three elements are known as the *citizen science system assemblage* (Prestopnik & Crowston, 2012) and it is therefore important to define the key organisational, social and human elements as related to the water project to assist in systems design. The work of Sharp (2002:128-145) sheds valuable light on this issue.

7.2.1 Organisational element

Sharp (2002:132-137) reveals the following characteristics of universities as organisations:

Universities are multi-structured, *complex organisations* without a single control centre. Within the university as an organisation there are various subcultures regarding decision-making, time and priority management (Sharp, 2002:132). Universities engage

in excessive growth as far as student numbers, workload of personnel, the use of water and energy and the generation of waste are concerned (Sharp, 2002:133).

The university community, like people everywhere else in society, have a number of *mental frameworks* which inform their behaviour towards the environment. These mental frameworks include unspoken assumptions, for example, that individuals are powerless to effect change within such a large system. In order to address environmental imperatives there is a need to replace these unspoken mental frameworks with truths, for example via individuals who can create systemic change within large and complex environments (Sharp, 2002:134).

Wide-scale participation in environmental imperatives at universities is challenged by *absurd consensus*. Absurd consensus allows people to be manipulated or controlled to achieve short-term peace of mind. An example of absurd consensus is the idea that a single person who saves electricity or water has not made any impact on the total saving of energy or water. People are conditioned to accept the behaviour of the group. For example, some individuals argue that leaving lights on or letting tap water run while brushing one's teeth is acceptable because they believe they cannot contribute to the saving of electricity or water (Sharp, 2002:135).

Universities are among the oldest formal institutional systems in the world. The *image of rationality* is a cultural assumption which persists in the design of processes and structures of universities. Sharp (2002:135) indicates that the image of rationality is a matter of system patterns which are repeatedly used within the organisation becoming a *system archetype*. Sharp (2002:136) maintains that university staff are under stress in order to sustain the myth of organisational rationality while facing organisational irrationality. The image of rationality prevents institutions from analysing and introducing reform by inhibiting systemic transformation (Sharp, 2002:136).

The researcher acknowledges that the characteristics as described by Sharp (2002:132-137) were identified during this research study. The complexity of the NWU as an educational organisation is indicated in *The Government Gazette* of 2 February 2009 and is discussed below.

The North-West University (NWU) comprises three campuses, located at Vanderbijlpark, Mahikeng and Potchefstroom. The hub of NWU's organisation is the

Institutional Office, located in Potchefstroom, which is responsible for strategic planning, policy development, allocation of resources to the campuses, designing the institutional process, branding and positioning as well as assuring overall quality. The Institutional Office is therefore the formal seat of governance which interacts through formal meetings with the NWU (Vaal Campus) management. The Institutional Office is directly responsible for land use issues and the construction of buildings. *The Government Gazette* (2009) indicates that this particular institutional framework is costly and leads to the duplication of structures and services. According to the *Government Gazette* (2009) communication and decision-making between campuses are hindered and the self-sufficiency of campuses is limited due to separate management structures.

In 2015 the vice chancellor of the NWU, Prof Dan Kgwadi began a restructuring process to align activities on campuses (NWU News, 2016). At the time of the implementation and reporting on the water monitoring project the NWU was divided into four components, namely three campuses (Potchefstroom, Mahikeng, Vanderbijlpark) and an institutional (management) office in Potchefstroom. Draft legislation submitted to the national Department of Higher Education towards the end of 2016, with a view to approval by the legislative assembly in 2017, made provision for the integration of all NWU entities into a single entity. The outcome of the restructuring process was accepted and published on 24 March 2017 in the *Government Gazette*.

In order to design a system on three levels, the researcher acknowledges the management of the NWU's Vaal Campus as the organisational element in the second level. The NWU (Vaal Campus) is directly in charge of technical services regarding environmental matters on its campus. The two NWU (Vaal Campus) collaborate in formal meetings which include GCI meetings. The Green Campus Initiative (GCI) of the NWU provides a platform for various role players of the university to participate in environmental matters. The GCI embraces emerging opportunities to address Sharp's *absurd consensus* and image of rationality at university and on campus level (Sharp, 2002:136). Diverse groups of participants from faculty, administration and student organisations provide for a broad spectrum of participation. Sharp (2002:137) argues that institutional change can occur when such groups have a shared vision and alignment in respect of taking action. The researcher is aware that the GCI plays an important role in this research because GCI meetings provided opportunities to collaborate with campus and technical management through formal meetings. The GCI

meetings also helped to inform the rest of the Vaal Campus community about the progress of the water monitoring project and the difficulties encountered.

The final organisational element in the system is the Department of Education and school management. The researcher applied for consent to perform the water monitoring project with the Gauteng Department of Education (GDE) early in 2015 (MPA 10 (2015)). She decided to perform the water monitoring only in schools of the D 7 and D 8 districts of the GDE because these schools are near the NWU (Vaal Campus) and are easily accessible to the pre-service teachers. The researcher phoned and e-mailed the Physical Science subject advisors at the schools to inform them about the project. She then visited the schools and informed the head master and Physical Science teachers responsible for teaching the subject to Grade 10, about the water monitoring project. She later revisited schools to deliver consent forms for parents and assent forms for learners. Monitoring was carried out at times that suited the schools. One of the schools indicated that it was not interested in participating in the project, which decision the researcher respected.

Dealing with the schools as an organisational element in the research project was the most challenging part of the whole project. Initially the researcher phoned schools with requests, but because of a poor/lack of response she revisited schools to finalise arrangements. The monitoring at schools was enjoyable for the researcher, pre-service teachers and learners, all of whom were afforded excellent opportunities to share scientific knowledge about water in an informal and spontaneous manner. This indicated to the researcher that although it was initially difficult to incorporate community schools in the water monitoring project, the collaboration between a university, the campus community and local schools, was fruitful. By crossing conservative boundaries, the so-called traditional image of rationality, the researcher succeeded in making a purposeful effort to reform systematic thinking on the purpose of a university campus. The pre-service teachers' views of their purpose as university students reached a new level of rationality about their role in the community.

This brings us to the second element, namely the university society or social element.

7.2.2 Social element

In the water monitoring system the following groups present the social element: the faculty and administrative staff at university and at university campus level; the students at campus level; and the learners at local school level.

Faculty members are often, due to academic demands, not involved in the management of campus activities. A focus on the campus and its environment is seen as a distraction from teaching and research. A few faculty members commit to voluntary public service, although community service is in fact a key demand to which all South African universities have agreed. (Sharp, 2002:139). Administrative staff is usually seen as having no direct influence on the core mission of universities. Sharp (2002:140) reports that the administration is the closest to the pressure point of the “image of reality” and can be valuable to support environmental imperatives. The GCI meetings provided a safe, comfortable environment where the monitoring team could share their experiences and discuss their findings (*cf.* 4.2.3). Except for the GCI meetings where administrative personnel are poorly represented, the total lack of awareness and interest of other students, administrative and academic personnel certainly dampened the positive experience of the monitoring project for the researcher and pre-service teachers (*cf.* 4.2.3 & 4.2.4). The pre-service teachers were concerned that their efforts went virtually unnoticed. The researcher therefore argues that contrary to Sharp’s observation, the administration of the NWU (Vaal Campus) did not support environmental imperatives.

In the initial stages of the water monitoring project the pre-service teachers had no resources, a very limited understanding of water monitoring and no access at all to influencing the decision-making processes on the Vaal campus. Student engagement in environmental matters on university campuses is a short-term process and realistically, students are only committed to the university for the duration of their studies (Sharp, 2002:137). The water monitoring project provided an opportunity to engage pre-service teachers in an activity in which they realised their potential to influence systemic change. Apart from learning more about water quality, these pre-service teachers began to understand campus organisation. They were also allowed to voice their findings at GCI meetings and at a teaching symposium in October 2016 (MPA 7.1 (2015.10.26)). The water monitoring project provided a shared vision on water quality and created opportunities for training and dialogue about water. By working in groups

the pre-service teachers learned about team building and how to master their personal knowledge about water (Sharp, 2002:138).

The water monitoring project was performed **once** at schools. The learners met with the researcher and pre-service teachers for about an hour and a half in classes. During these meetings the learners were engaged in practical experiments with their own water samples. Learners indicated in their responses that they enjoyed the monitoring. The learning opportunity was informal and learners asked spontaneous questions. The researcher, in the process of personal observation, came to the conclusion that although the exposure of learners in the water quality project was short in duration, it provided a lasting impression for those who participated. Again Sharp's opinion (2002:137) that learners are only committed to environmental action for the duration of their studies is disputed.

Interaction between different groups of participants in the water monitoring project is also seen as part of the initiative's social component. Discussions in GCI meetings between the researcher, pre-service teachers and the technical and management staff, helped to cohere or divert the experience of the project. Interaction on the campus between the pre-service teachers and other students, many of whom take no responsibility for the environment, was a social element that created a negative impression. The pre-service teachers wanted other students to acknowledge their efforts to contribute to water quality. Interaction between pre-service teachers and school learners, who enjoyed the monitoring activities, left a positive impression, one which served to enhance environmental awareness and add value to the social element of the project. The responses of learners provided the pre-service teachers with acknowledgement of their gained knowledge and practical skill on water quality measurements. The human element is discussed below.

7.2.3 Human element

Sharp (2002:135) claims that understanding the human element indicates that humans are conditioned by an *absurd consensus* which allows for a belief that individual behaviour cannot impact the environment with the same effect as that of a group. University campuses as a *system archetype* traditionally resist changed behaviour and persist in organisational system patterns.

In the water monitoring project the researcher regarded the human element at university level as part of the ethical clearance she needed to conduct perform this research project. To ensure ethical clearance from the university proved a lengthy process. The researcher attended two compulsory meetings, namely an Info Ed meeting on the global electronic ethical platform; and a NWU (Vaal) research ethics meeting. She then completed her research proposal, gained approval of her research proposal from the faculty and then submitted it (with other necessary information) on Info Ed. The ethics committee duly granted its consent for the research to continue (MPA 14.5 & 14.6 (2016.06.08, 24)).

A human element component which influences the outcome of citizen science projects such as the water monitoring project, is something of a conflict of interests. During 2015 and 2016 most university campuses in South Africa were negatively affected by the Fees must Fall protests which put government under severe pressure to not raise university fees, and later to consider scrapping university fees (Hanly, 2015). Some of the students' demands were met at the end of 2015 and there was no increase of fees for 2016. By September 2016 the minister of Higher Education, Dr Blade Nzimande, indicated that the decision on raising fees was up to the management of each university. The provision was that the increase should not exceed 8%. The students responded by resuming their protest action which then turned violent, with significant damage to public property. This turn of events placed a high demand on available funds at universities.

When comparing environmental demands to those made by students, the environment was certainly the loser (Mosiuoa, 2016). University campuses encourage electricity savings when supporting a global initiative like Earth Hour, but at NWU Vaal water quality is neglected when electricity is saved by reducing pump cycles and the water in campus dams stagnates (Muller, 2014:71; *cf.* 5.3.2). University campuses operate in the same manner as businesses. The Fees must Fall campaign left universities with a financial deficit and with more students to cater for; small increases in fees by no means covered the shortfall (Ngoepe, 2016). A high drop-out rate of first year students and the unpreparedness of students to enter higher education, had a negative impact on available funding for environmental matters. The concern is now the provision of academic bridging programmes to under privileged students (Essop, 2016)

At the campus level the researcher regards the human element as the effort to obtain funding for the water monitoring project. She applied for Scholarship of Teaching and Learning (SOTL) funding which is administrated by the NWU (Vaal) Academic Development and Support (ADS). It was agreed that the researcher could purchase the necessary water quality monitoring kits from a specialised commercial provider. Funding is often seen as a stumbling block in citizen science projects.

On the third level of the system the researcher gained consent from the Gauteng Department of Education (GDE) and was granted permission (with a time limit) to conduct research at local schools. The researcher agreed to inform the GDE on the progress of the project and compile a report on the research findings. At these schools, the principals and heads of department (HOD) of Physical Science as well as the responsible teacher for Grade 10 Physical Science and learners comprised the human element.

The researcher acknowledges that the three elements of organisation, social and human, are overlapping concepts, linked and often represented in more than one element and level.

In the next section, the focus falls on the citizen science processes that are to be incorporated into the system.

7.3 COMPONENTS REQUIRED IN FUTURE CITIZEN SCIENCE PROJECT SYSTEMS

Inclusion of diverse participants is essential for citizen science projects (Newman, Wiggins, Crall, Graham, Newman & Crowston 2012:301-303). Sensitivity to social, cultural, economic and political factors determines the success of projects that cross boundaries. The involvement of local or indigenous knowledge is important (Ballard *et al.*, 2008:188) and was addressed by the researcher when identity and culture of participants were linked to social learning (*cf.* 2.3.2.7).

The enjoyment and motivation of volunteers are crucial to the success of citizen science projects (Newman *et al.*, 2012:301). Intrinsic motivation is gained by enjoyment during participation and collaborative group work.

The adoption of new technologies and the sharing of geographic locations enhances citizen science projects. These new technologies provide, for example, participants with the ability to collect data via mobile cellular phones and send the data to collection centres for processing. In future, projects are sure to become unique assemblages of yet-to-be-determined technology, better informed people and new socio-cultural situations (Cuff, Hansen, & Kang, 2008:33).

Networking and open science will encourage participation of younger and ethnically diverse participants. Continental-scale, mobile and web-based activities will reach broader audiences. For citizen science projects to maintain momentum the inclusion of new technology such as “apps” and smart phones, will be a necessity (Cuff *et al.*, 2008:34). Newman *et al.* (2012:302) foresee that the concept of citizen science could become blurred because data collection can even include games and be linked to social interaction as an integrated part of daily life.

Citizen science needs to emerge as an important form of volunteer service including local, regional, national and international organisations as well as professional associations which support practitioners, scientists and other stakeholders (Newman *et al.*, 2012:303).

Citizen science projects rely on standardised field protocols to collect and visualise data and address local and societal issues and challenges. It is feasible that wireless sensor networks may connect the laboratory to the natural environment, allowing ordinary citizens to work in partnership with professional scientists (Newman *et al.*, 2012:303).

The researcher acknowledges that the field of citizen science is an ever-emerging concept. Newman *et al.* (2012:303) claim that the institutional and organisational base of citizen science will inevitably broaden from local projects to national or international projects. The inclusion of citizen science initiatives by institutions as volunteer service needs to be researched. Partnership between diverse groups, academia and ordinary citizens will thereby promote social learning. It is clear that social learning incorporates far more than scientific knowledge, but includes sensitivity for cultural differences and indigenous knowledge.

In the next section, the system in relation to transdisciplinary research is discussed.

7.4 TRANSDISCIPLINARY RESEARCH AND A SYSTEM REPRESENTING A CITIZEN SCIENCE PROJECT

The water monitoring project adhered to three of the four core foci of transdisciplinary research, namely (a) it focused on the life-world issue of water quality; (b) the knowledge fields of environmental education, physical science (chemistry) and adaptive management were successfully merged; and (c) it incorporated participants with heterogeneous knowledge and skill backgrounds. The construction of a system to guide a citizen science project will enable the researcher to adhere to the final focus, namely to unite knowledge beyond the confines of a single discipline (Hirsch Hadorn *et al.*, 2008:29) (*cf.* 3.3.2.1).

The construction of the tiered system is an inter-institutional approach as proposed by Bergmann *et al.* (2012:117) (*cf.* 3.3.2.1) involving the collaboration of different groups of participants (such as GCI members, pre-service teachers, learners and Rand Water experts) as sub-projects contributing to the overall water monitoring project.

The water monitoring project adhered to the three phases required in transdisciplinary research as outlined by Hirsch Hadorn *et al.* (2008:36) (*cf.* 3.3.2.1). Firstly, the problem of water quality at participating educational institutions was identified and placed in context (*cf.* 1.3). Then followed the formulation of research questions and research objectives to address the diverse aspects of water quality as relevant; and the provision of a comprehensive overview to direct the research and complete the second phase (*cf.* 1.4). Descriptive, qualitative data were gleaned which displayed the experience of the heterogeneous groups who participated in the monitoring project (*cf.* 4.2 & 4.3) and semiotic, quantitative data indicated the current water quality of campus dams and river (*cf.* 5.3.2 & 5.3.2). Finally adaptive management measures were proposed (*cf.* 5.3.3), bringing results to fruition and completing the final phase.

The construction of a system to indicate the components of the water monitoring project and a more generic tiered system to give an overview of the project and provide guidance for future citizen science projects, were part of the final phase to bring results to fruition. This means that the research study may well contribute to future citizen science projects at educational institutions by the application of the generic system as proposed in this chapter (Fig. 7.2).

In the next section the construction of a three-tiered water monitoring system applicable to the project conducted at the NWU (Vaal Campus) is discussed.

7.5 A THREE-TIERED WATER MONITORING SYSTEM PRESENTING RELEVANT COMPONENTS OF THE NWU (VAAL CAMPUS) WATER MONITORING PROJECT

The researcher acknowledges that the construction of a system on three levels is more advanced than the construction of a general framework for the water monitoring project. The researcher opted to construct a three-tiered system specifically for the NWU (Vaal Campus) water monitoring project. This system focused on the system components of a natural resource (water) and the system elements linked to organisation, social and human elements. The link between the system components and system elements is best explained by the concept of social-ecological systems. A social-ecological system is a dynamic, integrated living system consisting of agents (human and other), their actions and behavioural patterns interacting in a physical environment (chemicals, water and energy) (Du Plessis (2008:65-67). The researcher aims to link the three system elements with social learning.

