https://dspace.org/

Assessment of water quality status of the Woestalleen wetland before and after rehabilitation

Mbulaheni, Lindelani

2022

https://hdl.handle.net/10539/37028

Downloaded from a DSpace repository. https://dspace.org/

UNIVERSITY OF THE WITWATERSRAND

FACULTY OF SCIENCE

SCHOOL OF GEOGRAPHY, ARCHAEOLOGY AND ENVIRONMENTAL STUDIES

(GAES)

MSC ENVIRONMENTAL SCIENCE

Name: **Lindelani Mbulaheni**

Student No: 693748

Course: GEOL 7006

Research Report PT2

Supervisors: Prof Christopher Curtis and Prof Jennifer Fitchett.

Assessment of water quality status of the Woestalleen wetland before and after rehabilitation

August 2022

Declaration

I, Lindelani Mbulaheni, hereby declare that this research report submitted for the Degree of Master of Science at the University of Witwatersrand, Johannesburg, South Africa, has not been submitted before for a degree at this university or at any other institution of higher learning for a degree and that is my own work in design and implementation, and that all reference materials confined in this report have been properly acknowledged.

Signature……lmbulaheni…… Date: 08/08/2022

Acknowledgements

Firstly, I would like to convey my profound appreciation to my supervisors, Professor C. Curtis and Professor J. Fitchett for their advice and supervision. May God bless them for making a significant contribution to my academic and career growth.

Secondly, I would like to convey my heartfelt gratefulness to Eco Elementum Environmental and Engineering for helping me with the study area and collection of water quality, and wetland data.

Thirdly, my sincere appreciation goes to Department of Water and Sanitation for granting me bursary to pursue my studies.

In conclusion, I would like to convey my genuine gratefulness to God almighty for guiding me, giving me power and strength since I started with my studies.

Abstract

The key objective was to assess the water quality status of the Woestalleen wetland before and after rehabilitation using water quality data from five monitoring points, two upstream (KFBM1 and Dam), one within the wetland (KFBM2) and two downstream (KFBM3 and KFBM4) and to determine if the ecological status of Woestalleen wetland class has been upgraded from a Class D to a Class C or higher.

The channelled valley bottom wetland conditions for the post rehabilitation activities of the Roodepoort Colliery were found to be badly altered (Category E). Changes to the wetland and the subsequent consequence on the condition of the wetlands is mainly linked to the widespread alien invasive vegetation, erosion, damming and current mining activities from the Colliery adjacent to the wetland area. Monitoring data during study period 1, before rehabilitation (July 2018 to July 2019), study period 2, during rehabilitation (August 2019-January 2020) and study period 3, after rehabilitation (February 2020-June 2020) indicated higher values of electrical conductivity, turbidity, suspended solids, total alkalinity, chloride, sulphate, ortho phosphate, and sodium at the upstream site KFBM1 which were not compliant to the provided water quality limits on the WUL. Therefore, there are water contamination issues that emanated from upstream of the mining area. Higher values of TSS, EC, turbidity, and sulphate during study period 1 at downstream sites than upstream sites were also observed, this implies that the mine may have contributed to the water contamination of Woestalleen Spruit.

Most of the water quality variables such as electrical conductivity, turbidity, suspended solids, total alkalinity, sulphate, ortho phosphate, and sodium were found to be non-compliant to the WUL both at upstream sites and downstream sites during study periods 1, 2 and 3. Significantly higher concentrations of variables such as hydrogen ions, sodium, chloride and sulphates were observed at downstream sites, KFBM2, KFBM3 and KFBM4 as compared to upstream sites, KFBM1 and Dam before, during and after rehabilitation. Therefore, mining activities may have contributed to acid mine drainage leading to these changes, even though the upstream water quality arriving at the mining area was already non-compliant and lastly the Woestalleen wetland

rehabilitation has not yet improved water quality downstream. The PES of Woestalleen wetland further degraded from class D to E.

Contents

Declaration i

Acknowledgements ii

Abstract iii

List of Figures vii

List of Tables viii

List of scientific terms ix

1.1 Background 1

1.2 Rationale of Study 2

1.3 Wetland Rehabilitation Strategy Targets 4

1.4 Hypotheses 5

1.5 Objectives 5

1.5.1 Main objective 5

1.4 Specific objectives 6

Chapter 2: Literature Review 7

2.1 Value of Wetlands 7

2.1.1 Provisioning Services 8

2.1.2 Regulating Services 9

2.1.3 Habitat Services 10

2.1.4 Cultural Services 10

2.2 Threats to Wetlands 10

2.3 Water Quality and Phytoremediation in Wetlands 13

2.4 Wetland Rehabilitation 15

2.5 Rehabilitation Roles and Specifications 15

2.6 Legislative Framework and Wetlands in South Africa 18

2.7 The Wetland Index of Habitat Integrity (WETLAND-IHI) 19

Chapter 3. Methodology 21

3.2 Water Quality Threshold 23

3.3 Wetland Data Acquisition 24

3.3.1 Desktop Work 24

3.3.2 Field Assessment 25

3.4 Water Quality Data Acquisition 30

3.5 YSI probe calibration and in situ measurement 32
3.6 Water Sample Analysis 33
3.7 Laboratory Analytical Methods 34
3.8 Data Analysis 35
Chapter 4. RESULTS 37
4.1 Wetland Delineation and Assessment 37
4.1 .1 Desktop Assessment 37
4.1.2 Soil form indicator 38
4.1.3 Vegetation indicator. 39
4.1.4 Wetland Delineation 40
4.1.5 Channelled valley bottom wetland 42
4.2 Water Quality Results 42
4.2.1 Water quality data summary 42
4.2.2 Normality Test 60
4.2.3 Correlation 61
4.2.4 Box Plots and Kruskal- Wallis Test: Temporal difference (before-during-after) 62
4.2.5 Upstream and Downstream Comparison (spatial comparisons) 69
4.2.6 Water quality summary 74
4.3. In situ Measurements 76
4.3.1 Correlation Test 76
4.3.2 Box plots for in situ measurements 76
Chapter 5: Discussion, Conclusions and Recommendations 78
5.1 Discussion 78
5.1.1 Wetland water flow path and pollution sources 78
5.1.2 Wetland assessment 78
5.1.3 Water quality results 79
5.2 Conclusions 83
5.3 Recommendations 85
Appendices 1

List of Figures

Figure 3. 1 Site Location. Roodepoort Farm: north-west of the Hendrina Power Station and southwest of the Optimum Coal operations. Base map source: Eco Elementum. 22
Figure 3. 2 Quaternary Catchment map for Roodepoort Colliery. Source: Oasis Environmental Specialists. 22
Figure 3. 3 Land cover map in proximity of Roodepoort Colliery. Source: Oasis Environmental Specialists. 23
Figure 3. 4 Water quality monitoring points. 31

Figure 4. 1 shows pictures taken on site before, during and after rehabilitation of Woestalleen wetland. A: before mining through the wetland (taken: 07/12/2018), B: during wetland rehabilitation (taken:25/09/2019), C: after rehabilitation of the wetland (taken:31/01/2020) and D: during wetland assessment (27/11/2020). Photographs Taken by Lindelani Mbulaheni. 37
Figure 4. 2 Roodepoort Colliery - NFEPA Wetland map. Source: Oasis Environmental Specialists. 38
Figure 4. 3 Soils sampled within the stream diversion and permanent wetland areas. 39
Figure 4. 4 Riparian plants (*Kniphofia fluviatilis, Typha capensis*, *Cyperus spp* and *Juncus spp.)* which have established in the permanent wetland areas and stream diversion. Source: Oasis Environmental Specialists. 40
Figure 4. 5 Roodepoort Colliery Current wetland delineation post mining and post rehabilitation. Source: Oasis Environmental Specialists. 41
Figure 4. 6 pH levels at upstream sites, KFBM1 and Dam. 43
Figure 4. 7 pH levels at downstream sites, KFBM2 and KFBM3. 43
Figure 4. 8 pH levels at furthest downstream site, KFBM4. 44
Figure 4. 9 TSS concentration at upstream sites, KFBM1 and Dam. 45
Figure 4. 10 TSS concentration at downstream sites, KFBM2 and KFBM3. 45
Figure 4. 11 TSS concentration at furthest downstream site, KFB4. 46
Figure 4. 12 EC concentration at upstream sites, KFBM1 and Dam. 47
Figure 4. 13 EC concentration at downstream sites, KFBM2 and KFBM3. 47
Figure 4. 14 EC concentration at furthest downstream site, KFBM4. 48
Figure 4. 15 Turbidity concentration at upstream sites, KFBM1 and Dam. 48
Figure 4. 16 Turbidity concentration at downstream sites, KFBM2 and KFBM3. 49
Figure 4. 17 Turbidity concentration at furthest downstream site, KFBM4. 49
Figure 4. 18 Alkalinity concentration at upstream sites, KFBM1 and Dam. 50
Figure 4. 19 Alkalinity concentration at downstream sites, KFBM2 and KFBM3 50
Figure 4. 20 Alkalinity concentration at furthest downstream site, KFBM4. 51
Figure 4. 21 Chloride concentration at upstream sites, KFBM1 and Dam. 52
Figure 4. 22 Chloride concentration at downstream site, KFBM2 and KFBM3. 52
Figure 4. 23 Chloride concentration at furthest downstream site, KFBM4. 53
Figure 4. 24 Sulphate concentration at upstream sites, KFBM1 and Dam. 54
Figure 4. 25 Sulphate concentration at downstream sites, KFBM2 and KFBM3. 54
Figure 4. 26 Sulphate concentration at furthest downstream site, KFBM4. 55
Figure 4. 27 Nitrate concentration at upstream sites, KFBM1 and Dam. 55
Figure 4. 28 Nitrate concentration at downstream sites, KFBM2 and KFBM3. 56
Figure 4. 29 Nitrate concentration at furthest downstream site, KFBM4. 56

Figure 4. 30 DO concentration at upstream sites, KFBM1 and Dam. 57
Figure 4. 31 DO concentration at downstream sites, KFBM2 and KFBM3. 57
Figure 4. 32 DO concentration at furthest downstream site, KFBM4. 58
Figure 4. 33 Sodium concentration at upstream sites, KFBM1 and Dam. 59
Figure 4. 34 Sodium concentration at downstream sites, KFBM2 and KFBM3. 59
Figure 4. 35 Sodium concentration at furthest downstream site, KFBM4 60
Figure 4. 36 nitrate concentration for KFBM4 site during study periods 1, 2 and 3. 63
Figure 4. 37 Sulphate concentration for Dam site during study periods 1,2 and 3. 64
Figure 4. 38 Chloride concentration for Dam site during study periods 1,2 and 3. 65
Figure 4. 39 Total alkalinity concentrations for KFBM1 site during study periods 1, 2 and 3. 66
Figure 4. 40 Total alkalinity concentration for Dam site during study periods 1, 2 and 3. 67
Figure 4. 41 Hydrogen ion concentration for the Dam site during time periods 1, 2 and 3. .. 68
Figure 4. 42 Hydrogen ions concentrations between all sites during study periods 1,2 and 3. 70
Figure 4. 43 Chloride concentrations between all sites during study periods 1,2 and 3. 71
Figure 4. 44 Sulphate concentrations between all sites during study periods 1, 2 and 3. 72
Figure 4. 45 Sodium concentration between all sites during study periods 1,2 and 3. 73
Figure 4. 46 Rainfall data. 77

List of Tables

Table 2. 1 Explanations of the A-F ecological classes (Kleynhans, 1996, 1999). 20

Table 3. 1 monitoring parameters and water quality limits. 24
Table 3. 2 water quality monitoring points. 31
Table 3. 3 Water Lab laboratory analysis methods 34
Table 3. 4 Yanka laboratory analysis methods. 35

Table 4. 1 Summary of overall PES scores for the HGM Units found for the post rehabilitation activities of the Roodepoort Colliery 42
Table 4. 2 Kruskal-Wallis test for nitrate at KFBM4 for study periods 1, 2 and 3. 64
Table 4. 3 Kruskal-Wallis test for sulphate at Dam for study periods 1, 2 and 3. 65
Table 4. 4 Kruskal-Wallis test for chloride at Dam for study periods 1, 2 and 3. 66
Table 4. 5 Kruskal-Wallis test for total alkalinity at KFBM1 for study periods 1, 2 and 3. 67
Table 4. 6 Kruskal-Wallis test for total alkalinity at Dam for study periods 1, 2 and 3. 68
Table 4. 7 Kruskal-Wallis test for hydrogen ions at the Dam for time Periods 1, 2 and 3. 69
Table 4. 8 Kruskal-Wallis test for hydrogen ions between all sites during study periods 1,2 and 3. 70
Table 4. 9 Kruskal-Wallis test for Chloride between all sites during study periods 1, 2 and 3. 71
Table 4. 10 Kruskal-Wallis test for sulphate between all sites during study periods 1, 2 and 3. 72
Table 4. 11 Kruskal-Wallis test for sodium between all sites during study periods 1, ... 73

List of acronyms

AMD	Acid Mine Drainage
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CWs	Constructed Wetlands
DWS	Department of Water and Sanitation
EI	Ecological Importance
ES	Ecological Sensitivity
HGM	Hydrogeomorphic Units
MPRDA	Mineral and Petroleum Resources Development Act, act 28 of 2002
MEA	Millennium Ecosystem Assessment
NBA	National Biodiversity Assessment
NEMA	National Environmental Management Act, Act 107 of 1998
NAEHMP	Ecosystem Health Monitoring Programme
NFEPA	National Freshwater Ecosystem Priority Areas
NWA	National Water Act, 36 of 1998
RDMs	Resource Directed Measures
SDCs	Source Directed Measures
PES	Present Ecological Status
UN	United Nations
WETLAND-IHI	Wetland Index of Habitat integrity
WUL	Water Use Licence

List of scientific terms

Present Ecological Status (PES) is described as the present ecological state of the resource evaluated in relation to the changes from the original state.

Reserve is described as the quantity and quality of water necessary for human being and ecological requirements.

Chapter 1: Introduction

1.1 Background

Globally, wetlands are affected by land conversions and cumulative ecosystem stress (Taddeo and Dronova, 2018). In South Africa (SA) particularly, wetlands are poorly protected due to the underestimation of their ecological and economic significance (Swanepoel and Barnard, 2007). Subsequently, most of the wetlands in SA are exposed, with nearly 80% of SA's 135 wetland ecosystem types found inland categorized as endangered (NBA, 2018). Therefore, numerous organizations have introduced large scale reinstatement efforts to rehabilitate degraded ecosystem functions and increase the quality and range of wetland habitats (Taddeo and Dronova, 2018).

Wetlands are defined as land *"which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil*" according to the National Water Act (NWA, 1998. p. 9). Wetlands are sensitive ecosystems that execute several ecosystem functions such as water quality maintenance, stream flow regulation, social profits, carbon storage, flood control, and preservation of biodiversity (Kotze et al., 2008).

Wetland restoration is important in terms of returning a wetland from a degraded condition, due to anthropogenic activities, to its natural and undisturbed condition (Mitsch, 2013). The main contributing elements to the degradation of wetlands in SA comprise mining, agricultural and industrial activities and poorly treated wastewater generated from industry and mining (Oberholster et al., 2011). This can result in wetlands being degraded or hydrologically altered. Consequently, wetland restoration may also include re-establishing hydrologic conditions to restore former vegetation communities (Mitsch, 2013).

Mining activities occurring within the wetland or 500m radius of the wetland need a Water Use Licence (WUL) from the Department of Water and Sanitation (DWS) in terms of Section 21 of the NWA, Act 36 of 1998. DWS uses water use licences as a tool to minimise mining activity impacts on the wetland and to ensure rehabilitation of the affected areas after the life span of the mine. Therefore, licensees are expected to always comply with the licence conditions to prevent wetlands degradation (NWA, 1998).

The main objectives of wetland reinstatement projects consist of reinstating ecosystem services and encouraging the resilience of local communities to climatic changes (Kentula, 2000). Without regular monitoring, it becomes extremely difficult to categorize the site physical characteristics, land factors, or controlling decisions that affect the post reinstatement route of sites (Brudvig et al., 2017).

This study investigates the impact of post mining rehabilitation of a mined wetland on water quality within the Woestalleen Spruit in Mpumalanga. Kebrafield (Pty) Ltd**:** Roodepoort Colliery mined coal within the wetland through an open cast mine following issuance of a 20-year Water Use License, reference number (04/B12B/ABCGIJ/2868) by DWS in October 2015 allowing them to mine on both sides of the Woestalleen Spruit linked to the channelled valley bottom wetland. The operations occurred between 2015 and 2019. As part of the licence conditions, Kebrafield was required to monitor quality of water upstream and downstream of the Woestalleen wetland and to rehabilitate its effects on the wetland after the life span of the mine. Woestalleen wetland assessment was initially conducted by M2 Environmental Connections consultants in July 2013 as appointed by Kebrafield and the ecological status was reported as D.

1.2 Rationale of Study

The objective of the wider rehabilitation project was to facilitate the protection, conservation, re-establishment, and sustainable use of the Woestalleen wetland in the upper Olifants River Water Management Area (the B12B catchment), in accordance

with national policies and commitment to regional relationships with other stakeholders in the catchment.

Given this approach of associating wetland rehabilitation to sustainable economic development (primarily within the mining sector), the wider project forms part of the compliance of WUL conditions. The project seeks to ensure the restoration of largely modified wetland systems to an improved Present Ecological Status (PES). The wider project is thus focused on the rehabilitation and restoration of disturbed wetlands in a way that attempts to maximize wetland functionality, increase wetland biodiversity and the overall improvement of environmental integrity and sensitivity of degraded riparian zones.

Implementation of the agreed rehabilitation plan is meant to achieve the ecosystem conservation target set for the catchment by improving a channelled valley bottom wetland system from a present ecological class of Class D to a Class C or higher (please refer to Table 2.1). PES is defined as the present ecological state of the resource evaluated in relation to the deviation from the original status (DWAF, 2007). The improvement is based on increased biodiversity, indigenous riparian vegetation and improved hydrological characteristics feeding the Woestalleen Spruit as well as the natural recharge of the wetland due to the removal of impermeable barriers.

The Woestallen wetland was mined through an open cast mining from January 2019 to June 2019. The rehabilitation of the Woestallen wetland system linked to the Woestalleen Spruit was started in July 2019 and completed in January 2020 and it included backfilling of open voids, seeding of free draining backfilled areas and diversion of the Spruit to the unmined area.

Therefore, my research seeks to understand the ecological integrity status of Woestalleen wetland before and after rehabilitation. The following research questions will help to understand the ecological integrity of Woestalleen wetland before and after rehabilitation:

1. What was the water quality compliance status to the water quality limit on the issued licence (ref: 04/B12B/ABCGIJ/2868)?
2. What was the status of downstream and upstream water quality before and after rehabilitation?
3. What was the ecological status class of Woestalleen wetland before and after rehabilitation according to WETLAND- IHI classification system?

1.3 Wetland Rehabilitation Strategy Targets

This section presents specific objectives for Woestalleen wetland rehabilitation. The following management measures and actions were identified and included in the Woestalleen wetland rehabilitation strategy (Nieman & Mare, 2013).

- Design the optimal route and location for the stream diversion and wetland establishment according to the natural topography as far as possible away from the opencast mining area.
- Cap the overburden of mined areas with a clay liner (previously mined material) to form an impeding layer and direct runoff towards the new wetland areas.
- Establish micro-topography (e.g., swales along contour) to facilitate diffused flow from the catchment areas towards the newly designed stream and wetland.
- Establish favorable conditions to enhance the organic matter in the soil by revegetation and inundation for both the catchment and newly designed stream and wetland.
- Prevent rill erosion by controlling surface runoff, creating an undulating topography and surface roughness on steeper slopes on the rehabilitated uplands.
- Establish natural flow patterns, especially within the newly designed stream and wetland areas by following the requirements for the geomorphology rehabilitation.
- Upgrade the existing dam retaining wall and move current outlet to a suitable location away from the opencast mining area to support and enable water flow towards the newly constructed stream diversion and associated wetlands.

- Construct energy dissipaters and spreader canals at the newly designed dam outflow point to spread water across the wetland.
- Re-vegetate exposed surfaces and mulch re-vegetated areas.
- Select appropriate species for wetland and terrestrial areas and ensure species diversity is enhanced.
- Consider plugs for wet areas with species commonly found in the natural wetland area.
- For the upland and catchment areas, include a combination of seeds mimicking local vegetation of the area.

By implementing the above stated wetland objectives at Kebrafield the ecosystem conservation target set for the catchment will be achieved by improving a channelled valley bottom wetland system from Class E to a Class D and higher. The improvement is based on increased biodiversity, indigenous riparian vegetation and improved hydrological characteristics feeding the Woestalleen Spruit as well as the natural recharge of the wetland due to the removal of impervious barriers (Nieman & Mare, 2013).

1.4 Hypotheses

- Mining activities will lead to reduction in water quality in the Woestalleen wetland.
- Proposed rehabilitation objectives will improve Woestalleen wetland ecological status from Class D to a Class C or higher.

1.5 Objectives

1.5.1 Main objective

The core objective was to evaluate the water quality status of the Woestalleen wetland before and after rehabilitation using water quality data from five monitoring points, two upstream (KFBM1 and Dam), one within the wetland (KFBM2) and two downstream (KFBM3 and KFBM4) sampled monthly from January 2018 to June 2020. Water quality sampling for laboratory analysis was conducted by Eco Element Environmental and Engineering as appointed by Kebrafield. In addition, *in situ* measurements for DO,

EC, Temperature and pH were taken from August 2019 to February 2020 to complement water quality laboratory results. This was my own data collection in the field to provide additional data. One additional site (*In situ1*) was established upstream of all other sites to establish if there were water quality issues emanating from further upstream.

1.4 Specific objectives

- To evaluate efficacy of the Woestalleen wetland rehabilitation through the evaluation of water quality status during study periods 1 (July 2018 to July 2019), 2 (August 2019-January 2020) and 3 (February 2020-June 2020). Study period 1 represents before rehabilitation, study period 2 represents during rehabilitation and study period 3 represents after rehabilitation.
- To determine whether Woestalleen wetland rehabilitation improves downstream water quality of the Woestalleen Spruit by measuring the following water quality parameters: pH, EC, turbidity, suspended solids, total alkalinity, chloride, sulphate, nitrate, nitrite, dissolved oxygen, and sodium.
- To compare Woestalleen wetland water quality status with the water quality limit on the issued licence (ref: 04/B12B/ABCGIJ/2868).
- To conduct Woestalleen wetland assessment after rehabilitation.
- To determine if the ecological status of Woestalleen wetland class has been upgraded from a Class D to a Class C or higher.

Chapter 2: Literature Review

2.1 Value of Wetlands

The Millennium Ecosystem Assessment (MEA) led by the United Nations (UN), described an ecosystem as “a dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a functional unit” (MEA, 2005). People are an important portion of the environments. Therefore, ecosystem services are described as being the aids humans attain from the ecosystems, these include food and water serving as provisioning services; floods, drought and waste regulations serving as regulating services; and spiritual, religious, and recreational services serving as cultural services (MEA, 2005).

These services are based on supporting services e.g., photosynthesis, soil formation and water cycling (MEA, 2005). The most important thing here is that the humans are essentially reliant on the ecosystem services (MEA, 2005). The relationship between the two is mutual. Humans and their actions have an impact on ecosystems and their services. Humans deplete resources and threaten ecosystems as the human populations grow there will be an increase in resource consumption and impacts on ecosystems and their services. (MEA, 2005). According to MEA (2005), an ecosystem that is well managed plays a significant part in reducing the risk of natural disasters and human conflict, while a poorly managed ecosystem can increase the same risk.

There is a rising awareness of ecological and socioeconomic importance for remote wetland systems; for example, in Europe, isolated wetlands are listed as important habitat under the EU Habitats Directive because of their exposure to climate change and anthropogenic activities (Céréghinor et al., 2008). In SA, remote wetlands under same pressure are not as protected. The NWA is a framework that describes water resource protection and how to utilise water in a sustainable way. The act made a provision for the evaluation of present ecological integrity of the water resource. For a more operative use of the NWA, the ecological state of the aquatic habitat needs to be determined (NWA, 1998).

In Europe, research focusing on isolated depressional wetlands, particularly their biodiversity, has been developed (Lane et al., 2009). For South Africa, by contrast, in regions such as the Mpumalanga Highveld with exceptionally numerous remote wetlands locally known as pans, there is surprisingly limited information and knowledge considering how unique the water quality, flora and fauna is (Hutchinson et al., 1932).

The Working for Wetlands Programme that launched in South Africa in June 2000, has helped enhance the alertness on the importance of wetlands, and with that came more environmental education campaigns that mainly focus on these ecosystems (Sieben, 2011). The programme of restoration activities includes construction of gabion structures that will help to reduce erosion, building structures that divert water flow or raise water levels, digging artificial drainage channels, and the elimination of invasive plants. Since the programme was established, approximately R530 million has been spent in wetland rehabilitation, involving over 900 wetlands, with over 70,000 hectares of wetlands upgraded (DEA, 2014).

According to Guo et al. (2001), wetlands are the kidney of the earth, and their ecological systems have distinctive hydrologic standing. The wetland ecosystem is a vital part of the terrestrial ecosystem, and it has several beneficial services and functions such as to improve water quality and the regulation of runoff (de Groot at al., 2018). Wetlands provide crucial and diverse benefit to people globally, contributing to the provisioning, regulating, as well as habitat and cultural services (de Groot at al., 2018).

2.1.1 Provisioning Services

Wetland ecosystems provide natural resources, freshwater, and agricultural land, leading to wetlands being one of the best productive ecosystems in the globe yet they remain vulnerable to degradation or loss (Beal, 2007). Wetlands are known to clean water, recharge ground water supply, reduce risk of flooding, act as habitat for wildlife and provide recreational opportunities like camping, hunting, and fishing thus making wetlands very valuable (Beal, 2007). Other benefits derived from wetlands include

animal grazing, sources of water, fibre production and animal protein, cultivation, and some food crops (Kotze et al., 1995). The same ecosystems also offer beauty and comfort for people who like spending time in nature through sight, smell, and sounds (Mitsch and Gosselink, 2000).

Wetlands are sources of vegetation, animal, and mineral products, additionally, they provide a habitat for animals such as fish, these products are then harvested for individual and commercial use for example, fish which is one of the main sources of protein globally in addition to supplying products such as oil (de Groot et al., 2018). The grasses found in wetlands are used for livestock grazing and harvested for hay. Wetlands are also used for leisure activities such as, fishing, hiking, and hunting. Most of the activities and products produced from wetlands lead to direct and indirect economic profits to surrounding local communities (Wohlgemuth, 1991).

2.1.2 Regulating Services

The four main wetland regulating services are flood control, climate regulation, water quality improvement, and carbon storage (Qing-Jun et al., 2009). Wetlands decontaminate water through storing nutrients, particularly phosphorus and nitrogen which are usually associated with agricultural runoff and sewage effluent, and trapping pollutants and sediments in their soils and vegetation (Qing-Jun et al., 2009).

Wetlands are natural preventers of damages from disastrous weather events such as floods by providing a physical barrier that slows down the speed of floods and reduces the altitude and energy of floodwaters thereby also controlling the flow by slowly releasing the flood water downstream (de Groot et al., 2018). Wetlands inside drainage basins weaken flood peaks and total stream flows by holding them in depressional wetlands (Wohlgemuth, 1991)

Wetlands play a very significant part in preventing climate change and storing carbon (de Groot et al., 2018). Wetlands retains large quantities of carbon as peat, while drainage, peat extraction and burning of these releases carbon into the atmosphere as greenhouse gases (de Groot et al., 2018).

2.1.3 Habitat Services

Wetlands play important roles on land by providing distinctive habitats for an extensive diversity of flora and fauna (Mitsch et al., 2009). Wetlands provide habitat services like lifecycle maintenance and gene pool protection, which are essential in terms of sustaining important ecosystem services and the creation of all other ecosystem services. Wetlands cover a lesser area of the Earth's surface, but host biodiversity and many are exceptionally rich in flora and fauna, while numerous have common species restricted to wetlands (de Groot et al., 2018).

Wetlands offer food and habitat for various terrestrial and aquatic animals such as birds, fish, mammals, and invertebrates and wetlands also provide vital habitat for many birds. Some species may use the ecosystem all year round whereas others only use the ecosystem seasonally for breeding, feeding, resting, or overwintering (Wohlgemuth, 1991).

2.1.4 Cultural Services

Wetlands supply important non-materialistic benefits such as spiritual, cultural, and educational values (de Groot et al., 2018). The landscapes and wildlife found in wetland ecosystems are a result of complex interactions that have existed between people and nature over centuries and once damaged or destroyed, they may be impossible to restore (de Groot et. al, 2018). Wetlands also draw various recreational and ecotourism activities, which create incomes benefiting local communities and the national economy (de Groot et. al, 2018). Regarding custom values and functions, the major issues of wetlands is that they are home to species of which are categorized as being rare, endangered or endemic and relic (Smardon, 2006).

2.2 Threats to Wetlands

Globally, around 64% of wetlands have been destroyed in the 1900s; as compared to 1700s and most of the remaining wetlands are under increasing pressure from economic and infrastructure development that does not consider their valuable role

(DWS, 2017). The area of global wetlands is commonly understood to be from 5-9 million km^2 (Mitsch, 2013).

It is projected that the worldwide area of wetlands has reduced by 54 to 64% from the 1900s, with a possible 87% degradation in wetland area since 1700 (Reeves et al., 2018). The overall degradation of wetlands globally is largely due to human activities and cannot be easily quantified (Mitsch, 2013). Coastal wetlands have been degraded over a long time period due to a combination of extreme vegetation clearance, hydrologic alteration, contamination, and other anthropogenic activities. Equally, wetlands located inland are insistently impacted, mainly because of hydrologic alteration, farming activities and development as a whole (Mitsch, 2013). In 1985, an estimated 2% in Africa, 6% in South America, 27 % in Asia, another estimated 65% of wetlands in Europe and North America, were depleted for agricultural activities (Mitsch, 2013).

South Africa loses most of the wetland ecosystems to human activities such as dam construction, overgrazing, veld fires, the production of crops, pollution, urbanisation, and the unsustainable use of land resources (King et al., 2005). Based on a 2018 National Biodiversity Assessment (NBA), wetlands are found inland are greatly unprotected with about 6% of wetland environment types found inland are well protected (NBA, 2018). About 61% of wetland ecosystem types found inland are unprotected. However, better protected wetland ecosystems are gathered in the eastern portion of Mpumalanga province in the Kruger National Park, wetlands found inlands are extremely endangered, with nearly 80% of SA's 135 inland wetlands reported as vulnerable (NBA, 2018).

Floodplains face the greatest threat in South Africa as most are located inlands with soil rich in nutrients making it most suitable for agricultural production (SANBI, 2013). Both rural and urban areas experience threats, for urban areas it's due to urban expansion, while in rural areas loss is mostly due to agricultural activities (Davinson, 2014).

For example, Mamalana wetland located near Bushbuckridge in Mpumalanga, with a population of 500,000 people, has 70% of the population living off the wetland one way or the other, and 25% of the population depending on it as their only source of food and income (SANBI, 2013). The wetland has lost tonnes of soil and 863 farming plots due to erosion and degradation (SANBI, 2013).

Despite the fact that wetlands deliver valuable ecosystem services and contribute meaningfully towards the world's biodiversity, still over half of the globe's wetlands were damaged mainly due to agricultural activities (Bartzen et al., 2010). Most of the wetlands that are remaining have been changed because of hydrological modification, salinization, sedimentation, eutrophication, and invasion by dangerous species (Brock et al., 2003). These activities can lead to continuous effects which are more challenging to quantify than clear wetland degradation (Brock et al., 2003). Furthermore, wetlands can recover from impacts depending on their severity (Brock et al., 2003). It is expected that stable wetlands are less exposed to agricultural activities because of water presence and have lesser impact rate as compared to seasonal wetlands (Whigham, 1999). Similarly, wetlands located in cultivated farms are likely to have greater impact rates than wetlands found in the woodlands and grasslands areas (Whigham, 1999).

Agricultural activities, such as cultivation, have harshly impacted wetlands and their biodiversity across the globe (Liu et al., 2004). Cultivation of wetland areas has aggravated soil erosion and wetland pollution (Liu et al., 2004). This speedy alteration from natural wetlands to agricultural land has caused not only wetland area degradation but also fast decreases in population size and amount of several wildlife species that use wetland as their habitat; for example, waterfowl and plants (Liu et al., 2004).

Wetlands in cultivated fields obtain more sediments from upstream land than wetlands found in grassland areas (Liu et al., 2004). Therefore, they are exposed to premature filling (Liu et al., 2004). Wetlands have been used for growing crops either by drainage, as with corn or potatoes, or by flood management, as with rice. However, drainage of wetlands for agricultural activities is more recent and increasingly becoming common

(Liikanen et al., 2006). This transition will result in more degradation occurring where wetlands are most abundant (Liikanen et al., 2006).

Open cast mining can destroy wetlands and result in the loss of the wetland ecosystem service values through direct and indirect effect on the nearby wetland ecosystems and in areas where the ecological system is delicate and sensitive, the mining activities have led to several ecological and environmental problems and social issues (Demirel et al., 2011). Open cast mining totally removes vegetation in the mining area and impact on the hydrological cycle (Demirel et al., 2011).

2.3 Water Quality and Phytoremediation in Wetlands

Wetlands, usually recognized as biological filters, have appeared as feasible alternatives towards resolving an extensive variety of water pollution and environmental difficulties (Sheoran and Sheoran, 2006). The removal rate of heavy metals in both natural and artificial wetland ecosystems has been reported as being approximately 100% (Sheoran and Sheoran, 2006). Effective load rates and removal of metals were normally higher in the artificial wetlands in comparison to the organic wetlands (Sheoran and Sheoran, 2006). The concept of constructed/artificial wetland was first conceived from observations of natural *Sphagnum* wetlands getting acid mine drainage (AMD) resulting in better water quality not including any noticeable environmental impacts on the wetland ecosystems (Huntsman et al., 1978). Even though issues may arise with constructed wetland ecosystems, present research shows that they are of low expense and ecologically more valuable than chemical treatments systems (Brenner, 2001).

Constructed Wetlands (CWs) have been utilized for mine water treatment comprising heavy metals, metalloids and radionuclides for approximately 40 years (Kuschk et al., 2006). CWs are utilized around the globe to treat agricultural wastewaters due to their low cost and marginal preservation, energy, and management necessities (Cronk, 1996).

Wetlands are capable of increasing the retention time of pollutants through a water flow mechanism of wetland vegetation and then decrease the dispersion of contamination to the nearby environment (An et al*.,* 2011). Wetland topography and vegetation type plays a vital role for nutrient accumulation rates in the wetlands (Hemond and Benoit, 1988). Invasive and other floating plants use nutrients straight from the water, rooted plants take nutrients from both sediments and water (Hemond and Benoit, 1988). Longer transportation times of nutrients enable their uptake by wetland plants, which can additionally decrease downstream nutrient fluctuations (Smith et al*.,* 2020).

Heavy metals elimination from AMD in wetlands occurs through chemical, physical and several biological processes such as filtration, sedimentation, settling, adsorption, and precipitation (Sheoran and Sheoran, 2006). Wetland sediments are typically rich in organic matter, more suitable for sorption of metals compared to upland soils with lower organic content (Hemond and Benoit, 1988).

Wetlands decrease the COD and BOD of wetland waters due to breakdown of organic material through aerobic bacterial respiration (De jong, 1976). De jong, (1976) reported that BOD elimination is reliant on wetland hydrology and wetlands with extensive residence times are possibly best suitable for reducing BOD and COD. The most significant mechanism for bacterial elimination by wetlands is simple confinement, whereby natural die-back happens.

Wetlands are not just sinks for contaminants, but often act as short and long-term storage reservoirs for particular water quality elements such as nitrogen (Hemond and Benoit, 1988). Nitrogen from wetlands is removed through three processes i.e., utilization by vegetation and microorganisms, sedimentation and denitrification (Hemond and Benoit, 1988). CW have been utilized effectively to hold nutrients from purified wastewaters and lately to refine diffuse source discharge such as from peat mining and agriculture activities (Liikanen et al., 2006).

AMD occurs as sulphide minerals get exposed to air and water; oxidation of sulphide releases sulphuric acid and discharges heavy metals and other contaminants to

surface waters and wetlands (Sheoran and Sheoran, 2006). AMD is one the worst environmental hazards as a result of mining of base metals from sulphide bearing deposits (Fernandez-Rojo et al., 2019), and remains a significant water pollution problem in mining operations around the globe (Sheoran and Sheoran, 2006). Wetlands are also very important in terms of treating AMD, many years ago, environmental reports emerged on mine waste management, which indicated that wetlands could be valuable in treating AMD (Kalin, n.d). Evidence showed that wetland plants could survive severe conditions in tailing dams and AMD seepages, and water quality improves when AMD passes through constructed wetlands (Kalin, n.d).

2.4 Wetland Rehabilitation

Rehabilitation of wetlands has been recognized by water resource experts as gradually important in improving environmental standards and reinstating ecosystem functions (Reeves et al., 2018). These functions are usually degraded as a result of developments impacting on wetlands (Reeves et al., 2018). The evaluation of impacts on the wetland are not directly or readily obtainable and to successfully plan for wetland rehabilitation, defining whether and how fast wetlands can improve from impacts is very important (Bartzen et al., 2010).

Knowledge of how presumed aspects contribute to wetland losses and reclamation can assist categorize wetlands at threat and, thus, concentrate preservation efforts where they are most required and effective (Bartzen et al., 2010). Recovery rates of wetland from impacts is dependent on several factors such as human factors i.e., land uses and economy, climate factors such as temperature and rain and lastly conditions related to individual wetlands for example wetland type, depth and vegetation type (Bartzen et al., 2010).

2.5 Rehabilitation Roles and Specifications

The necessity for rehabilitation of wetlands in SA is very important. Wetland depletion and destruction have been huge and as a result there was a need to have national policy and legislation that offers clear guidance and assistance in terms of wetlands

rehabilitation. However, rehabilitation of wetlands is usually a difficult process because the relationships between wetlands and people is complex. Therefore, a string of means has been established to help those wanting to embark on wetland rehabilitation in a proper and efficient way (Armstrong, 2009). The acknowledgment of advantages linked with wetland systems and the necessity to repair ecosystem degradation has resulted in the beginning of wetland rehabilitation projects between individuals and organizations around the world (Cowden, 2014).

Present approaches to the preservation and sustainable use of wetlands should take into consideration the substantial historical loss of wetland area together with the present pressures and threats confronting wetlands. Consequently, there is a common perception that in order to be successful, approaches for wetland protection should involve a mixture of proactive precautionary measures (i.e., wetland safeguard and sensible use), together with corrective interventions aimed on overturning previous degradation (i.e., wetland rehabilitation). In South Africa, all these measures are being gradually communicated across a variety of policy and legislative frameworks, especially in the environment and water sectors (Kotze, 2009).

For rehabilitation to be successful one needs to try to mimic natural processes and restore the natural ecological driving processes in such a manner that we assist the preservation of energetic wetland ecosystems so that, even though they are not likely to be a duplicate to their natural wetlands, but they will be similar in terms functioning (Kotze, 2009).

The most widely used rehabilitation methods to support in the regaining of destroyed wetland ecosystems are ‘plugs’ built inside unnatural drainage channels. The ‘plugs’ are positioned with the objective of re-instating a new natural hydrology. Other options for sustaining the condition of wetland ecosystems that are in degrading state are the installation of erosion management structures which help in stopping wetland erosion. Lowering livestock grazing pressure or decreasing the occurrence of burning are also other rehabilitation options that can be considered (Kotze, 2009).

Wetlands result from numerous major ecological forces, such as hydrology, geomorphological setting, and physical processes such as fire and sediment movement, biogeochemical processes for example nutrient cycling and biological processes such as competition. These driving forces act together to develop the ecosystem services delivered by wetlands. Therefore, rehabilitation focuses on the reinstatement of these driving forces to a level close to the initial natural system (Kotze, 2009). The objective of wetland rehabilitation should not be to return and preserve the wetland in a stationary state but instead to attain a strong wetland ecosystem that is mainly self-sustaining and can react to alteration with slight human involvement. Wetland rehabilitation and management should be combined with management of the general catchment in order to address sources of wetland degradation and not just the indicators (Kotze, 2009).

Proper rehabilitation includes the management of the physical (for example blocking drainage canals), chemical, or biological features (supporting the renewal of the natural vegetation and/ or removal of invasive alien species within wetland buffer zone) of a destroyed wetland ecosystem in order to restore wetland integrity and related ecosystem services (SANBI, 2013). Gabion weirs are normally utilized in wetland rehabilitation. The usage of gabion structures must be considered wisely and even prevented and/or restricted in the mining site as bad water quality, such as the formation of AMD, can compromise the usefulness and permanency of such structures (Macfarlane,2016).

Achieving wetland restoration ultimately depends on effective project execution and proper aftercare management. Execution should therefore be guided by a good program and enhanced by the supervision and oversight of appropriately qualified personnel. These necessities are often incorporated into a Construction Environmental Management Plan (CEMP). This is basically an environmental management tool that must address all aspects related to the recovery and operational phases of the project. The CEMP form is an important part of the agreement between the client and the executing agent (Macfarlane, 2016).

Rehabilitation should understand and deal with the problems associated with wetland degradation in order to make interventions cost-effective. This needs those goals should be specified openly before rehabilitation starts (Erwin, 2009). The objectives of wetland rehabilitation will vary according to the scale and impact. However, it is likely that there would be an obligation to show an enhancement in functioning from the impacted wetland. Improvement in functioning could be measured in an increased capacity to treat polluted water or an increase in functional wetland hectare equivalents (Oberholster, 2016).

2.6 Legislative Framework and Wetlands in South Africa

Wetland legislation started with the Conservation of Agricultural Resources (Act 43 of 1983), which provided for the conservation of wetlands and which to date still provides an essential legal platform for the protection of wetlands (DWS, 2017). In the late 1990s the NWA and the NEMA were introduced and became the first to address the concept of sustainable development (DWS, 2017).

DWS is the main custodian of SA's water resources. The Department is accountable for the drafting and execution of the policy set to govern the management of water resources ensuring that water/ water resources are used in a sustainable manner and are of good quality. The 1998 National Water Act (NWA) provides that activities that impact on wetlands must be controlled and authorized from a water resource quality perspective (NWA, 1998).

DWS is seen as the public trustee by the NWA with regards to the country’s water resources and thus acknowledges the Department's overall responsibility for and authority over the resource and its sustainable use, while maintaining its environmental integrity. The aim of the Act, as described in Section 2 of the NWA, is to make sure that the natural water resources are well protected, utilized, established, conserved, managed, and regulated effectively (NWA, 1998).

The NEMA, the NWA and the environmental provisions of MPRDA safeguard the degrading of the natural state of wetlands by urban and commercial developments.

Principles like the ‘duty of care’, as outlined in section 28 of the NEMA, requires landowners to take responsibility in preventing, minimizing, and rectifying environmental degradation on their land (DWS, 2017).

The conservation, usage, development, control, and management of water resources are the mandate of the DWS. This may be achieved through a number of measures including the setting of Resource Directed Measures (RDMs), for example resource quality objectives, preliminary reserves and the implementation of Source Directed Controls (SDCs), for example Water Use Licences. The control of impacts on wetlands is however limited to activities such as mining and construction of infrastructures (bridges, power lines, sewage and water pipelines, roads), that constitute a water use as per Section 21 of the NWA that take place within the wetland (DWS, 2017).

DWS applies a “no net loss in wetland functions and values” principle to all applications that have potential to negatively impact on wetland ecosystem services. This implies that all development in or next to wetlands must occur in such a manner that the wetland functioning and/ or health is not degraded irrespective of the PES, and EIS of the wetland (DWS, 2017). PES is defined as the present ecological condition of the resource evaluated in relation to the deviation from the reference state (DWAF, 2007). This requires the implementation of a mitigation hierarchy by taking the following steps: avoid/prevent, minimize/reduce, remediate/rehabilitate impacts and lastly, wetland offset and may also require the rehabilitation of the system to ensure its ecological sustainability (DWS, 2017). The aim of this principle is to prevent degradation of a resource in which destruction is estimated at 35-50%, In addition it is hoped that this principle would highlight the values provided by wetlands (DWS, 2017).

2.7 The Wetland Index of Habitat Integrity (WETLAND-IHI)

The WETLAND- IHI is a system/model established for use in the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP) for the evaluation and classification of the PES of several biophysical attributes of wetland relative to the natural reference state and this is done to understand the impacts and sources of impacts causing the deviation from the wetland reference state (DWAF, 2007). This

index also provides the necessary information required to formulate important future ecological aims for the wetland (Kleynhans and Louw, 2007). This index is specifically developed to assist with the assessment of South African floodplain and channelled valley bottom wetlands. The outcome scores from this model are shown in Table 2.1 below showing the standard DWS A-F ecological categories which will be used to score the Woestalleen wetland Ecological Category after evaluation (DWAF, 2007).

Table 2. 1 Explanations of the A-F ecological classes (Kleynhans, 1996, 1999).

Ecological Category	**PES % Score**	**Category**
A	90-100%	Not modified.
B	80-90%	Mostly in natural conditions with less alterations on the natural habitat and biota.
C	60-80%	Moderate changes occurred on the ecosystem natural habitat and biota, but the essential ecosystem services are mostly unmodified.
D	40-60%	Mainly changed. with great degradation of wetland habitat and biota, and essential ecosystem services has happened.
E	20-40%	Extremely changed. With wide degradation of environmental habitat, biota and fundamental ecosystem services.
F	0-20%	Significantly changed. With permanent alterations on natural habitat and biota. Changes on the wetland system are irreversible.

Chapter 3. Methodology

3.1 Site Description

Woestalleen Spruit which is associated with a Channelled Valley Bottom Wetland is located in the B12B quaternary catchment, where the mining activities took place. The Spruit is located within Roodepoort Farm, specifically Portion 17, close to the town of Pullenshope between Middelburg and Hendrina (Figure 3.1). The site is north-west of the Hendrina Power Station and southwest of the Optimum Coal operations in Mpumalanga Province. Present land uses within this portion are mostly for maize production and grazing (Figure 3.3). The PES of this catchment is measured as a Category E (seriously modified) and moderate Ecological Importance (EI) and a High Sensitivity (HS). DWS conducted a broad study in 2012 of the Olifants Catchment and split it into various Integrated Units of Analysis (IUA), the IUA relevant to the evaluation area (catchment B12B, Figure 3.2), is the Upper Olifants Catchment unit (unit II). This unit is viewed as extremely significant in terms of ecological sensitivity and is distinguished by the below listed impacts (DWA, 2012):

- Declining quality of water due to mining and industry.
- Riparian areas and bank characteristics are greatly impacted by farming activities.
- Flow changes because of impoundments; and bed alteration because of sedimentation.

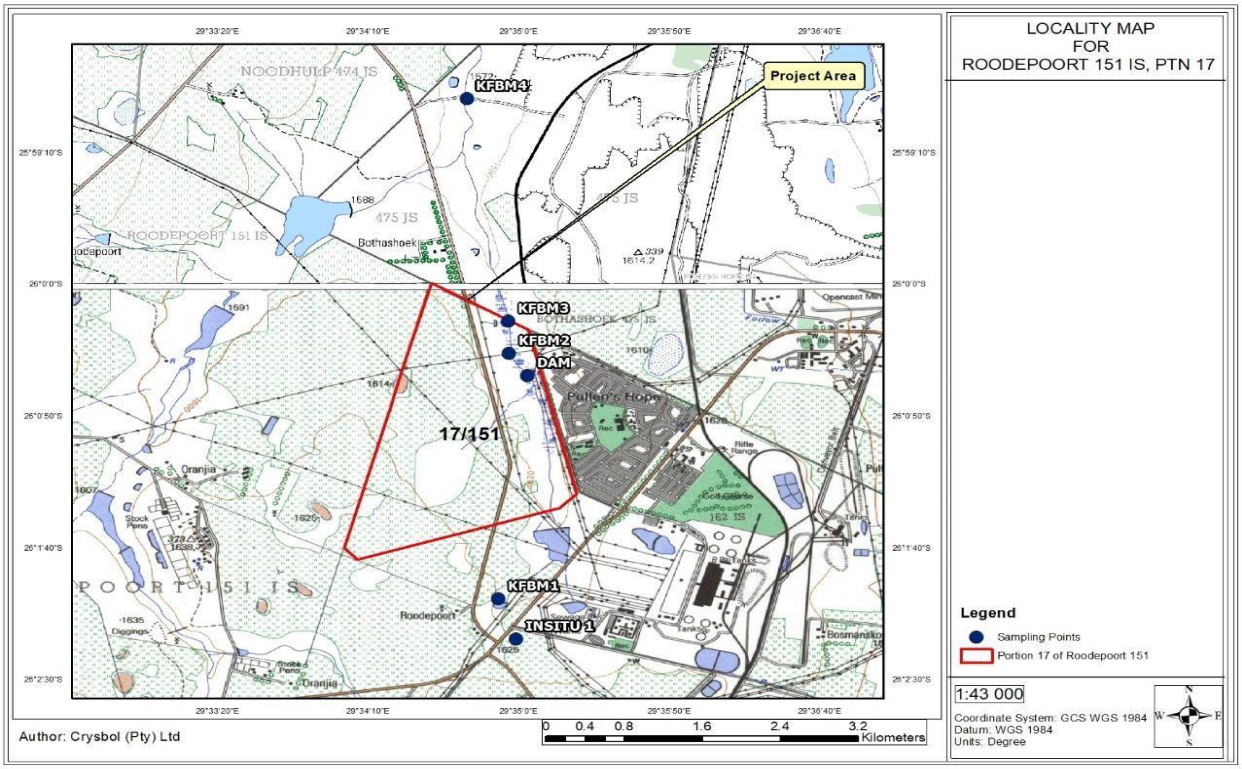


Figure 3. 1 Site Location. Roodepoort Farm: north-west of the Hendrina Power Station and southwest of the Optimum Coal operations. Base map source: Eco Elementum.

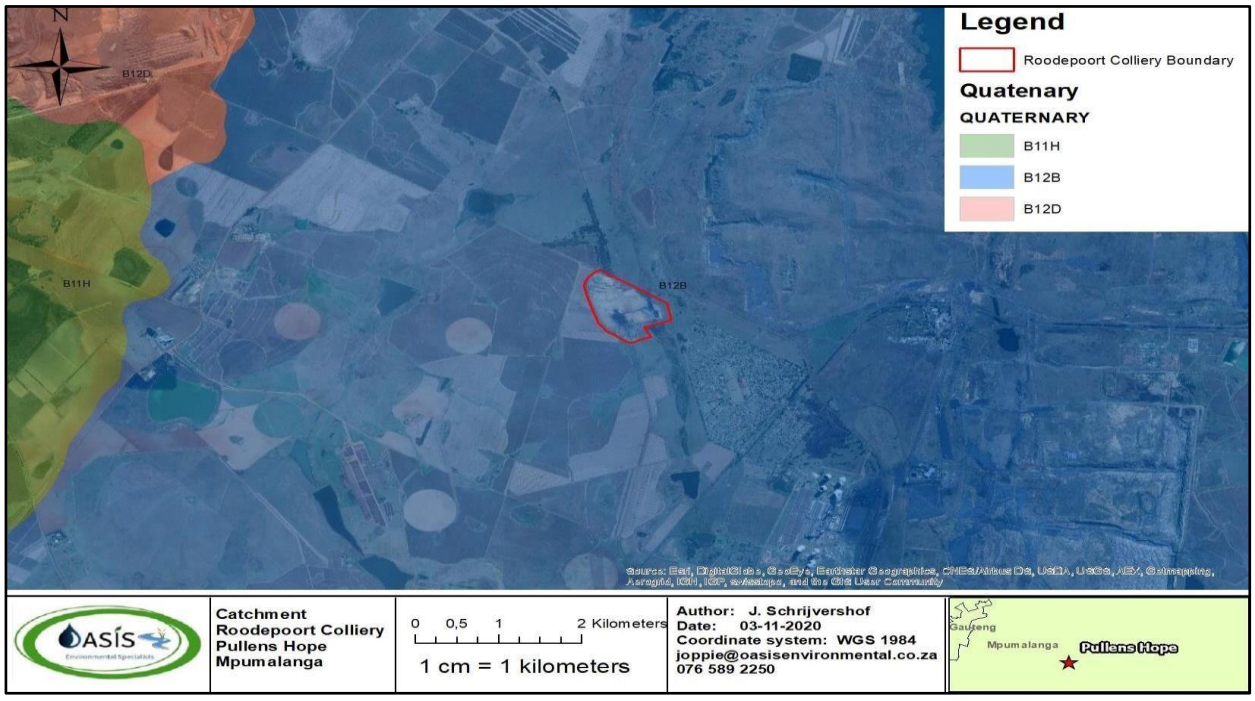


Figure 3. 2 Quaternary Catchment map for Roodepoort Colliery. Source: Oasis Environmental Specialists.

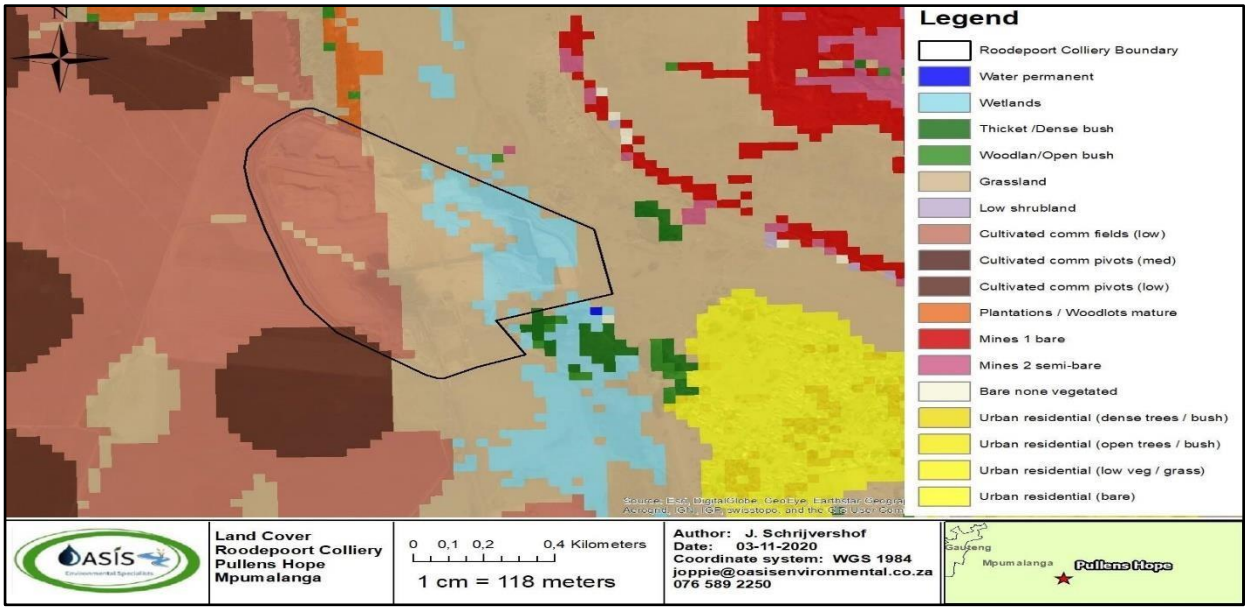


Figure 3. 3 Land cover map in proximity of Roodepoort Colliery. Source: Oasis Environmental Specialists.

3.2 Water Quality Threshold

DWS issued a licence (ref: 04/B12B/ABCGIJ/2868) to Kebrafield with conditions to monitor water quality upstream and downstream of the Woestalleen wetland (Figure 3.1 and 3.4). The issued licence also specified preferred thresholds for different parameters. Therefore, the water quality limit on the issued licence was compared to the monitoring results to see if the monitored parameters are within the required limit or not. The water quality limits were set according to the reserve for B12B catchment (NWA, 1998). Table 3.1 below indicates relevant parameters for monitoring and water quality limits as specified in the issued licence.

Table 3. 1 Monitoring parameters and water quality limits.

Variable	**Limit**
pH	6.5-8.4
Electrical Conductivity (EC) (mSm)	≤40
Suspended solids (SS) (mg/l)	≤25
Dissolved oxygen (mg/l)	≥6.0
Sulphate ($S0_4$) (mg/l)	≤30
Sodium (Na) (mg/l)	≤20
Chloride (Cl) (mg/l)	≤30
Turbidity (NTU)	≤5
Alkalinity ($mgCaC0_3$/l)	≤120
Nitrite/Nitrate ($N0_{2/3}$ as N (mg/l)	≤6.0
Orthophosphate ($P0_4$ as P) (mg/l)	≤0.05

3.3 Wetland Data Acquisition

The manual for the evaluation of a Wetland Index of Habitat Integrity for South African channelled valley bottom wetland and floodplain types was used to inform wetland data acquisition after the rehabilitation of the wetland as the current status is known as class D (DWAF, 2007).

3.3.1 Desktop Work

The desktop information was acquired from the Eco Elementum Environmental and Engineering data base as the project managers for the Kebrafield Mine.

Step1: collection of available data.

The following information was obtained from Eco Elementum Environmental and Engineering before conducting the wetland evaluation:

- A 1:50 000 map of the area.
- Recent aerial photos and good quality Google Earth imagery.

- Land-cover information and/or aerial survey information.

River water quality monitoring data such as water quality data from downstream and upstream of the site was also obtained from Eco Elementum. Information about the catchment current status and the types of activities in the catchment area was gathered in collaboration with Eco Elementum and Oasis Environmental Specialists (e.g., forestry, dams, hydrological information of the main rivers in the catchment).

The Woestalleen wetland assessment report compiled by M2 Environmental Connections for Eco Elementum in July 2013 was used as the primary data source for the baseline information about the wetland.

Step 2: study area delineation and selection of the site.

In collaboration with Oasis Environmental Specialists, maps, aerial photographs, and Google Earth imagery were applied to map out the estimated size of the Woestallen valley bottom wetland. Major breaks between different units were delineated (DWAF, 2007). Sites were then selected for field assessment i.e., access points to the wetland used to obtain wetland ecological condition. All obtainable maps and images were taken onsite during the site visit assessment. Information from the desktop data base were used to evaluate the extent of the land use activities and this was also verified during the wetland assessment.