The researcher then constructed a second, more generic three-tiered system incorporating the future proposals as discussed by Newman *et al.* (2012). The construction of the second system helped the researcher to identify possible limitations as well as suitable components in her unique system for the NWU's Vaal Campus. This construction is therefore likely to be a reflective overview on citizen science projects.

In a socio-ecological system, the three components of **input**, **process** and **output** are interlinked. The ecological system is indicated in Figure 7.1 in green. The **input** of the ecological system and the natural resource, is water in the water storage dams on the NWU (Vaal Campus) (Dams 1-5) which are filled with water from the Vaal River. If the water of the Vaal River is contaminated with acid mine drainage or sewage, the water in the campus dams is also polluted.

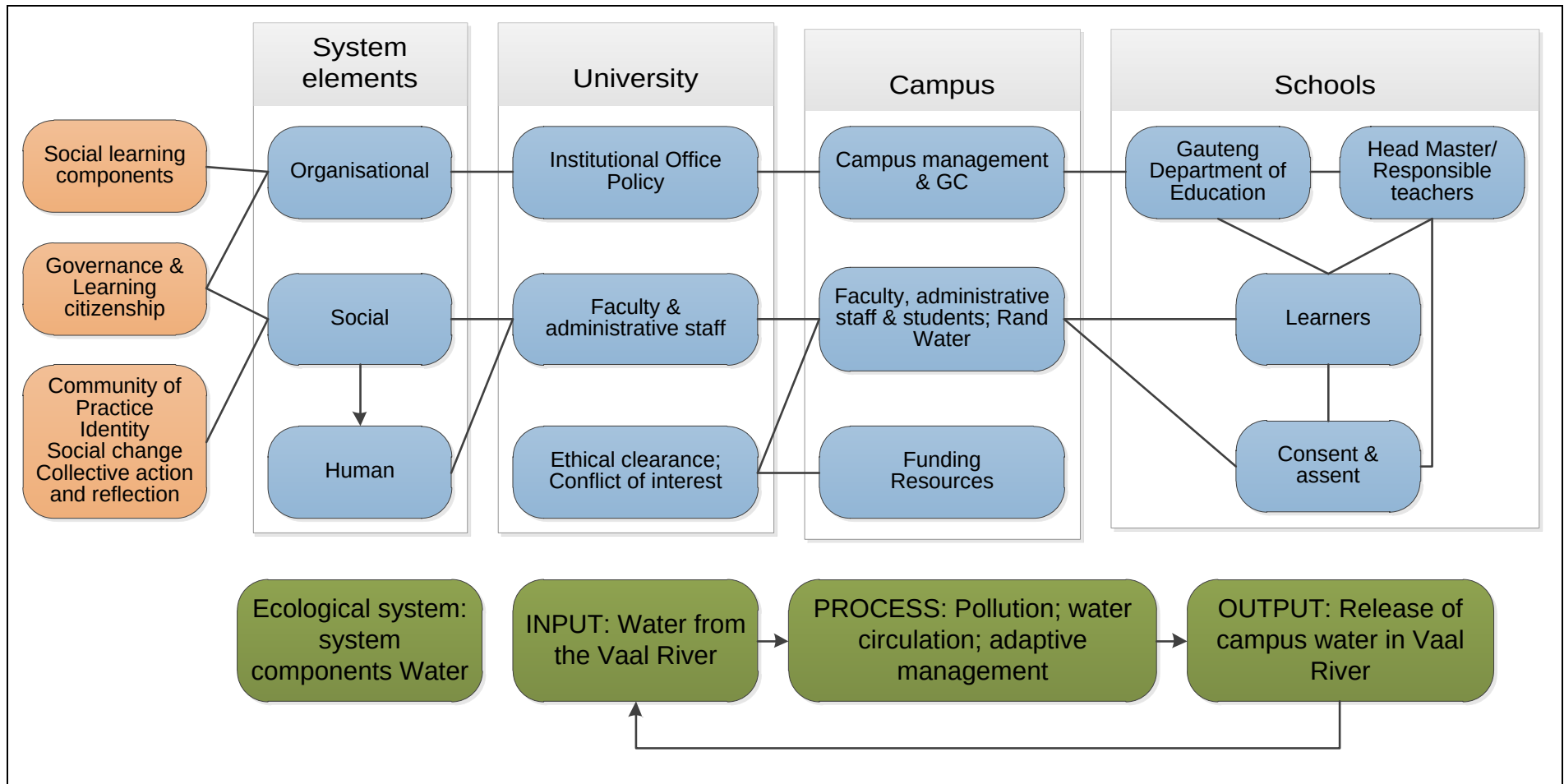


Figure 7.1: A three-tiered social-ecological system framework for the water monitoring project at NWU (Vaal)

In the next section, the researcher elaborates on the proposed three system components.

The **process** of the ecological system is the piping of water from the inlet, the Vaal River, to the campus dams. In the water pipes it is possible that physical or chemical changes may take place. If pipes corrode, the water reacts with metal to produce rust. If a pipe bursts, a water leakage occurs and water is wasted. This impacts the output because less water will be pumped back into the Vaal River. The experts from Rand Water, who visited the campus in 2015, stressed the importance of the connectedness between the campus water storage resource and the Vaal River (*cf.* 5.2). Polluted water from the campus that is pumped back into the river adds to the pollution of the Vaal River.

The system elements as proposed by Sharp (2002:128-145) are presented in blue as three system elements, namely **organisational**, **social** and **human** (Fig. 7.1). The three-tiered approach provided for a three-tiered educational system, namely the North-West University, the Vaal Campus and local, community schools. Each of the levels is indicated in its own column. The NWU (via the Institutional Office in Potchefstroom), manages the university's three campuses (Potchefstroom, Vanderbijlpark and Mahikeng). On the Vaal Campus, campus management with a campus rector as head, manages the campus. Schools are managed in Gauteng province by the Gauteng Department of Education (GDE). School principals, as representatives and employees of the GDE, manage local community schools.

The water monitoring project at NWU (Vaal Campus) linked the NWU, as an institution of higher education, with the GDE and community schools. This was not a unique collaboration between a university and schools because many higher education research projects include schools. The researcher is of the opinion that this project linked different educational institutions in a successful, informal learning opportunity.

The social element of the water monitoring project is emphasised. The social element refers to ways in which communication or discussions were encouraged between different groups of participants in this study. Formal communication consisted of an ethical application and a written proposal; a request for a letter of consent from the campus rector; and written consent after formal application to the GDE to initiate the project. The researcher communicated in person with school principals and responsible

teachers at participating schools by visiting them and supplying them with the written consent received from both the university and the GDE. The researcher took the pre-service teachers to Rand Water to discuss the possibility of water quality monitoring project with the experts there. Rand Water employees were on occasion also personally in attendance on campus while the water samples were taken and tests conducted. The pre-service teachers were given open-ended questionnaires to prepare them for the project and what it entailed. After monitoring activities she provided them with open-ended questionnaires to reflect upon their participation and how they experienced the project. The researcher often used a few minutes at the end of formal lectures to discuss the project and the experience with the pre-service teachers. Learners in schools were provided with scientific report forms to record the data on their water samples. Learners had the opportunity to reflect on the monitoring activities in class by writing their responses to open-ended questions. Findings of the monitoring on campus were discussed in GCI meetings. Both the researcher and the pre-service teachers gained additional knowledge on water monitoring by attending various symposia (MPA 11.1–11.5, (2015-2016)). The researcher is of the opinion that the wide variety of communication methods enhanced the social element in the system. Evidence from discussions and findings proved the success of the monitoring project (*cf.* 4.2 & 4.3).

The human element, as the final system element, was the most difficult to control during the monitoring project. The formal application for ethical clearance from the university required resilience on the side of the researcher. The GDE provided its consent for the research study, but to gain assent from learners and consent from parents at schools the researcher had to make more than one visit to the schools. The support of the NWU with SOTL funds helped the researcher to buy the necessary apparatus to complete the project. However, conflict of interest, especially with the water quality management proposals made on the management of campus dams, indicated to the researcher and her team that environmental concerns often play second fiddle to other demands.

The researcher is of opinion that none of the three system elements: organisation, social and human elements, or, for that matter, the ecological elements such as water/soil/air exist in isolation. A change in one of these elements will always spark a reaction or a change in another element. A good example is the shortage of water experienced at the Potchefstroom Campus in 2013 (Beisheim, 2013) as discussed below.

The water shortage incident was initiated when the Tlokwe Municipality neglected to maintain the water pump system to the town of Potchefstroom. After four days of water shortages, the NWU (Potchefstroom Campus) had to send students home. In this way the municipality was able to fill the water reservoirs without the extra demand (Beisheim, 2013). During this crisis, students in the residences swam in the campus swimming pool and had to flush toilets using buckets (Roets, 2013). In this instance an environmental change sparked effects on social, organisational and human elements. Organisational management of the NWU (Potchefstroom Campus) intervened to assist the municipality of Tlokwe by not allowing formal lectures for a day, and sending the students for a weekend off campus to their parent's homes. The human element was characterised by the arrangements by the NWU (Potchefstroom Campus) and Tlokwe Municipality to issue and implement water restriction measures and health and safety warnings to the campus and the Potchefstroom community at large. The social element was seen in the reaction of the students, who made the best of a possibly explosive situation by using the opportunity to connect socially at the campus swimming pool. In reality the "fun" of coping with the water restrictions on the Potchefstroom Campus could not last forever. The intervention of NWU (Potchefstroom campus) management, the organisational element, helped to solve a situation that might have led to conflict.

The different dimensions of the social element displayed in the research study correspond with findings in the literature review. The researcher notes that the different groups of participants involved on different levels of the water monitoring project formed a *community of practice* (COP). This shared social partnership which was formed corresponds to the different disciplines indicated by Wenger (1998a) (*cf.* 2.3.2.1). The *discipline of domain* is indicated by the concern for water quality. The *discipline of community* was displayed in the trust between different groups of participants while they were involved in the water monitoring project. The monitoring on campus and in community schools indicated that water quality measurements can indeed be presented as a visible curriculum and therefore displayed the *discipline of practice*. The *discipline of convening* was evident in the persistence of participants gain funding and complete the planned project over two years. Finally, the *social discipline* was displayed by all participants who indicated awareness of water as a scarce and vital resource, worthy of conserving and managing for future safe use (*cf.* 2.3.2.1).

The shared social partnership between the different groups on a multi-scale level contributed to the formation of a unique *identity* (Wenger, 1998a) (*cf.* 2.3.2.1). An identity is allocated to a group who has shared a successful and enjoyable experience. The water monitoring project at the NWU (Vaal Campus) was unique regarding the inclusion of a certain group of pre-service teachers and GCI team in a specific timeframe. The awareness by participants that this exact scenario with the same participating group will never be repeated and is thus part of the social element.

The water monitoring project also provided a *learning citizenship* opportunity to both pre-service teachers and learners (Wenger, 1998a) (*cf.* 2.3.2.1). Learning citizenship promoted social capital and prepared the pre-service teachers to contribute to their communities by providing information on water quality. This ability links well with the organisational element where pre-service teachers and learners can assist with proposals and decision making in their communities about water and water quality.

The water monitoring project displayed evidence of the social element of *collective action and reflection* (Keen *et al.*, 2005) (*cf.* 2.3.2.1). Pre-service teachers and learners learnt from one another as well as from other participants. They were able to reflect on their participation in the project by indicating their views when answering the open-ended questions.

Pahl-Wostl *et al.* (2007) (*cf.* 2.3.2.1) indicate that *governance* comprises the linked organisational, cultural and social-ecological system elements of social learning. In the meetings of the GCI the of researcher, pre-service teachers, GCI members, campus management and Rand Water were part of a unique group of participants acting and collaborating in an organisational role.

Reed *et al.* (2010) (*cf.* 2.3.2.1) claims that individuals who participate in social learning are able to create *social change* beyond the individual level in a wider, social context. The researcher feels that the pre-service teachers especially, with the knowledge and skill acquired will be able to change levels of understanding and provide others aid with water quality knowledge once they start teaching and form part of a wider audience. Related concepts of social learning are linked to the three system elements and are indicated in orange.

In the next section, the researcher elaborates on the proposed three-tiered system for citizen science projects by providing some suggestions to make the tiered system relevant for future use in citizen science projects.

7.6 REFLECTION ON THE THREE-TIERED SYSTEM AND THE DESIGN OF A SYSTEM FOR USE IN FUTURE CITIZEN SCIENCE PROJECTS

Reflection on the organisational element of the three-tiered system revealed that the role of Rand Water, as expert group, must be included in the organisational element. The three educational levels of the university, campus and schools can benefit from an added fourth level, namely that of involvement of expert groups or inclusion of international organisations to support a citizen science project. This reflection by the researcher concurs with the findings by Newman *et al.* (2012:303) (*cf.* 7.3) who suggests that future citizen science projects will be broadened to include national or global projects. The organisational element can thus include multiple institutions whether they are international non-governmental organisations (NGOs) or international research initiatives in water such as the United Nations Education, Scientific and Cultural Organisation (UNESCO), and the Institute for Water Education in Delft, Netherlands.

The human element of the current design can benefit from inclusion of standardised field protocols to collect and visualise data that will link citizens with direct input of expertise to validate their findings and direct their interpretations. The inclusion of standardised protocols will incorporate the use of modern technology, for example, “apps” and smart phones. This notion ties in with the work of Cuff *et al.* (2008:34) (*cf.* 7.3) who suggest that citizen science projects can span across locational boundaries and move from a local to a continental scale.

Regarding the social element, the water project of the NWU (Vaal Campus) included a diverse group of participants and was sensitive to different social, cultural, economic and political factors. The recognition and making allowance for indigenous knowledge and the views of learners and pre-service teachers, as well as acceptance by the research team of responses by campus management on adaptive management proposals are cases in point (Ballard *et al.*, 2008:188) (*cf.* 2.4.2; *cf.* 5.3.3).

The pre-service teachers were exposed to volunteer service while participating in monitoring activities on the campus and in schools (Newman *et al.*, 2012:303) (*cf.* 7.6). Globally, volunteer service is included in university curricula when training nurses, doctors and engineers for example. Teacher training includes volunteer service as work-integrated learning (WIL) when sending pre-service teachers for fixed periods to schools for observation and lesson presentation. The opinion of the researcher is that environmental volunteer service, in the form of citizen science projects, needs to be included in the higher education curricula to promote environmental awareness and to build social capital on natural resources (Newman *et al.* 2012:303) (*cf.* 7.6). Although more research needs to be done, emphasis must be placed on the value and enjoyment of citizen science projects to enhance the quality of life in impoverished communities.

Figure 7.2 displays a generic system which can be used as an overview of a citizen science project. The researcher is of the opinion that initiating a project from this broad perspective will be of assistance in the planning of a citizen science project by including the most relevant components in its planning stage. The natural resource involved, be it water, soil or air can be added in the green blocks.

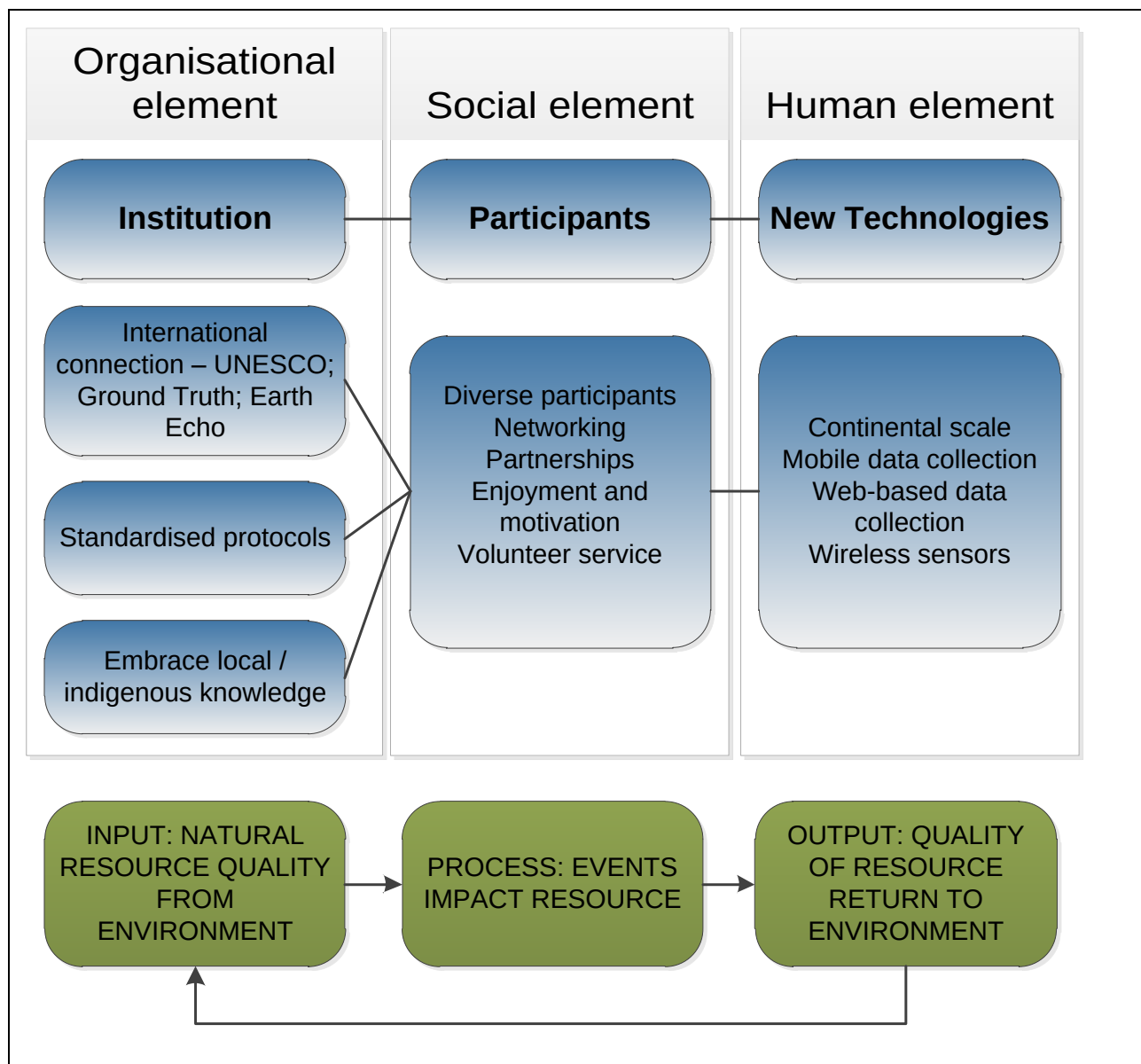


Figure 7.2: A generic system for citizen science projects which promote natural resource management

The organisational element may consist of four to five levels depending on the inclusion of more than one expert/national or global group. Inclusion of diverse groups of participants in the governance of a citizen project is of importance to allow for scientific and indigenous knowledge of the natural resource.