3.3.2 Field Assessment

The field assessment was performed on the 27th of November 2020. The following steps and information were assessed, and the scoring of the wetland was recorded on the field form (Appendix B) during the field assessment, with the aid of the wetland specialist (Oasis Environmental Specialists). Therefore, all the wetland rating and scoring in this section was conducted with the help of the wetland specialist (Schrijvershof, 2020). The field information was subsequently fed into the EXCEL based WETLAND-IHI model (Appendix C), and this computes the PES scores for the wetland. The Manual for the assessment of a Wetland Index of Habitat Integrity for

South African channelled valley bottom and floodplain wetland categories was used to assess the following data sets. (DWAF, 2007).

3.3.2.1 Site information.

The information below was captured on the field form (DWAF, 2007).

- name of the site.
- Co-ordinates.
- 1:50 000 topographical map.
- Eco-Region of the site location.
- Project area geology.
- The name of the evaluator; and
- The assessment dates.

3.3.2.2 Categorization of the wetland.

The reference state of the Woestallen wetland was determined by considering how the Woestallen wetland originally looked like without land use activities and impacts on hydrology, geomorphology, and water quality (DWAF, 2007).

Woestallen wetland system was assessed to determine if it was originally a channelled valley bottom wetland in reference settings, as unchannelled valley bottoms can sometimes develop to channelled as a result of increased runoff from fast urbanising catchments or due to construction (canalization) activities of landowners. The floodplain surface and aerial photographs were therefore evaluated for indication of the natural original channel (DWAF, 2007).

3.3.2.3 Evaluation of vegetation alteration.

An evaluation of the percentage of the levels of the land uses and variations in the wetland, and impact rating was done under this section. Scoring was done according to the following impact weighting. The total of the extent of various land use activities was equal to 100% *(*DWAF, 2007). (See Appendix D).

3.3.2.4 Evaluation of hydrological PES.

Evaluation of the changes on the water regime in the wetland was conducted at the catchment level. The following criteria were assessed and rated.

Flood peaks and/or frequencies changes:

Deviations in the catchment which might be impacting flood peaks were rated using the changes in flood peaks table (See Appendix D) (DWAF, 2007).

Base flows change:

Several deviations in the base flows from the catchment such as impacts of water extraction and inter-basin transfer such as return flows, water releases for the purpose of irrigation, water contributions from suburban areas in the catchment was conducted in this section. Rating of the modifications in the catchment that are impacting base flows were done through the changes in base flows table ((See Appendix D). (DWAF, 2007).

Seasonality changes:

Flow seasonality modifications, because of upstream activities were evaluated. Impact of attenuation of early wet season flows because of dams upstream and any seasonality changes due to abstraction related to irrigation were evaluated. Rating was conducted using changes in seasonality table (See Appendix D). (DWAF, 2007).

Occurrence changes and phase of zero flow periods:

Ranking of the changes was done using changes in existence and period of zero flow table (See Appendix D) (DWAF, 2007).

Wetland Connectivity - altered channel size/competency.

Changes in terms of increase in the channel competency was evaluated under this section. Changes in the channel competency are mostly due to erosion within the channel and this leads to high flows being confined in the channel and low flows onto the floodplain. These alterations must be assessed in relation to the reference state of the system (DWAF, 2007). Connectivity - altered channel size/competency table was used for rating (See Appendix D).

Increased water retention on the floodplain:

The extent of increased water retention was evaluated and rated as per the guidelines provided on increased water retention on the floodplain table (See Appendix D) (DWAF, 2007).

Decreased water retention on the floodplain:

Factors that contribute to decreased water retention were assessed and rated according to the criteria as provided on decreased water retention on the floodplain (See Appendix D). (DWAF, 2007).

3.3.2.5 Evaluation of geomorphological PES.

The geomorphological processes were evaluated at catchment level and inside the wetland. At the catchment scale, changes to the balance amongst sediment deposition and sediment transportation were evaluated and the interaction between sediment deposition and transportation was evaluated and rated in terms of the fluctuations in sediment supply and changes in sediment transport capacity tables (See Appendix D) (DWAF, 2007). Wetland areas were largely demarcated in terms of the occurrence of hydric soil types. Hydric soils are described as the soils which show redoximorphic features as a result of extended and recurring saturation. Features consist of the occurrence of mottling.

The occurrence of redoximorphic features is the greatest vital pointer of wetland existence because these soil wetness pointers persist in wetland soils, even if they are destroyed or dry (DWAF, 2005). Redoximorphic features are soil characteristics which arise due to continued and recurring wetness. A hand auger was used to collect soil samples randomly in the rehabilitated wetland area.

Erosional Processes:

The effects of erosional processes such as indication of ditches and amount of overgrazing or cultivation on the floodplain were assessed using the erosional processes table (See Appendix D) (DWAF, 2007).

Depositional Processes:

The impact of depositional processes was evaluated by looking at evidence of new sediment deposition and it was rated using the depositional processes table (See appendix D) (DWAF, 2007).

3.3.2.6 Evaluation of water quality PES.

The following seven components of water quality were evaluated:

pH, Salts, Nutrients, Water temperature, Turbidity, Oxygen; and Toxics (e.g., Heavy Metals and Pesticides).

Evaluation on how the above water quality components have likely altered due to some or all the following impacts in the catchment was conducted, rated, and recorded on the field form (see Appendix B)

- Modified flow conditions.
- Accumulation by dams and weirs.
- Effluent emanating from metropolitan areas.
- Wastewater from farming activities.
- Return flows.

- Wastewater from industrial areas.
- Wastewater discharged from mining.
- Instream plants such as macrophytes and algae.
- Plantation.
- Roads and bridges.
- Invasive riparian species.
- Riparian vegetation degradation.
- Bed disturbance as a result of bull dozing and sand mining.
- Bank disruption because of vegetation removal and artificial covering.
- Disposal of solid waste.

The impact rating was assigned in the white boxes on the data sheet, indicating the modification in the above-mentioned water quality variables related to each of the above listed land use activity (See appendix B) (DWAF, 2007).

3.3.2.7 Evaluation of the overall PES.

After collection of all the data, the significance of the driving processes against onsite impacts were scored and then entered into the EXCEL-based WETLAND-IHI model (Appendix C), and this estimates the overall PES scores for the wetland (DWAF, 2007).

3.4 Water Quality Data Acquisition

Water samples were collected by Eco Elementum for lab analysis from five of six selected monitoring points (KFBM1, DAM, KFBM2, KFBM3 and KFBM4) (Figure 3.4 and Table 3.2**)** monthly from January 2018 to February 2020. *In situ* measurements at five of six selected monitoring sites (INSITU1, KFBM1, DAM, KFBM2, and KFBM3) excluding KFBM4 due to accessibility challenges were conducted. INSITU 1 was added upstream of all other monitoring points for *in situ* measurements in order to complement lab results.

	ID NO	Description	Coordinates
1.	INSITU 1	Upstream of the wetland	26°2'15"S 29°34' 58.944"E
2.	KFBM1	Upstream of the wetland	26° 1' 59.68"S 29° 34' 53.17"E
3.	DAM	Immediately upstream of disturbance	26°0' 34.83"S 29° 35' 2.80"E
4.	KFBM2	Disturbed/rehabilitated	26°0' 26.33"S 29° 34' 56.64"E
5.	KFBM3	Downstream of mining and rehab wetland	26°0' 14.26"S 29° 34' 56.41"E
6.	KFBM4	Downstream of mining and rehab wetland	25° 58' 49.82"S 29° 34' 42.62"E

Table 3. 2 Water quality monitoring points.

Figure 3. 4 Water quality monitoring points.

Lab results for water quality before, during and after wetland rehabilitation were obtained from Eco Elementum Environmental and Engineering. Eco Elementum Environmental and Engineering was responsible for water quality monitoring upstream and downstream of the Woestalleen wetland on behalf of Kebrafield as required in

terms of the issued water use licence. Base line lab water quality data collected 12 Months (July 2018 - June 2019) before rehabilitation of the wetland and 12 months (August 2019 to July 2020) lab water quality data collected during and after rehabilitation were obtained from Eco Elementum and Engineering. The following variables were analysed: pH, electrical conductivity, turbidity, suspended solids, total alkalinity, chloride, sulphate, nitrate, nitrite, dissolved oxygen, and sodium.

3.5 YSI probe calibration and in situ measurement

In situ measurements were performed for DO, EC, Temperature, and pH monthly from August 2019 to February 2020 in order to complement the laboratory data collected by Eco Elementum Environmental and Engineering.

3.4 .1 YSI probe calibration.

Calibration of Electrical Conductivity (EC) and pH was done in the GAES water laboratory at the University of the Witwatersrand before taking the YSI probe onsite for measuring of *in situ* temperature, pH, Dissolved Oxygen (DO) and EC. pH calibration was done using a two-point calibration with buffer solutions of pH 4 and 7. EC was calibrated using an EC standard solution of 1413 µS/cm (25°C).

pH Calibration

The following steps were followed to ensure proper pH calibration:

- The sensor and calibration cup are rinsed through a little volume of pH buffer.
- The cup was filled with pH buffer to ensure that the pH sensor tip and the temperature sensor are immersed in buffer.
- The pH value of the buffer solution was entered, and the calibration accepted after the pH had stabilized in each buffer.
- The sensor and calibration cup were rinsed with a small amount of the next buffer between calibration points.
- Two-point calibration was done using pH 7 and pH 4.
- After pressing enter to accept the last calibration point, the “cal” button was pressed to complete the calibration.

EC Calibration

The followings steps were followed for EC calibration:

- The conductivity sensor was cleaned and dried before performing a specific conductance calibration.
- Fresh, traceable EC calibration mixture of 1413 µS/cm (25 °C/77 °F) was used when calibrating the conductivity sensor.
- The cal cup and sensors were pre-rinsed with a small amount of calibration standard and rinse standard.
- The calibration solution covered the top vent holes of the conductivity sensor.
- The entire conductivity sensor was submerged in the solution to ensure that the instrument read accurately.
- Calibrating for Specific Conductance, the value of the conductivity solution as it is listed for 25°C is entered, then the calibration was accepted.

Dissolved Oxygen (DO) calibration

DO was calibrated every time the instrument was used onsite. A 1-point calibration in water-saturated air was performed by placing the sensor in a 100% humid environment (the loosened calibration chamber with a small quantity of water in the base) and after entering the % calibration mode, a period of approximately 5-15 minutes was allowed for the storage container to become completely saturated before accepting the calibration.

3.6 Water Sample Analysis

Variables for analysis were chosen based on the anthropogenic activities (agricultural and coal mining) and sources of pollutants occurring upstream and adjacent to the wetland in question. Water samples were collected and sent to two commercial accredited laboratories (Water Lab and Yanka Laboratory) monthly for the analysis of the following water quality variables: pH, electrical conductivity, turbidity, suspended solids, total alkalinity, chloride, sulphate, nitrate, nitrite, ortho phosphate, dissolved oxygen, and sodium.

3.7 Laboratory Analytical Methods

Water Lab and Yanka laboratory were utilised for water samples analysis during the study period. Samples collected from July 2018 to March 2020 were analysed by Water Lab using different analytical methods as indicated in table 3.3 below.

Table 3. 3 Water Lab laboratory analysis methods

Analysis	Standard Method/Method Base	Instruments/ Techniques
Alkalinity	YE010Alk / * SM 2320 ** / ISO 9963	Titrimetric (Indicator/pH)
Conductivity	YE020Con / * SM 1057 / * ISO 7888 (SANS)	Conductimetric
pH	YE030pH / * SM 11 / * ISO 10523 / * SANS 5011	Electrometric
Solids - Suspended	YE081TSS / * SM 1049 / * SANS 6049	Gravimetric (105 C)
Turbidity	YE082TB / * SM 197 / * ASTM D 1889 / * SANS 5197	Nephelometric
Oxygen Dissolved #	YE051OD / * SM 1047 / * SANS 6047	Membrane Electrode
Chloride	YE070AK / * ISO15923 / * ISO 15682 (SANS)	Spectrophotometric
Nitrate	YE070AK / * ISO15923 / * ISO 13395 (SANS) / * SANS 5210	Spectrophotometric
Nitrite	YE070AK / * ISO15923 / * ISO 13395 (SANS) / * SANS 5210	Spectrophotometric
Phosphate - Ortho	YE070AK / * ISO15923 / * ISO 6878 (SANS)	Spectrophotometric
Sulphate	YE070AK / * ISO15923 / * ISO 6310 (SANS)	Spectrophotometric

Water Lab temporarily closed in March and as a result water samples that were collected from April 2020 to June 2020 were analyzed at Yanka laboratory using

different analytical methods as indicted in table 3.4 below. No changes were observed as result of switching from Water Lab to Yanka laboratory.

Table 3. 4 Yanka laboratory analysis methods.

Method Name	**Method Number**	**Method Type**
pH	WLAB/001/pH/Method	Potentiometric
EC	WLAB/002/E.C./Method	Conductometric
Total Dissolved Solids	WLAB/003/T.D.S./Method	Gravimetric
Suspended Solids	WLAB/004/S.S./Method	Gravimetric
Turbidity	WLAB/005/Turbidity/Method	Colorimetric/Spectrophotometric
Dissolved Oxygen	WLAB/040/D.O./Method	Potentiometric
Nitrates	WLAB/046/Discrete analyser/Method	Colorimetric/Spectrophotometric
Ortho Phosphate	WLAB/046/Discrete analyser/Method	Colorimetric/Spectrophotometric
Chloride	WLAB/046/Discrete analyser/Method	Colorimetric/Spectrophotometric
Sulphates	WLAB/046/Discrete analyser/Method	Colorimetric/Spectrophotometric
Nitrite	WLAB/046/Discrete analyser/Method	Colorimetric/Spectrophotometric

3.8 Data Analysis

Microsoft Excel and the commercial plugin XLSTAT were used to calculate summary statistics i.e., minimum, average, and maximum values of different variables mentioned above at different sites for different time periods (before, during and after

rehabilitation). Normality tests (Jarque-Bera, Shapiro-Wilk, Anderson-Darling and Lilliefors) were conducted on XLSTAT to establish if the data was normally distributed. Since it was established that the data was not normally distributed, non-parametric tests (Kruskal-Wallis Test) were performed for all variables between sampling sites at different time periods to establish significant differences ($p<0.05$) of concentration distributions for different parameters.

Box plots were created using XLSTAT in order to compare the concentration levels of pH, electrical conductivity, turbidity, suspended solids, total alkalinity, chloride, sulphate, nitrate, nitrite, ortho phosphate, dissolved oxygen, and sodium at different water quality monitoring sites during study periods 1 (July 2018 to July 2019), 2 (August 2019-January 2020) and 3 (February 2020-June 2020). Study period 1 represents before rehabilitation, study period 2 represents during rehabilitation and study period 3 represents after rehabilitation. XLSTAT was also used to run Spearman correlation tests for lab and *in situ* water quality results at different sites before rehabilitation, during rehabilitation and after rehabilitation.

Chapter 4. RESULTS

4.1 Wetland Delineation and Assessment

This section outlines the outcomes of the wetland assessment conducted on 27th of November 2020, 10 months later after the completion of the rehabilitation work in January 2020. Wetland assessment and scoring was done in collaboration with Oasis Environmental Specialists. Wetland data such as satellite images, wetland delineation maps and land cover information were obtained from Eco Elementum Environmental and Engineering and Oasis Environmental Specialists. During the study period some pictures were taken i.e., before wetland mining, during wetland rehabilitation and after wetland rehabilitation (Figure 4.1).

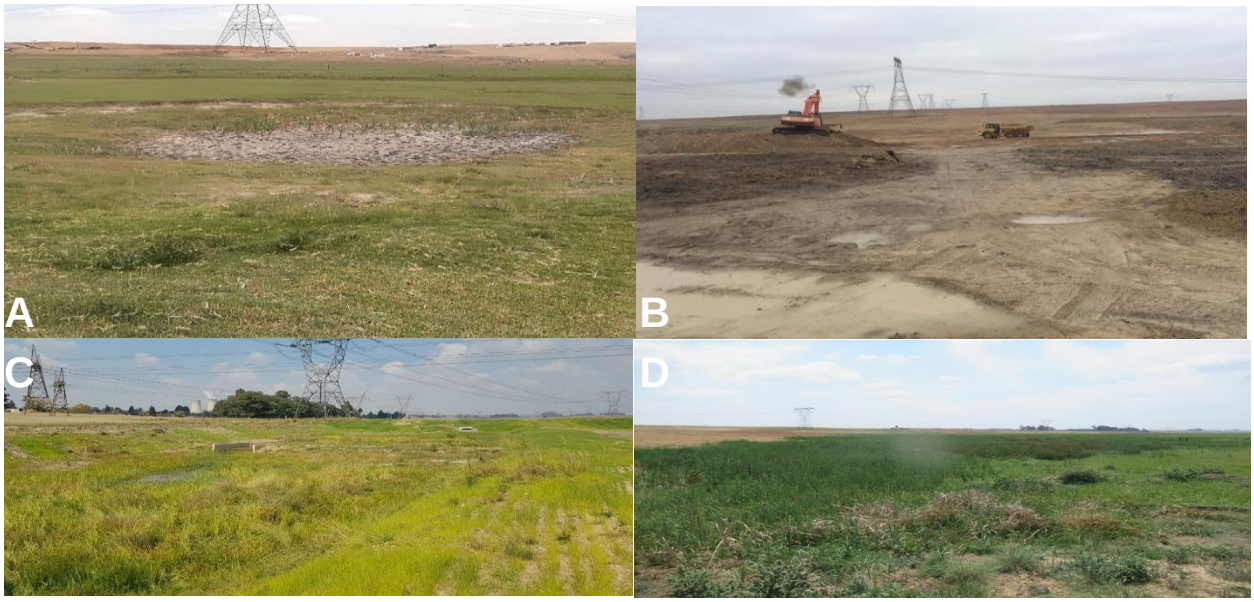


Figure 4. 1 shows pictures taken on site before, during and after rehabilitation of Woestalleen wetland. A: before mining through the wetland (taken: 07/12/2018), B: during wetland rehabilitation (taken:25/09/2019), C: after rehabilitation of the wetland (taken:31/01/2020) and D: during wetland assessment (27/11/2020). Photographs Taken by Lindelani Mbulaheni.

4.1 .1 Desktop Assessment

Valley bottom and depression National Freshwater Ecosystem Priority Areas (NFEPA) wetlands were categorized in the study area through the desktop evaluation (Figure 4.2). Though, true information of the existence and state of NFEPA wetlands is imperative to know regional activities which impacted on the wetland system, their functional integrity and condition.

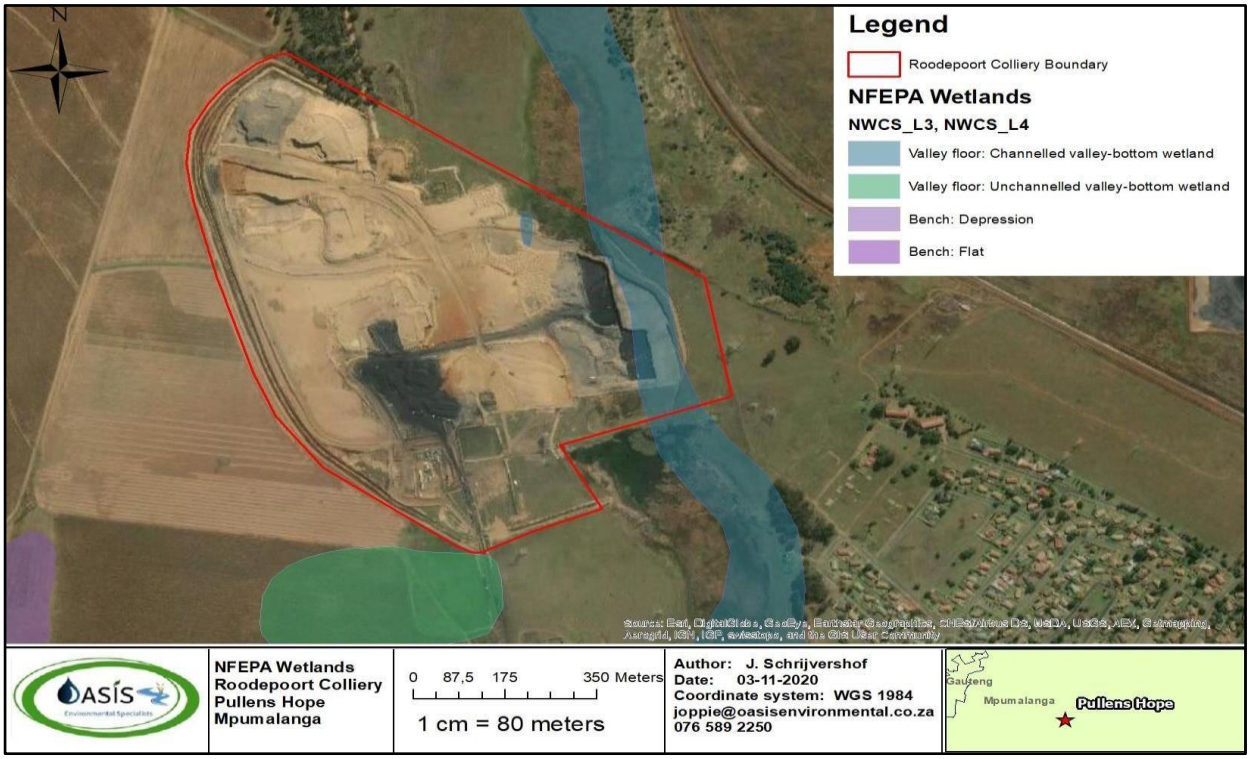


Figure 4. 2 Roodepoort Colliery - NFEPA Wetland map. Source: Oasis Environmental Specialists.

4.1.2 Soil form indicator

Hydric soils observed in the study site were categorized as a sandy clay loam (Figure 4.3). There was evidence that the hydric soil structures are beginning to settle and forming in the wetland areas and stream diversion area.

Figure 4. 3 Soils sampled within the stream diversion and permanent wetland areas.

Source: Oasis Environmental Specialists.

4.1.3 Vegetation indicator.

Vegetation is viewed as an important factor to be used for wetlands delineation. Vegetation is also a dominant portion of the wetland description in the NWA. Though, relying on vegetation as a major wetland pointer needs an uninterrupted condition (DWAF, 2005). changes were though prominent in the wetland systems causing it hard to only depend on vegetation as a wetland indicator. Changes comprised the occurrence of alien invasive species, damming, mining and erosion within the area. Wetland riparian vegetation consisted of mainly of *Kniphofia fluviatilis, Typha capensis*, *Cyperus spp* and *Juncus spp.* (Figure 4.4).

Figure 4. 4 Riparian plants (*Kniphofia fluviatilis, Typha capensis*, *Cyperus spp* and *Juncus spp.)* which have established in the permanent wetland areas and stream diversion. Source: Oasis Environmental Specialists.

4.1.4 Wetland Delineation

The wetlands discovered on the sites were classified according to the WETLAND-IHI (DWAF, 2007). Wetland areas were categorized as channelled valley bottom wetland based on the observed water source to the wetland, geomorphic setting, and the water flow directions (MacFarlane et al., 2008).

In the baseline study conducted in 2013 by M2 Environmental Connections cc they have categorized the PES for the channelled valley bottom wetland as a Largely Modified (Category D) (Nieman & Mare, 2013). It can be stated that a huge modification in wetland processes and degradation of biota and habitat has happened inside the wetland areas due to opencast mining (Nieman & Mare, 2013).

The rehabilitation process for the wetland area included a stream diversion with the re-establishment of hydric soils with wetland and terrestrial vegetation for the disturbed areas due to the mining activities within the channelled valley bottom wetland system.

The channelled valley bottom wetland has been changed in terms of hydrology, geomorphology, and vegetation, which impacted subsurface flow and the ecology of the wetland. This system was reassessed in terms of the WETLAND-IHI (DWAF, 2007).

Channelled valley bottom wetlands are defined by their position on valley floors and the occurrence of a channel flowing over the wetland. Main water sources to these types of wetlands are from/into a channel, in this example an upstream source, flowing across the wetland as surface flows because of flooding and as subsurface flow. (Ollis *et al*., 2013).

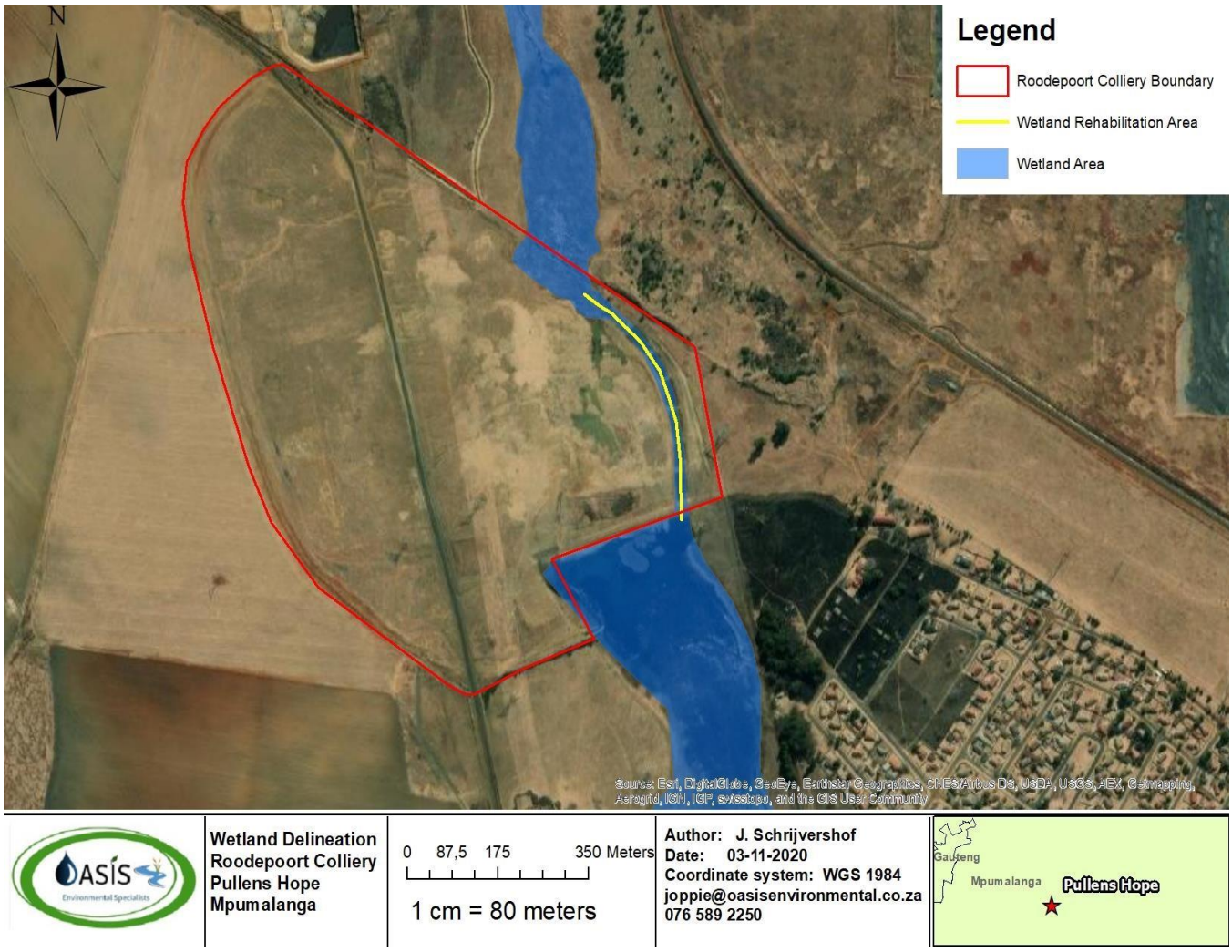


Figure 4. 5 Roodepoort Colliery Current wetland delineation post mining and post rehabilitation. Source: Oasis Environmental Specialists.

4.1.5 Channelled valley bottom wetland

The channelled valley bottom wetland conditions for the post rehabilitation activities of the Roodepoort Colliery were found to be seriously modified (Category E) (Table 4.1). changes to the wetland and the subsequent impact on the state of the wetlands is mainly linked to the widespread alien invasive vegetation, erosion, damming and current mining activities from the Colliery adjacent to the wetland area. The wetland area is surrounded by urban and industrial development. Hydrology, geomorphology, and water quality weightings were used to calculate the driving processes and overall weightings are 100 for the driving processes and 80 for wetland land use.

Table 4. 1 Summary of overall PES scores for the HGM Units found for the post rehabilitation activities of the Roodepoort Colliery

TOTAL PES SCORE			
	Ranking	**Weighting**	**Score**
DRIVING FORCES:		**100**	**59,3**
Hydrology	1	100	68,4
Geomorphology	2	80	68,9
Water Quality	3	30	3,5
WETLAND LANDUSE:		**80**	**3,2**
Floodplain Landuse Impacts	1	100	3,2
TOTAL SCORE:		*180*	**34,4**

4.2 Water Quality Results

4.2.1 Water quality data summary

Lab water quality results before, during and after wetland rehabilitation were obtained from Eco Elementum Environmental and Engineering.

Microsoft EXCEL time series histograms were used to analyze monthly water quality data for each site during different study periods 1 (July 2018 to July 2019), 2 (August

2019-January 2020) and 3 (February 2020-June 2020). Study period 1 represents before wetland rehabilitation, 2 represents during rehabilitation of the wetland and 3 represents after rehabilitation of the Woestalleen wetland.

Monthly concentration values were used to compare with WUL water quality standards (Table 3.2) as provided by the DWS on WUL (ref:04/B12B/ABCGIJ/2868). The comparison was done to ascertain if the water quality of the Woestalleen complies with the specified water quality standards on the WUL.

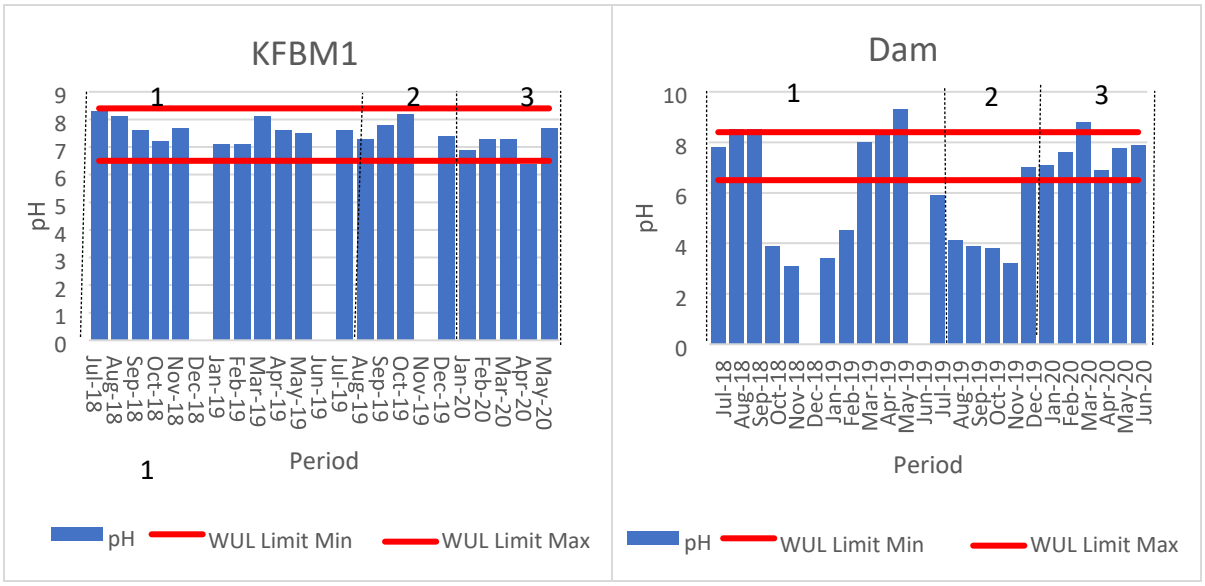


Figure 4. 6 pH levels at upstream sites, KFBM1 and Dam.

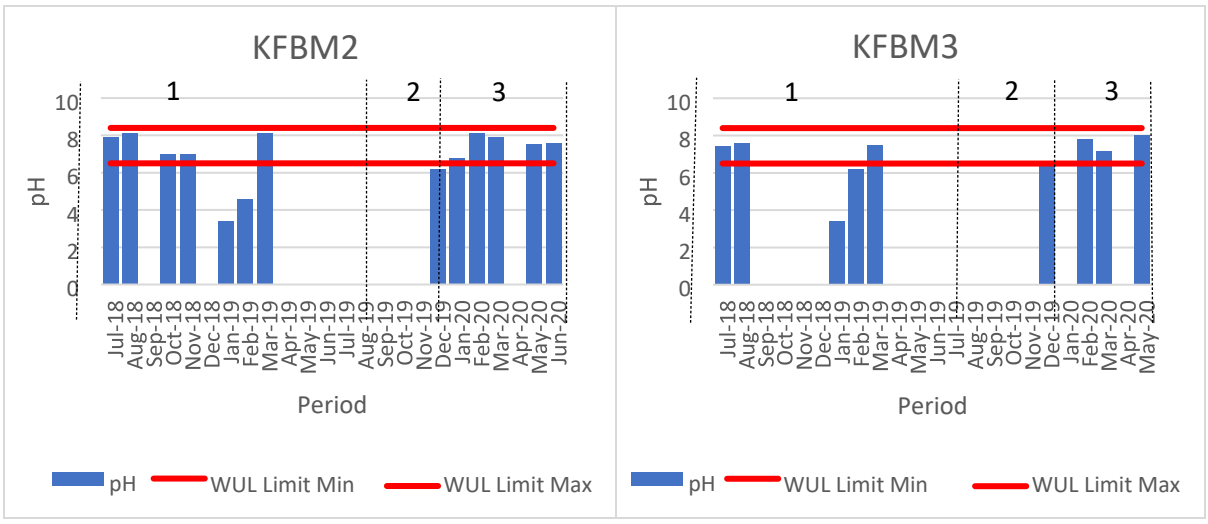


Figure 4. 7 pH levels at downstream sites, KFBM2 and KFBM3.

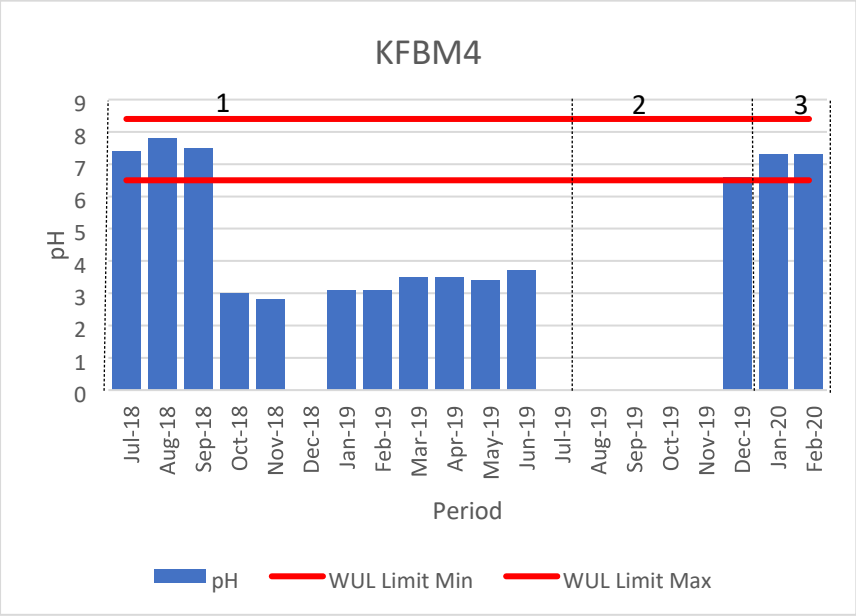


Figure 4. 8 pH levels at furthest downstream site, KFBM4.

At Dam site, pH remained within the WUL limit from July to September 2019, March to April 2019 during study period 1, during study period 2, pH remained within the WUL limit from December 2019 to January 2020 and during study period 3, pH exceeded the WUL limit only in March 2020 and remained within the WUL limit for all other sampling events during study period 3. At KFBM2, pH exceeded the WUL limit from January 2019 to February 2019 during study period 1 and in December 2019 during study period 2, and it was within the WUL limit throughout study period 3. At KFBM3, pH only exceeded the WUL limit in January and February 2019, similar trend was observed at KFBM2. During study period 2 and 3 pH remained within the WUL limit. At KFBM4, pH remained within the WUL limit during study periods 2 and 3 and exceeded the WUL limit in October, November 2018, from January 2019 to June 2019.

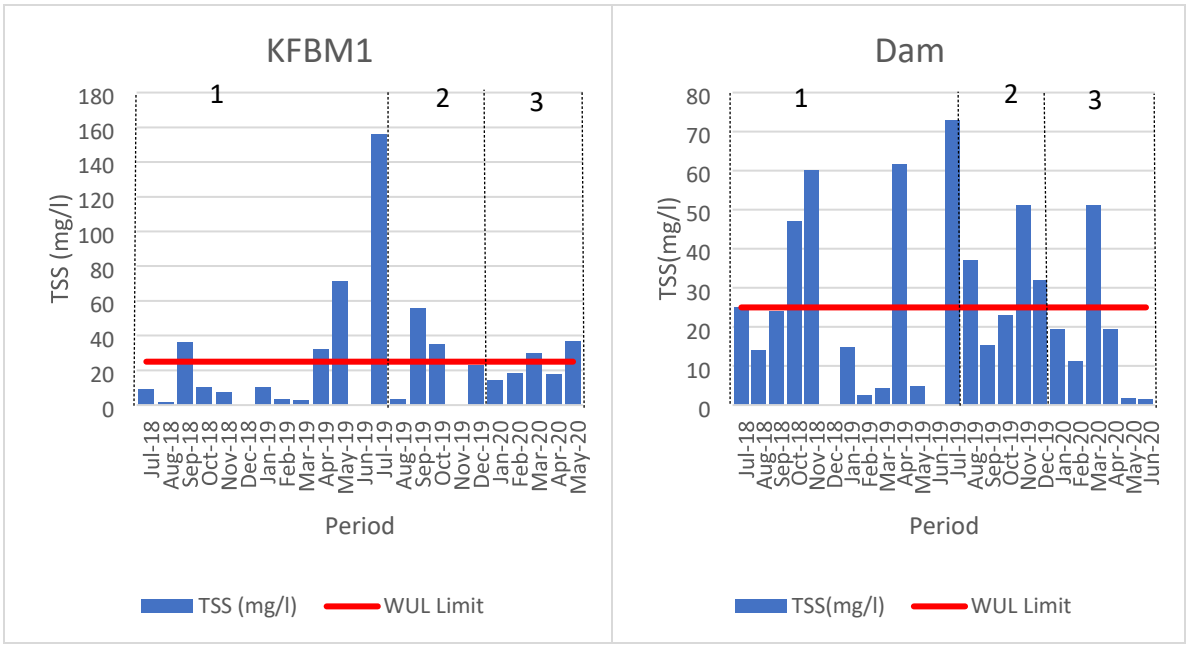


Figure 4. 9 TSS concentration at upstream sites, KFBM1 and Dam.

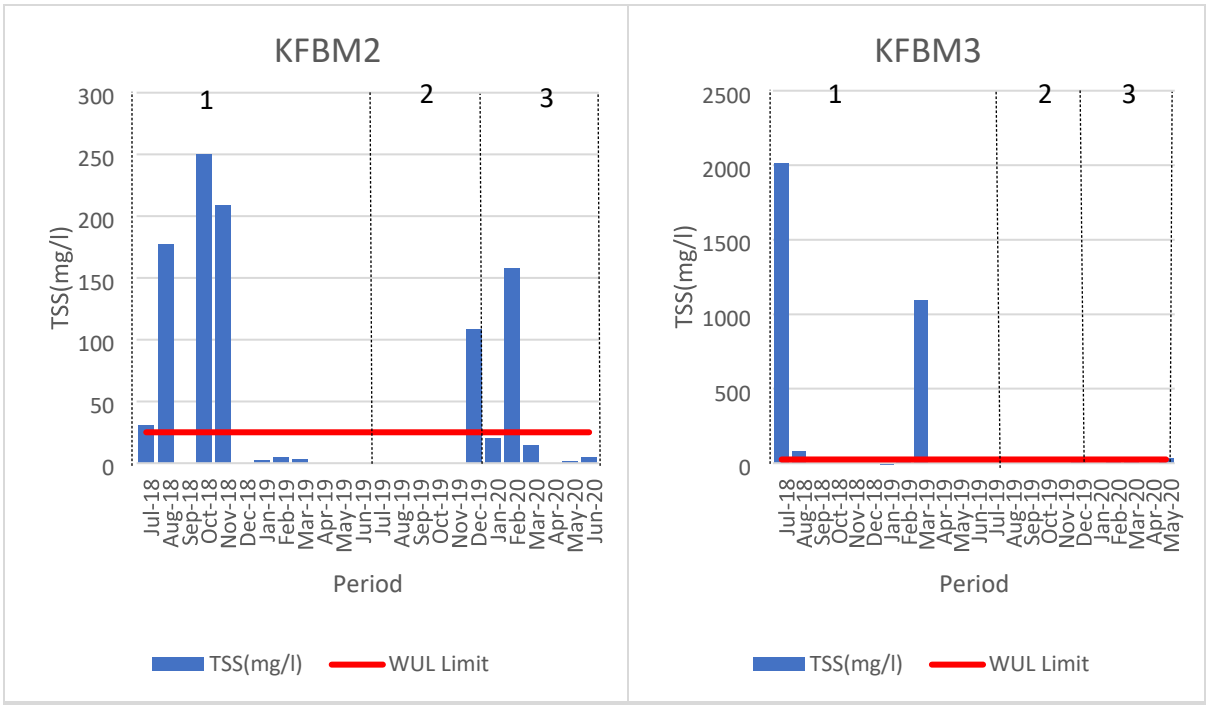


Figure 4. 10 TSS concentration at downstream sites, KFBM2 and KFBM3.

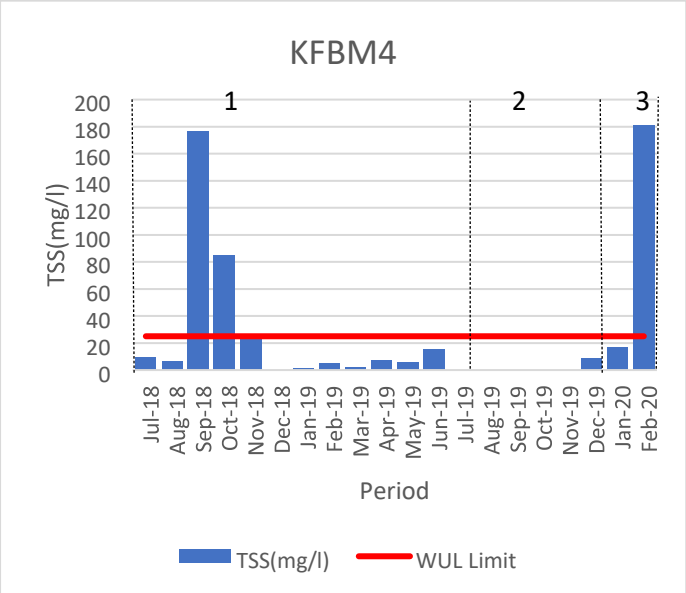


Figure 4. 11 TSS concentration at furthest downstream site, KFB4.

At KFBM1, TSS was above the WUL limit in September 2018, April, May, and July 2019 during study period 1. During study period 2 TSS exceeded the WUL limit in September and October 2019 and during study period 3, TSS exceeded the WUL limit in March and May 2020. At Dam, TSS exceeded the WUL limit in October, November 2018, April, and July 2019 during study period 1. During study period 2, pH exceeded the WUL limit in August, November, and December 2019 and during study period 3, it only exceeded the WUL limit in March 2020. At KFBM2, TSS exceeded the limit in August, October, and November 2018 during study period 1. During study period 2, TSS only exceeded the WUL limit in December 2019 and during study period 3, TSS only exceeded in February 2020. At KFBM3, TSS only exceeded the WUL limit in July, August 2018, and March 2019 during study period 1. A spike of TSS was observed in July 2018 and March 2019. TSS remained within the WUL limit during study periods 2 and 3. At KFBM4, TSS exceeded the limit in September and October 2018 during study period 1 and February 2020 during study period 3 and it remained within the limit during study period 2.

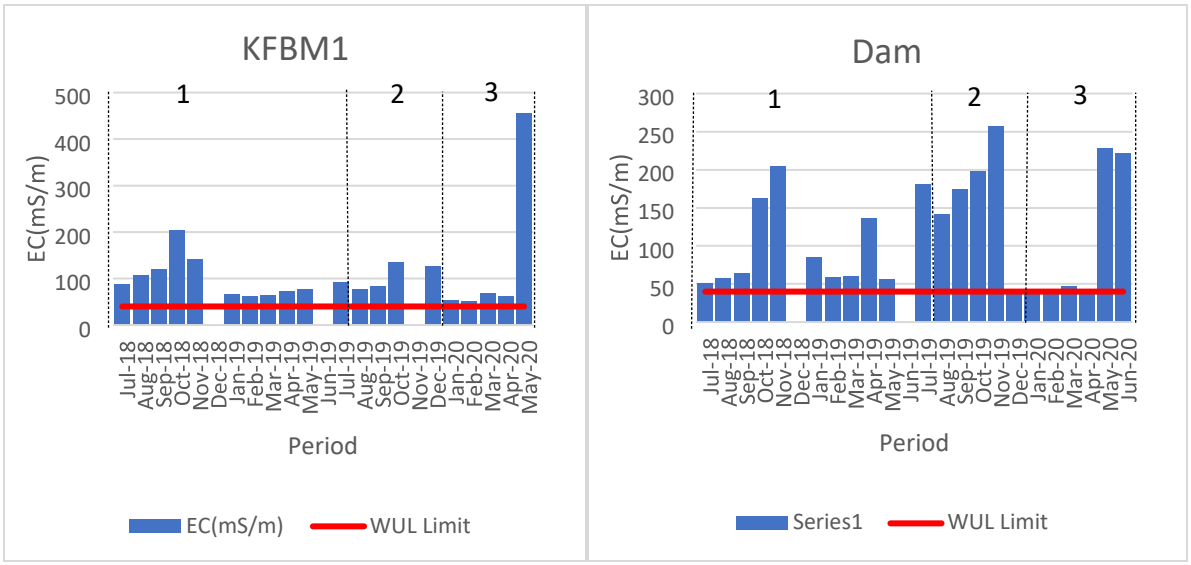


Figure 4. 12 EC concentration at upstream sites, KFBM1 and Dam.

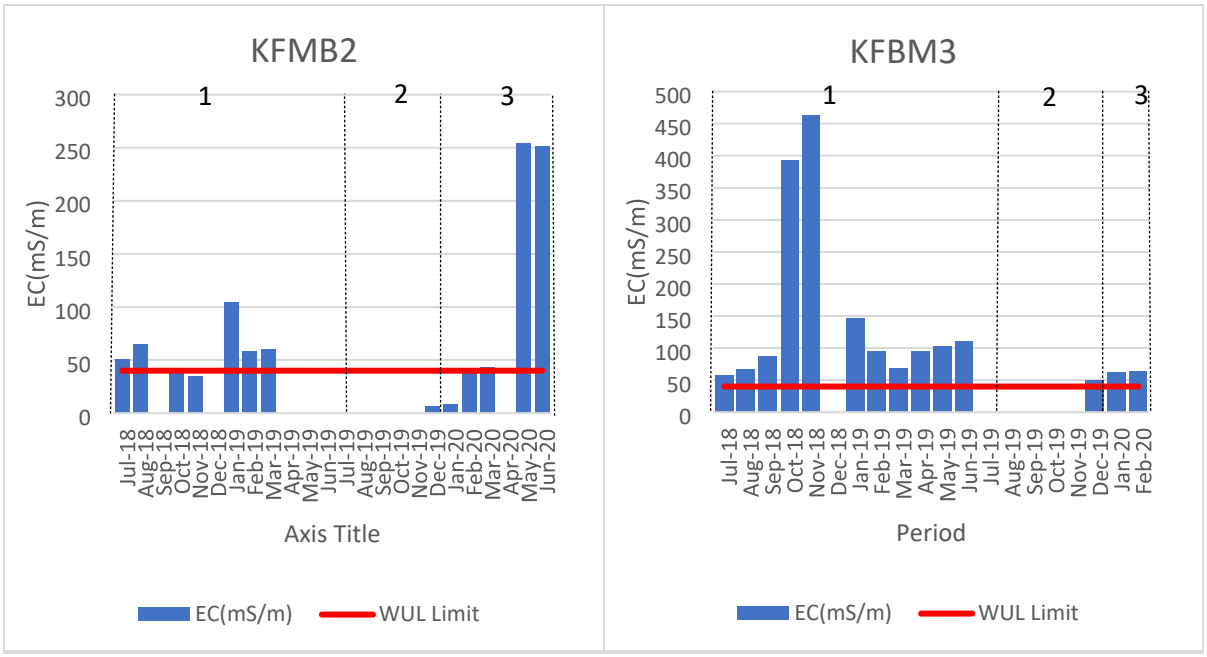


Figure 4. 13 EC concentration at downstream sites, KFBM2 and KFBM3.

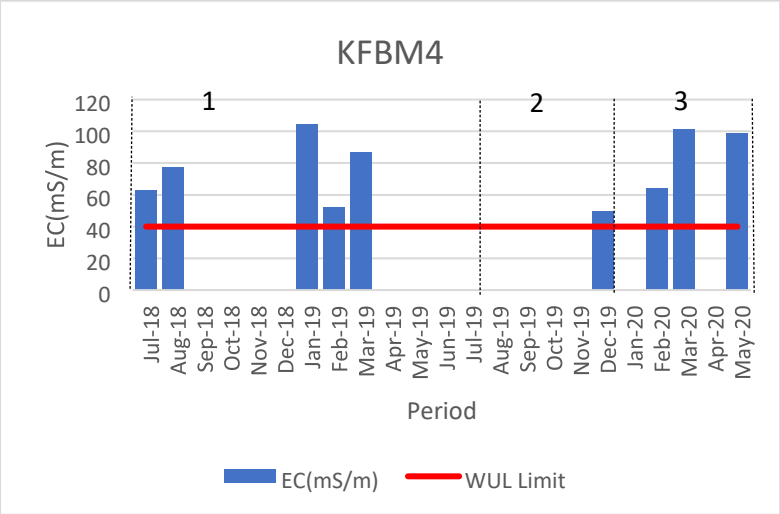


Figure 4. 14 EC concentration at furthest downstream site, KFBM4.

At KFBM1, Dam, KFBM3 and KFBM4, EC exceeded the WUL limit through the study period. EC was only within the WUL limit in October, November 2018, and December 2019, January, February, and March 2020 at KFMB2.

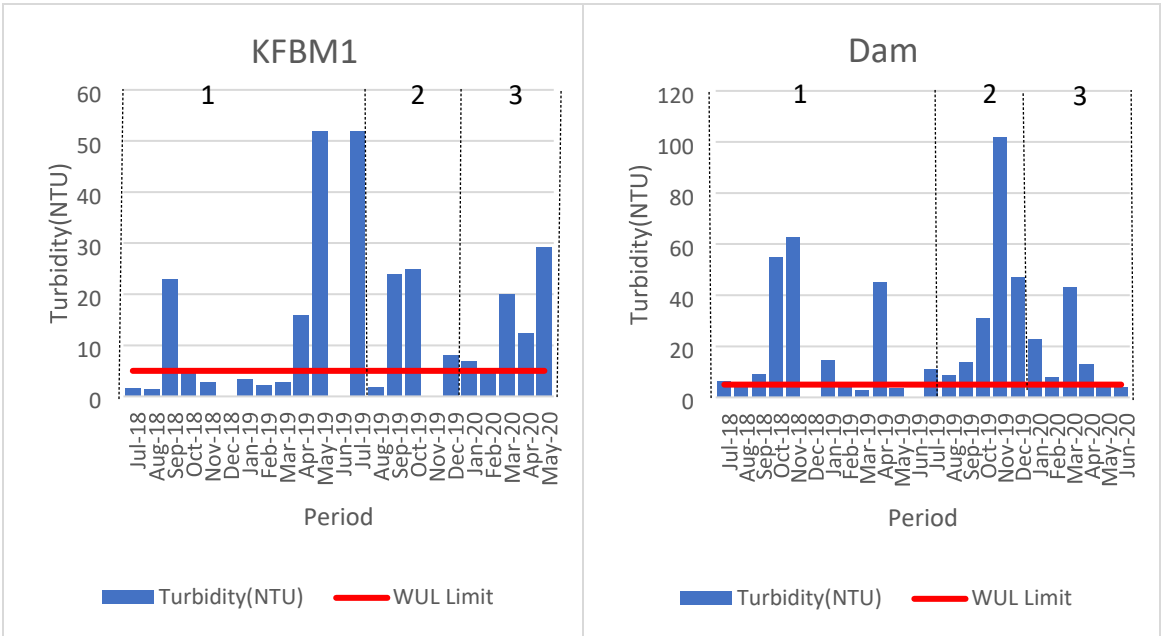


Figure 4. 15 Turbidity concentration at upstream sites, KFBM1 and Dam.

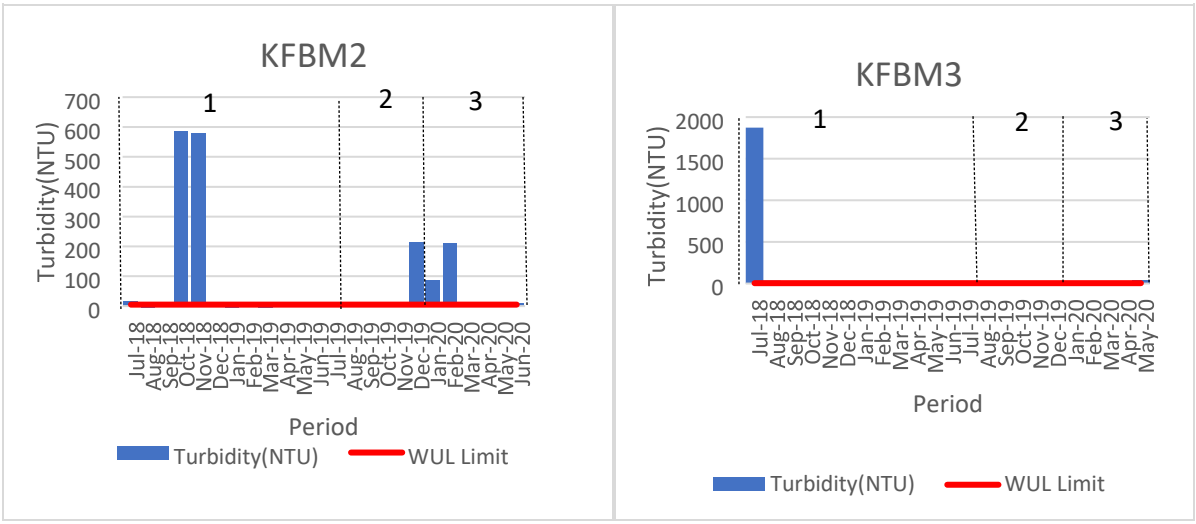


Figure 4. 16 Turbidity concentration at downstream sites, KFBM2 and KFBM3.

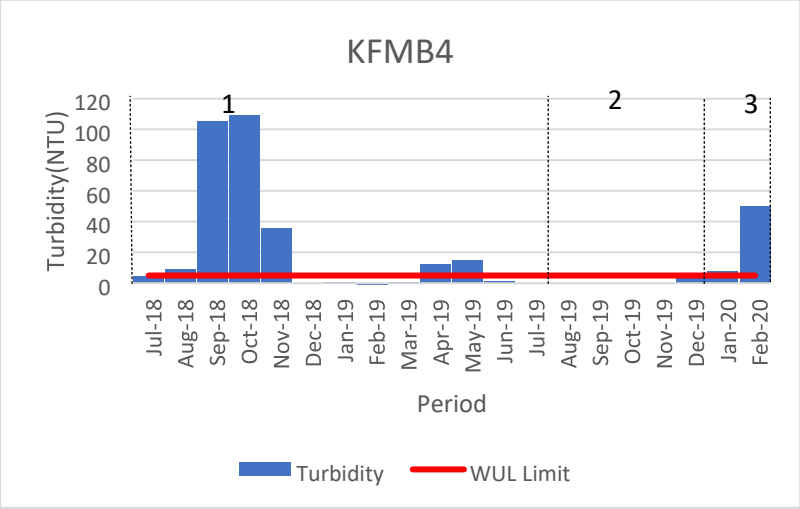


Figure 4. 17 Turbidity concentration at furthest downstream site, KFBM4.

At KFBM1, Turbidity exceeded the WUL limit in September 2018, April, May, and July 2019 during study period 1. During study period 2, Turbidity was above the WUL limit in September, October, and December 2019. During study period 3, Turbidity was above the WUL limit in January, March, April, and May 2020. At Dam, Turbidity remained within the WUL limit in August 2018 and March 2019 during study period 1 and it I was above the limit throughout study periods 2 and 3. At KFBM2, Turbidity exceeded the WUL limit in October, November 2018 during study period 1, December

2019 during study period 2 and January, and February 2020 during study period 3. At KFBM3, Turbidity highly exceeded the WUL limit in August 2018 during study period 1 and the rest of the sampling period Turbidity remained within the WUL limit. At KFMB4, Turbidity spikes exceeding the WUL limit were observed in September and October 2018 during study period 1 and in February 2020 during study period 3. WUL limit exceedances were also observed in august 2018, November 2018, April, May 2019, and January 2020.

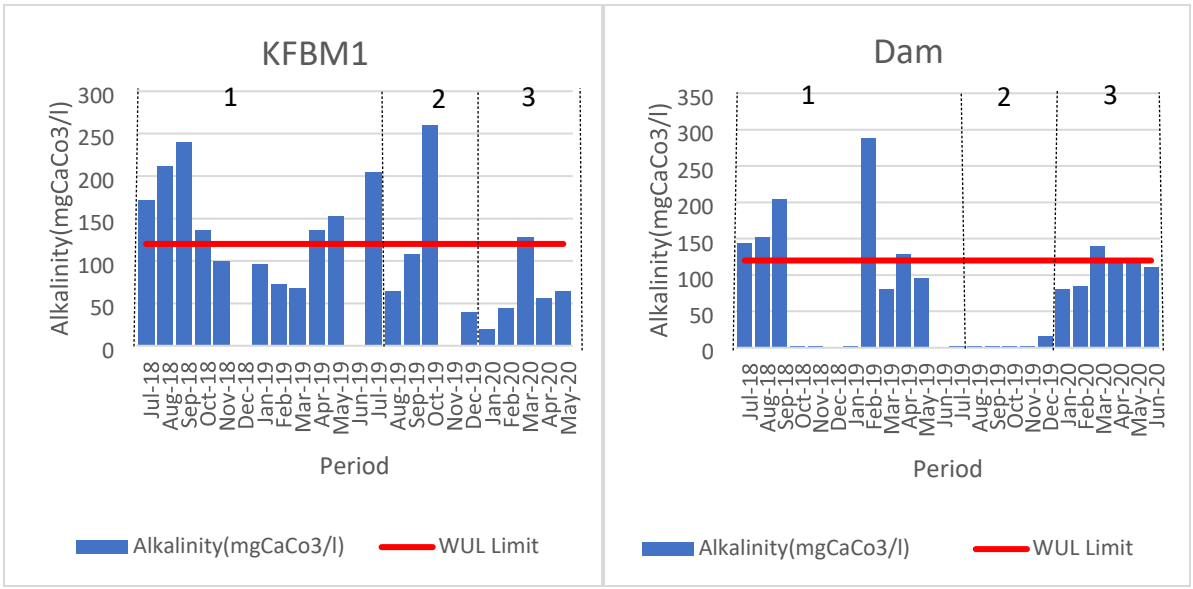


Figure 4. 18 Alkalinity concentration at upstream sites, KFBM1 and Dam.