The human element must embrace new technology in the form of “apps” and web connections. The ability to design a citizen science project for the broader community can include input from scientists and concerned academics, as well as ordinary citizens with the same interest – therefore benefiting the establishment of communities of practice. The validity of the project is enhanced with broad, diverse participating groups.

The main aim of citizen science projects is to improve social learning and social capital. The inclusion of diverse groups promotes collaboration and networking – thereby creating an inclusive identity among participants. Establishing group identity, may aid with continued volunteer service and the enjoyment of the citizen scientists.

7.7 CHAPTER SUMMARY

The development of a tiered systems framework for the water monitoring project at the NWU (Vaal Campus) provided an overview on the research project itself. The research design of this research study was transdisciplinary in nature (*cf.* 3.3.2.1). In Chapter 6 the researcher identified the necessary elements for an appropriate tiered system for the project. In discussing system elements and indicating how they related to the NWU (Vaal Campus) monitoring project the researcher reflected on the project and related activities showing that the project adhered to the three phases of trans-disciplinary research, namely (a) problem identification and structuring; (b) actual research and (c) bringing the results to fruition (*cf.* 3.3.2.1).

The design of both the tiered and generic system to provide an overview and direct citizen science projects made the researcher aware of the interaction of system elements upon one another. The design of a future system for citizen science projects helped the researcher realise the limitations and possible challenges of the water monitoring project.

CHAPTER 8

OPERATIONALISING ENVIRONMENTAL EDUCATION THROUGH CITIZEN SCIENCE: CONTRIBUTIONS, CHALLENGES AND LIMITATIONS, RECOMMENDATIONS, SUGGESTIONS AND CONCLUSION

8.1 INTRODUCTION

This research study was conducted to investigate the experience of different groups of participants in a community-based water monitoring project. The target group was pre-service teachers and Grade 10 Physical Science learners. The study explored the use of a project-based teaching approach to enhance environmental education (EE) about water quality. The main aim and objectives that were formulated at the outset of the study are revisited in this chapter to determine whether the aims were indeed achieved.

The literature review and data collected by means of participatory action research contributed to answering the problem statement upon which the study was based, and assisted the researcher in reaching the primary aim and objectives of the study. This chapter provides information on: findings from the literature review; findings from the empirical research; findings in relation to the aims of the study; recommendations for citizen science projects; the contributions of this research study; challenges of the study; and suggestions for further research.

8.2 A SUMMARY OF THE FINDINGS FROM THE LITERATURE REVIEW

The literature review focused on the clarification of various key concepts including citizen science and community-based monitoring; EE and social learning; water quality and adaptive management.

The concept of *citizen science* indicates the inclusion of community members in this research, notably pre-service teachers and Grade 10 learners, in the collection of data for scientific research (Buytaert & Zulkafli, 2014:3; Whitelaw *et al.*, 2003:410; *cf.* 2.2.1). Citizen science is a multi-faceted concept and may include community science and civic science. *Community-based monitoring* as a form of citizen science is a process in which concerned citizens, government agencies, industry, academia and community groups

collaborate to monitor, track and respond to common community concerns (Conrad & Hilchey, 2011:275; *cf.* 2.2.2). Examples of university/community partnerships are found in the USA and Canada (Savan *et al.*, 2003:563-565; *cf.* 2.2.2) but as far as the researcher could determine, the collaborative, multi-party water monitoring project at the NWU (Vaal Campus), is a first in South Africa. The various participant groups had diverse knowledge bases but all benefited from social learning in the execution of the project (*cf.* 2.2.2).

Citizen science is practised globally on a wide variety of topics. In the case of water quality studies they rely on the collection of biological data like micro invertebrates, while others, for example, focus on frog and bird counts (Matthews, 2014:13; NVT, 2016; South African National Biodiversity Institute, 2016; *cf.* 2.2.1.1). This particular water monitoring study focused on the physical data (pH, temperature, dissolved oxygen, bio-dissolved oxygen, water hardness, turbidity). It is unique, in that more than one educational institution (university campus and local schools) participated in the monitoring and the determination of water quality status. Moreover, diverse groups of participants (pre-service teachers, learners, campus management and GCI members) collaborated in the collection and sharing of data.

Environmental education is defined by Reddy (2011:14; *cf.* 2.3) as an essential dimension of basic education that lies at the root of personal and social development. Hungerford (2009:3-4; *cf.* 2.3) indicates that EE is about teaching participants about the environment rather than taking responsible citizenship decisions about the environment. Implementation of the water monitoring project with pre-service teachers fulfils the call made by Campbell *et al.* (2010:25) (*cf.* 2.3.1.1), that all teacher education programmes must include EE. Phillipson-Mower and Adams (2010:66; *cf.* 2.3.1.2) agree that it is vital to introduce EE into educational programmes as service learning, as do Newman *et al.*, (2011:218) (*cf.* 6.2.5) who indicated that volunteer service will no doubt form part of citizen science projects in the near future.

The NWU (Vaal) water monitoring project adheres to the characteristics of service learning by enhancing the Physical Science curriculum and provided ample room for reflection on experience when pre-service students and learners answered open-ended questions at a suitable time and place after performing the monitoring. The pre-service teachers were also provided with frequent opportunities to use their newly acquired skills and knowledge in real life classroom scenarios (*cf.* 2.3.1.2). Service learning also

promoted affective learning (*cf.* 2.3.1.2). Pre-service teachers and learners learned to listen to and respond appropriately in interaction with others. The pre-service teachers and learners demonstrated that they value water quality as important, and indicated that after participation in the project they regarded water quality in a new light and appreciated clean, healthy water. The objectives of environmental education which were mastered included knowledge acquisition, skills participation and change in environmental attitude and awareness (*cf.* 2.3.1.2).

Bandura (1971:3; *cf.* 2.3.2.1) indicates that *social learning* is learning through experience which links well with the previous concepts on EE. Exposure of pre-service teachers to 10 sessions of water quality experiments (over two successive years) and school learners to a once-off opportunity to perform monitoring experiments, provided both groups with learning through experience. The work of Wenger (1998b:14; *cf.* 2.3.2.1) indicates that social learning helps to establish *community of practices* (COPs) which are social learning systems. All five disciplines of COPs as indicated by Wenger (1998b:12; *cf.* 2.3.2.2) were visible in the NWU (Vaal) water monitoring project. The indication that participants care about water quality indicates the *discipline of domain*. During water monitoring the pre-service teachers and learners relied on and trusted each other and thereby operated in a *discipline of community*. The *discipline of practice* became evident from the fact that water quality monitoring experiments fitted perfectly into the school and university curricula. The *discipline of convening* was displayed by the pre-service teachers taking the lead in classrooms and the researcher who organised resources for the water quality measurements. The *social discipline* was evident in the spontaneous participation of pre-service teachers and learners in the monitoring process.

Each participant in the project brought his/her own identity to the study. *Identity* is defined by Wenger (1998b:11; *cf.* 2.3.2.1) as a multi-scaled, multi-membership which includes all memories, competencies, events, relationships with people, places and communities which is shared with others. The diverse response of pre-service students, their concerns and/or fears in choosing to participate, the different views on what they regarded as important in the monitoring project and the indication made by the groups of learners on new content they had learnt, all indicated the unique identity of individuals and groups in the project.

Wenger (1998:5; *cf.* 2.3.2.1) argues further that knowledge consists of a landscape of practice. The landscape of practice relevant to the NWU water quality project, implies the engagement of both pre-service teachers and learners in water quality measurements and reporting back on their experience of the process. The researcher believes that a landscape of engagement was created during this research study.

The work by Keen *et al.* (2005:4; *cf.* 2.3.2.1) indicates that social learning can be regarded as both a *collective action* and a *reflection*. The collection of data by both pre-service teachers and learners as well as the responses of these participants to open-ended questions can be seen as collective action and reflection.

Pahl Wostl *et al.* (2007) (*cf.* 2.3.2.1) link social learning to *governance*. The involvement of NWU (Vaal Campus) management and technical service in water quality issues confirmed that governance is part of social learning.

Reed *et al.* (2010, *cf.* 2.3.2.1) regards social learning as *active social participation* in community practices. Engaging both learners and pre-service teachers in water quality measurements provided for active participation in a community process, namely water health. Responses from both groups are provide evidence of awareness of their ability to inform their communities about water quality and water health.

Project-based teaching was the teaching strategy used to convey social learning in this research study. Project-based learning is active learning which places the responsibility for learning on the student (Doppelt, 2003:256; *cf.* 2.3.3.1). Project-based learning is also place-based which accentuates the relationship between educational institutions and the community (Powers, 2004:417; *cf.* 2.3.3.3). For the water monitoring project the relationship between the NWU (Vaal Campus) and community schools was warm and accommodating and of mutual benefit to all participants. The proposals by Killen (2010:249-250) and SAIDE (2012:292-294; 306) (*cf.* 2.3.3.1) were followed during the project-based teaching approach by allowing pre-service teachers and learners to work in groups; allowing them to take responsibility for their part of learning; creating opportunities for learning in a real-life environment, encouraging the development of practical skills; and answering open ended reflective questions after the monitoring activity.

The water monitoring project also relates to water quality management (WQM) and the following concepts were defined:

Water quality is the chemical, physical and biological characteristics of water in respect of its suitability for intended purposes (Department of Water Affairs, (DWS), 2017; *cf.* 2.4.1). Water quality is influenced by human and natural processes and water quality management is therefore an ongoing process of planning, development, implementation and administration of policy, the authorisation of water use and the monitoring and auditing of water quality (DWS, 2017; *cf.* 2.4.1).

In South Africa WQM is a complex issue and consists of a tiered management system on water legislation, responsibility; instruments and application (*cf.* 2.4.1.1). The management of NWU (Vaal Campus) water storage resource is a civil management with cooperative governance.

Adaptive management is seen as a management action which uses structured experiments to respond to both planned and unplanned environmental surprises (Huitema *et al.*, 2009; *cf.* 2.4.2). The adaptive management action at the NWU (Vaal Campus) is non-technocratic, polycentric adaptive management because it includes both learning and co-management of the campus water storage resource with a variety of stakeholder involvement (*cf.* 2.4.2). Applying an adaptive management approach indicates that the pre-service teachers experienced a sense of place by taking responsibility and caring for their campus (*cf.* 2.4.2.2 & 4.2.1), true to environmental education's objective of participation. Both scientific and indigenous knowledge were shared between the researcher, pre-service teachers and learners (Raymond *et al.*, 2010:1767; *cf.* 2.3.2.7 & 2.4.2.3). This speaks to new knowledge, skills and awareness that was gained.

Social learning occurred in this research study on the scale dimension as context-specific knowledge when pre-service teachers and learners gained knowledge on the water quality status of their community water storage resource. In the functional dimension the pre-service teachers were able to link their actions to the status of the campus water storage resource, in general therefore they gained phenomenological knowledge. In the cognitive dimension pre-service teachers and learners both acquired experiential learning and partook in a unique experience. Both groups gained scientific knowledge being able to report their findings explicitly in a scientific report (Enengel *et al.*, 2012:107; *cf.* 2.4.2.4).

Public participation refers in this instance to the way in which role players collaborated in the monitoring. The type of public participation in the water monitoring project is regarded as collaborative participation due to the diverse groups of participants who took part in the gathering of data, as well as the adaptive management practices on campus. Internal value was gained by both pre-service teachers and learners who gained scientific content knowledge as well as practical skill. External value gained is evident in the adaptive management proposals and raising of awareness of water quality problems on campus to management and technical services (Lawrence, 2006:292, *cf.* 2.4.3).

Community involvement in adaptive management is seen in co-management. A well-organised public participation process like the water monitoring project increased the positive experience for the participants involved and will, if only in the longer term, influence campus management to initiate a culture of change regarding water management (Huitema *et al.*, 2009 & *cf.* 2.4.3.1). The public participation process followed in the water monitoring project, is a strategy to guide the way forward towards community resilience at the NWU (Vaal Campus). The use of socially diverse groups like management, pre-service teachers and technical services provided for a local community who faces up to and addresses its own environmental problem, namely water quality (Tidball & Krasny, 2007:150, *cf.* 2.4.2.2).

8.3 A SUMMARY OF THE FINDINGS FROM THE EMPIRICAL RESEARCH

The findings from the empirical research that were reported in Chapter 4 were the qualitative, multiple case study findings and in Chapter 5 the findings on the quantitative water monitoring data were provided. These are summarised in this below.

Firstly, the qualitative findings on the experiences of pre-service teachers and learners are discussed in separate participation groups.

Pre-service teachers

The pre-service teachers indicated that a project-based teaching approach focuses on real-life problems, in this case, poor water quality (*cf.* 4.2.1 activity 1). By engaging pre-service teachers in a long-term study fulfilled the aims of gaining both knowledge and skills. Monitoring was seen by the pre-service teachers as an activity to determine water

quality. They felt that engaging in water monitoring would enable them to educate their communities and ensure water health. For the pre-service teachers environmental stewardship meant the protection of and taking responsibility for the natural environment. Being part of this water monitoring project the pre-service teachers felt better equipped to teach in the classroom and inform their communities, thereby raising awareness of the importance of water quality. They expected to learn from the water monitoring project and were initially concerned about their safety, and that of learners in their classrooms, when performing monitoring activities (*cf.* 4.2.1 activity 1).

The visit to Rand Water (*cf.* 4.2.2 activity 2) was fun and enjoyable for the pre-service teachers. They learnt about water purification during the Rand Water visit and acquired diverse pre-knowledge on water as a complex resource. The visit was relevant and involved learning about the real-life practices of water purification (*cf.* 4.2.2 activity 2).

Early in the monitoring process the pre-service teachers were already aware that the main purpose of the water monitoring project at the NWU (Vaal Campus) was to determine the water quality and the level of pollution of the campus water storage resources. A related purpose of the project was to take action (*cf.* 4.2.3 activity 3). This response was indicative of an awareness of another objective of the project i.e. the adaptive management proposals formulated by the researcher, in collaboration with the Rand Water expert team (*cf.* 4.3.4). The responses from the pre-service teachers also indicated the realisation that monitoring practices on campus can be improved by comparing results and by involving other groups (*cf.* 4.2.3 activity 3). The researcher complied with these responses by involving Mrs Nyree Steenkamp of Rand Water to validate pre-service teacher monitoring activities and the reliability of the Somerset Water Quality test kits on two occasions during 2015 (*cf.* 4.3.4). The pre-service teachers were excited about the water monitoring project and true to environmental education practices wanted to convey their knowledge and skills to others. Accordingly, they were allowed to share their knowledge and skills when they performed monitoring activities at community schools with Grade 10 Physical Science learners (*cf.* 4.2.3 activity 3 & 4.2.5). Furthermore, this group of student teachers regarded the water monitoring project as challenging partly because of their own uncertainty about practical skills, but also because of the responsibility and extended commitment the project required (*cf.* 4.2.3 activity 3). The pre-service teachers indicated that the variables they were testing in the water samples were previously unknown to them so they were

acquiring new knowledge. Challenges of participating included anything from gathering data and interpreting it correctly to the possibility of accidentally falling into the dams when taking samples (*cf.* 4.2.3 activity 3). They indicated that the water monitoring project raised their environmental awareness and provided them with an opportunity to play a role in influencing water health (*cf.* 4.2.3 activity 3).

After five monitoring sessions the researcher asked the pre-service teachers to write a reflective essay on their experience of being part of the project. No prescriptions were given to them and the researcher urged them to convey their experience with honesty. The following themes emerged from these essays:

All the pre-service teachers indicated that: (a) they gained practical skills. This was evidence of experimental learning which enabled them to plan, act and reflect on their experiences as participants in the project (*cf.* 2.3.1.2); (b) they gained content knowledge and were empowered with knowledge and skills, therefore had personal development and internal gain when participating in the monitoring (*cf.* 2.2.1.1). The knowledge gained s empowered them to solve a real-world problem, namely poor water quality, and provided them with a holistic view on water as a valuable natural resource (*cf.* 3.3.2.3); (c) the lengthened exposure to monitoring activities benefited the pre-service teachers. The prolonged engagement of pre-service teachers in the water monitoring project was evidence of a unique feature of participatory action research and showed persistence to a worthy cause (*cf.* 3.3.2.3); (d) the water monitoring project empowered them to teach others and help others in their communities with water quality. The role of the pre-service teachers was a bottom-up approach to solve communal problems. By gaining knowledge and skill of water as a complex resource, they were able to address current and future water quality related problems in their communities (*cf.* 3.3.2.3); (e) an increase in their environmental awareness was achieved. Participatory action research is known as a life changing research methodology which proved to be true for the NWU (Vaal Campus) water monitoring project (*cf.* 3.3.2.3). The pre-service teachers became aware of their role in the environment and indicated a change in attitude towards the natural environment; (f) they enjoyed displaying their knowledge and skill at the Teaching Practice symposium held at the university. This made it clear that communities have unique environmental problems to address and generalised findings are not applicable to all environmental scenarios (*cf.* 3.3.2.3); (g) social learning, in the form of group work, secured their

actions and let them feel safe when taking samples and conducting the tests for variables. This indicates that a community of practice was formed between the researcher, pre-service teachers, learners, GCI members, campus management and the Rand Water experts. The participatory action research in this study was therefore collaborative and provided for the opinions and acknowledgment of all participants (*cf.* 2.4.3 & *cf.* 3.3.2.3) (*cf.* 4.2.4 activity 4).