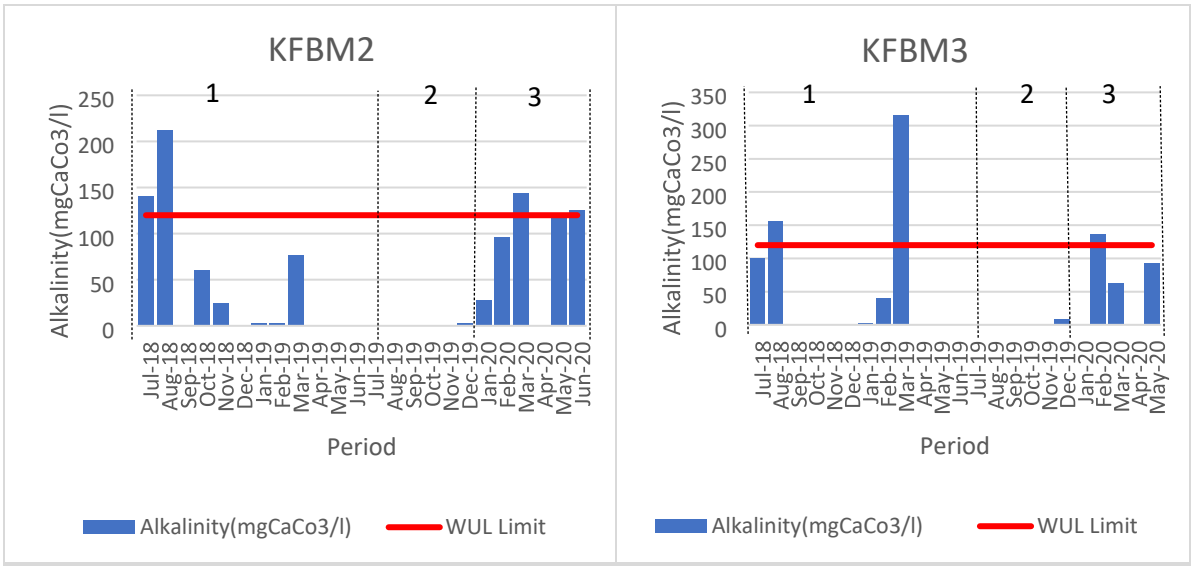


Figure 4. 19 Alkalinity concentration at downstream sites, KFBM2 and KFBM3

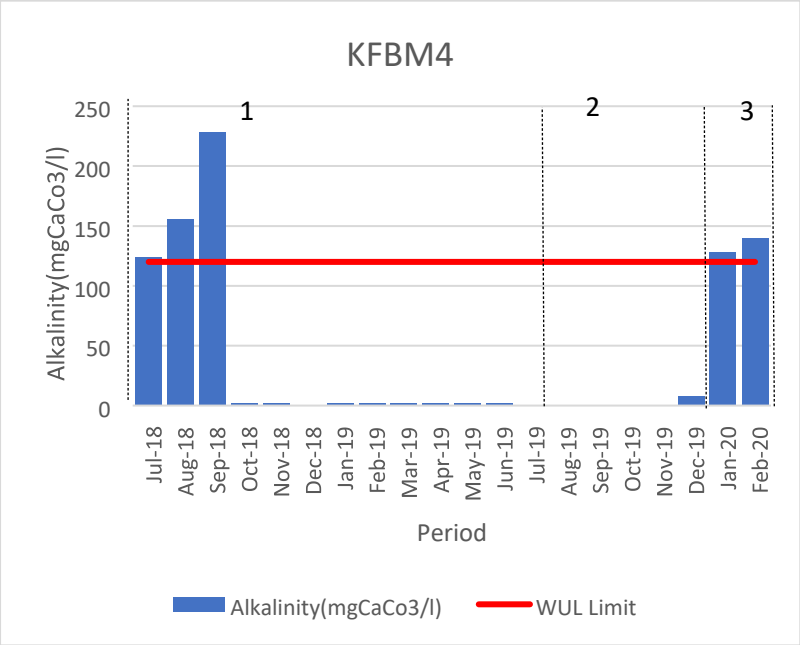


Figure 4. 20 Alkalinity concentration at furthest downstream site, KFBM4.

At KFBM1, Alkalinity exceeded the WUL limit in July, August, September, and October 2018, April, May, and July 2019 during study period 1, October 2019 during study period 2 and in March 2020 during study period 3. At Dam, Alkalinity exceeded the WUL limit in July, August, September 2018, February, and April 2019 during study period 1, no exceedance was observed during study period 2 and during study period 3, and Alkalinity only exceeded the WUL limit in March 2020. At KFBM2, WUL limit exceedances were observed in July and August 2018 during study period 1 and in February 2020 during study period 3. No limit exceedance was observed during study period 2. At KFBM3, Alkalinity was above the WUL limit in August 2018 and March 2019 during study period 1. No exceedance was observed during study period 2. During study period 3 exceedance was only observed in February 2020. At KFBM4, Alkalinity exceeded the WUL limit in July, August, September 2018 during study period 1 and January, and February 2020 during study period 3. Alkalinity remained within the WUL limit during study the period 2.

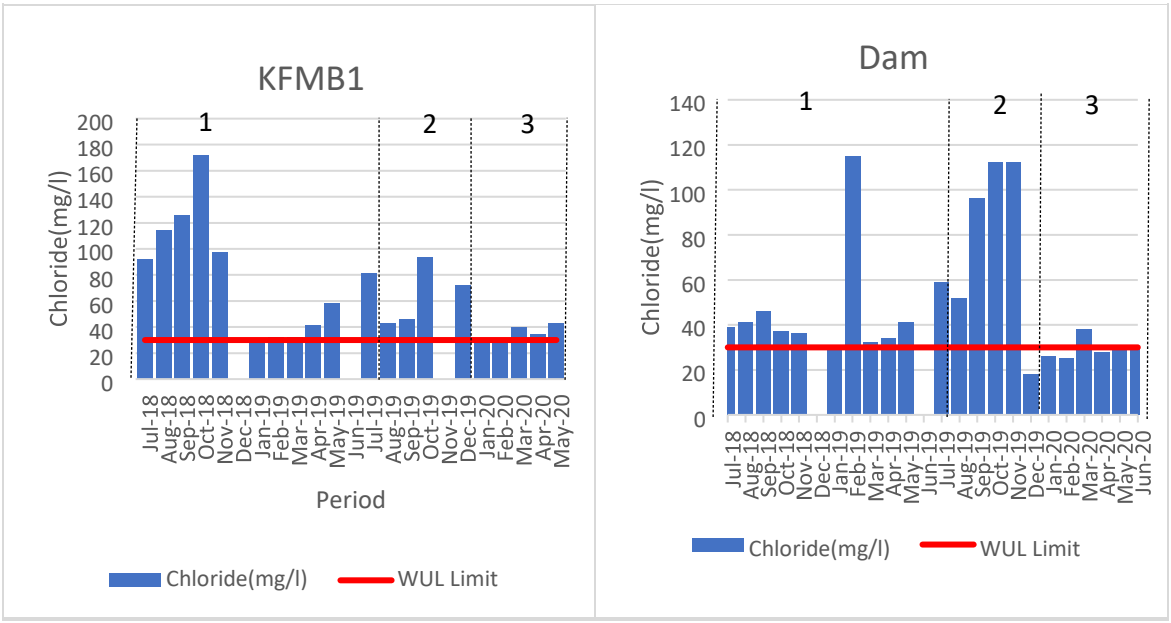


Figure 4. 21 Chloride concentration at upstream sites, KFBM1 and Dam.

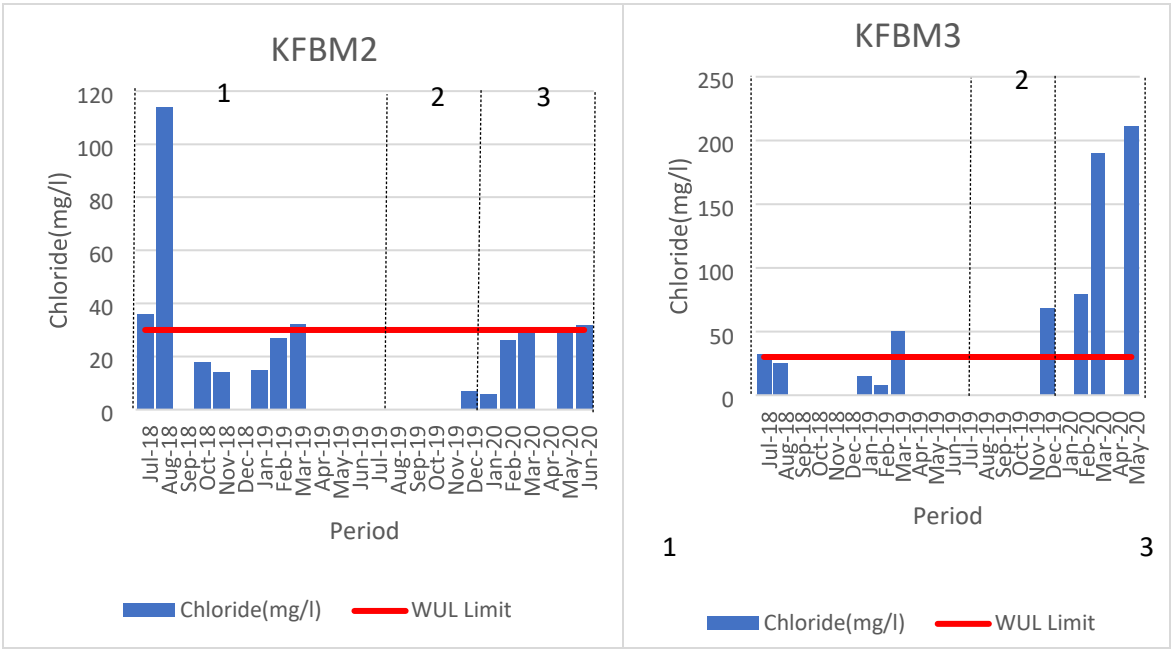


Figure 4. 22 Chloride concentration at downstream site, KFBM2 and KFBM3.

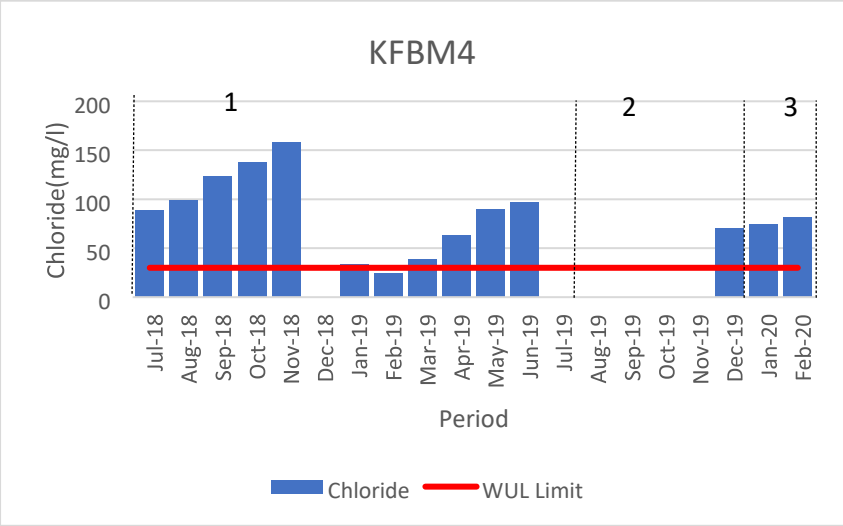


Figure 4. 23 Chloride concentration at furthest downstream site, KFBM4.

At KFMB1, Chloride only remained within the WUL limit in January and February 2020 during study period 3. At Dam, Chloride remained within the WUL limit in December 2019 during study period 1. During study period 2, Chloride was within the WUL limit throughout. During study period 3, Chloride was above the limit for all sampling events. At KFBM2, Chloride was above the WUL limit in July, August 2018, and March 2019 during study period 1 and in June 2020 during study period 3. Chloride remained within the WUL limit during study period 2. At KFBM3, Chloride was above the WUL limit in March 2019 during study period 1 and throughout period 3. At KFBM4, Chloride only remained the limit in February 2019 during study period 1.

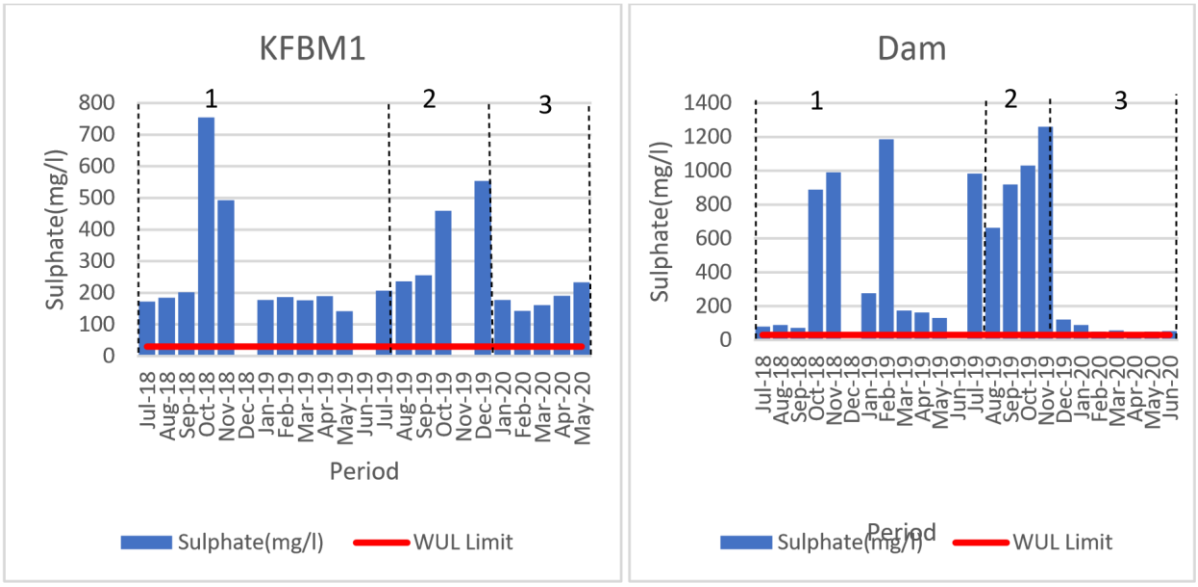


Figure 4. 24 Sulphate concentration at upstream sites, KFBM1 and Dam.

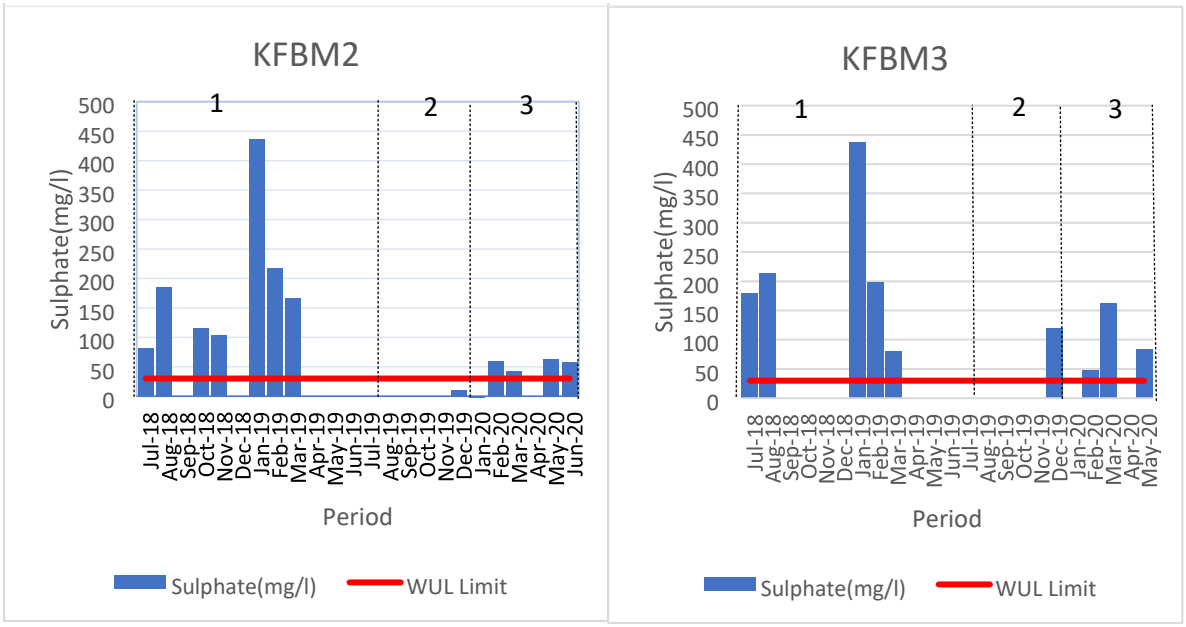


Figure 4. 25 Sulphate concentration at downstream sites, KFBM2 and KFBM3.

At Dam, KFBM1, KFBM3 and KFBM4, Sulphate was above the limit during study period 1, 2 and 3. Sulphate only remained within the WUL limit at KFBM2 in December 2019 during study period 2 and January 2020 during study period 3.

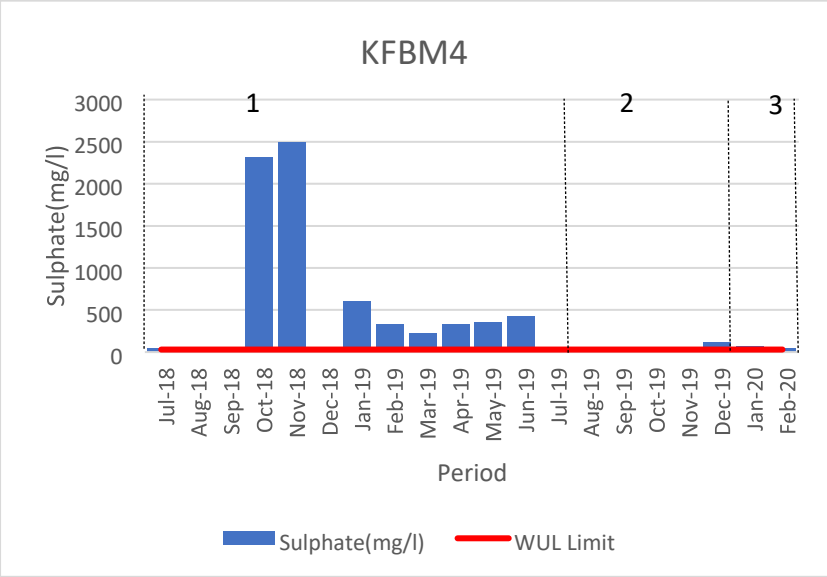


Figure 4. 26 Sulphate concentration at furthest downstream site, KFBM4.

At Dam, KFBM1, KFBM3 and KFBM4, Sulphate was above the limit during study period 1, 2 and 3. Sulphate only remained within the WUL limit at KFBM2 in December 2019 during study period 2 and January 2020 during study period 3.

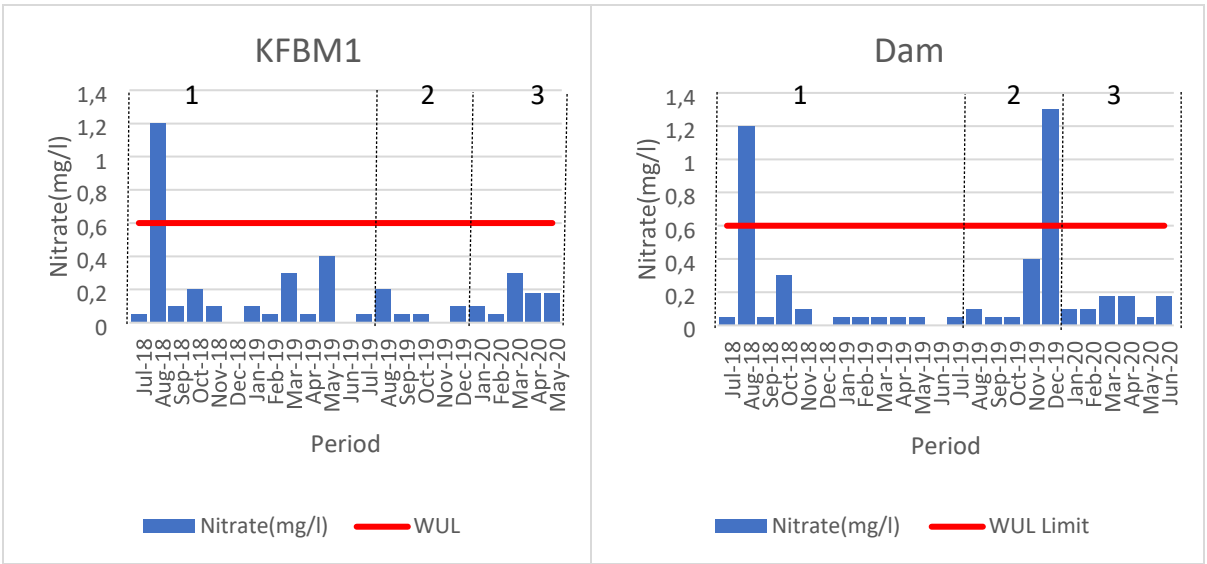


Figure 4. 27 Nitrate concentration at upstream sites, KFBM1 and Dam.

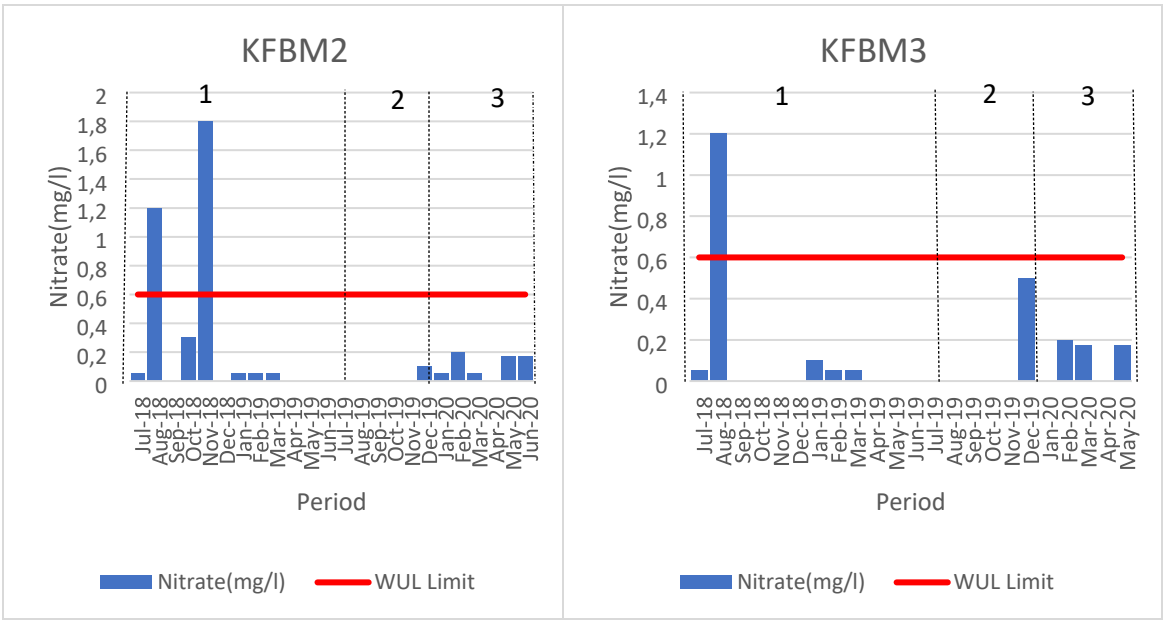


Figure 4. 28 Nitrate concentration at downstream sites, KFBM2 and KFBM3.

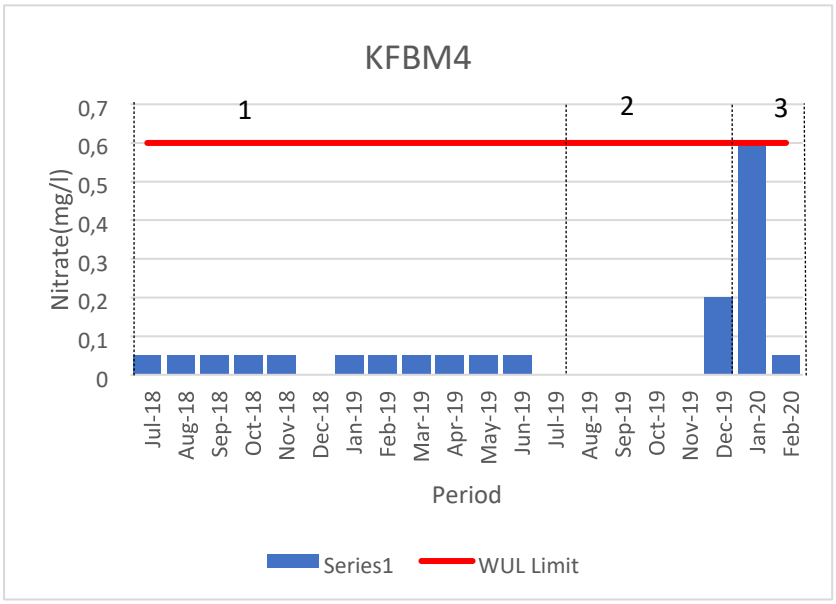


Figure 4. 29 Nitrate concentration at furthest downstream site, KFBM4.

At KFBM1, nitrate only exceeded the WUL limit in August 2018 during study period 1. nitrate remained within the WUL limit during study period 2 and 3. At Dam, nitrate was above the limit in August 2018 during study period 1 and December 2019 during study period 2. nitrate remained within the WUL limit during study period 3. At KFBM2, nitrate was only above the WUL limit in August and November 2018 during study period 1

and it remained within the WUL limit during study periods 2 and 3. At KFBM3, nitrate only exceeded the WUL limit in August 2018 and remained within the WUL limit during study periods 2 and 3. At KFBM4, nitrate remained within the limit during the study period.

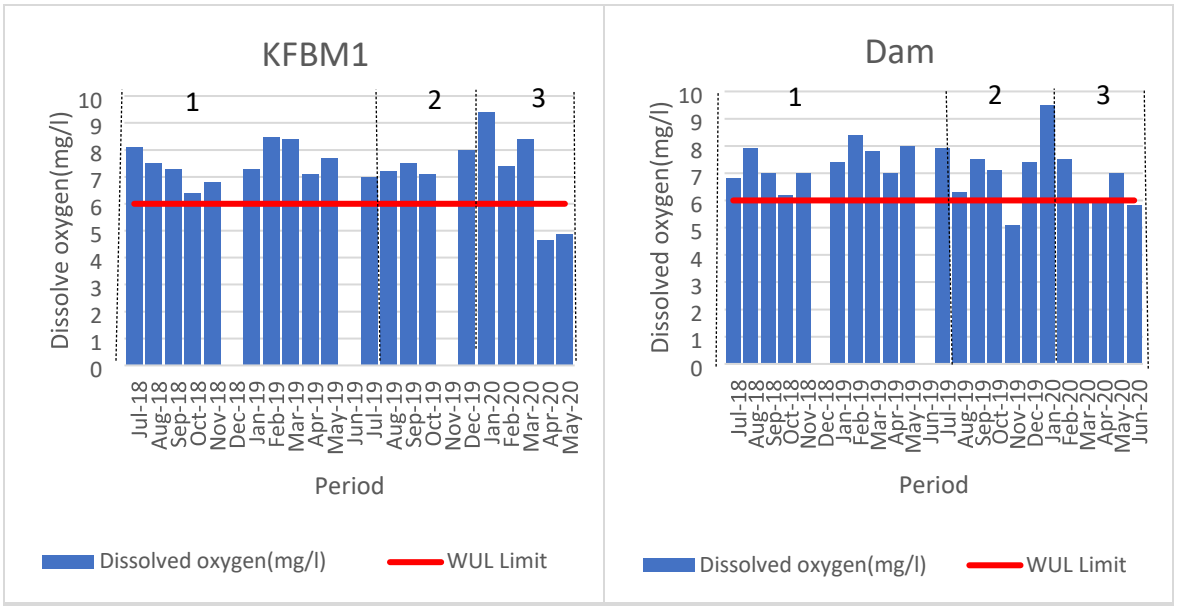


Figure 4. 30 DO concentration at upstream sites, KFBM1 and Dam.