In the final activity the pre-service teachers reflected upon was their supervision of monitoring at schools. The pre-service teachers indicated that the monitoring project held on the NWU Vaal Campus had given them good exposure to water quality measurements and enabled them to conduct the monitoring at schools. The ongoing feedback from pre-service teachers after each monitoring session provided them with opportunities to reflect on knowledge and practical skills gained and made them confident of supervising the water quality testing at schools. The repetition of reflective questions corresponded with participatory action research methodology of plan, act, develop and reflect (*cf.* 3.3.2.3). The pre-service teachers enjoyed the activities with learners and were able to apply their knowledge. The water monitoring project created a suitable context for knowledge development and change to occur (*cf.* 3.3.2.3). Social learning is defined as learning through experience (*cf.* 2.3.2.1) and this was evident in the monitoring project. The pre-service teachers had the privilege of experiencing a real-life scenario and exposure to practical Physical Science with learners in a school. In response to questions posed they indicated that classroom management with practical work could be a challenge but as Bandura (1971) (*cf.* 2.3.2.1) suggests, social learning requires participants to display attention (the recognition of features), retention (remembering features), motoric reproduction (displaying skills) and self-reinforcement and motivation (the urge to display learned knowledge and skills). The pre-service teachers were required not only to memorise how to perform monitoring activities, but also had to guide learners and manage the classroom environment. They agreed that participating in the monitoring project had given them the confidence to work with the learners (*cf.* 4.2.5 activity 5). Performing monitoring at schools also enabled the pre-service teachers to display learning citizenship as explained by Wenger (1998a) (*cf.* 2.3.2.1) by investing time and energy in local schools. They also demonstrated multi-membership and the ability to act as bridge builders between different groups in their respective communities (*cf.* 2.3.2.1).

In the next section, the findings on the experience of learners is summarised.

Learners

Learners found the water monitoring activities interesting, enjoyable and saw it as an opportunity to gain knowledge and skills. Learners indicated that the monitoring activities were easy to perform because clear instructions and guidance was provided by the pre-service teachers. Learners responded with diverse answers when asked what they learnt that was new, indicating that unique pre-knowledge accumulation on water as a complex resource emanated from different groups. All learner groups realised that the quality of water is important and the monitoring is a way of ensuring whether water is safe for use and healthy (*cf.* 4.2.6).

GCI

The GCI meetings provided a platform for the researcher and pre-service teachers to share their findings on the water quality of campus water storage resources. The meetings with representatives from other groups, for example management and technical services, helped to connect the researcher with others who are able to assist with adaptive management of campus dams (*cf.* 4.3.1).

Campus management

Mr Jacob Simango represented campus management at GCI meetings. He provided feedback to and from management regarding environmental matters (*cf.* 4.3.1 & 4.3.2).

Technical services

Technical services is the section responsible for implementing environmental management at the NWU (Vaal Campus) and was represented by different officials at GCI meetings. Mr Burger Scholtz often took the lead here and with his sound knowledge provided valuable guidance on environmental matters, especially on the status of the campus dams. (*cf.* 4.3.3).

Rand Water

Rand Water, as the experts engaged in the project, provided valuable guidance for the duration of the monitoring process. Mrs Nyree Steenkamp visited the NWU (Vaal Campus) more than once to validate the monitoring and check the apparatus. She also

arranged for the group of experts to visit the campus to make proposals for the adaptive management of the campus dams (*cf.* 4.3.4).

Scientific report on observation of water storage resource

The quantitative data collected during the monitoring process were summarised in a single scientific report. The locality of each of the campus dams was explained and mapped. The activity in the vicinity of each dam was discussed (*cf.* 5.2). The readings for each of the nine parameters selected for measurement were analysed and interpreted (*cf.* 5.3).

The pH value refers to the acidity of water. The pH of most campus water storage resource was near neutral, namely between 6 and 8 (*cf.* 5.3.1.2).

Temperature is an indication of the average kinetic energy of matter. The lowest water temperature recorded in the campus water storage resource was 11 °C and the highest temperature 28 °C. This relates well with the high heat capacity of water, which means that water does not gain or lose heat easily (*cf.* 5.3.1.1).

Dissolved oxygen (DO) provides an indication of water health. Healthy water has high readings of DO. According to the readings taken, the DO decreased from 2015 to 2016. The most repeated reading of DO in water storage resource was 4 ppm which indicated highly polluted water (*cf.* 5.3.1.1).

The relation between water temperature and DO is given by the percentage (%) saturation. The percentage saturation decreased in 2016 despite higher water temperatures. Low percentages of saturation indicate water which is not flowing and is polluted (*cf.* 5.3.1.1).

Bio-dissolved oxygen (BOD) is the demand that organic matter places on the oxygen in water and thus lowers/decreases the amount of oxygen in the water. The BOD levels of the campus water storage resources were mostly 0 which indicates an excessively high demand for oxygen by organic matter. The campus water storage resource was unable to replace the oxygen demanded and therefore reached an anaerobic phase of the septic zone in 2016 (*cf.* 5.3.1.1).

Chloride is used as a disinfectant in water to promote water health. The campus water storage resource is not supposed to have any visible chloride in it. Findings of chloride

in the dams can be traced back to the local authorities and sewage discharge into the Vaal River; adding chloride is an emergency measure to maintain water health at an acceptable standard of quality (cf. 5.3.1.2).

Nitrite and nitrate concentrations that are found in water storage resources may be due to the use of fertilisers or the activity of cyanobacteria. The readings of nitrite and nitrate ions in the campus water storage dams can be traced back to the activity of bacteria in dams or possible sewage spills into the Vaal River (cf. 5.3.1.2).

Hardness indicates magnesium and calcium ions in water. Water in campus dams is regarded as hard water due to high readings of 125 to 250 ppm. The water may well be hard due to the ongoing building activity on campus (cf. 5.3.1.2).

Turbidity refers to the scattering of light by suspended particles in water storage resources. High turbidity levels (> 30) indicate high concentrations of suspended matter in campus water storage resource (cf. 5.3.1.2).

E. coli, is a sub-group of faecal coliform, and is one of the major readings that provides a view of water health. Positive measurements of *E. coli* found in all campus water storage resources as well as in the Vaal River, confirms that the water is contaminated with pathogens which may affect human health. Deposits of animal manure in campus dams is responsible for the positive *E. coli* measurements. The sewage discharge, due to the malfunction of pump station 10 in Mario Milani Road, was most likely responsible for the positive *E. coli* test in the Vaal River (cf. 5.3.1.3).

The campus dams were polluted as indicated by the selected parameters (cf. 5.3.2). With this in mind, in November 2015 a group of experts from Rand Water visited the campus to make proposals on the adaptive management of the dams. The group explained that the water in the dams had to be circulated more often. The erosion of dams could be kept at bay by the use of gabions and the construction of suitable storm water channels. Furthermore the reeds in Dam 2 should be removed. The expert group also suggested that the campus dams be stocked with indigenous fish species like yellow fish (cf. 5.3.5). Photographs proved valuable to record the level of erosion of the dam walls and visible pollution due to human activity and these were shown to the representatives of campus management and in GCI meetings (cf. photo's 5.1-5.6).

Campus management responded that it was circulating the water in dams as often as the budget allowed. Management representatives noted the erosion and later consulted with an engineer on the safety of the road near building 25. Management expressed a willingness to build gabions and remove reeds from Dam 2, but said that finances remained a challenge (cf. 5.3.6). On a positive note, in June 2017 gabions were indeed constructed to limit the erosion of Dam 4, see Photo 5.6.

The researcher is of opinion that the management of environmental issues at the NWU (Vaal Campus) will remain problematic until a full-time environmental manager is appointed. The commitment of campus management to environmental concerns and the allocation of finances for this task remains a challenge.

8.4 A SUMMARY OF THE FINDINGS IN RELATION TO THE AIM AND OBJECTIVES OF THE STUDY

In this section the researcher revisits the aim and each of the objectives of the research study, and explains how and to what extent they were achieved.

Main aim

To explore how a citizen science water quality-monitoring project, involving Physical Science pre-service teachers and Grade 10 Physical Science learners, could contribute to environmental education, social learning and adaptive management.

This objective was achieved by analysing all data obtained when pre-service teachers and learners participated in the water monitoring project. Document reviews clarified relevant concepts such as citizen science, community-based monitoring (cf. 2.2), environmental education (cf. 2.3), project-based teaching and learning and adaptive management (cf. 2.4). The interrelatedness between these various concepts was accentuated in Chapter 2. The research methodology in Chapter 3, based on document reviews, indicated the use of transdisciplinary techniques, participatory action and concurrent, embedded mixed method research. The open-ended questions answered by pre-service teachers and learners were analysed with the Atlas ti qualitative data programme and discussed in Chapter 4. The quantitative data on the water quality variables were analysed statistically and reported in scientific format in Chapter 5. Included in the scientific report on the water quality of the NWU (Vaal Campus) dams, observations were reported in writing and by means of photographs. Adaptive

management as a concept was discussed and proposals were made on the adaptive management of campus dams. Chapters 6 and 7 revealed the design of the citizen science framework and the three-tiered systems framework compiled by the researcher. These frameworks were constructed by engaging with the relevant literature and reflecting on the real-life learning opportunity of the water monitoring project. This chapter, Chapter 8, displays the reflective nature of both transdisciplinary and participatory action research where the water monitoring project was evaluated by connecting experience and revealed opportunities.

Environmental learning gains

In Chapter 4, the researcher discusses the responses from pre-service teachers and Grade 10 Physical Science learners who participated in the water monitoring project. All the pre-service teachers indicated that they had gained practical skills in that they knew how to test for water quality. They also increased their content knowledge of Physical Science and became more aware of how, as future teachers, their actions could have a positive influence on the natural environment. The pre-service teachers valued their group work and explained how the support of other participants was also a positive aspect of their participation in the project. They realised that they could help their communities with water health and thereby increase social capital. Furthermore they enjoyed the water monitoring project and especially the opportunity of presenting their findings at a teaching and learning symposium. They felt that their exposure to the water monitoring project at the NWU (Vaal Campus) helped them to gain confidence and practical skills, and that this enabled them to conduct water quality measurements with learners in the classrooms, an experience they enjoyed. At the schools they learnt about classroom management and were able to apply their subject knowledge (*cf.* 4.2.5).

The Grade 10 Physical Science learners who participated in monitoring activities at schools enjoyed taking the practical measurements and were pleased it had been done in groups. They found the water testing interesting and learnt from it. The learner groups saw the water quality measurements as an opportunity to learn more about water as a complex substance and agreed that the water quality experiments were explained clearly by the pre-service teachers and the printed instructions. They found the water testing easy. The knowledge gained by the learner groups was diverse and depended

on their pre-knowledge and interest in different water quality concepts. All the groups of learners indicated that healthy water is safe to drink and for human use (cf. 4.2.6).

Community gains

Theoretically the research study contributed to a context-situated citizen science framework which could guide the conceptualisation and implementation of a community-based project in the future (cf. 6.3). The three-tiered systems framework that was developed (cf. 7.5) provides a view on how different education institutions could be incorporated into a single framework to direct citizen science projects in the community in future.

In the light of the explanation above, the researcher concludes that she achieved the main aim of the study.

Objective 1

Define and clarify the concepts environmental education, social learning, project-based teaching, water quality monitoring, community-based monitoring and adaptive management at educational institutions with reference to the context of a citizen science community-based water monitoring project at the NWU (Vaal Campus).

This objective was achieved by performing a document review and literature review focusing on the concepts citizen science and community-based monitoring, environmental education, social learning, project-based teaching, water quality management and adaptive management.

Citizen science is described as a process in which members of civil society (citizens) become actively involved in science as researchers. These 'scientists' are literally novices, but are notable for their keen interest in scientific matters. (cf. 2.2.1).

Community-based monitoring is an approach whereby concerned citizens, industry, academia, community groups and local institutions collaborate to monitor, track and respond to environmental issues (cf. 2.2.2).

Environmental education was enhanced by the water monitoring project because an integrated research study was launched to solve a communal problem, namely poor water quality (cf. 2.3.1). All three approaches of environmental education were practised

in the water monitoring project, namely i) education about the environment where pre-service teachers learnt about water quality in the natural environment that was exposed to harsh weather and seasonal changes; ii) education through the environment where pre-service teachers and learners indicated their appreciation of clean, healthy water; and iii) education for the environment where the pre-service teachers and learners were equipped to inform their communities about water quality (*cf.* 2.3.1; *cf.* 4.2.1 – 4.2.6).

Social learning was displayed by the pre-service teachers in line with Bandura's (1971) framework when they were able to perform water quality activities with learners at schools (*cf.* 2.3.2; *cf.* 4.2.2). The pre-service teachers who worked in groups of two, and the learners (groups of four) both displayed the community of practice (COP) theory propounded by Wenger (1998a) which is a social learning system (*cf.* 2.3.2.2 & 2.4.3.2).

The project-based teaching approach allowed for the pre-service teachers and groups of learners to solve a real-life problem, namely poor water quality (*cf.* 2.3.3). Project-based learning also supports meta-cognition which calls for learners to reflect on their learning activity and recognise the value of social structures and resource in learning (*cf.* 2.3.3.1). The pre-service teachers realised they have a responsibility towards the natural environment and can make a positive contribution on water quality in their respective communities. They also took note of the value of working in groups, in other words, social learning (*cf.* 4.2.1). Learners were able to reflect on their monitoring activities and indicated that they enjoyed them; the instructions and practical work were deemed "easy" (*cf.* 4.2.2).

Water quality management involves the maintenance of the fitness level of water sources on a sustainable basis. Water quality management aims to achieve a balance between socio-economic development and the protection of water as a scarce natural resource (*cf.* 2.4.1).

Adaptive management is management that has the ability to overcome limitations of command-and-control mechanisms in natural resource management. It treats management actions as structured experiments which include attempts to document and learn from both planned and unplanned environmental surprises (*cf.* 2.4.2).

Objective 2

Understand the relation between campus community and environment.

This objective was achieved by the review of relevant documents such as academic articles on citizen science, water quality and adaptive management. A close study was also made of the available guidelines for water quality such as the South African Water Quality Guidelines and the Rand Water Vaal Barrage Catchment Guidelines. Good water quality is a global concern and needs to be infused into academic programmes and school curricula. Environmental education must be introduced to provide opportunities to teach learners and students about water as a scarce, valuable resource (cf. 2.3). Water quality, which is a societal gain or problem, is best addressed when incorporating communities such as universities and schools. Citizen science is a vehicle to take scientific research into the wider social domain (cf. 2.2). Through citizen science, social learning, which embraces unique identities and knowledge of diverse participants, creates a suitable opportunity to understand the relation between the campus community and environment.

Objective 3

Investigate how environmental education, in the form of citizen science, can be integrated and presented in teaching and learning of pre-service teacher education and Grade 10 Physical Science using project-based teaching to advance environmental learning.

The objective was achieved by analysing and interpreting the measurements of variables and then indicating the water quality in the NWU (Vaal Campus) dams and the neighbouring Vaal River in a scientific report. As shown above, active involvement in the measurement of water quality variables increased the knowledge and practical skill of pre-service teachers and Grade 10 learners (cf. 4.2).

Planning of the water monitoring project according to a project-based teaching approach was addressed in Chapter 3 (cf. 3.7). A project-based teaching approach allows for teachers/lecturers to facilitate learning and enables students/learners to take responsibility for their own learning (cf. 2.3). The planning and management of the water monitoring project on the NWU (Vaal Campus) and gaining the acceptance and funding of the research project took a great deal of persistence by the researcher but the

outcome of the project and the gain for the pre-service teachers and learners was well worth the effort (MPA 1).

Reflecting back on the evaluation of the monitoring programme as set in Chapter 3 (cf. 3.7) the conclusion can be made: Participants, both novices and experts, were successfully engaged as stakeholders in the project. The monitoring project proved a success and achieved the estimated gain for both the participants and other organisations involved. Indicators of a successful conclusion of the project include the following:

Pre-service teachers and Grade 10 learners gained subject knowledge about water quality variables as well as the practical skill of how to test for water quality status. The NWU (Vaal Campus) as an organisation gained a scientific report on the water quality of campus dams which assisted with the formulation of adaptive management proposals regarding campus dams. Campus management responded to the adaptive proposals and implemented some of them. The qualitative data collected displayed the value of social learning opportunities to enhance environmental education at school and university level. The findings of the research study will be sent to the Gauteng Department of Education and finally, Rand Water, as the expert group on water monitoring, was successfully incorporated as a research partner in the project.

The dams of the NWU (Vaal Campus) are polluted and have poor water quality; the level of pollution increased from 2015 to 2016. The rising pollution level, according to the researcher, is due to: (a) limited circulation of water in dams and use of pumps in efforts to save electricity; (b) the countrywide drought conditions at the time of the research as a result of the *El Niño* phenomenon; (c) frequent winds which carry dust and pollutants to water bodies; (d) increased student numbers which means more people on the campus and leads to pollution of the environment because waste material is discarded into the water; (e) the ongoing construction of new buildings on the campus; (f) more students using motorised vehicles on the campus' roads; and (g) limited awareness on the part of the university community about the deterioration of the environment (cf. 5.3.2).

Chapter 5 (cf. 5.3) analysed and interpreted the parameters that were measured. These variables were: pH, temperature, dissolved oxygen, percentage saturation, bio-dissolved oxygen, concentration of chloride, nitrite and nitrate, hardness and turbidity,

as well as *E. coli* contamination. Point and non-point source pollution of the campus water storage resource was identified. Point source pollution occurs when sewage or spills from industries is discharged into water bodies, especially into the Vaal River. Non-point pollution comes from mining and building dust, run-off of animal manure, chemicals, tarred and dirt roads and soil sediments that found their way into campus dams, as well as pollution via tins and food containers in the dams. The researcher concluded that the condition of campus dams deteriorated in 2016 and that the water quality is unhealthy. Proposals were made, with the aid of Rand Water experts, to improve the water quality but progress in this regard is slow and lacks urgency due to various factors (*cf.* 5.4).

Objective 4

Explore how participation in a community-based water-monitoring project could contribute to making proactive suggestions in developing and implementing a citizen science management framework for education institutions.

This objective was achieved by incorporating real-life experiences into the water monitoring project such as interviews, open questions, jotting down observations and taking photographs.

In Chapter 6 the researcher discussed her approach to designing a citizen science framework which can be implemented at any education institution. In accordance with the suggestions made by Newman *et al.* (2011; *cf.* 6.2) the purpose and objective, management of data, as well as the number of participants determine the choice of a framework. The researcher discussed six possible frameworks which could contribute to the construction of a citizen science framework, as well as factors that must be considered in the design process (*cf.* 6.2). The researcher decided on a seven step process based on the frameworks discussed in the literature, and indicated the following about each step as relevant to the NWU (Vaal Campus) water monitoring project (*cf.* 6.3). The researcher then constructed two prototype frameworks and tested these by applying the relevant information extracted from the monitoring project to the prototype frameworks. The proposal by Lewenstein (2016; *cf.* 6.3.1) urged a focus on a generic framework and a real-life learning opportunity as provided by the natural environment. Finally, a generic NWU (Vaal Campus) monitoring project framework was designed and tested by the researcher against the real-life situation of water quality in the campus

dams. The researcher was of the view that a framework of citizen science such as this was best suited to see the so-called bigger picture of the project in a simplified way (cf. 6.4).

Objective 5

Understand how participation in a community-based water monitoring project that includes a university campus and a high school science class could contribute towards developing and implementing a citizen science management systems framework for education institutions.

This objective was achieved by performing a document review on related sources indicating systems elements and different system frameworks. Knowledge gained from real-life experience such as interviews, monitoring the water samples and responses to open-ended questions helped to provide perspective on achieving objective 5.

The researcher outlined a system as a set of components which function and interact in a regular way. Most systems have the key components of inputs, flows (or throughputs) and outputs (cf. 7.2). Sharp's (2002:128-145) three elements, namely organisational, social and human, were seen as crucial in the structure of a system (cf. 7.2.1-7.2.3). The first system was created specifically for the scenario of the water monitoring project at the NWU (Vaal Campus). The researcher wanted to accentuate that the system she designed was only temporarily of value because the socio-ecological environment is ever changing. The data collected at various points in time displayed the situation at the time of the monitoring on the campus. The researcher also took careful note of the work by Newman *et al.* (2012) and included newer trends in the practice of citizen science to create a second, more generic system to use for citizen science initiatives on natural resource management (cf. 7.3 & 7.5).

Objective 6

Identify the challenges and advantages of performing a citizen science water-monitoring project to enhance environmental education and social learning at education institutions.

This objective was achieved by reflecting on the water monitoring project broadly. The challenges and the advantages of the NWU (Vaal Campus) monitoring project are indicated in the following sections of Chapter 8 (cf. 8.6 & 8.7).

Objective 7

Draw conclusions and make recommendations to promote citizen science water quality monitoring and management at teaching and learning institutions.

This objective was achieved when the researcher reflected on her journal entries in relation to the water monitoring project, revisited the research questions and objectives, and reviewed the qualitative findings from multiple case studies as well as the scientific report on quantitative data. The NWU (Vaal Campus) citizen science framework and the three-tiered systems framework acted as a reflective exercise on the elements required for future citizen science projects.

The researcher prefers to discuss the achievement of this objective under the headings of 8.5 to 8.8.

8.5 RECOMMENDATIONS FOR CITIZEN SCIENCE PROJECTS

Citizen science projects are complex and diverse by nature. Attempting a citizen science project to investigate a natural resource, for example, water quality, prompted the researcher to make the following recommendations:

Take into account the relevance of the natural resource in real life. The NWU (Vaal Campus), with multiple campus dams and access to the Vaal River provides a suitable context and real-life scenario for performing water quality studies (*cf.* 6.3.1).

The input of experts in citizen science projects not only validates findings but provides fruitful social learning opportunities for all participants. Rand Water experts provided insight into adaptive management at the campus and gave valuable support in monitoring for the duration of the project (*cf.* 2.2.1.1).

Motivating the volunteers is as important as training them. Initially the pre-service teachers lacked confidence; they were worried about whether they had sufficient practical skill and subject content. Furthermore, most of them were frightened of water. Once they became more proficient at performing the monitoring they became bored with repeatedly conducting the same procedure. The visits to schools provided the next challenge and helped to keep them interested in the project.

The human element of citizen science projects needs to be nurtured. Citizen science projects function with the involvement of groups of people who collect data, but the

success of a project depends on individuals. The initiator of a citizen science project needs to be skilful in the following areas: i) have the ability to design a monitoring and assessment programme; ii) have the ability to arrange funding and apparatus to perform the monitoring; iii) be adept in connecting with different groups of people, for example, experts, the data collectors, those who manage the resource and the community; iv) be able to undertake the training or arranging for training of the volunteers; and v) be able to design a suitable system to collect and interpret data.

Connections with other individuals is vital. For example, an expert who takes particular interest in the project or a management official who is willing to transfer information to the management group is particularly useful. In the NWU (Vaal Campus) water monitoring project the researcher valued the input of Mrs Nyree Steenkamp, the Rand Water expert who supported the project with visits to validate monitoring activities and data. She also arranged with other Rand Water experts to visit the campus dams to assist with adaptive management proposals. Mr Jacob Simango, who participated in GCI meetings and transferred the findings of the project to management played a vital role, as did Prof Johann Tempelhoff who supported the monitoring project through his unstinting, ongoing interest, support and acknowledgment of the efforts of the researcher and the pre-service teachers (MPA 6.1 (2015-2016)).

8.6 CONTRIBUTIONS OF THIS RESEARCH STUDY

The researcher is of the opinion that the water monitoring project of the NWU (Vaal Campus) contributed in the following ways:

- Both pre-service teachers and learners gained practical skill and subject knowledge regarding water quality (*cf.* 4.2.1 - 4.2.6).
- Pre-service teachers and learners enjoyed performing the monitoring activities and learned in conjunction with their peers and from others such as the Rand Water experts, thereby benefiting from social learning (*cf.* 4.2.1 - 4.2.6).
- The water monitoring project at community schools provided pre-service teachers with an opportunity to indicate their skill and knowledge about water quality in a safe, supported environment. The researcher offered support by visiting schools with them. The water quality activities at schools were evidence of work-integrated learning (WIL) for the pre-service teachers (*cf.* 2.3.3.1).

- Pre-service teachers, learners, the researcher and GCI members, which includes campus management and technical service personnel, gained knowledge of the water quality of campus dams, the Vaal River, and of water sources in their community (*cf.* 4.2.1-4.2.6; 4.3; 5.3).
- The water monitoring project helped in the creation of social capital. The project raised awareness of water quality in general in the community by engaging a variety of role players (*cf.* 4.2 & 4.3).
- The research report, especially Chapter 5, provides a comprehensive picture of the current state of water in campus dams. The proposed adaptive management advice can aid campus management and motivate technical services to implement measures that will in turn mean a healthier water storage resource on campus (*cf.* 5.3.5).
- The citizen science framework and the three-tiered system created by the researcher could be applied to other citizen science projects on natural resources and may guide further research in the field of citizen science (*cf.* 6.3.1).
- This research study was a first in South Africa to combine the efforts of a university, a campus, community schools and experts to work together to gain insight in a community problem, namely water health. This combined effect was best displayed by the creation of the three-tiered system in Chapter 7 (*cf.* 7.5).
- The water monitoring project of the NWU (Vaal Campus) provided an opportunity to display how a campus can initiate social responsibility and raise environmental awareness in one project (*cf.* 4.2; 4.3 & 5.3).
- The informal and social learning opportunity of the water monitoring project provided the researcher with an opportunity to learn about and from her students. The relevance of indigenous knowledge and water mythology were accentuated during these learning opportunities (MPA 1 (2015.02.20)).

8.7 CHALLENGES AND LIMITATIONS OF THE STUDY

The following challenges were noted by the researcher in conducting the water monitoring project at the NWU (Vaal Campus):

Performing a citizen science project involving education institutions such as university campuses and schools is challenging with regard to planning. The water monitoring

project at the NWU (Vaal Campus) had to be conducted alongside other academic responsibilities. The researcher and pre-service teachers decided to monitor dams once a month on a Friday over a period from 2015 to 2016. The researcher had to plan monitoring sessions around pre-service teachers' tests, examinations and compulsory practical teaching. Arranging monitoring activities at schools was also problematic because teachers did not respond to numerous phone calls or emails and the researcher had to visit schools in person to arrange the times and dates to hold the monitoring process. It was only after the third visit to schools that the monitoring was arranged (MPA 1, 13.1 (2015-2016)).

In the view of the researcher, performing the monitoring, i.e. the testing of physical parameters, is more difficult than biological monitoring (*cf.* 2.2.1.1). Citizen scientists will engage in biological monitoring for their own interest and often to conserve and count species like birds, frogs or butterflies. Seeing these creatures provides fulfilment to the citizen scientists and makes the task worth the effort. Water, air or soil monitoring as opposed to biological monitoring, is only relevant once long-term data are interpreted and analysed and the citizen scientist gains very little fulfilment from the monitoring activity. Volunteer motivation is therefore of utmost importance to maintain physical monitoring (*cf.* 3.7.1). The main gain of involvement in physical monitoring of a natural resource is the social learning which takes place (*cf.* 4.2.1-4.2.6; 5.3).

Sufficient funding is a necessary component of any citizen science project. In the water monitoring project held at the NWU (Vaal Campus) funding provided by the Scholarship of Teaching and Learning (SOTL) in 2015 allowed the researcher to buy the Somerset Water Quality test kits (MPA 9.1 (2015)).

While conducting the research and writing the report, the researcher was alert to the challenges of transdisciplinary research as indicated by Lang *et al.* (2012: 35-40) (*cf.* 1.6). The decision to determine the water quality of campus dams was therefore a joint decision by the researcher, pre-service students and the GCI committee. The lack of problem awareness was addressed and the challenge of problem ownership was solved by incorporating stakeholders such as Rand Water (the expert group); the GCI management committee (as communication steering base); and the pre-service teachers and learners (as data collectors). The legitimacy of participants was assured by using diverse participant groups which contributed to cultivating and nurturing unique insights and knowledge in the research study (4.2 & 4.3). Quality standards were

ensured by using the Somerset test kits (which Rand Water prescribed) and having measurements validated by Rand Water officials. Adherence to the South African Water Quality Guidelines (1996 a&b) and the Rand Water Water Quality Guidelines for the Barrage Catchment (*cf.* 5.3) also validated the data.

None of the participants withdrew before the finalisation of the project showing that there was continuous participation. Fear of failure was addressed when the research project was completed within six months of the final measurements and school visits. The case-specific solutions which arose from the research, were generalised at the time of developing the citizen science framework (*cf.* 6.3) and the three-tiered systems framework (*cf.* 7.5). The outcomes of this transdisciplinary study were realised when some of the adaptive management proposals (*cf.* 5.3.5) were implemented at NWU (Vaal Campus).

Possible limitations of the NWU (Vaal Campus) water monitoring project include the following:

The water monitoring team was not supported by other students on the campus – therefore it could not serve as a social learning opportunity for more people. Attempts were made in 2015 to raise awareness among the wider student population about the campus's unique water storage resource but this proved largely unsuccessful and tended to discourage the pre-service teachers in their efforts. The researcher had to work hard to maintain the focus of the pre-service teachers on the added benefits of the monitoring project (MPA 1 (2015.03.13)).

To make the water monitoring project sustainable, the campus water storage resources must be monitored continuously. The appointment of an environmental manager at the NWU (Vaal Campus) as proposed by the researcher would mean that monitoring could be sustainable. A fulltime environmental manager could also act more efficiently on the adaptive management proposals regarding the campus water storage resource (*cf.* 5.5).

The data gleaned from water samples tested at schools could perhaps have been included in this research to provide a comprehensive picture of community water. However the researcher decided against this because the exact location where the water samples were collected was often unclear. Furthermore, the inclusion of school water samples was problematic because the time available for monitoring at schools was limited and all samples had the same temperature, which was room temperature.

Temperature influences the dissolved oxygen, percentage saturation and bio-dissolved oxygen readings so only half of the parameters could be tested.

8.8 SUGGESTIONS FOR FURTHER RESEARCH

The broad scope of citizen science projects provides for possible research opportunities of which a few are mentioned below.

Citizen science projects, especially those which focus on physical parameters, can aid with pre-service teacher training to promote subject knowledge and practical skills. A possible research project could therefore study the classroom practice of teachers who were exposed to citizen science projects during teacher training and those who were not, in relation to specific themes.

The environmental attitude of pre-service teachers and learners can be established with closed questions before and after exposure to citizen science projects.

The self-efficacy of pre-service teachers and teachers who lead climate change projects could be researched by using quantitative and qualitative questionnaires, as well as interviews.

The deliberate inclusion of environmental education themes in module outcomes in university programmes and in school curricula could be researched by means of document analysis and focus-group interviews; or quantitatively by means of multiple choice questions.

The exposure of different groups of participants for different time periods in a citizen science project could be compared via interviews or open-ended questions.

The inclusion of both biological and physical parameters in a citizen science project will allow researchers to compare volunteer experience and attitudes towards the different parameters through interviews or open-ended questions.

A follow up research on an air quality project via citizen science and the involvement of an expert group at the NWU (Vaal Campus) is a possibility for future research which supports social capital.

The use of project-based teaching in different modules at a university campus can be compared on the scope and duration of the projects, as well as student responses to the project.

The use of newer technology, for example, telephone applications, and connections with global organisations as a possible means of sharing data from South Africa is another possible avenue of research.

8.9 CONCLUSION

This citizen science project which took the form of community-based water monitoring with pre-service teachers and Grade 10 Physical Science learners, provided an opportunity to explore environmental education, social learning and project-based teaching. The research study reveals that all participants gained from the NWU (Vaal Campus) monitoring project.

The focus of this research evolved around the theories of social learning and how to implement social learning in curricula at different educational institutions. Social learning is defined as being a landscape of practice which is dynamic and emerging; it may split, complete or complement communities. The NWU (Vaal Campus) water monitoring activity proved that a unique landscape of practice comprising diverse groups of participants with different degrees of involvement and contribution to water quality, did indeed aid social learning.

Social learning, as a landscape of practice, also provided for learning outside curriculum content. The researcher had the opportunity of getting to know her students, the pre-service teachers, in an informal manner. How many lecturers can claim to know the hometown of their students, their family structure, whether, for example, they are single parents or have disabled parents, and whether others in the family have had access to higher education? This bond of trust and respect between the researcher and her pre-service teachers is unique and remains beyond the NWU (Vaal Campus) water monitoring project. Although the pre-service teachers are in their final year of the BEd programme and the researcher does not currently teach them they often visit her in her office just to greet her, ask for advice or indicate that they are available if she needs them in any way.

The learners treated both the researcher and the pre-service teachers like celebrities at schools. The researcher attended the monitoring exercise in the classrooms; her white laboratory jacket was an instant success and many learners posed for cell phone photos with both pre-service teachers and the researcher.

Different time scales were appropriate for different groups of learners. The pre-service teachers were engaged in the project for a period of two years and the school learners only for an hour and a half. The pre-service teachers' extended exposure made it possible for the researcher to realise that the pre-service teachers showed signs of a change of attitude on environmental matters. Social learning supports double loop learning which refers to gained subject knowledge and skills, and a change in attitude which results in action. This double loop learning was certainly in evidence in the student teachers' contribution to community-based monitoring on the campus and in their service learning at schools.

In this research study all participants were treated as valuable contributors to the acquisition of knowledge. This approach of mutual respect between participants embraced the inclusion of indigenous knowledge and diverse contributions of different forms of knowledge whether it was novice, expert, organisational or systemic. Social learning has the ability to cross all manner of boundaries and in this project the central focus of water quality diminished these boundaries and different groups of participants were able to meet on common ground.

The engagement of the researcher in the monitoring project, which consisted of planning, assessment and reflective practices, provided for an in-depth view on social learning. Presenting the research findings of the water monitoring project to academia at symposiums and PhD seminars exposed the researcher to a wide range of knowledgeable scholars. The transdisciplinary nature of the research study provided for extended application of this research study in several interrelated fields and opened the way for networking with academics at other higher education institutions.