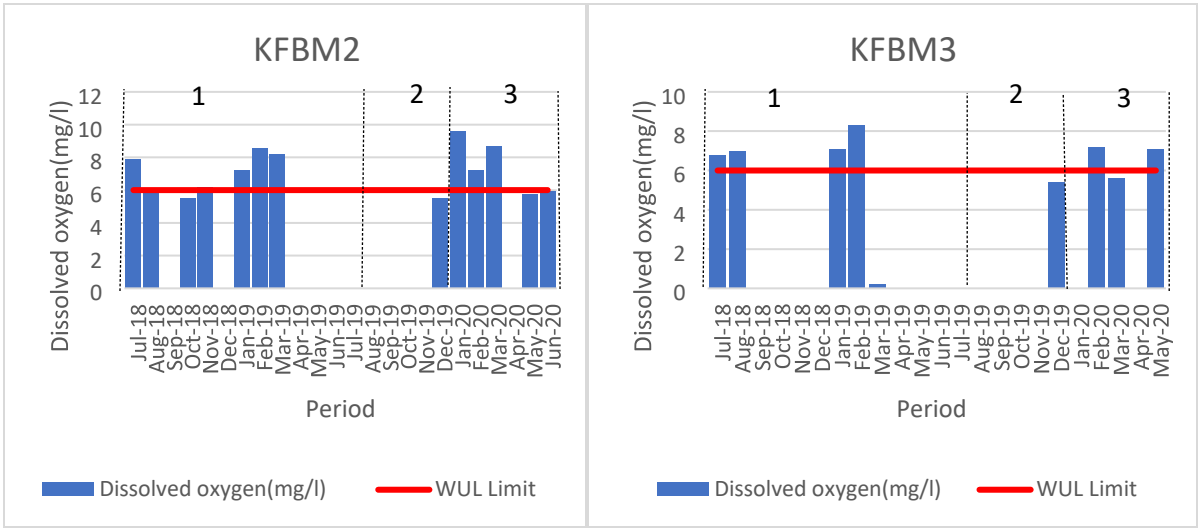


Figure 4. 31 DO concentration at downstream sites, KFBM2 and KFBM3.

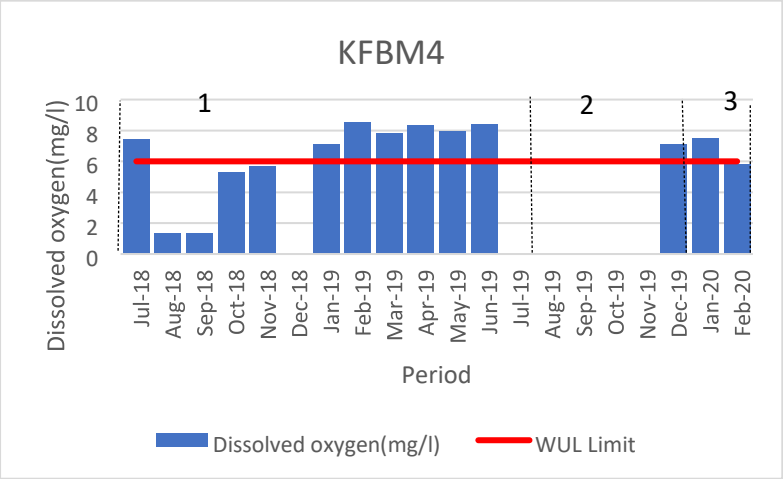


Figure 4. 32 DO concentration at furthest downstream site, KFBM4.

At KFBM1, DO was below the required WUL limit in April and May 2020 during study period 3. DO was compliant with the WUL limit during study periods 1 and 2. At the Dam site, DO was below the required WUL limit in November 2019 during study period 2, April and June 2020 during study period 3. DO was compliant to the WUL limit throughout period 1. At KFBM2, DO was below required WUL limit in October 2018 during study period 1 and December 2019 during study period 2, and May and June 2020 during study period 3. At KFBM3, DO was compliant to the WUL limit in July, August 2018, January, February 2019 during study period 1 and, February and May 2020 during study period 3. DO was below the required WUL limit during study period 2. At KFBM4, DO was compliant to the WUL limit in July 2018, January, February, March, April, May, June 2019, during study period 1 and in December 2019 during study period 2 and January 2020 during study period 3.

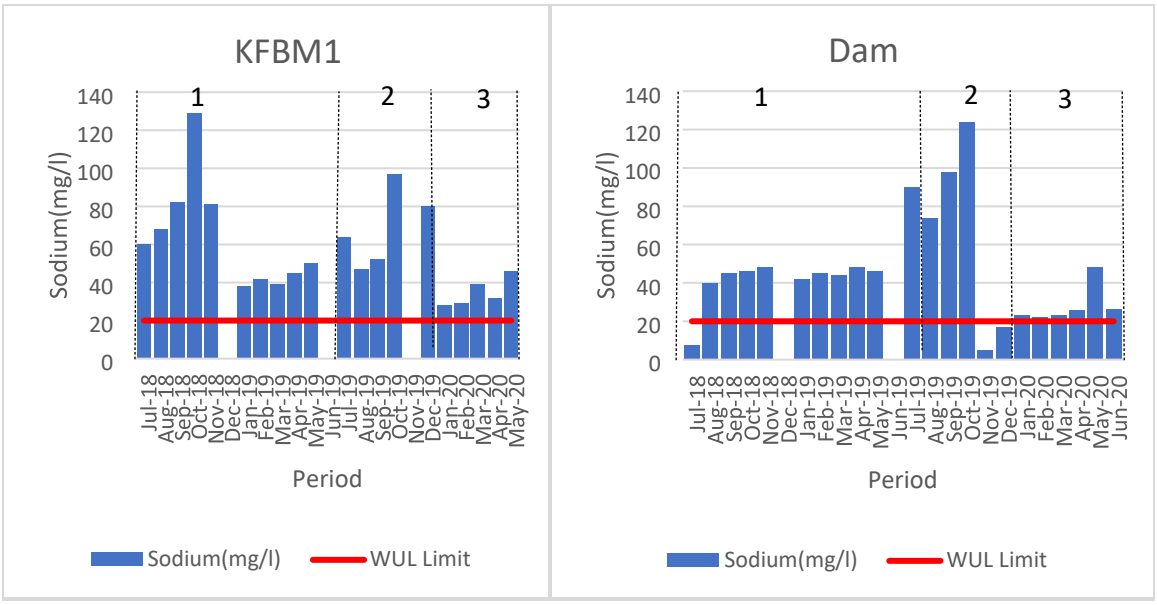


Figure 4. 33 Sodium concentration at upstream sites, KFBM1 and Dam.

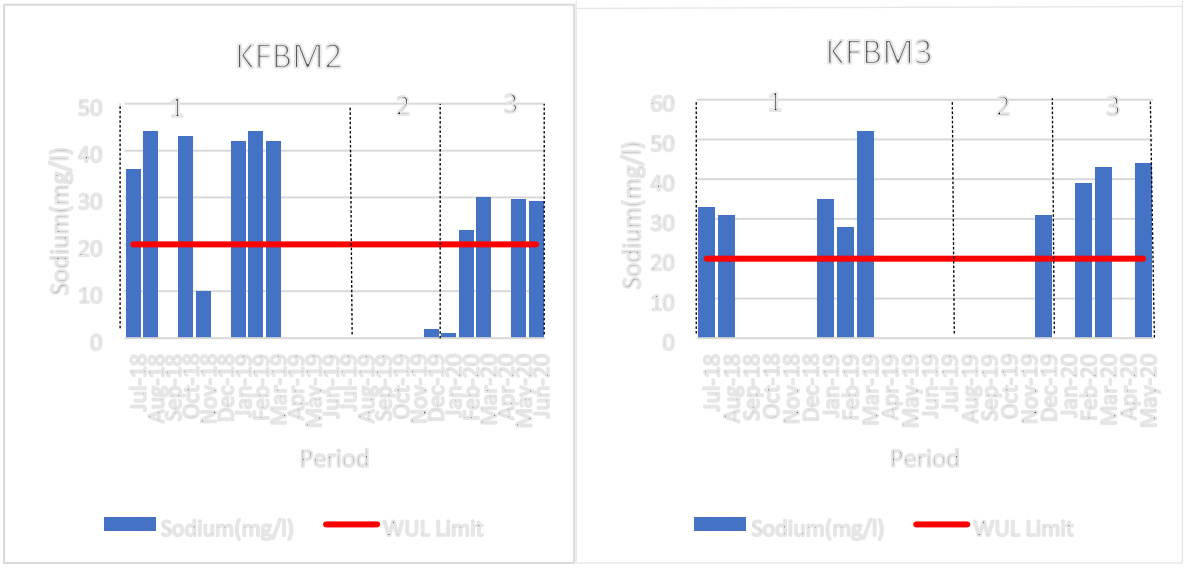


Figure 4. 34 Sodium concentration at downstream sites, KFBM2 and KFBM3.

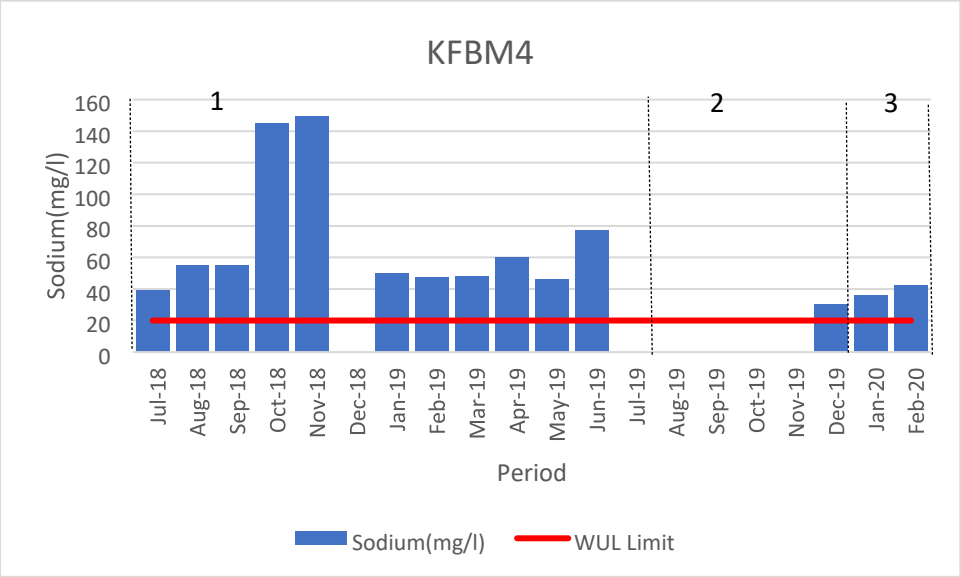


Figure 4. 35 Sodium concentration at furthest downstream site, KFBM4.

At KFBM1, KFBM3 and KFBM4, Sodium was above the WUL limit during study periods 1, 2 and 3. At Dam, Sodium only remained within the WUL limit in July 2018 during study period 1 and in November 2019 during study period 2. At KFBM1, Sodium was within the WUL limit only in November 2018 during study period 1, December 2019 during study period 2 and January 2020 during study period 3.

4.2.2 Normality Test

XLSTAT was utilized to perform normality tests on the water quality data (lab results and in situ measurements) to determine whether parametric or non-parametric tests should be conducted. Three tests (Jarque-Bera, Shapro-Wilk, Anderson-Darling and Lilliefors) were conducted on the data and indicated that the data were not normally distributed; as result a non-parametric test (Kruskal-Wallis test) was conducted to establish significant differences in concentration distributions between sites and different study periods (1, 2 and 3). Study period 1 represents before wetland rehabilitation, 2 represents during rehabilitation of the wetland and 3 represents after rehabilitation of the Woestalleen wetland.

4.2.3 Correlation

Spearman's Correlation was conducted for water quality parameters at all the sites (KFBM1, Dam, KFBM2, KFBM3 and KFBM4). For KFBM1, Dam and KFBM4 correlation tests were conducted for all study periods (1, 2 and 3) and for KFBM2 and KFBM3 correlation tests were performed for study periods 1 and 3 as there were no data for study period 2. Correlation tests were conducted to establish the relationship between the different analyzed variables (see Appendix E for all performed correlation tests).

4.2.3.1 Correlation tests summary

At KFBM1 EC was significantly correlated with chloride ($r=0.93$, $p<0.0001$) and sodium ($r=0.95$, $p<0.0001$) and TSS was significantly correlated with turbidity ($r=0.91$, $p<0.0001$) for study period 1. For study period 2 nitrate was inversely correlated with TSS ($r=-0.95$, $p=0.017$) and turbidity ($r=0.95$, $p=0.017$). No correlation was observed for study period 3.

At the Dam for study period 1 turbidity was significantly correlated with EC ($r=0.80$, $p=0.008$), TSS ($r=0.806$, $p=0.004$) and inversely correlated with dissolved oxygen ($r=0.69$, $p=0.006$). For period 2 hydrogen ion was significantly correlated with EC ($r=0.86$, $p=0.034$), chloride ($r=0.92$, $p=0.012$), sulphate ($r=0.89$, $p=0.012$) and was inversely correlated with total alkalinity ($r=-0.802$, $p=0.034$). Sodium was inversely correlated with nitrate ($r=-0.917$, $p=0.007$) and nitrite ($r=-0.867$, $p=0.012$), and nitrite and nitrate were significantly correlated with each other ($r=0.898$, $p=0.0003$.). No correlation was observed for study period 3.

For study period 1 at KFBM2 TSS was significantly correlated with turbidity ($r=0.73$, $p=0.037$) and nitrate ($r=0.86$, $p=0.006$), EC was significantly correlated with sulphate ($r=0.89$, $p=0.005$) and inversely correlated with turbidity ($r=-0.85$, $p=0.006$). Dissolved oxygen was inversely correlated with nitrate ($r=-0.74$, $p=0.025$) and nitrite (-0.72, $p=0.037$), sodium was significantly correlated with chloride ($r=0.74$, $p=0.031$) and sulphate ($r=0.82$, $p=0.011$). No correlation was observed for study period 3.

For study period 1 at KFBM3 total alkalinity was significantly correlated with TSS ($r=0.94$, $p=0.017$) and inversely correlated with hydrogen ion ($r=-0.89$, $p=0.033$). Dissolved oxygen was inversely correlated with chloride ($r=0.94$, $p=0.017$). No correlation was observed for study period 3.

For study period 1 at KFBM4 hydrogen ion was significantly correlated with sulphate ($r=0.88$, $p=0.001$), EC ($r=0.79$, $p=0.005$) and inversely correlated with total alkalinity ($r=0.778$, $p=0.007$). EC was significantly correlated with sulphate ($r=0.93$, $p<0.0001$), TSS was significantly correlated with turbidity ($r=0.79$, $p=0.006$) and chloride ($r=0.84$, $p=0.003$). Sodium was significantly correlated with EC ($r=0.65$, $p=0.036$) and chloride ($r=0.66$, $p=0.032$). Dissolved oxygen was inversely correlated with total alkalinity ($r=0.63$, $p=0.045$) and chloride ($r=-0.64$, $p=0.038$). No correlation was observed for study periods 1 and 2.

4.2.4 Box Plots and Kruskal- Wallis Test: Temporal difference (before-during-after)

The box plots were used to understand the differences for individual water quality variables between samplings sites for different study periods (1, 2 and 3). Study period 1 represents before wetland rehabilitation, 2 represents during rehabilitation of the wetland and 3 represents after rehabilitation of the Woestalleen wetland. In this chapter only box plots that showed significant differences in concentrations of the individual water quality variables were included. Other box plots are included in Appendix F.

Kruskal- Wallis Tests were performed for all parameters between sampling sites at different study periods to establish significant differences ($p<0.05$) of concentrations for different parameters. According to Kruskal-Wallis tests performed, no significant differences were found for electrical conductivity, turbidity, suspended solids, total alkalinity, nitrite, ortho phosphate, dissolved oxygen, and sodium between sites KFBM1, Dam, KFBM2, KFBM3 and KFBM4 during any of the study periods (before, during and after rehabilitation) (see Appendix G for results of all statistical analyses performed). For hydrogen ions, sulphate, and chloride concentrations there were no

significant differences between sites KFBM1, KFBM2, KFBM3 and KFBM4 throughout study periods 1,2 and 3 and no significant difference was found for nitrate between sites (KFBM1, Dam, KFBM2, and KFBM3 during study periods 1,2 and 3 (see Appendix G for results of all statistical analyses performed).

However, a significant difference for nitrate concentration was found at KFBM4 between study periods 1 and 2 (Table 4.8). No significant differences were found for total alkalinity between KFBM2, KFBM3 and KFBM4 during study periods 1,2 and 3 (see Appendix G for results of all statistical analyses performed).

Some significant differences were found for sulphate at the Dam between study periods 1,2 and 3, (Table 4.2) for chloride at Dam between study periods 1 and 3 (Table 4.3) and lastly for total alkalinity between KFBM1 and Dam during study periods 1 and 2 and 2 and 3 respectively (Table 4.4).

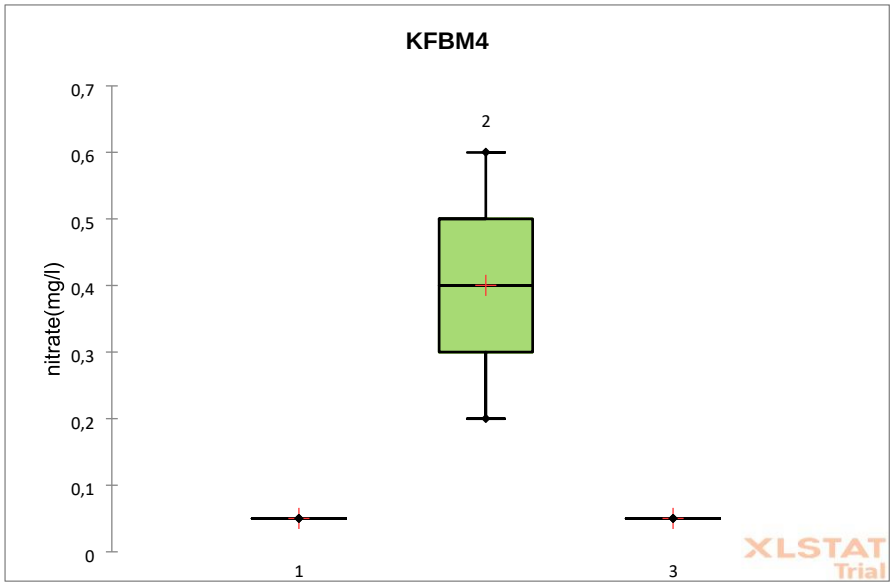


Figure 4. 36 nitrate concentration for KFBM4 site during study periods 1, 2 and 3.

Table 4. 2 Kruskal-Wallis test for nitrate at KFBM4 for study periods 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	**0.002**	1.000
2	**0.002**	**1**	0.438
3	1.000	0.438	1
Significant differences:			
	1	2	3
1		**Yes**	No
2	**Yes**		No
3	No	No	

Nitrate concentration at KFBM4 dramatically increased throughout study period 2 and dramatically decreased during study period 3 and according to Kruskal-Wallis test conducted there was a significant difference between study periods 1 and 2. However, no significant difference was observed between study periods 1 and 3 and periods 2 and 3 respectively.

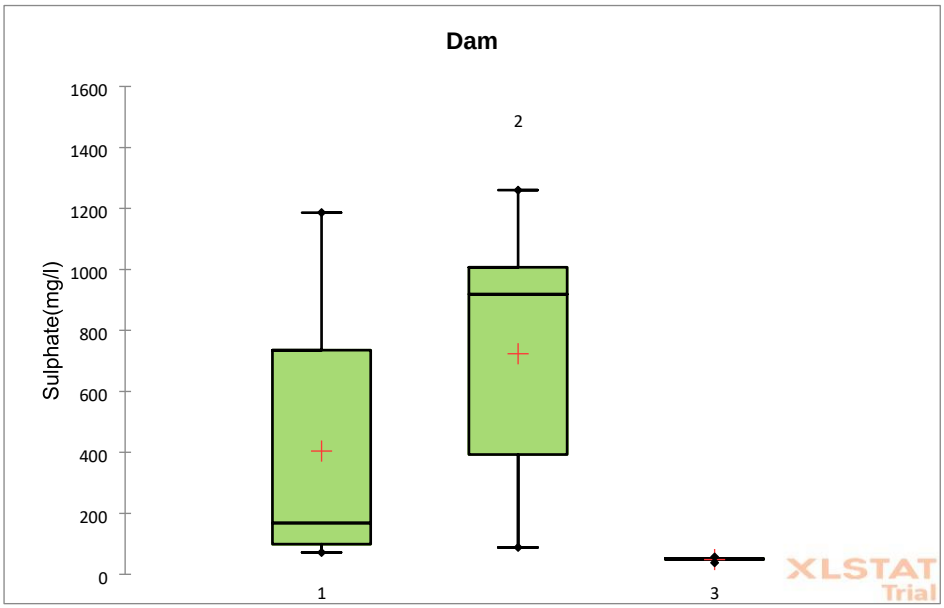


Figure 4. 37 Sulphate concentration for Dam site during study periods 1,2 and 3.

Table 4. 3 Kruskal-Wallis test for sulphate at Dam for study periods 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0.441	**0.006**
2	0.441	**1**	**0.012**
3	**0.006**	**0.012**	1
Significant differences:			
	1	2	3
1		No	**Yes**
2	No		**Yes**
3	**Yes**	**Yes**	

At the Dam, sulphate concentration increased in study period 2 in comparison to study period 1 and dramatically decreased during study period 3 in comparison to study periods 1 and 2. According to the Kruskal-Wallis test, significant differences were observed among study periods 1 and 3 and 2 and 3. However, no significant difference was observed between study periods 1 and 2 for sulphate concentration at this site.

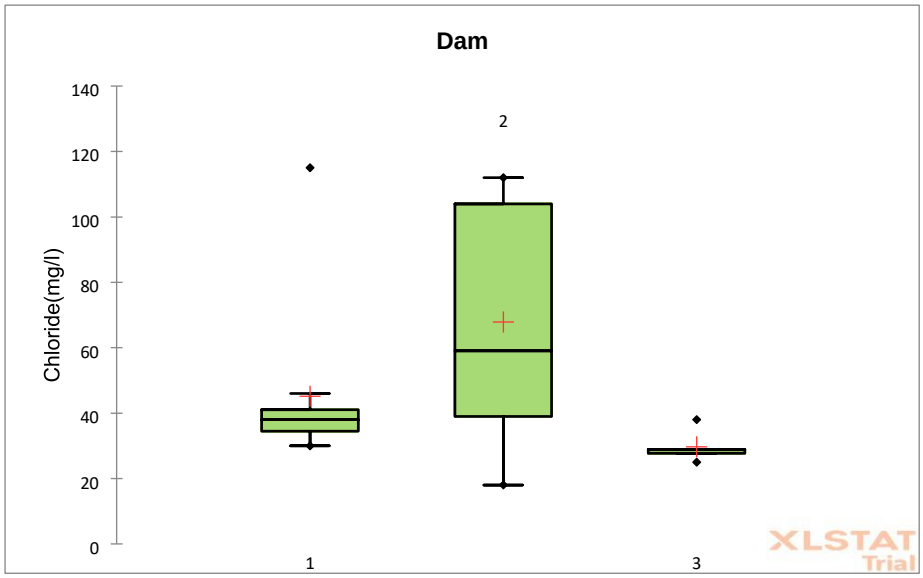


Figure 4. 38 Chloride concentration for Dam site during study periods 1,2 and 3.

Table 4. 4 Kruskal-Wallis test for chloride at Dam for study periods 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0.591	**0.038**
2	0.591	**1**	0,350
3	**0.038**	0.350	1
Significant differences:			
	1	2	3
1		No	**Yes**
2	No		No
3	**Yes**	No	

Chloride concentration at the Dam slightly increased during study period 2 in comparison to study period 1 and dramatically decreased during study period 3 in comparison to study period 1 and 2. According to the Kruskal-Wallis test conducted no significant difference was observed through study periods 1 and 2 and 2 and 3. However, a significant difference between study periods 1 and 3 was observed.

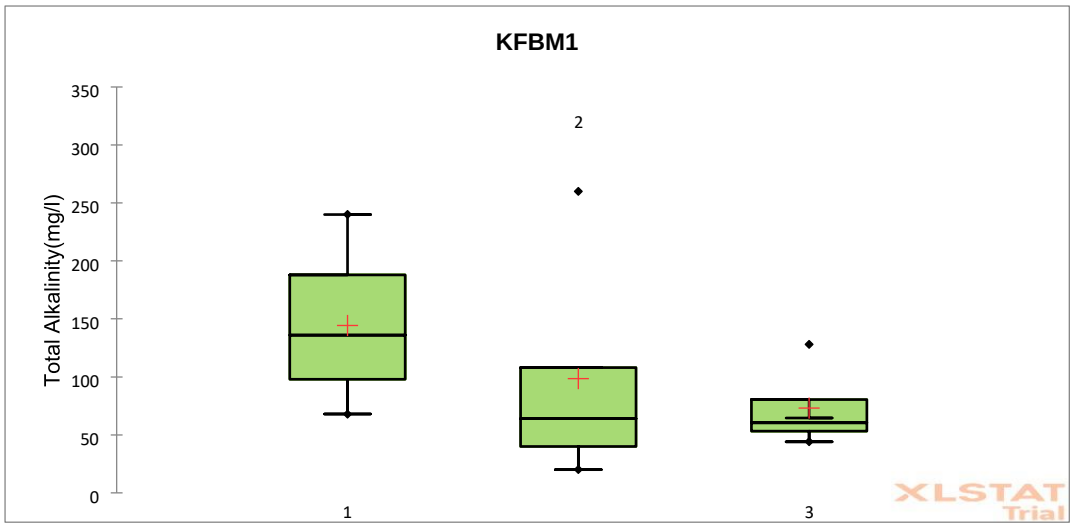


Figure 4. 39 Total alkalinity concentrations for KFBM1 site during study periods 1, 2 and 3.

Table 4. 5 Kruskal-Wallis test for total alkalinity at KFBM1 for study periods 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0.332	**0.049**
2	0.332	**1**	0.967
3	**0.049**	0.967	1
Significant differences:			
	1	2	3
1		No	**Yes**
2	No		No
3	**Yes**	No	

Total Alkalinity concentration at KFBM1 decreased during study period 2 in comparison to study period 1 and further decreased during study period 3 as compared to study periods 1 and 2. Kruskal-Wallis test conducted showed no significant difference among study periods 1 and 2, 2 and 3 respectively. However, a significant difference between study periods 1 and 3 for total alkalinity concentration was observed at KFBM1.

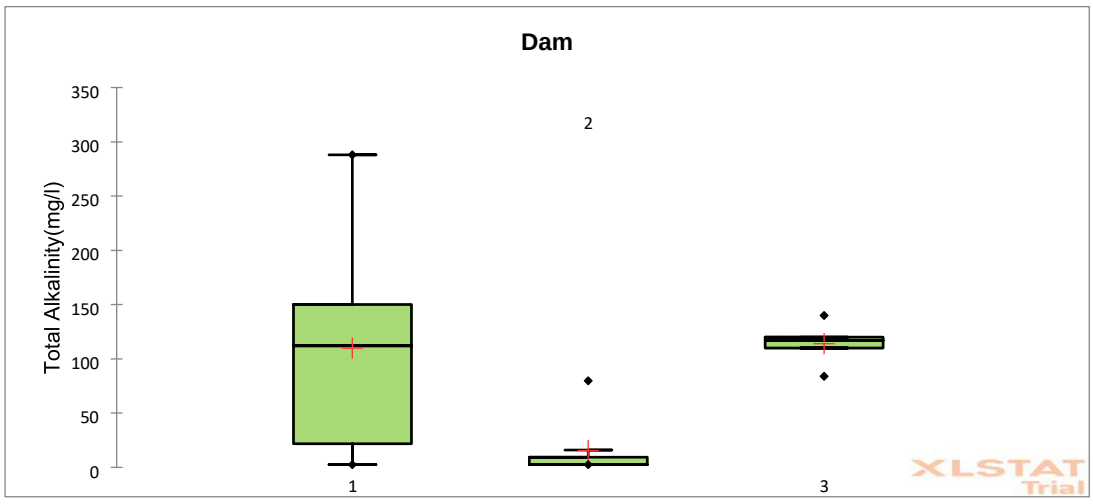


Figure 4. 40 Total alkalinity concentration for Dam site during study periods 1, 2 and 3.

Table 4. 6 Kruskal-Wallis test for total alkalinity at Dam for study periods 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0.077	1.000
2	0.077	**1**	**0.009**
3	1.000	**0.009**	1
Significant differences:			
	1	2	3
1		No	No
2	No		**Yes**
3	No	**Yes**	

Total Alkalinity concentration at the Dam dramatically decreased during study period 2 in comparison to study period 1 and dramatically increased during study period 3 in comparison to study period 2. However, no significant difference was observed between study periods 1 and 2, or 2 and 3 respectively, but a significant difference was observed among study periods 2 and 3.