Although the NWU (Vaal Campus) does not provide for a formal BSc. Chemistry course, the lecturer successfully incorporated a scientific inquiry with BEd. students. The citizen science framework and three-tiered system framework which the researcher structured in Chapter 6 and 7, provides valuable guidance for future projects that incorporate similar contexts (*cf.* 6.3.1 & 7.5).

The water monitoring project at the NWU's Vaal Campus indicated the commitment of the NWU Vaal campus community to community service. Currently all work-integrated learning (teaching practice) by pre-service teachers consists of video recorded lessons distributed to BEd lecturers via e-mail. Lecturers assess the students' teaching and learning practice from the recorded video lessons. The water monitoring project at local schools allowed the researcher to assess the Physical Science pre-service teachers in a real-life scenario. Not only was the researcher able to direct them on matters of discipline and classroom practice, but she was immediately available to facilitate pre-service teacher concerns about subject content and the monitoring process per se.

The commitment of university campuses to communities and involvement of expert groups, for example, Rand Water, in teaching and learning cannot be over-emphasised. Higher education institutions, as demanded by business policy, need to commit to social and community support. The inclusion of expert groups or organisations NWU Vaal projects not only exposed students to social learning, but also fulfilled a higher aim of social responsibility. The main gain for students is in the interaction with a wider pool of learning which proved fruitful for both students and experts. The position of the researcher in this research study as a co-learner enabled the pre-service teachers to let go of learning fears and embrace the exposure to new learning opportunities.

Participant involvement in the community-based water monitoring project is a bottom-up approach. The involvement of pre-service teachers and learners indicated that community members can contribute to problem-solving regarding environmental matters. The NWU (Vaal Campus) monitoring project had unique properties which could not be generalised in another context. Involvement of these groups of participants indicated a healthy community which responded to the call of a complex community problem.

The water monitoring project (NWU Vaal Campus) increased community resilience by enhancing social learning. The pre-service teachers became aware of the lack of environmental concern among their fellow students and the campus management's lack of financial support to deal with environmental concerns on the campus. Campus management was provided with a scientific report revealing the water quality status of the campus water storage resource and adaptive management proposals. It was alerted to the health risks involved if the water quality was allowed to deteriorate even further. The water monitoring project called for commitment and persistence from the pre-

service teachers over an extended two year period. Although the final reward for this commitment was not immediately evident, the possibility of future advantages from the monitoring project in their teaching careers is assured.

Citizen science is an emerging research field in South Africa, one that provides multiple opportunities for accommodating new technology, international expertise and the acquisition of knowledge, skills and social capital. The adaptive management proposals made to the NWU (Vaal Campus) management will hopefully bear fruit in the near future. This research study adhered to the core principles of transdisciplinarity by providing both scientific and societal targeted products. The thesis, possible articles which may arise from it and the theoretical frameworks on which it is based, make a contribution to scientific knowledge.

BIBLIOGRAPHY

Sources consulted

Primary sources

Available on attached CD

Irene Muller Private Archive (MPA) content list

MPA 1 Reflections by researcher

MPA 1.1 Reflective diary

MPA 1.2 Table 1.1 Co-creation of knowledge in water monitoring project

MPA 2 Photographs

MPA 3 Interviews

MPA 3.1 Steenkamp, N. (Rand Water representative) (08/05/2015 & 20/07/2015)

MPA 3.2 Tempelhoff, J. (8, 20/02/2015; 22/07/2015)

MPA 3.3 Scholtz, B. (2015/07/22)

MPA 4 Open-ended questionnaires to students (NWU (Vaal Campus) water monitoring project) – (in pdf format) (06/02/2015; 13/02/2015; 20/02/2015; 08/05/2015; 20/10/2015) (05/09/2016)

MPA 4.1 Student 1

MPA 4.2 Student 2

MPA 4.3 Student 3

MPA 4.4 Student 4

MPA 4.5 Student 5

MPA 4.6 Student 6

MPA 4.7 Student 7

MPA 4.8 Student 8

MPA 4.9 Researcher analysis of student questionnaires

Atlas ti program – available on personal computer

MPA 5 Open-ended questions to learners

School visits: (14/04/2016; 20/07/2016; 02/08/2016; 31/08/2016)

MPA 6 Green Campus Initiative-documentation

MPA 6.1 GCI agenda for meetings

Date of relevant meetings: (11/05/2015; 20/07/2015; 09/09/2015; 13/10/2015; 16/02/2016; 11/04/2016; 23/05/2016; 18/07/2016; 23/08/2016; 27/09/2016; 21/11/2016)

MPA 6.2 GCI minutes of meetings

Date of relevant minutes of meetings: (11/05/2015; 20/07/2015; 09/09/2015; 13/10/2015; 16/02/2016; 11/04/2016; 23/05/2016; 18/07/2016; 23/08/2016; 27/09/2016; 21/11/2016)

MPA 6.3 GCI actions

MPA 7 Video recordings

MPA 7.1 Teaching Practice Symposium, NWU (Vaal) (26/10/2015)

MPA 8 Quantitative data of NWU Vaal Campus Dams – Excel sheet

MPA 9 Funding: evidence of Scholarship of Teaching and Learning (NWU) SOTL application and Somerset Educational

MPA 9.1 SOTL application 2016

MPA 9.2 SOTL approval 2016

MPA 10 Gauteng Department of Education – documents and communication

MPA 10.1 GDE approval of project (30/06/2015)

MPA 10.2 GDE approval of project 2016 (27/10/2015)

MPA 10.3 Report to GDE after completion of project (01/11/2016)

MPA 11 Power Point Presentations

MPA 11.1 Going places – Water monitoring at the NWU (Vaal Campus) – a project-based teaching approach (31/05/2016) – presentation at ADS Teaching Seminar (NWU Vaal Campus)

MPA 11.2 Project-based inquiry – an approach in teaching practise (26/10/2016) – presentation with pre-service teachers at Teaching –Learning Symposium (NWU Vaal Campus)

MPA 11.3 A community-based water monitoring project: a trans-disciplinary case study (11/06/2016) – presentation at Community Involvement Symposium (NWU Vaal Campus)

MPA 11.4 Real life learning opportunities and project-based teaching practice – a match made in water (11/10/2016) – presentation at Teaching –Learning Symposium (NWU Vaal Campus)

MPA 11.5 Ph D colloquium: A citizen science water monitoring project: an environmental education opportunity from university campus to community school (01/02/2017)

MPA 12 Water Quality Monitoring Documents to pre-service teachers

MPA 12.1 WQM document to collect data

MPA 12.2 Pre-service teachers' arrangements for WQ measurements at schools

MPA 13 Water Quality Monitoring Documents to schools and learners

MPA 13.1 Letter to schools to arrange WQ measurements with learners

MPA 13.2 WQ scientific report for learners

MPA 13.3 Letter to Grade 10 learners to arrange WQ measurements

MPA 13.4 Open-ended questions to learners

MPA 13.5 WQ rubric to aid with assessment of learner WQ reports

MPA 14 Ethical documents

MPA 14.1 Consent of campus rector for WQ project at NWU (Vaal Campus)
(16/06/2016)

MPA 14.2 Parent consent letter in English

MPA 14.3 Parent consent letter in Sesotho

MPA 14.4 Learner assent letter in English

MPA 14.5 Approval of study: CAD (08/06/2016)

MPA 14.6 Approval of study: BassREC (24/08/2016)

Secondary sources

Alcock, P.G. 2010. Rainbows in the mist: indigenous weather knowledge, beliefs and folklore in South Africa. Pietermaritzburg: Intrepid Printers.

Alender, B. 2016. Understanding volunteer motivations to participate in citizen science projects: a deeper look at water quality monitoring. *Journal of science communication*, 16(3):1-19.

Ayas, K. & Zeniuk, N. 2001. Project-based learning: building communities of reflective practitioner. *Management learning*, 32(1):61-76.

Babbie, E. 2013. The practice of social research. 13th ed. Wadsworth: Cengage Learning.

Ballard H.L., Trettevick, J.A. & Collins D. 2008. Comparing participatory ecological research in two contexts: an immigrant community and a Native American community on Olympic Peninsula, Washington. (In Wilmsen, C., Elmendorf, W., Fisher, L., et al., eds. Partnerships for empowerment: participatory research for community-based natural resource management. London: Earthscan. p. 187-215).

Bandura, A. 1971. A theory of social learning. New York: General Learning Press.

Bandura, A. 1977. Social learning theory. New York: General Learning Press.

Bandura, A. 1986. Social foundations of thought and action. Englewood Cliffs, N.J.: Prentice Hall.

Barnard, P. & De Villiers, M. 2012. Biodiversity early warning systems: South African citizen scientists monitoring change. Pretoria: South African National Biodiversity Institute (SANBI).

Barron, B.J.S. 1998. Doing with understanding: lessons from research on problem- and project-based learning. *Journal of learning sciences*, 7(3&4):271-311.

Baum, F., MacDougall, C. & Smith, D. 2006. Participatory action research. *Journal of epidemiology and community health*, 60(10):854-857.

Beisheim, D. 2013. Potchefstroom water crisis continues: full list of designated water tanker areas. <http://www.ofm.co.za/article/local-news/129220/potch-water-crisis-continues-full-list-of-designated-water-tanker-areas> Date of access: 3 Feb 2017.

Bergmann, M., Jahn, T., Knobloch, T., Krohn, W., Pohl, C. & Schramm, E. 2012. Methods for transdisciplinary research: a primer for practice. Frankfurt: Campus Verlag.

Blackmore, C. 2007. What kinds of knowledge, knowing and learning are required for addressing resource dilemmas?: a theoretical overview. *Environmental science and policy*, 10(6):512-523.

Bonney, R., Cooper, C.B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K.V. & Shirk, J. 2009a. Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience*, 59(11):977-984.

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J. & Wilderman, C.C. 2009b. Public participation in scientific research: defining the field and assessing its potential for informal science education. Washington, D.C.: Centre for Advancement of Informal Science Report. (A CAISE Inquiry Group Report.)

Braskamp, L. & Wergin, J. 1998. Forming new social partnerships. (In Tierney, W., ed. The responsive university: restructuring for higher performance. Baltimore, Md.: Johns Hopkins University Press. p. 62-91).

Breiting, S. & Wickenberg, P. 2010. The progressive development of environmental education in Sweden and Denmark. *Environmental education research*, 16(1):9-37.

Brundiers, K., Wiek, A. & Redman, C.L. 2010. Real-world learning opportunities in sustainability: from classroom into the real world. *International journal of sustainability in higher education*, 11(4):308-324.

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Bastiaensen, J., De Bievre, B., Bhusai, J., Clark, J., Dewulf, A., Foggin, M., Hannah, D.M., Hergarten, C., Isaeva, A., Karpousoglou, T., Pandya, B., Paudel, D., Sharma, K., Steenhuis, T., Tilahun, S., Van Hecken, G. & Zhumanova, M. 2014. Citizen science in hydrology and water sources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontier earth science*, 2(16).

Date of access: 30 Aug. 2016.

Campbell, T., Medina-Jerez, W., Erdogan, I. & Zhang, D. 2010. Exploring science teachers' attitudes and knowledge about environmental education in three international teaching communities. *International journal of environmental and science education*, 5(1):3-29.

Carr, A.J.L. 2004. Why do we all need community science? *Society and natural resource*, 17:841-849.

Carter, R.L. & Simmons, B. 2010. The history and philosophy of environmental education. (In Bodzin, A.M., Klein, B.S. & Weaver, S., eds. The inclusion of environmental education in science teacher education. New York: Springer. p. 3-16).

Conrad, C.C. & Hilchey, K.G. 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. *Environmental monitoring assessment*, 176(1):273-291.

Conrad, C.T. & Daoust, T. 2007. Community-based monitoring frameworks: increasing the effectiveness of environmental stewardship. *Environmental management*, 41(3):358-366.

Cooper, C.B., Dickinson, J., Phillips, T. & Bonney, R. 2007. Citizen science as a tool for conservation in residential ecosystems. *Ecology and society*, 12(2):11.

Council of Scientific and Industrial Research (CSIR). 2010. A CSIR perspective on water in South Africa - 2010. <http://www.csir.co.za>. Date of access: 25 Jan. 2016.

Craigie, F., Saayman, P. & Fourie, M. 2010. Environmental compliance and enforcement institutions. (In Paterson, A. & Kotze, L.J., eds. Environmental compliance and enforcement in South Africa: legal perspectives. Claremont: Juta. p. 65-102).

Creswell, J.W. 2009. Research design: qualitative, quantitative and mixed methods approaches. 3rd ed. Los Angeles, Calif.: Sage Publications.

Cuff, D., Hansen, M. & Kang, J. 2008. Urban sensing: out of the woods. *Communications of the ACM*, 51(3):24-33.

Cundill, G. 2010. Monitoring social learning processes in adaptive co-management: three case studies from South Africa. *Ecology and society*, 15(3):28-47.

Curtin, M. & Fossey, E. 2007. Appraising the trustworthiness of qualitative studies: guidelines for occupational therapists. *Australian occupational therapy journal*, 54(2):88-94.

Danielsen, F., Burgess, N.D., Balmford, A., Donald, P.F., Funder, M., Jones, J.P.G., Alviola, P., Balete, D.S., Blomley, T., Brashares, J., Child, B., Enghoff, M., Fjeldsa, J., Holt, S., Hubertz, H., Jensen, A.E., Jensen, P.J., Massao, J., Mendoza, M.M., Ngaga, Y., Poulsen, M.K., Rueda, R., Sam, M., Skielboe, T., Stuart-Hill, G., Topp-Jorgensen, E. & Yonten, D. 2008. Local participation in natural resource monitoring: a characterization of approaches. *Conservation biology*, 23(1):31-42.

De Klerk, P. & Moller, P. 2005. Ontstaan en ontwikkeling van die Vaaldriehoekskampus. (In Van Eeden, E.S., red. In U lig: die PU vir CHO van selfstandigwording tot samesmelting, 1951 tot 2004. Potchefstroom: Noordwes-Universiteit. p. 443-485).

Dickenson, J.L., Shirk, J., Bonter, D., Bonney, R., Crain, R.L., Martin, J., Phillips, T. & Purcell, K. 2012. The current state of citizen science as a tool for ecological research and public engagement. *Frontier ecology environment*, 10(6):291-297.

Disterheft, A., Ferreira da Silva Caeiro, S.S., Ramos, M.R. & De Miranda Azeiteiro, U.M. 2012. Environmental management systems (EMS) implementation processes and practices in European higher education institutions: top-down versus participatory approaches. *Journal of cleaner production*, 31:80-90.

Doppelt, Y. 2003. Implementation and assessment of project-based learning in a flexible environment. *International journal of technology and design education*, 13(3):255-272.

Du Plessis, A. 2010. Understand the legal context. (In Paterson, A. & Kotze, L.J., eds. Environmental compliance and enforcement in South Africa: legal perspectives. Claremont: Juta. p. 11-40).

Du Plessis, C. 2008. A conceptual framework for understanding social-ecological systems. (In Burns, M.E.R & Weaver, A., eds. Exploring sustainability science: a Southern Africa perspective. Stellenbosch: African Sun Media. p. 59-90).

Du Toit, J. 2015. South Africa's drought angles step up. *SA People News*, 30 December 2015. <http://www.sapeople.com/2015/12/30/south-africas-drought-angles-step-up/> Date of access: 1 Feb. 2015.

Earth Echo Water Challenge. 2016. News. <http://www.monitorwater.org/> Date of access: 29 Jul. 2016.

Ebersöhn, L., Eloff, I. & Ferreira, R. 2007. First steps in action research. (In Maree, K., ed. *First steps in research*. Pretoria: Van Schaik Publishers. p. 124-141).

Emfuleni Local Municipality. 2017. Water restrictions. http://www.emfuleni.gov.za/images/docs/notices/2017/water_restrictions.pdf. Date of access: 31 Jan. 2017.

Enengel, B., Muhar, A., Penker, M., Freyer, B., Drlik, S. & Ritter, F. 2012. Co-production of knowledge in transdisciplinary doctoral theses on landscape development: an analysis of actor roles and knowledge types in different research phases. *Landscape and urban planning*, 105(1):106-117.

Environmental Protection Agency (EPA). 2017. Health effects of polluted water. <https://www.epa.gov/nutrientpollution/effects-human-health> Date of access: 1 Feb. 2017.

Equal Education. 2013. School infrastructure: overview and history. *Equal education*. <http://www.equaleducation.org.za/page/school-infrastructure>. Date of access: 9 Feb. 2016.

Essop, A. 2016. Fees must fall but not at the expense of quality higher education. <http://theconversation.com/fees-must-fall-but-not-at-the-expense-of-quality-higher-education-62520> Date of access: 2 Feb. 2017.

Fazey, I. 2010. Resilience and higher order thinking. *Ecology and society*, 15(3):52.

Fernandez-Gimenez, M.E., Ballard, H.L. & Sturtevant, V.E. 2008. Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organisations in the western USA. *Ecology and society*, 13(2):4. <http://www.ecologyandsociety.org/vol13/iss2/art4/> Date of access: 27 Mar. 2015.

Fodder Solutions. 2017. Barley fodder. <http://www.foddersolutions.com.au/nutrition>
Date of access: 1 Feb. 2017.

Freire, P. 2005. Pedagogy of the oppressed. 30th ed. New York: Continuum International Publishing Group.

Gasa, S. & Dougan, L. 2016. Fees must fall 2016: where to from here? <http://www.groundup.org.za/article/fees-must-fall-2016-where-here/> Date of access: 1 Feb. 2017.

Grauer, K. 2012. A case for case study research in education. (*In Klein, S.R., ed. Participatory action research methods plain and simple. New York: Palgrave Macmillan. p. 69-80*).

Gray, D.E. 2012. Doing research in the real world. 2nd ed. Los Angeles, Calif.: Sage Publications.

Hirsch Hadorn, G.H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Hoffman-Riem, H., Joye, D., Pohl, C., Wiesmann, U. & Zemp, E. 2008. The emergence of transdisciplinarity as a form of research. (*In Hirsch Hadorn, G.H., Hoffmann-Riem, H., Biber-Klemm, S., Grossenbacher-Mansuy, W., Joye, D., Pohl, C., Wiesmann, U. & Zemp, E., eds. Handbook of transdisciplinary research. New York: Springer. p. 19-42*).

Hanly, P. 2015. Fees must fall. *MyNews24*, 22 Oct. <http://www.news24.com/MyNews24/Fees-must-Fall-20151022> Date of access: 23 Sept. 2016.

Harding, R.W. 2006. A research strategy for the detection and management of algal toxins in water source. A report to the Water Research Commission, South Africa. Gezina: Water Research Commission.

Harris, F. & Lyon, F. 2013. Transdisciplinary environmental research: building trust across professional cultures. *Environmental science and policy*, 31:109-119.

Hartleb, T. 2015. SA's water treatment works in critical state. *News 24*, 29 July. <http://www.news24.com/SouthAfrica/News/SAs-water-treatment-works-in-critical-state-20150729> Date of access: 1 Mar. 2016.

Hawker, D. 2015. Pit toilet death haunts mother despite changes at Limpopo school. *ENCA news*, 12 January 2015. <https://goo.gl/lxEYYz> Date of access: 8 February 2016.

- Hinckley, C. 2005. Exploring the use of television for guidance of expectant fathers. (In Maree, K. First steps in research. Pretoria: Van Schaik Publishers. p. 284-302).
- Holbrook, J. & Rannikmae, M. 2007. The nature of science education for enhancing scientific literacy. *International journal of science education*, 29(11):1347-1362.
- Holling, C.S. 1973. Resilience and stability of ecological systems. *Annual review of ecology and systematic*, 4(1):1-23.
- Huitema, D.E., Mostert, E., Egas, W., Moellenkamp, S., Pahl-Wostl, C. & Yalcin, R. 2009. Adaptive water governance: assessing the institutional prescriptions of adaptive (co-)management from a governance perspective and defining a research agenda. *Ecology and society*, 14(1):26. <http://www.ecologyandsociety.org/vol14/iss1/art26/>. Date of access: 18 Apr. 2015.
- Hungerford, H.R. 2009. Environmental education (EE) for the 21st century: where have we been? Where are we now? Where are we headed? *Journal of environmental education*, 41(1):1-6.
- Ivankova, N.V., Creswell, J.W. & Plano Clark, V.L. 2007. Foundations and approaches to mixed methods research. (In Maree, K., ed. First steps in research. Pretoria: Van Schaik Publishers. p. 253-282).
- James, E.A., Slater, T. & Bucknam, T. 2012. Action research for business, non-profit and public administration: a tool for complex times. Thousand Oaks, Calif.: Sage Publications.
- James, M. & Card, K. 2012. Factors contributing to institutions achieving environmental sustainability. *International journal of sustainability in higher education*, 13(2):166-176.
- Jickling, B. & Wals, A.E.J. 2008. Globalization and environmental education: looking beyond sustainable development. *Journal of curriculum studies*, 40(1):1-21.
- Keen, M., Bruck, T. & Dyball, R. 2005. Social learning: a new approach to environmental management. (In Keen, M., Brown, V. & Dyball, R., eds. Social learning in environmental management: towards a sustainable future. London: Earthscan. p. 3-21).

- Kidd, S.A. & Kral, M.J. 2005. Practicing participatory action research. *Journal of counselling psychology*, 52(2):187-195.
- Killen, R. 2010. Teaching strategies for quality teaching and learning. Claremont: Juta.
- Kings, S. 2015. Sewage in Gauteng's drinking water. <http://mg.co.za/article/2015-07-23-sewage-in-gautengs-drinking-water> Date of access: 1 Feb. 2017.
- Klein, S.R. 2012. Participatory action research: before you dive in, read this! (In Klein, S.R., ed. Participatory action research methods plain and simple. New York: Palgrave Macmillan. p. 1-20).
- Klein, S.R. & Agostinone-Wilson, F. 2012. Visual research, visual data. (In Klein, S.R., ed. Participatory action research methods plain and simple. New York: Palgrave Macmillan. p. 81-103).
- Krathwohl, D.R. 2002. A revision of Bloom's taxonomy: an overview. *Theory into practice*, 41(4):212-218.
- Kruger, L.E. & Shannon, M.A. 2010. Getting to know ourselves and our places through participation in civic social assessment. *Society & natural resource: an international journal*, 13(5):461-478.
- Lang, D.J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M. & Thomas, C.J. 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainable science*, 7(1):25-43.
- Lawrence, A. 2006. 'No personal motive?' Volunteer biodiversity and the false dichotomies of participation. *Ethics, place & environment*, 9(3):279-298.
- Le Grange, L. 2002. Towards a "language of probability" for environmental education in South Africa. *South African journal of environmental education*, 22(2):83-87.
- Lee, K.N. 1999. Appraising adaptive management. *Conservation ecology*, 3(2):3. <http://www.consecol.org/vol3/iss2/art3/> Date of access: 30 Jul. 2016.
- Legg, C.J. & Nagy, L. 2006. Why most conservation monitoring is, but need not be, a waste of time. *Journal of environmental management*, 78(2):194-199.

- Lemkowitz, M., Bibo, B.H., Lameris, G.H. & Bonnet, J.A.B.A.F. 1996. From small scale, short term to large scale, long term: integrating 'sustainability' into engineering education. *European journal of engineering education*, 21(4):353-386.
- Lewenstein, B.V. 2016. Can we understand citizen science. *Journal of science communication*, 14(4). http://jcom.sissa.it/archive/15/01JCOM_1505 Date of access: 1 May 2017.
- Littledyke, M. 2008. Science education for environmental awareness: approaches to integrating cognitive and affective domains. <http://www.tandfonline-com.nwulib.nwu.ac.za/doi/pdf/10.1080/13504620701843301?needAccess=true> Date of access: 18 Jul. 2017.
- Lombard, J. 2004a. Waterslangverhale in Afrikaans: die relevansie van mitiesiteit. *Literator*, 25(1):113-137.
- Lombard, J. 2004b. Mitiesiteit as basis vir vergelykende literatuurstudie, met verwysing na waterslangsimboliek. *Literator*, 25(1):91-112.
- Lotz-Sisitka, H. 2002. Curriculum patterning in environmental education: a review of developments in formal education in South Africa. (In Janse van Rensburg, E., Hattingh, J., Lotz-Sisitka, H. & O'Donoghue, R., eds. *Environmental education, ethics and action in Southern Africa monograph*. Cape Town: HSRC Press. p. 97-120).
- Macknick, J.E. & Enders, S.K. 2012. Transboundary forestry and water management in Nicaragua and Honduras: from conflicts to opportunities for cooperation. *Journal of sustainable forestry*, 31(4-5):376-395.
- Maila, M.W. & Loubser, C.P. 2003. Emancipatory indigenous knowledge systems: implications for environmental education in South Africa. *South African journal of education*, 23(4):276-280.
- Maree, K. & Van der Westhuizen, C. 2007. Planning a research proposal. (In Maree, K., ed. *First steps in research*. Pretoria: Van Schaik Publishers. p. 26-44).
- Markham, T. 2011. Project based learning. *Teacher librarian*, 39(2):38-42.
- Matthews, S. 2014. Citizens indispensable in modern biodiversity protection. *The Water wheel*, 13(3):10-13. <http://www.wrc.org.za/> Date of access: 1 Sept. 2015.

Maxwell, J.A. 2013. Qualitative research design: an interactive approach. 3rd ed. Washington, D.C.: Sage Publications:

McCarthy, T.S. & Pretorius, J.P. 2009. Coal mining on the Highveld and its implication for future water quality in the Vaal River system. (Water Institute of Southern Africa (WISA) and International Mine Water Association (IMWA), Proceedings. p. 56-65).

McLoughlin, S. 2015. Enlisting citizen scientists MiniSASS evolves into a Smartphone app: what's in the citizen science toolkit. <http://www.news24.com/SouthAfrica/News/Enlisting-citizen-scientistsMiniSASS-evolves-into-a-smartphone-appWhats-in-the-citizen-science-toolkit-20150521> Date of access: 3 Mar. 2016.

Mertler, C.A. 2012. Action research improving schools and empowering educators. 3rd ed. Thousand Oaks, Calif.: Sage Publications.

Mezirow, J. 1997. Transformative learning: theory to practice. *New directions for adult and continuing education*, 74:5-12.

Miller, G.T. & Spoolman, S.E. 2012. Living in the environment. 17th ed. London: Cengage learning.

Mills, G.E. 2007. Action research: a guide for the teacher researcher. Upper Saddle River, N.J.: Pearson Education.

Minkler, M. 2000. Using participatory action research to build healthy communities. *Public health reports*, 115(2-3):191-197.

Mokgoatsana, S.N.C. 1997. Revisioning myth and ritual towards a reclamation and reconstruction of Sepedi traditional religious conceptions. *South African journal folklore studies*, 8(2):18-26.

Mosiua, T. 2016. Fees must fall reloaded: what does it all mean? <http://www.okayafrica.com/news/fees-must-fall-reloaded-south-africa-student-protests/> Date of access: 23 Sept. 2016.

Mostert, E., Craps, M. & Pahl-Wostl, C.M. 2008. Social learning: the key to integrated water resource management. *Water international*, 33(3):293-304.

Muller, I. 2014. Using the resilience assessment approach to evaluate social-ecological systems at the NWU (Vaal Campus). Potchefstroom: North-West University. (Dissertation - M Env Man).

Munnik, V., Molose, V., Moore, B., Tempelhoff, J., Gouws, I., Motloun, S., Sibiya, Z., Van Zyl, A., Malapela, P., Buang, B., Khoadi, J., Mhlambi, L., Morotolo, M., Mazibuko, R., Mlambo, M., Moeketsi, M., Qamakwane, N., Kumalo, N. & Tsotetsi, A. 2011. Final consolidated report: the potential of civil society organisations in monitoring and improving water quality. <http://cer.org.za/wp-content/uploads/2011/11/Mvula-final-WQ-report-nov-2011iw.pdf> Date of access: 18 Jun. 2015.

My Vaal River. 2016. Pump station 10 Vereeniging Mario Mulani. [Youtube video.] <https://www.youtube.com/watch?v=tmkgpbQDvkk> Date of access: 14 Oct. 2016.

Natures Valley Trust (NVT). 2016. Citizens science project. <http://www.Naturesvalleytrust.co.za/programmes/ecological-research/citizen-science-projects/> Date of access: 25 Jan. 2016.

Newman, G., Graham, J., Crall, A. & Laituri, M. 2011. The art and science of multi-scale citizen science support. *Ecological informatics*, 6(3):217-227.

Newman, G., Wiggins, A., Crall, A., Graham, E., Newman, S. & Crowston, K. 2012. The future of citizen science: emerging technologies and shifting paradigms. *Frontiers ecology environment*, 10(6):298-304.

Ngoepe, K. 2016. More students, no fees, puts pressure on universities. <http://www.news24.com/SouthAfrica/more-students-no-fees-puts-pressure-on-universities-20160810> Date of access: 2 Feb. 2017.

Nieuwenhuis, J. 2007. Qualitative research designs and data gathering techniques. (In Maree, K., ed. First steps in research. Pretoria: Van Schaik Publishers. p. 70-92).

North-West University. 2010. Campus plan Vaal Triangle before 2010. Vanderbijlpark: NWU.

North-West University. 2012. Campus plan Vaal Triangle 2010-2020. Vanderbijlpark: NWU.

North-West University. 2013. NWU Potchefstroom Campus suspends classes due to water crisis. <http://potchnews.nwu.ac.za/n/en/49> Date of access: 8 Feb. 2015.

North-West University. 2016. Statement by the NWU institutional management. *North-West University News*, 4 April. <http://news.nwu.ac.za/statement-nwu%C2%B4s-institutional-management> Date of access: 22 Sept. 2016.

Olivier, C. 2016. Seasonal climate watch December 2016 to April 2017. <http://www.gfcsa.net/SAWS/saws.pdf>. Date of access: 30 Jan. 2017.

Osborne, J., Simon, S. & Collins, S. 2003. Attitudes towards science: a review of the literature and its implications. *International journal of science education*, 25(9):1049-1079.

Otieno, F. & Adeyemo, J. 2012. Drinking water quality at some schools in the rural areas of Kwazulu-Natal Province of South Africa. (Paper presented at the WISA 2012 Bi-annual Conference and Exhibition, Cape Town.) <http://www.ewisa.co.za/literature/files/ID77%20Paper56%20Otieno%20F.pdf>. Date of access: 8 Feb. 2016.

Overdevest, C., Orr, C.H. & Stepenuck, K. 2004. Volunteer stream monitoring and local participation in natural resource issues. *Human ecology review*, 11(2):177-185.

Pahl-Wostl, C., Craps, M., Dewulf, A., Mostert, E., Tabara, D. & Tailieu, T. 2007. Social learning and water resource management. *Ecology and society*, 12(2):5. <http://www.ecologyandsociety.org/vol12/iss2/art5/> Date of access: 29 Sept. 2015.

Pauw, J. 2009. SAEON pays tribute to SA's citizen scientists. <http://www.saeon.ac.za/enewsletter/archives/2009/july-2009/saeon-pays-tribute-to-sa2019s-citizen-scientists> Date of access: 3 Mar. 2016.

Petterson, D. 2016. Vaal system under threat of collapse. <file:///E:/info%20chpt%205/Vaal%20System%20under%20threat%20of%20collapse%20%20Infrastructure%20news.html>. Date of access: 31 Jan. 2017.

Phillipson-Mower, T. & Adams, A.D. 2010. Environmental education service-learning in science teacher education. (In Bodzin, A.M., Shiner Klein, B. & Weaver, S., eds. The inclusion of environmental education in science teacher education. Singapore: Springer. p. 65-79).

Pietersen, J. & Maree, K. 2007a. Statistical analysis I:descriptive statistics. (In Maree, K., ed. First steps in research. Pretoria: Van Schaik Publishers. p. 182-196).

Pietersen, J. & Maree, K. 2007b. Statistical analysis II:inferential statistics. (In Maree, K., ed. First steps in research. Pretoria: Van Schaik Publishers. p. 197-213).

Polk, M. 2015. Transdisciplinary co-production: designing and testing a transdisciplinary research framework for societal problem solving. *Futures*, 65:111-122.

Pollock, R.M. & Whitelaw, G.S. 2005. Community-based monitoring in support of local sustainability, local environment. *Local environment*, 10(3):211-228.

Porteous, A. 2008. Directory of environmental science and technology. 4th ed. West Sussex: Wiley.

Potschin, M. & Haines-Young, R. 2006. Rio+10, sustainability science and landscape ecology. *Landscape and urban planning*, 75(3):162-174.

Pouliot, C. 2009. Using the deficit framework, public debate framework and co-production of knowledge frameworks to interpret points of view of students concerning citizens' participation in socioscientific issues. *International journal of environmental and science education*, 4(1):49-73.

Powers, A.I. 2004. An evaluation of four place-based education programs. *Journal of environmental education*, 35(4):17-32.

Prestopnik, N.R. & Crowston, K. 2012. Citizen science system assemblages: understanding the technologies that support crowd sourced science. (Proceedings of a Conference, February, 7-10, 2012. Toronto, Ontario, Canada).

Prinsloo, E. 2015. Afriforum worried about drinking water and rivers in Emfuleni. Afriforum, 24 April. <https://www.afriforum.co.za/afriforum-worried-drinking-water-rivers-emfuleni/> Date of access: 18 Jun. 2015.

Ramsarup, P. 2013. Reviewing national ESD experiences: South Africa (In UNESCO National journeys towards education for sustainable development Paris: UNESCO p.55 - 84.)
https://books.google.co.za/books?id=0Fiw6H_eWd8C&pg=PP4&lpg=PP4&dq=Ramsarup+2013&source=bl&ots=obr_ESf76E&sig=ceZy6ZdeS7FJNM5L3edqXFSxuSU&hl=en&

sa=X&ved=0ahUKEwjfl-K0vZfVAhWGOxQKHcc_DqEQ6AEIODAF#v=onepage&q=Ramsarup%202013&f=false

Date of access: 20 Jul. 2017.

Rand Water. 2014. Water purification. <http://www.randwater.co.za/WaterAndInfrastructureManagement/Pages/WaterPurification.aspx> Date of access: 1 Apr. 2016.

Rand Water. 2015. Water pollution and your health. <http://www.randwater.co.za/CorporateResponsibility/WWE/Pages/WaterPollution.aspx>

Date of access: 19 Jul. 2017.

Rand Water. 2016a. Rand Water information. <http://www.randwater.co.za/AboutUs/Pages/Default.aspx> Date of access: 25 Jul. 2016.

Rand Water. 2016b. Water and infrastructure management. <http://www.randwater.co.za/WATERANDINFRASTRUCTUREMANAGEMENT/Pages/WaterQuality.aspx> Date of access: 25 Jul. 2016.