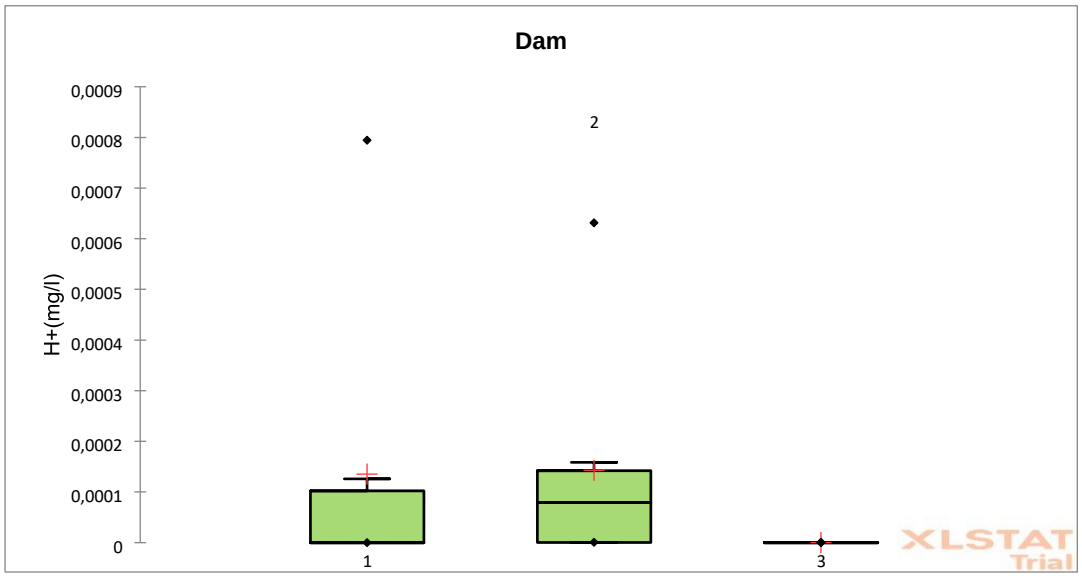


Figure 4. 41 Hydrogen ion concentration for the Dam site during time periods 1, 2 and 3.

Table 4. 7 Kruskal-Wallis test for hydrogen ions at the Dam for time Periods 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0.332	0.992
2	0.332	**1**	**0.032**
3	0.992	**0.032**	1
Significant differences:			
	1	2	3
1		No	No
2	No		**Yes**
3	No	**Yes**	

At the Dam, concentration of hydrogen ions was constant between study periods 1 and 2. However, it highly decreased during study period 3 in comparison to study periods 1 and 2. According to the Kruskal-Wallis test, no significant difference was observed between study periods 1 and 2, or 2 and 3. However, there was a significant concentration difference among study periods 2 and 3.

4.2.5 Upstream and Downstream Comparison (spatial comparisons)

All sites were used i.e. KFBM1, Dam (upstream) and KFBM2, KFBM3, KFBM4 (downstream) to compare concentration differences of analysed variables upstream and downstream of the Woestalleen wetland during study periods 1,2 and 3. According to Kruskal-Wallis tests performed, no significant differences were found for electrical conductivity, turbidity, suspended solids, total alkalinity, nitrate, nitrite, ortho phosphate and dissolved oxygen, between KFBM1, Dam, KFBM2, KFBM3 and KFBM4 during any of the study periods (before, during and after rehabilitation) (see Appendix G for results of all statistical analyses performed).

Significant differences were only found for hydrogen ion, chloride, sulphate, and sodium concentration between upstream and downstream sites as indicated in figures and tables below.

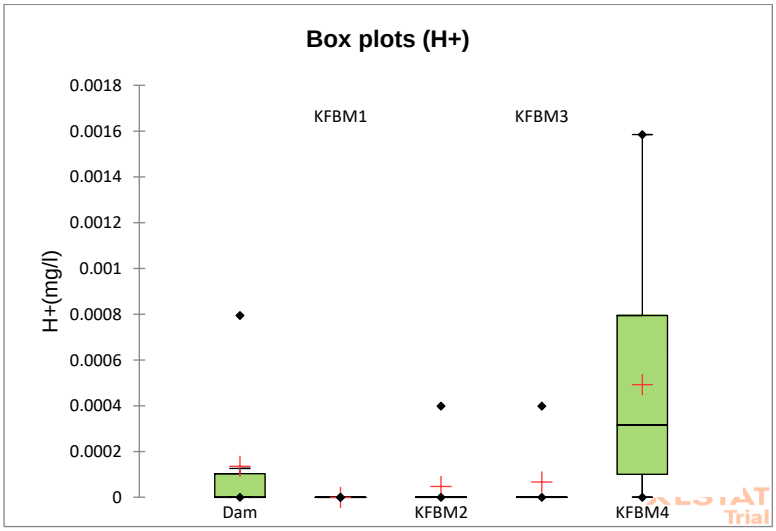


Figure 4. 42 Hydrogen ions concentrations between all sites during study periods 1,2 and 3.

Table 4. 8 Kruskal-Wallis test for hydrogen ions between all sites during study periods 1,2 and 3.

p-values:						
		Dam	KFBM1	KFBM2	KFBM3	KFBM4
Dam		**1**	0.863	0.988	1.000	0.154
KFBM1		0.863	**1**	0.967	0.814	**0.010**
KFBM2		0.988	0.967	**1**	0.969	0.080
KFBM3		1.000	0.814	0.969	**1**	0.272
KFBM4		0.154	**0.010**	0.080	0.272	1
	Significant differences:					
		Dam	KFBM1	KFBM2	KFBM3	KFBM4
Dam			No	No	No	No
KFBM1		No		No	No	**Yes**
KFBM2		No	No		No	No
KFBM3		No	No	No		No
KFBM4		No	**Yes**	No	No	

Hydrogen ion concentration was similar at Dam, KFBM2 and KFBM3 and slightly decreased at KFBM1 and dramatically increased at KFBM4 site located further downstream. According to the Kruskal-Wallis test conducted there was no significant

difference for hydrogen ion concentrations between Dam, KFBM2 and KFBM3. However, there was significant difference between KFBM1 and KFBM4.

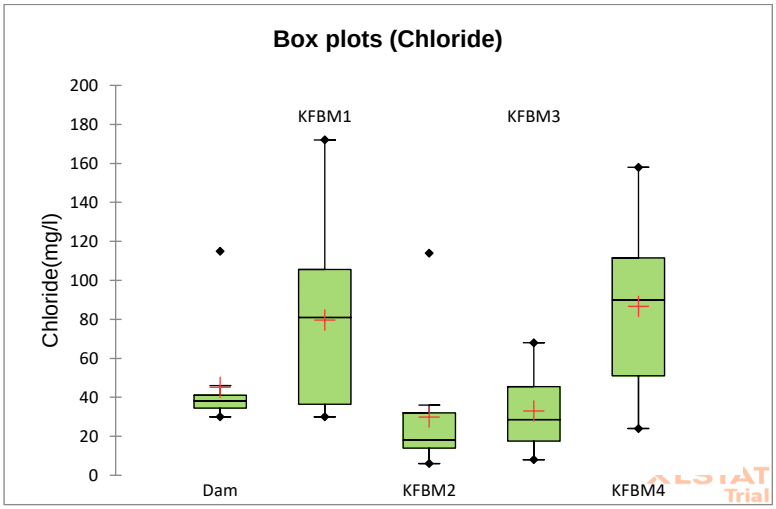


Figure 4. 43 Chloride concentrations between all sites during study periods 1,2 and 3.

Table 4. 9 Kruskal-Wallis test for Chloride between all sites during study periods 1, 2 and 3.

p-values:					
	Dam	KFBM1	KFBM2	KFBM3	KFBM4
Dam	**1**	0.489	**0.049**	0.999	0.074
KFBM1	0.489	**1**	**0.004**	0.990	0.639
KFBM2	**0.049**	**0.004**	**1**	0.474	**0.004**
KFBM3	0.999	0.990	0.474	**1**	0.716
KFBM4	0.074	0.639	**0.004**	0.716	1
Significant differences:					
	Dam	KFBM1	KFBM2	KFBM3	KFBM4
Dam		No	**Yes**	No	No
KFBM1	No		**Yes**	No	No
KFBM2	**Yes**	**Yes**		No	**Yes**
KFBM3	No	No	No		No
KFBM4	No	No	**Yes**	No	

Chloride concentration was similar at three sites i.e., Dam, KFBM2 and KFBM3 but was much greater at two sites i.e., KFBM1 and KFBM4. According to Kruskal-Wallis

test KFBM2 was significantly lower than Dam, KFBM1 and KFBM4 but not significantly different from KFBM3.

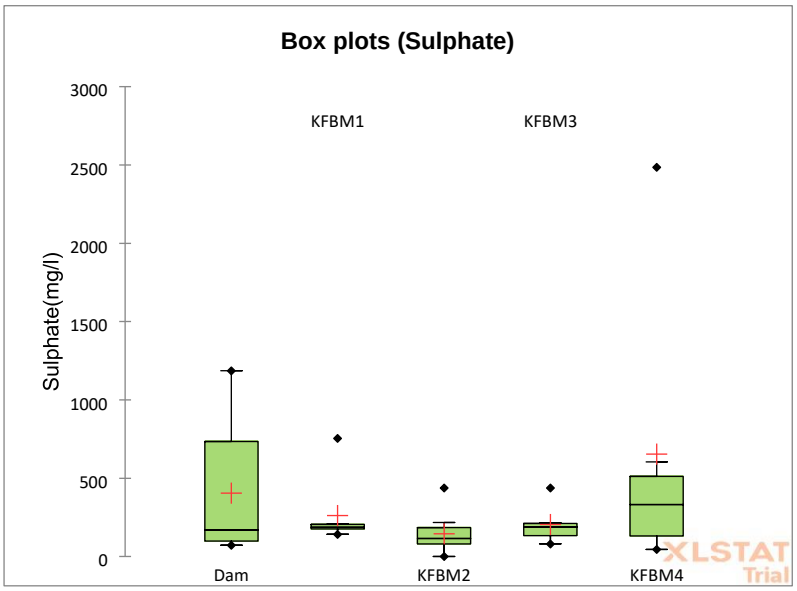


Figure 4. 44 Sulphate concentrations between all sites during study periods 1, 2 and 3.

Table 4. 10 Kruskal-Wallis test for sulphate between all sites during study periods 1, 2 and 3.

		Dam	KFBM1	KFBM2	KFBM3	KFBM4
Dam		**1**	0.874	0.429	0.989	0.998
KFBM1		0.874	**1**	**0.008**	0.325	1.000
KFBM2		0.429	**0.008**	**1**	0.647	0.465
KFBM3		0.989	0.325	0.647	**1**	0.980
KFBM4		0.998	1.000	0.465	0.980	1
	Significant differences:					
		Dam	KFBM1	KFBM2	KFBM3	KFBM4
Dam			No	No	No	No
KFBM1		No		**Yes**	No	No
KFBM2		No	**Yes**		No	No
KFBM3		No	No	No		No
KFBM4		No	No	No	No	

Sulphate concentration was high at Dam and KFBM4, lower at KFBM1, KFBM2 and KFBM4. However, according to the Kruskall-Wallis test conducted there was only a significant concentration difference between KFBM1 site located upstream and

KFBM2 site located downstream but no significant differences between any other sites.

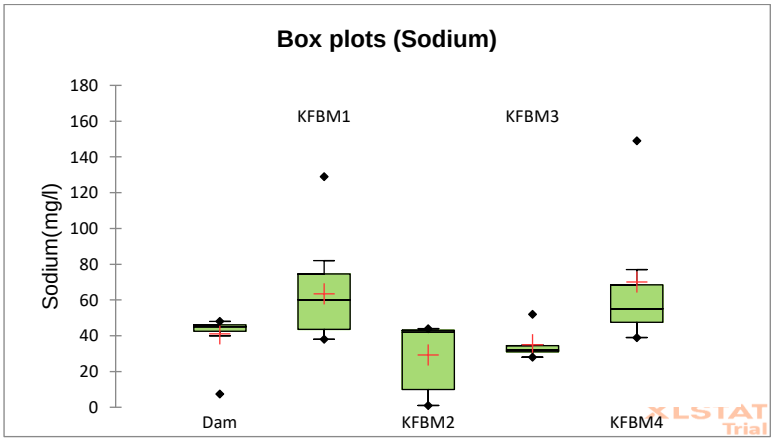


Figure 4. 45 Sodium concentration between all sites during study periods 1,2 and 3.

Table 4. 11 Kruskal-Wallis test for sodium between all sites during study periods 1, 2 and 3.

p-values:					
	Dam	KFBM1	KFBM2	KFBM3	KFBM4
Dam	**1**	0.418	0.338	0.983	0.291
KFBM1	0.418	**1**	**0,012**	0.141	1.000
KFBM2	0.338	**0.012**	**1**	0.787	**0.006**
KFBM3	0.983	0.141	0.787	**1**	0.079
KFBM4	0.291	1.000	**0.006**	0.079	1
Significant differences:					
	Dam	KFBM1	KFBM2	KFBM3	KFBM4
Dam		No	No	No	No
KFBM1	No		**Yes**	No	No
KFBM2	No	**Yes**		No	**Yes**
KFBM3	No	No	No		No
KFBM4	No	No	**Yes**	No	

Sodium concentration was low at three sites i.e., Dam, KFBM2 and KFBM3 and was higher at KFBM1 and KFBM3. According to the Kruskal-Wallis test conducted, KFBM2 was significantly lower than KFBM1 and KFBM4.

4.2.6 Water quality summary

This section provides a summary of the water quality results. All Box plots and KruskalWallis tests are included in appendix F and G.

4.2.6.1 Before rehabilitation

Water quality monitoring data before the rehabilitation period showed no significant difference between any sites for hydrogen ions, EC, sodium, nitrate and DO. However, higher sulphate concentrations were observed at the downstream site KFBM4 than at other sites and lower concentrations of total alkalinity were observed at two downstream sites, KFBM2 and KFBM4. Higher concentrations of TSS and turbidity were observed at the downstream site KFBM3 than at other downstream sites, KFBM2, KFBM4 and upstream sites, Dam and KFBM1. This could be as result of mining activities that occurred upstream of these sites.

4.2.6.2 During rehabilitation

Sodium concentration was similar at KFBM1, Dam and KFBM4 but slightly increased at Dam and decreased at KFBM4 during rehabilitation as compared to before rehabilitation. DO was similar before rehabilitation and during rehabilitation at KFBM1, Dam and KFBM4. Nitrate concentration was similar at all sites before and during rehabilitation. Sulphate concentration increased at KFBM1, Dam and KFBM4 during rehabilitation as compared to before rehabilitation at the same sites. No data was analyzed at KFBM2 and KFBM3 during rehabilitation. Concentration of chloride was similar at KFBM1 and KFBM4 before rehabilitation and decreased at the same sites during rehabilitation. Total alkalinity concentration was similar at KFBM1 and Dam before rehabilitation, but it dramatically decreased at the same sites during rehabilitation. Turbidity concentration was similar at KFBM2, Dam and KFBM4 before and during rehabilitation, no data for KFBM2 and KFBM3. EC levels were similar at KFMB1, Dam and KFBM4 before rehabilitation but increased at Dam and decreased at KFBM4 during rehabilitation. TSS concentration was similar at KFBM1, Dam, and

KFBM4 before rehabilitation but it increased at Dam and slightly decreased at KFBM4 during rehabilitation. Hydrogen ion concentration was similar before and during rehabilitation at KFBM1, Dam and KFBM4.

4.2.6.3 After rehabilitation

Sodium concentration slightly decreased at 4 sites (KFBM1, Dam, KFBM2, and KFBM3) after rehabilitation as compared to before rehabilitation. It only increased at KFBM4 after rehabilitation in comparison to before rehabilitation. DO decreased at 4 sites (KFBM1, Dam, KFBM2, and KFBM4) after rehabilitation as compared to before rehabilitation and slightly increase at KFBM3 after rehabilitation. Nitrate concentration was similar at all sites before and after rehabilitation. Sulphate concentration decreased at all sites after rehabilitation as compared to before rehabilitation, but significant decrease was only observed at the Dam. Chloride at KFBM1 and Dam slightly decreased after rehabilitation as compared to before rehabilitation and it was similar at KFBM2 and KFBM4 before and after rehabilitation. Chloride dramatically increased at KFBM3 after rehabilitation as compared to before rehabilitation. Total alkalinity dramatically decreased at KFBM1 and increased at KFBM4 after rehabilitation as compared to before rehabilitation. After rehabilitation Turbidity was similar at sites, KFBM1, Dam, KFBM3 and KFBM4 but highly decreased at KFBM2 as compared to before rehabilitation. EC increased at KFBM2 and KFBM3 after rehabilitation. TSS concentration was similar before and after rehabilitation. Hydrogen ion increased at KFBM1 and decreased at KFBM4 after rehabilitation as compared to before rehabilitation.

4.2.6.3 During rehabilitation vs after rehabilitation

There was a spike of sodium during rehabilitation at sites, Dam, and KFBM4, which decreased back to normal concentrations as observed after rehabilitation. DO slightly decreased after rehabilitation as compared to before rehabilitation at sites, Dam and KFBM4. At KFBM4 there was a spike of nitrate concentration during rehabilitation which dropped after rehabilitation. Sulphate and chloride were high during rehabilitation at Dam and KFBM4 and they later decreased after the rehabilitation.

Total Alkalinity increased after rehabilitation at KFMB4 as compared to before rehabilitation. Turbidity decreased at Dam and KFBM3 and increased at KFBM4 after rehabilitation as compared to before rehabilitation. EC and TSS decreased at Dam after rehabilitation. Hydrogen ion concentration slightly decreased after rehabilitation as compared to before rehabilitation. High concentration of sulphate, hydrogen ion, EC, TSS and chloride, and low alkalinity during rehabilitation at the affected sites could be as a result of disturbance and oxidation during rehabilitation e.g., sulphide minerals oxidation would increase sulphate, EC, hydrogen ion and reduce alkalinity.

4.3. In situ Measurements

4.3.1 Correlation Test

Spearman Correlation tests were conducted for all in situ data for study period 2 to establish the relationship between the different in situ measurements. A correlation matrix for study period 3 could not be created due to insufficient data (n=1) during study period 3. The correlation test conducted indicated no correlation between any of the measured *in situ* variables (see Appendix E).

4.3.2 Box plots for in situ measurements

The box plots were used in order to understand the concentration differences of in situ measurements between sampling sites for different study periods (2 and 3). Study period 2 represents the period during rehabilitation of the wetland and 3 represents the period after rehabilitation of the wetland.

Kruskal-Wallis tests were performed for all *in situ* measurements and no significant differences were found for pH, Temperature, DO and EC between sites Insitu1, KFBM1, Dam, KFBM2 and KFBM3 during study periods 2 and 3 (see Appendix G for results of all statistical analyses performed).

4.3.3 *In situ* measurements summary

EC concentration at INSITU 1, KFBM1 and Dam was lower throughout study period 2 in comparison to study period 3. At KFBM2 and KFBM3 EC concentration slightly increased during study period 3 in comparison to study period 2. DO dramatically decreased at all sites during study period 3 in comparison to study period 2. pH level at INSITU 1 and KFBM1 decreased during study period 3 in comparison to study period 1 and it increased during study period 3 at Dam, KFBM2 and KFBM3 in comparison to study period 2. Temperature decreased at KFBM1 during study period 3 in comparison to study period 2 and increased during study period 3 in comparison to study period 2 at INSITU 1, Dam, KFBM2 and KFBM3.

4.4 Rainfall Data Analysis

Rainfall data were obtained from South Africa Weather Service Hendrina (04793698) for a period of 3 years i.e., January 2018 to December 2020. The study area is situated in the summer rainfall area of Southern Africa with rainfall generally happening in the manner of convectional thunderstorms. The annual average rainfall recorded through a period of 3 years is about 807,77 mm, with the above average rainfall period being between October and March. (Figure 4.45). The significance of rainfall data will be further discussed under chapter 5.

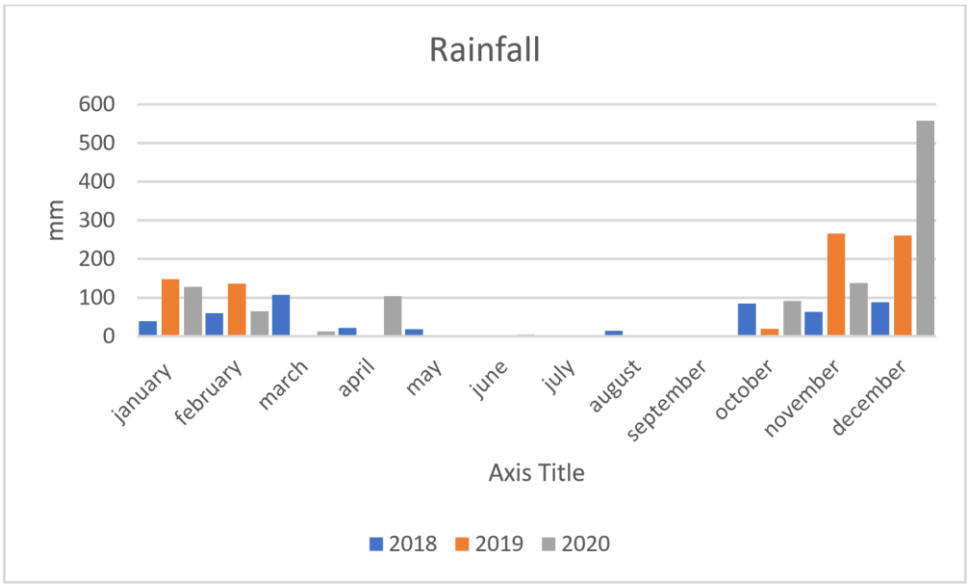


Figure 4. 46 Rainfall data.

Chapter 5: Discussion, Conclusions and Recommendations

5.1 Discussion

The main objectives were to evaluate the status of the Woestalleen wetland water quality before and after rehabilitation and to evaluate if the ecological status of Woestalleen wetland has been upgraded from a Class D to a Class C or higher. The above-mentioned objectives are part and parcel of Woestalleen wetland rehabilitation strategy targets. Therefore, they were used in this research to measure the success of the rehabilitation work done.

My role in the main project includes the following:

- Field work: *In situ* measurements were performed for DO, EC, Temperature, and pH monthly from August 2019 to February 2020 to complement the laboratory data collected by Eco Elementum Environmental and Engineering.
- Wetland rating and scoring was conducted with the help of the wetland specialist

5.1.1 Wetland water flow path and pollution sources

Woestalleen wetland is linked to the unnamed tributary of Woestallen Spruit. Power station and Wastewater Treatment Works that are located upstream of the wetland were identified as potential sources of pollution to the wetlands as they are near to the wetland. Agricultural activities occurring upstream and adjacent to the wetland were also identified as other potential pollution sources. No wastewater discharge into the wetland from the mine was observed during the study period.

5.1.2 Wetland assessment

The main aim of the wetland assessment was to find out if the wetland status changed from Class D to C or higher. The assessment involved desktop assessment and field

assessment using the WETLAND-IHI (DWAF, 2007). Desktop assessment entailed the collation of available data such as 1:50000 topographical map and aerial photographs and field assessment involved wetland categorization, evaluation of vegetation alteration, Hydrological PES, geomorphological PES, water quality PES and overall PES. The wetland was categorized as a channelled valley bottom wetland, and the outcome of the wetland assessment indicated that the PES of the wetland was seriously modified (category E) (Kleynhans, 1996, 1999).

Therefore, the wetland status was downgraded from a Class D to E; modifications of the wetland were mostly associated to the extensive alien invasive vegetation, erosion, damming (King et al., 2005) and the current mining activities from the Colliery adjacent to the wetland area (Oberholster et al., 2012). The channelled valley bottom wetland has been changed in terms of hydrology, geomorphology, and vegetation, which impacted subsurface flow and the ecology of the wetland (Brock et al*.,* 2003).

Wetland assessment was conducted ten months later after the rehabilitation work which was completed in January 2020. Therefore, the wetland soils and vegetation had not yet properly established in the wetland. This was confirmed during the assessment. However, good signs of wetland soils and vegetation establishment were observed. The wetland PES is expected to improve in a few years to come if not disturbed again by human activities.

5.1.3 Water quality results

Water quality lab results for study periods 1, 2 and 3 were obtained from Eco Elementum Environmental and Engineering. XLSTAT was used to create box plots and to perform Kruskal-Wallis tests to understand the concentration differences of all variables between all sites during study periods 1, 2 and 3 and to establish if the wetland rehabilitation improved water quality status downstream of the rehabilitated wetland or not.

The water quality results analyzed didn't show evidence of water quality buffering by the Dam because concentration of variables such as turbidity and sulphates, were seen to be increasing at KFBM2 site which is downstream of the Dam. The other variables showed similar trends at Dam and other downstream sites.

Monthly water quality values were also compared with the water quality limits as specified by DWS on the Water Use Licence (ref: 04/B12B/ABCGIJ/2868). Electrical conductivity, turbidity, suspended solids, total alkalinity, chloride, sulphate, dissolved oxygen, and sodium were found to be generally non-compliant with the water quality limits on the WUL at site KFBM1 located upstream of the mining area and Woestalleen wetland. It is therefore evident that these water quality issues are not attributed to the mining activities as they are occurring upstream of the mining area and could be coming from other pollution sources such as power station and wastewater treatment works located upstream of the wetland and the mine. The power station and wastewater treatment works were observed upstream of the wetland during water quality testing and wetland assessment. Only pH, nitrate and nitrite were found to be compliant at KFBM1 during the whole study period.

At the Dam (upstream site) electrical conductivity, turbidity, suspended solids, chloride, sulphate, nitrate, nitrite, dissolved oxygen, and sodium levels and concentrations were found to be similar to concentrations and levels at the first upstream site (KFBM1). Total Alkalinity was generally found to be non-compliant at all sites during study periods 1,2 and 3, which could be attributed to contamination through runoff from the agricultural activities occurring adjacent to the KFBM1 (Liu et al., 2004). pH was found to be compliant throughout other study periods at the KFBM1. Therefore, low pH levels observed at downstream sites (KFBM2, KFBM3 and KFBM4) particularly during study period 2 could be because of activities related to coal mining.

The higher values of TSS, EC, Turbidity and sulphate during study period 1 at downstream sites were expected and could be as a result of mining impacts such as overburden removal which exposed the pyrite and led to leaching of acid mine drainage including chloride and sulphates (Sheoran and Sheoran, 2006).

During study period 2 concentrations of hydrogen, sulphates, chloride, and nitrate significantly increased at the Dam and KFBM4 (site located further downstream of the rehabilitation area and the mining area) respectively as compared to study period 1. This major change could be attributed to disturbances at the Dam during rehabilitation as the topsoil was removed and replaced during dam wall reconstruction. Through the results chapter the Dam was considered to be upstream of the disturbance from mining but there was clearly some disturbance at the dam wall. A significant decrease of total alkalinity concentration was also observed at Dam during study period 2 as compared to study period 1, this change can be attributed to the disturbance at the Dam wall. Other parameters showed similar trends during study period 1.

During study period 3 sulphate, chloride and hydrogen ion significantly decreased at the Dam site located just upstream of the rehabilitated wetland as compared to study period 1, and it could be because during study period 3 mining activities were no longer occurring hence the significant decrease in the concentrations of the above-mentioned variables. Nitrate concentration was similar with lower values during study period 1 and 3 at all sites. However, a significant spike was observed during study period 2 at KFBM4 and could be because of the development of the new Colliery upstream of KFBM4 which started during study period 2 (Figure 3.4). No evidence of water quality improvement during study period 3 was observed at downstream sites.

Water quality sampling during study period 3 was conducted for only six months, from February 2020 to June 2020. Therefore, continuous water quality monitoring should be implemented to establish long term effects of the rehabilitation work and it must be noted that rehabilitation is a lengthy process and takes years for the vegetation and soils components to establish. There is no specific literature to guide in terms of when the wetland becomes fully functional after rehabilitation as this could differ from one area to another as results of climate factors such temperature and rain, and human activities such as land use (Bartzen et al., 2010). For example: The Grootspruit case study which was conducted two years following the implementation of rehabilitation structures reported that there was a significant water quality improvement downstream of the rehabilitated area after rehabilitation and the rehabilitation of the wetland also

lead to an increase in the species diversity two years after rehabilitation (Oberholster et al., 2016).

Spatial comparison between upstream sites and downstream sites of the Woestalleen wetland was conducted for all variables throughout the study period and it was discovered that hydrogen ions, chloride, sulphate, and sodium were significantly higher at the downstream site KFBM4 as compared to other sites during all three study periods. This could be as a result of mining impacts such as overburden removal which exposed the pyrite and lead to leaching of acid mine drainage including chloride and sulphates (Fernandez-Rojo et al., 2019). This could also be as a result of the rehabilitation work which involved removal and replacement of the topsoil. Disturbed soils could also lead to increased oxidation and leaching. Site KFBM4 is located downstream and it's downstream of the new unknown Colliery that started during period 2 of the study (Figure 3.4). Therefore, higher concentration of hydrogen ions, chloride, sulphate, and sodium could also be as a result of the mining related activities from this new mine.

In situ measurements showed no significant differences between any sites during all time periods.