Rand Water. 2017a. Rand Water Reservoir Website. <http://www.reservoir.co.za/> Date of access: 1 Febr. 2017.

http://www.reservoir.co.za/forums/vaalbarrage/barrage_forum/barrage_chemical_2016/RW_Barrage_Jan-Mar2016.pdf

http://www.reservoir.co.za/forums/vaalbarrage/barrage_forum/barrage_chemical_2016/RW_Barrage_Apr-Jun2016.pdf

http://www.reservoir.co.za/forums/vaalbarrage/barrage_forum/barrage_chemical_2016/RW_Barrage_Jul-Sep2016.pdf

http://www.reservoir.co.za/forums/vaalbarrage/barrage_forum/barrage_chemical_2016/RW_Barrage_Oct-Dec2016_Monthly.pdf

Rand Water. 2017b. Rand Water In-stream Water Quality Guidelines for the Barrage Reservoir Catchment. http://www.reservoir.co.za/forums/vaalbarrage/barrage_forum/barrage_documents/Barrage_WQGuidelines.pdf Date of access: 18 Jul. 2017.

Rand Water 2017c. Water purification in Vaal Barrage.

<http://www.randwater.co.za/CorporateResponsibility/WWE/Pages/tapwater.aspx>

Date of access: 19 Jul. 2017.

Raymond, C.M., Fazey, I., Reed, M.S., Stringer, L.C., Robinson, G.M. & Evely, A.C. 2010. Integrating local and scientific knowledge for environmental management. *Journal of environmental management*, 91(8):1766-1777.

Reddy, C. 2011. Environmental education and teacher development: engaging a dual curriculum change. *Southern African journal of environmental education*, 28:9-29.

Reed, M.S., Evelyn, A.C., Cundill, G., Fazey, I., Glass, J., Laing, A., Newig, J., Parrish, B., Prell, C., Raymond, C. & Stringer, L.C. 2010. What is social learning? *Ecology and society*, 15(4):1.

Rivett, U., Champanis, M. & Wilson-Jones, T. 2012. Monitoring drinking water quality in South Africa: designing information systems for local needs. *Water SA*, 39(3):409-414.

Roets, L. 2013. Water problems at the NWU (Potchefstroom Campus). [Personal interview.] Vanderbijlpark, 31 March.

Rossman, G.B. & Rallis, S.F. 2012. Learning in the field: an introduction to qualitative research. 3rd ed. Los Angeles, Calif.: Sage Publications.

Rotman, D., Hammock, J., Preece, J.J., Boston, C.L., Hansen, D.L. & Bowser, A. 2014. Motivations affecting initial and long-term participation in citizen science projects in three countries. (Conference Proceedings, 2014. p. 110-124).

Ruiz-Mallen, I., Barazza, L., Bodenhorn, B., Del la PlazCeja-Adame, M. & Reyes-Garcia, V. 2010. Contextualizing learning through the participatory construction of an environmental education programme. *International journal of science education*, 32(13):1755-1770.

Salafsky, N., Margoluis, R. & Redford, K. 2001. Adaptive management: a tool for conservation practitioners. Biodiversity support program. Washington, D.C. [E-book.]

- Sauve, L. 2002. Environmental education: possibilities and constraints. *UNESCO international science, technology and environmental education newsletter*, 27(1-2):1-4.
- Savan, B., Morgan, A.J. & Gore, C. 2003. Volunteer environmental monitoring and the role of universities: the case of citizens' environment watch. *Environmental management*, 31(5):561-568.
- Scholtz, B. 2015. Biodiversity at the NWU (Vaal). [Personal interview.] 22 Jul. 2015. Vanderbijlpark,
- Sharp, L. 2002. Green campuses: the road from little victories to systemic transformation. *International journal of sustainability in higher education*, 3(2):128-145.
- Shephard, K. 2008. Higher education for sustainability: seeking affective learning outcomes. *International journal of sustainability in higher education*, 9(1):87-98.
- Shirk, J.L., Ballard, H.L., Wilderman, C.C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B.V., Krasny, M.E. & Bonney, R. 2012. Public participation in scientific research: a framework for deliberate design. *Ecology and society*, 17(2):29. <http://dx.doi.org/10.5751/ES-04705-170229> Date of access: 1 March 2016.
- Skelcher, C., Mathur, N. & Smith, M. 2005. Governance of collaborative spaces: discourse, design and democracy. *Public administration*, 83(3):573-596.
- Solomon, G. 2003. Project-based learning: a primer. *Technology and learning-Dayton*, 23(6):20-30.
- Somerset Educational. 2015. Micro Life water quality test manual (code: 25E035 SA). Somerset East: Somerset Educational.
- South Africa National Biodiversity Institute (SANBI). 2016. Citizen science project. <http://biodiversityadvisor.sanbi.org/participaton/citizen-science/-sanbi> Date of access: 25 Jan. 2016.
- South Africa. 1995. White Paper on Education and Training. Cape Town: Government Printer.

South Africa. 1996a. Constitution of the Republic of South Africa. Pretoria: Government Printer.

South Africa. 1996a. Department of Water Affairs and Forestry. South African Water Quality Guidelines Volume 1 Domestic Use.

http://www.dwa.gov.za/IWQS/wq_guide/Pol_saWQguideFRESHDomesticusevol1.PDF

Date of access: 25 Jul. 2016.

South Africa. 1996b. Department of Water Affairs and Forestry (DWAF). South African Water Quality Guidelines Volume 4 Agricultural Use: Irrigation.

http://www.dwa.gov.za/IWQS/wq_guide/Pol_saWQguideFRESHIrrigationvol4.pdf

Date of access: 25 Jul. 2016.

South Africa. 1997. National Water Services Act 108 of 1997. Pretoria: Government Printer.

South Africa. 1998a. National Water Act 36 of 1998. Pretoria: Government Printer.

South Africa. 1998b. South Africa National Environmental Management Act 107 of 1998. Pretoria: Government Printer.

South Africa. 2002. Revised National Curriculum Statement.

<http://www.education.gov.za/Curriculum/NationalCurriculumStatementsGradesR-12.aspx> Date of access: 24 Jul. 2017.

South Africa. 2009. Report of the investigation by the ministerial task team into the North West University. (Notice 136.) *Government Gazette*, 31863, 2 Feb.

South Africa. Department of Basic Education (DBE). 2011a. Curriculum and assessment policy statement: grades 10-12: Physical science. Pretoria: Department of Basic Education.

South Africa. Department of Basic Education. 2011b. National Education Infrastructure Management Support Report 2011. Pretoria: Department of Basic Education.

South Africa. Department of Basic Education. 2014. National Education Infrastructure Management Support Report 2014. Pretoria: Department of Basic Education.

<https://edulibpretoria.files.wordpress.com/2008/01/school-infrastructure-report-2014.pdf>

Date of access: 9 Feb. 2016.

South Africa. Department of Government Communication and Information Systems. 2014. South African Yearbook 2013/2014. Pretoria. [http://www.gcis.gov.za/content/resourcecentre/sa-info/yearbook 2013-2014](http://www.gcis.gov.za/content/resourcecentre/sa-info/yearbook%202013-2014). Date of access: 22 July 2015.

South Africa. Department of Water Affairs (DWA). 2013. National Water Resource Strategy – water for an equitable and sustainable future.

<http://www.dwa.gov.za/nwrs/LinkClick.aspx?fileticket=3AVrHanrkfw%3d&tabid=91&mid=496> Date of access: 18 Jul. 2017.

South Africa. Department of Water Affairs (DWA). 2016. Water quality management in South Africa. https://www.dwa.gov.za/dir_wqm/aboutFrame.html

Date of access: 25 Jan. 2016.

South Africa. Department of Water and Sanitation (DWS). 2017. Resource water quality objectives. <http://niwis.dws.gov.za/niwis2/rwqo> Date of access: 20 Feb. 2017.

South Africa. Department of Water and Sanitation (DWS). 2017. WUA and CMF. <http://www.dwa.gov.za/search.aspx> Date of access: 18 Jul. 2017.

South African Institute for Distance Education (SAIDE). 2012. Getting practical: a guide to teaching and learning. 3rd ed. Cape Town: Oxford University Press.

South African National Standards (SANS). 2015. Blue drop limits. [http://selectech.co.za/ what-you-should-know-about-the-new-2015-blue-drop-limits-sans-2412015-drinking-water/](http://selectech.co.za/what-you-should-know-about-the-new-2015-blue-drop-limits-sans-2412015-drinking-water/) Date of access: 10 Sept. 2016.

South African Weather Service (SAWS). 2017a. El Niño. <http://www.weathersa.co.za/learning/climate-questions/33-what-is-el-nino-la-nina-and-the-el-nino-southern-oscillation> Date of access: 10 Jan. 2017.

South African Weather Service (SAWS). 2017b. Thunderstorms in Gauteng. <http://www.weathersa.co.za/warnings> Date of access: 30 Jan. 2017.

South African Weather Service (SAWS). 2017c. What kind of drought did South Africa experience? <http://www.weathersa.co.za/learning/climate-questions/36-what-kind-of-droughts-does-south-africa-experience> Date of access: 31 Jan. 2017.

Stem, C., Margoluis, R., Salafsky, N. & Brown, M. 2005. Monitoring and evaluation in conservation: a review of trends and approaches. *Conservation biology*, 19(2):295-309.

Steyn, P. & Cilliers, S. 2016. Verval op platteland 'kan tot ramp lei'. <http://www.netwerk24.com/Nuus/Droogte/water-woesteny-belfast-4-van-5-pompstasies-kapot-carolina-winkelwater-hul-redding-modimolle-wil-jy-hierin-bad-verval-op-platteland-kan-tot-ramp-lei-n-beeld-ondersoek> Date of access: 18 Jul. 2016.

Strydom, H. 2007. Participatory action research. (In De Vos, A.S., Strydom, H., Fouché, C.B. & Delport, C.S.L. Research at grass roots: for the social sciences and human service professions. Pretoria: Van Schaik Publishers. p. 491-506).

Tandlich, R., Luyt, C.D. & Ngqwala, N.P. 2014. A community-based rainwater monitoring and treatment programme in Grahamstown, South Africa. *Journal of hydrocarbons, mines and environmental research*, 5(1):46-51.

Tbilisi Declaration, 1977. <http://resources.spaces3.com/a30712b7-da01-43c2-9ff0-b66e85b8c428.pdf> Date of access: 18 Jul. 2016.

Tempelhoff, J. 2015. Purpose of campus dams. [Personal interview]. 8 Feb. & 22 Jul. 2015. Vanderbijpark,

Tempelhoff, J., Munnik, V. & Viljoen, M. 2007. The Vaal River Barrage, South Africa's hardest working water way: an historical contemplation. *Journal for trans-disciplinary research in Southern Africa*, 3(1):107-133.

The Reservoir. 2017. Water quality guidelines.

http://www.reservoir.co.za/forums/vaalbarrage/barrage_forum/barrage_documents/Barrage_WQGuidelines.pdf Date of access: 19 Jul. 2017.

Tibane, E. & Vermeulen, A. 2014. South African Yearbook 2013/2014. 21st ed. http://www.gcis.gov.za/sites/www.gcis.gov.za/files/docs/resourcecentre/yearbook/2013-4Water_Affairs.pdf Date of access: 18 Jul. 2017.

Tidball, K.G. & Krasny, M.E. 2007. From risk to resilience: what role for community greening and civic ecology in cities? (*In* Glasser, H., ed. Social learning towards a sustainable world: principles, perspectives, praxis. Wageningen: Academic Publishers. p. 149-164).

Turpie, J.K., Marais, C. & Blignaut, J.N. 2008. The working for water programme: evolution of payments for ecosystem services: a mechanism that addresses both poverty and ecosystem service delivery in South Africa. *Ecological economics*, 65(4):788-798.

Turton, A. 2015. Sitting on the horns of a dilemma: water as a strategic resource in South Africa. *@Liberty*, 6(22):1-23.

Tyler Miller, G. & Spoolman, S.E. 2012. Living in the environment. 17th ed. Canada: Cengage Learning.

United Nations Conference on Environment and Development (UNCED). 1992. The Earth Summit. <http://www.un.org/geninfo/bp/enviro.html> Date of access: 18 Jul. 2016.

United States Department of Agriculture (USDA). 2010. Designing your monitoring strategy: basic questions and resource to help guide you - Factsheet IV. <http://www.usawaterquality.org/volunteer/> Date of access: 17 May 2016.

United States Department of Agriculture (USDA). 2012. Evaluating your volunteer water quality monitoring program - Factsheet XVI. <http://www.usawaterquality.org/volunteer/> Date of access: 17 May 2016.

United States Department of Agriculture (USDA). 2012a. Training volunteer water quality monitors effectively - Factsheet V. <http://www.usawaterquality.org/volunteer/> Date of access: 17 May 2016.

United States Department of Agriculture (USDA). 2012b. Volunteer management and support - Factsheet VIII. <http://www.usawaterquality.org/volunteer/> Date of access: 17 May 2016.

United States Department of Agriculture (USDA). 2015. Building credibility: quality assurance and quality control for volunteer monitoring programs - Factsheet VI. <http://www.usawaterquality.org/volunteer/> Date of access: 17 May 2016.

United States Department of Agriculture (USDA). 2016. Matrix of monitoring activities. <http://www.usawaterquality.org/volunteer/> Date of access: 17 May 2016.

VAAL eNUUS. 2017. Wat is aan die gang by die dam? https://vaalenews.files.wordpress.com/2017/07/what-is-happening-at-the-dam.pdf?utm_campaign=VaaleNUUSJunieJulie2017&utm_medium=email&utm_source=ListName Date of access: 25 Jul. 2017.

Viebahn, P. 2002. An environmental management framework for universities: from environmental guidelines to staff involvement. *Journal of cleaner production*, 10(1):3-12.

Viljoen, F.C. 2006. A critical overview of water quality management into the future: a holistic approach is essential. <http://www.ewisa.co.za/literature/files/273%20viljoen.pdf> Date of access: 25 Jan. 2016.

Waghid, Y. 2002. Knowledge production and higher education transformation in South Africa: towards reflexivity in university teaching, research and community service. *Higher education*, 43(4):457-488.

Washington State. Department of Health. 2016. Coliform bacteria and drinking Water. <http://www.doh.wa.gov/portals/1/Documents/Pubs/331-181.pdf> Date of access: 15 Oct. 2016.

Water Quality and Health Council. 2017. Wastewater chlorination: an enduring public health practice. [file:///E:/info%20chpt%205/Water%20Quality%20and%20Health%20Council%20-%20Wastewater%20-%20Wastewater%20Chlorination %20An%20Enduring%20Public%20Health%20Practice.html](file:///E:/info%20chpt%205/Water%20Quality%20and%20Health%20Council%20-%20Wastewater%20-%20Wastewater%20Chlorination%20An%20Enduring%20Public%20Health%20Practice.html) Date of access: 31 January 2017.

Water Quality Association. 2016. Scale deposits. <https://www.wqa.org/learn-about-water/perceptible-issues/scale-deposits>. Date of access: 15 October 2016.

Watson, A. 2016. Vaal River in danger of sewage contamination. <http://citizen.co.za/news/news-national/1377437/vaal-river-in-danger-of-sewage-contamination/> Date of access: 31 Jan. 2017.

Wenger, E. 1998a. Communities of practice: learning as a social system. *Systems Thinker*: 1-7. https://scholar-google-co-za.nwulib.nwu.ac.za/scholar?q=wenger+1998+communities&btnG=&hl=en&as_sdt=0%2C5&oq=wenger+1998 Date of access: 8 Mar. 2015.

Wenger, E. 1998b. Communities of practice: learning, meaning, and identity. New York: Cambridge University Press.

Whitelaw, G., Vaughan, H., Craig, B. & Atkinson, D. 2003. Establishing the Canadian community monitoring group. *Environmental monitoring and assessment*, 88(1):409-418.

Wiggins, A. & Crowston, K. 2011. From conservation to crowdsourcing: a typology of citizen science. <http://andreawiggins.com/research/Wiggins2011HICSS.pdf>. Date of access: 30 Aug. 2016.

Wikipedia. 2016. Citizen science projects. https://en.wikipedia.org/wiki/List_of_citizen_science_projects Date of access: 1 March 2016.

Wikipedia. 2017. Soap. <https://en.wikipedia.org/wiki/Soap> Date of access: 1 Feb. 2017.

Wildlife and Environmental Society of South Africa. 2016. Stop dreaming and start doing (without the overwhelm). <http://www.wessa.org.za/what-we-do/schools-programme/eco-schools.htm> Date of access: 29 Mar. 2016.

Wood, F. 2005. The snake will swallow you: supernatural snakes and the creation of the Khotso legend. *Indilinga - African journal of indigenous knowledge systems*, 4(1):347-359.

Woolley, A.W., Chabris, C.F., Pentland, C.F., Hashmi, N. & Malone, T.W. 2010. Evidence for a collective intelligence factor in the performance of human groups. *Science*, 330:686-688.

World Commission on Environment and Development. 1987. Our common future. Oxford: Oxford University Press.

World Health Organisation. 2011. Nitrates and nitrites in drinking water - background document for development of WHO Guidelines for Drinking-water Quality. <file:///F:/nitratenitrite2ndadd.pdf> Date of access: 15 Oct. 2016.

World Meteorological Organisation (WMO). 2013. Planning of water quality monitoring systems. Geneva, Switzerland: WMO. (Technical report series number 3.)

Yarnell, P. & Gayton, D.V. 2003. Community-based ecosystem monitoring in British Columbia: a survey and recommendations for extensions. Kamloops, BC: Forrex Publishing.

Yende, S.S. 2016. Standerton sewage flowing into Vaal. <http://www.news24.com/SouthAfrica/News/standerton-sewage-flowing-into-vaal-20161023-2> Date of access: 10 Mar. 2017.

Yin, R.K. 2009. Case study research design and methods. 4th ed. Thousand Oaks, Calif.: Sage Publications.

Zucker, L.G. 1986. Production of trust: institutional sources of economic structure 1840-1920. *Research in organisation behaviour*, 8:53-111.