Rainfall influence on water quality

In October and November 2018, 85mm and 63mm of rainfall were received respectively, TSS, and Turbidity spikes were also observed during the same months at KFBM2. EC and Turbidity spikes were also observed in October 2018 at KFBM3. In November 2019, a high rainfall of about 266mm was received and EC spike was observed at Dam site during the same period. On the other hand, Alkalinity spike was observed in February at Dam, this coincided with high rainfall of 136mm. Sulphate spikes were also observed in October 2018 at KFMB1, January 2019 at KFBM2 and KFBM3, November 2019 at Dam and October and November 2018 at KFBM4. Nitrate had two spikes one in November 2018 at KFBM2 and another one in December 2019 at Dam. These spikes coincided with high rainfall ranging between 85mm and 266mm (Figure 4.45). All observed spikes for different variables could be as a result of high

rainfall received between October and March as rain can transport pollutants and particles from upstream areas and deposit them into the water bodies.

5.2 Conclusions

The main aim of this research project was to assess the water quality status of the Woestalleen wetland before and after rehabilitation. Water quality data collected 12 months before rehabilitation and 12 months after rehabilitation were analyzed using Microsoft Excel and the commercial plugin XLSTAT. Wetland assessment was done using WETLAND-IHI (DWAF, 2007). The research conclusions for each research objective are indicated below:

To determine whether Woestalleen wetland rehabilitation improves downstream water quality of the Woestalleen Spruit by measuring the following variables: pH, electrical conductivity, turbidity, suspended solids, total alkalinity, chloride, sulphate, nitrate, nitrite, dissolved oxygen, and sodium, and to compare Woestalleen wetland water quality status with the water quality limit on the issued licence (ref: 04/B12B/ABCGIJ/2868). The following are the key findings for this objective:

- Monitoring data before, during and after wetland rehabilitation indicated higher values than WUL limits of electrical conductivity, turbidity, suspended solids, total alkalinity, chloride, sulphate, ortho phosphate, dissolved oxygen, and sodium at the upstream site KFBM1 which were not compliant to the provided water quality limits on the WUL. Therefore, there are water contamination/pollution issues that emanated from upstream of the mining site causing no-compliance to the WUL.
- Significantly higher concentrations of variables such as hydrogen ions, sodium, chloride and sulphates were observed at downstream sites, KFBM2, KFBM3 and KFBM4 as compared to upstream sites, KFBM1 and Dam before, during and after rehabilitation, indicating the likely impacts of pyrite exposure and oxidation leading to AMD.

- Woestalleen wetland rehabilitation has not yet improved water quality downstream but new mining activities may confound attempts to investigate longer term recovery responses.
- Higher values of TSS, EC, turbidity, and sulphate during study period 1 at downstream sites (KFBM2 and KFBM3) than upstream sites were also observed, this implies that the active mine at this time may have contributed to the water contamination of Woestalleen Spruit.
- Most of the water quality variables such as electrical conductivity, turbidity, suspended solids, total alkalinity, sulphate, ortho phosphate, dissolved oxygen, and sodium were found to be non-compliant to the WUL both at upstream sites and downstream sites during all study periods i.e. period 1, 2 and 3. This shows the importance of the monitoring/experimental design where the upstream sites are effectively control sites – without them, non-compliance may have mistakenly been attributed solely to the mine. Mining activities may have contributed to acid mine drainage leading to these changes, even though the upstream water quality arriving at the mining area was already non-compliant.

To conduct Woestalleen wetland assessment after rehabilitation and to determine if the ecological status of Woestalleen wetland class has been upgraded from a Class D to a Class C or higher: The following are the key findings for this objective:

- The wetland assessment after the wetland rehabilitation was conducted in collaboration with Oasis Environmental Specialists and reported a PES of E (Badly modified) i.e., degradation of natural habitat, biota and essential ecosystem service is widespread. Therefore, it is evident that the rehabilitation work conducted at the wetland after the mining has not yet improved the PES of the wetland.
- Rehabilitation is a lengthy process and takes years for the vegetation and soils components to establish. Therefore, it is predicted that the wetland PES might improve in the next few years.
- PES further degraded from category D to E as a result of the mining impacts.
- Viewed in isolation, the mine could have been blamed for non-compliant water quality and downgrading of wetland PES, but in fact the study was able to show

that other factors needed to be taken into account and it is still too early to assess the longer-term success of the rehab work.

5.3 Recommendations

From the results obtained during this study it was evident that the water quality and PES of the wetland has not yet improved after rehabilitation.

- Continuous PES and water quality monitoring should be implemented for several years in order to establish if the PES and water quality will improve as a result of the rehabilitation work conducted.

5.4 Avenues for future research

Further research is recommended in the study area to ascertain water quality and wetland PES improvement and the impacts of the identified new Colliery into the Woestalleen wetland.

References

An, J., Kim, J. Y., Kim, K. W., Park, J. Y., Lee, J. S., & Jang, M. (2011). Natural attenuation of arsenic in the wetland system around abandoned mining area. *Environmental Geochemistry and Health*, 33(1), 71–80. https://doi.org/10.1007/s10653-010-9361-3.

Armstrong A, (2009). WET-Legal: Wetland rehabilitation and the law in South Africa. WRC Report No. TT 338/09. Water Research Commission, Pretoria.

Bartzen, B. A., Dufour, K. W., Clark, R. G., & Dale Caswell, F. (2010). 525-538 Trends in agricultural impact and recovery of wetlands in prairie Canada. *Ecological Applications*, 20(2), 525–538. https://doi.org/10.1890/08-1650.1.

Beal, M. (2007). An investigation of the impacts of wetlands, wetland mitigation banks, and open spaces on nearby property values, *A Dissertation submitted to the Department of Economics in partial fulfilment of the requirements for the degree of Doctor of Philosophy.*

Brenner, F. J. (2001). Use of constructed wetlands for acid mine drainage abatement on a watershed basis. *Integrated Surface and Ground Water Management*, 267–276. https://doi.org/10.1061/40562(267)29.

Brock, M. A., D. L. Nielsen, R. J. Shiel, J. D. Green, and J. D. Langley. (2003). Drought and aquatic community resilience: the role of eggs and seeds in sediments of temporary wetlands. *Freshwater Biology* 48,1207–1218.

Brudvig, L. A., Barak, R. S., Bauer, J. T., Caughlin, T. T., Laughlin, D. C., Larios, L., Zirbel, C. R. (2017). Interpreting variation to advance predictive restoration science. *Journal of Applied Ecology*. https://doi.org/10.1111/1365-2664.12938.

Cereghinor, R., Biggs, J, Oertelli, B. & Declerck, S. (2008). The ecology of European ponds: defining the characteristics of a neglected freshwater habitat. *Hydrobiologia* 597: 1–6.

Cowden, C., Kotze, DC.,Ellery, WN., & Sieben, EJJ. (2014) Assessment of the long-term response to rehabilitation of two wetlands in KwaZulu-Natal, South Africa, African. *Journal of Aquatic Science,* 39:3, 237-247, DOI:10.2989/16085914.2014.954518e

Cronk, J.K. (1996). Constructed wetlands to treat wastewater from dairy and swine operations: A review. Agric. *Ecosyst. Environ.* 58:97–114.

Davinson, N. C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research*, doi: 10.1071/MF14173.

DeJong, J. (1976). The purification of wastewater with the aid of rush or reed ponds. Pages 133-139 in J. Tourbeir, and R. W Pierson, Jr (eds), *Biological Control of Water Pollution.* University of Pennslyvania Press, Philadelphia, Pennsylvania.

Department of Environmental Affairs (DEA) (2014). State of the wetlands in South Africa: *State of the environment.* Department of Environmental Affairs, South Africa.

Department of Water and Sanitation (DWS), (2017): *Wetland Policy (Draft)*. Department of Water and Sanitation, Pretoria, South Africa.

DWAF (2007). Manual for the assessment of a Wetland Index of Habitat Integrity for South African floodplain and channelled valley bottom wetland types by M. Rountree (ed); C.P.

DWAF. (2005). A practical field procedure for identification and delineation of wetland and riparian areas. Edition 1, September 2005. DWAF, Pretoria.

Demirel, N., Emil, M. K., & Duzgun, H. S. (2011). Surface coal mine area monitoring using multi-temporal high-resolution satellite imagery. *International Journal of Coal Geology*. https://doi.org/10.1016/j.coal.2010.11.010.

de Groot, D., Brander, L., & Max Finlayson, C. (2018). Wetland ecosystem services. *The Wetland Book*: Structure and Function, Management, and Methods, (Table 1), 323–333. https://doi.org/10.1007/978-90-481-9659-3_66.

Erwin, K. L. (2009). Wetlands and global climate change: the role of wetland restoration in a changing world. *Wetlands Ecology and management*, 17(1), 71-84.

Fernandez-Rojo, L., Casiot, C., Laroche, E., Tardy, V., Bruneel, O., Delpoux, S., Héry, M. (2019). A field-pilot for passive bioremediation of As-rich acid mine drainage. *Journal of Environmental Management.* https://doi.org/10.1016/j.jenvman.2018.11.116.

Guo, T., Zhang, X., & Cheng, T. (2011). Evaluation of wetland ecological restoration project based on SD: A case study on Qilihai wetland in Tianjin. *Procedia Environmental Sciences*, 10(PART C), 2587–2593. https://doi.org/10.1016/j.proenv.2011.09.402

Hemond, H. F., & Benoit, J. (1988). Cumulative impacts on water quality functions of wetlands. *Environmental Management*, 12(5), 639–653. https://doi.org/10.1007/BF01867542

Hutchinson, G.E., Pickford, G.E. and Schuurman, J.F.M. (1932). A contribution to the Hydrobiology of depression wetlands and other inland waters of South Africa. *Archive für Hydrobiologie* 24: 1–154.

Huntsman, B.E., Solch, J.G. and Porter, M.D. (1978). Utilization of Sphagnum species dominated bog for coal acid mine drainage abatement. Geol. Soc. Amer. *Annual Meeting Abst.*, Toronto, Ontario. p 322.

Kalin, M. (n.d.). Biogeochemical and ecological considerations in designing wetland treatment systems in post-mining landscapes. Retrieved from www.elsevier.nl/locate/wasman.

Kentula, M. E. (2000). Perspectives on setting success criteria for wetland restoration. *Ecological Engineering.* https://doi.org/10.1016/S0925-8574(00)00076-8

King, N., Rosmarin, T. & Friedman, Y. (2005). Biodiversity and ecosystem health, *South Africa Environment Outlook,* Department of Environmental Affairs and Tourism, South Africa.

Kleynhans, C.J. (1996). A qualitative procedure for the assessment of the habitat integrity status of the Luvuvhu River. *Journal of Aquatic Ecosystem Health* 5: 41 - 54.

Kleynhans, C.J. (1999). A procedure for the determination of the ecological reserve for the purposes of the national water balance model for South African Rivers. *Institute for Water Quality Studies*. Department of Water Affairs and Forestry, Pretoria.

Kleynhans CJ, Louw MD. (2007). Module A: EcoClassification and EcoStatus determination in River EcoClassification: *Manual for EcoStatus Determination (version 2).* Joint Water Research Commission and Department of Water Affairs and Forestry report. WRC Report No. TT 329/08.

Kotze, D.C., Breen, C.M and Quinn, N. (1995). Wetland losses in South Africa. In: Cowen G.I (Ed), *Wetlands of South Africa.* Department of Environmental Affairs and Tourism, Pretoria, South Africa.

Kotze, D.C, Marneweck, G.C, Batchelor, A.L, Lindley, D.S and Collins, N.B (2008) WETEcoServices: A technique for rapidly assessing ecosystem services supplied by wetlands. WRC Report No. TT 339/09. Water Research Commission, Pretoria

Kotze DC, Ellery WN, Rountree M, Grenfell MC, Marneweck G, Nxele IZ, Breen DC, Dini J, Batchelor AL, and Sieben E, (2009). WET-RehabPlan: Guidelines for planning wetland rehabilitation in South Africa. WRC Report No. TT 336/09. Water Research Commission, Pretoria.

Kuschk, P., Wiessner, A., Buddhawong, S., Stottmeister, U., & Kästner, M. (2006). Effectiveness of differently designed small-scale constructed wetlands to decrease the acidity of acid mine drainage under field conditions. *Engineering in Life Sciences*, 6(4), 394–398. https://doi.org/10.1002/elsc.200620143

Lane, C.R., Reiss, K.C., De Celles, S. & Brown, M.T. (2009). Benthic diatom composition in isolated forested wetlands subject to drying implications for monitoring and assessment. *Ecological Indicators* 9(6): 1121–1128

Liikanen, A., Huttunen, J. T., Karjalainen, S. M., Heikkinen, K., Väisänen, T. S., Nykänen, H., & Martikainen, P. J. (2006). Temporal and seasonal changes in greenhouse gas emissions from a constructed wetland purifying peat mining runoff waters. *Ecological Engineering*, 26(3), 241–251. https://doi.org/10.1016/j.ecoleng.2005.10.005

Liu, H., Zhang, S., Li, Z., Lu, X., & Yang, Q. (2004). Impacts on wetlands of large-scale land-use changes by agricultural development: *The Small Sanjiang Plain*, China. Ambio, 33(6), 306–310. https://doi.org/10.1579/0044-7447-33.6.306

Macfarlane, D. M., Kotze, D. C., Ellery, W. N., Walters, D., Koopman, V., Goodman, P. & Coge, C. (2008). WET-Health, Wetland Management Series: A Technique for

Rapidly Assessing Wetland Health. *Wetlands Research Programme:* Wetland Rehabilitation (WRC Project No. K5/1408). Pretoria: WRC.

Macfarlane, D., Dlamini, B., Marneweck, G., Kassier, D., Campbell, J., Young, A., Dini, J.A., Holness, S.D., de Klerk, A.R., Oberholster, P.J. and Ginsburg, A. (2016). Wetland rehabilitation in mining landscapes: *an introductory guide.*

Millennium Ecosystem Assessment. (2005). Ecosystems and Human Well Being: *Wetlands and Water Synthesis.* World Resources Institute, Washington, DC.

Mitsch, W. J. (2013). Wetland Creation and Restoration. *In Encyclopedia of Biodiversity: Second Edition* (pp. 367–383). https://doi.org/10.1016/B978-0-12-384719-5.00221-5

Mitsch WJ, Gosselink JG, Anderson CJ, and Zhang L (2009). *Wetland Ecosystems*, 295 pp. New York: John Wiley & Sons, Inc.

Mitsch, W.J. and Gosselink, J.G. (2000). *Wetlands.* John Wiley, New York,USA.

National Water Act, 1998 (Act No. 36 of 1998).

National Environmental Management Act (Act 108 of 1998).\

Nieman, F., & Mare, J. (2013). Wetland delineation report for the Pullenshope Project on the Farm Rodepoort 151 Is (Report No:WET/V1/PULLESHOPE/2013/07).

Oberholster, P. J., Myburgh, J. G., Ashton, P. J., Coetzee, J. J., & Botha, A. M. (2012). Bioaccumulation of aluminium and iron in the food chain of Lake Loskop, South Africa. *Ecotoxicology and Environmental Safety*. https://doi.org/10.1016/j.ecoenv.2011.08.018

Oberholster, P. J., De Klerk, A. R., Chamier, J., Cho, M., Crafford, J., De Klerk, L. P. & Schaefer, L. (2016). Assessment of the Ecological Integrity of the Zaalklapspruit Wetland in Mpumalanga (South Africa) Before and After Rehabilitation: The Grootspruit Case Study: *Report to the Water Research Commission.* Water Research Commission. WRC Report No. 2230/2/16. [online]. Available at: http://www.wrc.org.za/Knowledge%20Hub%20Documents/Research%20Reports/2230 %20Volume%202%20-%20Jo.pdf [Accessed 19 June 2021]

Ollis, D.J., Snaddon, K., Job N.M., & Mbona, N. (2013). Classification Systems for Wetlands and other Aquatic Ecosystems in South Africa. *User Manual: Inland Systems.* SANBI Biodiversity Series 22. South African National Biodiversity Institute, Pretoria

Qing-Jun, M., Qi-Yan, F., Qing-Qing, W., Lei, M., & Zhi-Yang, C. (2009). Distribution characteristics of nitrogen and phosphorus in mining induced subsidence wetland in Panbei coal mine, China. https://doi.org/10.1016/j.pro

Reeves, R. R., Wilke, M., Cashmore, P., Macdonald, N., & Thompson, K. (2018). Physical and ecological effects of rehabilitating the geothermally influenced Waikite Wetland, New Zealand. *Journal of Environmental Management*, 228(May), 279–291. https://doi.org/10.1016/j.jenvman.2018.09.027

Schrijvershof, J. (2020). Wetland PES and EIS monitoring for Roodeport Colliery near Pullens Hope, Mpumalanga (WET-200014).

Sieben, E.J.J. (2011). Compiling vegetation data on wetlands in KwaZulu-Natal, Free State and Mpumalanga Providing Minimum Data Requirements and a Sampling Protocol. *Water Research Commission.* WRC Report No. KV.258/10

Sheoran, A. S., & Sheoran, V. (2006). Heavy metal removal mechanism of acid mine drainage in wetlands: A critical review. *Minerals Engineering*, 19(2), 105–116. https://doi.org/10.1016/j.mineng.2005.08.006

Smardon, R. C. (2006). Heritage values and functions of wetlands in Southern Mexico. *Landscape and Urban Planning*, 74(3–4), 296 312.https://doi.org/10.1016/j.landurbplan.2004.09.009

Smith, A., Tetzlaff, D., Gelbrecht, J., Kleine, L., & Soulsby, C. (2020). Riparian wetland rehabilitation and beaver re-colonization impacts on hydrological processes and water quality in a lowland agricultural catchment. *Science of the Total Environment*,699(September 2019), 134302. https://doi.org/10.1016/j.scitotenv.2019.134302

South African National Biodiversity Institute (SANBI). 2019. National Biodiversity Assessment 2018: The status of South Africa's ecosystems and biodiversity. *Synthesis Report.* South African National Biodiversity Institute, an entity of the Department of Environment, Forestry and Fisheries, Pretoria. pp. 1–214

South African National Biodiversity Institute (2013). Life: the state of South Africa's biodiversity 2012. South African National Biodiversity Institute, Pretoria.

Swanepoel C.M., and Barnard R.O. (2007). Discussion paper. *Wetlands in Agriculture*. ARC Report Number GW/A/2007/43.

Taddeo, S., & Dronova, I. (2018, November 1). Indicators of vegetation development in restored wetlands. *Ecological Indicators,* Vol. 94, pp. 454–467. https://doi.org/10.1016/j.ecolind.2018.07.010

Whigham, D. F. (1999). Ecological issues related to wetland preservation, restoration, creation and assessment. *Science of the Total Environment* 240:31–40

Wohlgemuth, M., & Virginia Institute of Marine Science, Wetlands Program. (1991) Nontidal Wetland Functions and Values. *Wetlands Program Technical Report no. 91-A.* Virginia Institute of Marine Science, William & Mary. http://dx.doi.org/doi:10.21220/m2-8tn1-dt03

Appendices

Appendix A: water quality data

	ID No	period	date	pH	H+	TSS	EC	Turbity	Total Alkali	Chloride	Sulphate	nitrate	nitrite	disolved ox	Sodium
before reh	KFBM1	1	Jul-18	8,3	5,012E-09	9,3	86	1,6	172	92	172	0,05	0,025	8,1	60
	KFBM1	1	Aug-18	8	1E-08	1,3	106	1,5	212	114	185	1,2	0,025	7,5	68
	KFBM1	1	Sep-18	7,6	2,512E-08	36	120	23	240	126	202	0,1	0,025	7,3	82
	KFBM1	1	Oct-18	7,2	6,31E-08	10	203	5,1	136	172	754	0,2	0,025	6,4	129
	KFBM1	1	Nov-18	7,7	1,995E-08	7,2	141	2,8	100	97	493	0,1	0,025	6,8	81
	KFBM1	1	Jan-19	7,1	7,9E-08	10	66,2	3,4	96	30	177	0,1	0,025	7,3	38
	KFBM1	1	Feb-19	7,1	7,9E-08	3,2	62,5	2,2	72	32	187	0,05	0,025	8,5	42
	KFBM1	1	Mar-19	8,1	7,9E-09	2,8	63,4	2,9	68	32	176	0,3	0,025	8,4	39
	KFBM1	1	Apr-19	7,6	2,5E-08	32	71,6	16	136	41	190	0,05	0,025	7,1	45
	KFBM1	1	May-19	7,5	3,2E-08	71	77,7	52	152	58	142	0,4	0,025	7,7	50
	KFBM1	1	Jul-19	7,6	2,5E-08	156	92	52	204	81	207	0,05	0,025	7	64
during reh	KFBM1	2	Aug-19	7,3	5,012E-08	3,3	76,1	1,9	64	43	236	0,2	0,025	7,2	47
	KFBM1	2	Sep-19	7,8	1,585E-08	56	83,2	24	108	46	255	0,05	0,025	7,5	52
	KFBM1	2	Oct-19	8,2	6,31E-09	35	135	25	260	93	459	0,05	0,025	7,1	97
	KFBM1	2	Dec-19	7,4	4E-08	23	127	8,1	40	72	564	0,1	0,025	8	80
	KFBM1	2	Jan-21	6,9	1,3E-07	14	53,5	7	20	28	177	0,1	0,025	9,4	28
after rehab	KFBM1	3	Feb-20	7,3	5E-08	18	51,1	5	44	28	143	0,05	0,025	7,4	29
	KFBM1	3	Mar-20	7,3	5E-08	30	68,3	20	128	40	161	0,3	0,025	8,4	39
	KFBM1	3	Apr-20	6,37	4,3E-07	17,6	60,7	12,3	56,2	34,7	191	0,175	0,005	4,67	31,8
	KFBM1	3	May-20	7,69	2E-08	36,8	456	29,2	64,6	43	233	0,175	0,005	4,9	46,1

	ID No	period	date	pH	H+	TSS	EC	Turbity	Total Alkali	Chloride	Sulphate	nitrate	nitrite	disolved ox	Sodium
before reh	Dam	1	Jul-18	7,8	1,585E-08	25	50,9	6,3	144	39	79	0,05	0,025	6,8	7,4
	Dam	1	Aug-18	8,5	3,2E-09	14	57	4,2	152	41	88	1,2	0,025	7,9	40
	Dam	1	Sep-18	8,5	3,2E-09	24	63,9	8,9	204	46	72	0,05	0,025	7	45
	Dam	1	Oct-18	3,9	0,00013	47	163	55	2,5	37	888	0,3	0,025	6,2	46
	Dam	1	Nov-18	3,1	0,00079	60	205	63	2,5	36	991	0,1	0,025	7	48
	Dam	1	Jan-19	3,4	0,0004	14,7	84,4	14,7	2,5	30	276	0,05	0,025	7,4	42
	Dam	1	Feb-19	4,5	3,2E-05	2,4	58,2	5,9	288	115	1186	0,05	0,025	8,4	45
	Dam	1	Mar-19	8	1E-08	4,4	60,1	2,9	80	32	174	0,05	0,025	7,8	44
	Dam	1	Apr-19	8,4	4E-09	61,6	136	45	128	34	163	0,05	0,025	7	48
	Dam	1	May-19	9,3	5E-10	4,7	56,1	3,5	96	41	130	0,05	0,025	8	46
during reh	Dam	2	Jul-19	5,9	1,3E-06	73	181	11	2,5	59	983	0,05	0,025	7,9	90
	Dam	2	Aug-19	4,1	7,943E-05	37	142	8,7	2,5	52	664	0,1	0,025	6,3	74
	Dam	2	Sep-19	3,9	0,00013	15,3	174	14	2,5	96	919	0,05	0,025	7,5	98

	Dam	2	Oct-19	3,8	0,00016	23	198	31	2,5	112	1031	0,05	0,025	7,1	124
	Dam	2	Nov-19	3,2	0,00063	51	257	102	2,5	112	1260	0,4	0,1	5,1	5
	Dam	2	Dec-19	7	1E-07	32	36,3	47	16	18	122	1,3	0,3	7,4	17
	Dam	2	Jan-20	7,1	7,9E-08	19,3	37,8	23	80	26	88	0,1	0,05	9,5	23
er rehab	Dam	3	Feb-20	7,6	2,5E-08	11,3	36,3	8	84	25	49	0,1	0,025	7,5	22
	Dam	3	Mar-20	8,8	1,6E-09	51	47	43	140	38	57	0,175	0,005	5,89	23,2
	Dam	3	Apr-20	6,9	1,3E-07	19,4	40,3	13,1	120	27,7	38	0,175	0,15	5,88	26
	Dam	3	May-20	7,78	1,7E-08	1,6	228	4,29	117	28,8	49,1	0,05	0,07	7	48
	Dam	3	Jun-20	7,87	1,3E-08	1,4	222	4,11	110	28,9	52,1	0,175	0,005	5,82	26,6
	ID No	period	date	pH	H+	TSS	EC	Turbity	Total Alkali	Chloride	Sulphate	nitrate	nitrite	disolved ox	Sodium
fore reh	KFM2	1	Jul-18	7,9	1,3E-08	31	51,1	17	140	36	81	0,05	0,025	7,9	36
	KFM2	1	Aug-18	8,1	7,9E-09	177	65,1	1,5	212	114	185	1,2	0,025	6	44
	KFM2	1	Oct-18	7	1E-07	250	39,4	584	60	18	115	0,3	0,06	5,5	43
	KFM2	1	Nov-18	7	1E-07	209	34,4	579	24	14	103	1,8	0,08	6,2	10
	KFM2	1	Jan-19	3,4	0,0004	2	104	1	2,5	15	437	0,05	0,025	7,2	42
	KFM2	1	Feb-19	4,6	2,5E-05	4,8	58,1	2,4	2,5	27	217	0,05	0,025	8,6	44
	KFM2	1	Mar-19	8,1	7,9E-09	3,2	60	1,8	76	32	167	0,05	0,025	8,2	42
	KFM2	1	Dec-19	6,2	6,3E-07	108	6,3	213	2,5	7	11	0,1	0,2	5,5	2
	KFM2	1	Jan-20	6,8	1,6E-07	20	8,1	86	28	6	0,1	0,05	0,025	9,6	1
er rehab	KFM2	3	Feb-20	8,1	7,9E-09	158	38,1	210	96	26	59	0,2	0,025	7,2	23
	KFM2	3	Mar-20	7,9	1,3E-08	14,7	43,6	11	144	29	43	0,05	0,025	8,7	30
	KFM2	3	May-20	7,56	2,8E-08	1,4	254	4,46	119	29,9	62,9	0,175	0,005	5,74	29,6
	KFM2	3	Jun-20	7,61	2,5E-08	4,4	251	9,02	125	31,7	58,2	0,175	0,005	5,91	29,2
	ID No	period	date	pH	H+	TSS	EC	Turbity	Total Alkali	Chloride	Sulphate	nitrate	nitrite	disolved ox	Sodium
fore reh	KFM3	1	Jul-18	7,4	3,981E-08	2010	62,5	1875	100	32	179	0,05	0,025	6,8	33
	KFM3	1	Aug-18	7,6	2,5E-08	81	77,3	37	156	25	214	1,2	0,025	7	31
	KFM3	1	Jan-19	3,4	0,0004	2	104	1	2,5	15	437	0,1	0,025	7,1	35
	KFM3	1	Feb-19	6,2	6,3E-07	27	52	16	40	8	198	0,05	0,025	8,3	28
	KFM3	1	Mar-19	7,5	3,2E-08	109360	86,8	17	316	50	81	0,05	0,025	0,2	52
	KFM3	1	Dec-19	6,6	2,5E-07	8	49,7	5,5	8	88	119	0,5	0,3	5,4	31
er rehab	KFM3	3	Feb-20	7,8	1,6E-08	8,7	63,8	5,9	136	79	48	0,2	0,1	7,2	39
	KFM3	3	Mar-20	7,15	7,1E-08	28,8	101	36,3	62,6	190	162	0,175	0,005	5,6	43
	KFM3	3	May-20	8,02	9,5E-09	32	98,9	47,6	93,4	211	83,3	0,175	0,005	7,1	44
	ID No	period	date	pH	H+	TSS	EC	Turbity	Total Alkali	Chloride	Sulphate	nitrate	nitrite	disolved ox	Sodium
fore reh	KFBM4	1	Jul-18	7,4	3,981E-08	9,3	57,8	4,4	124	89	48	0,05	0,025	7,4	39

KFBM4	1	Aug-18	7,8	1,6E-08	6,7	67,6	8,8	156	99	47	0,05	0,025	1,3	55
KFBM4	1	Sep-18	7,5	3,2E-08	176	87,9	105	228	124	45	0,05	0,025	1,3	55
KFBM4	1	Oct-18	3	0,001	85	393	109	2,5	138	2309	0,05	0,025	5,3	145
KFBM4	1	Nov-18	2,8	0,00158	23	463	36	2,5	158	2486	0,05	0,025	5,7	149
KFBM4	1	Jan-19	3,1	0,00079	1,3	147	0,8	2,5	33	604	0,05	0,025	7,1	50
KFBM4	1	Feb-19	3,1	0,00079	5,2	95	0,3	2,5	24	331	0,05	0,025	8,5	47
KFBM4	1	Mar-19	3,5	0,00032	2	69	0,9	2,5	39	216	0,05	0,025	7,8	48
KFBM4	1	Apr-19	3,5	0,00032	6,8	95,4	12	2,5	63	328	0,05	0,025	8,3	60
KFBM4	1	May-19	3,4	0,0004	6	102	15	2,5	90	355	0,05	0,025	7,9	46
KFBM4	1	Jun-19	3,7	0,0002	15,3	111	1,3	2,5	97	419	0,05	0,025	8,4	77
KFBM4	2	Dec-19	6,6	2,5E-07	8,7	49,8	8	8	70	119	0,2	0,025	7,1	30
KFBM4	2	Jan-20	7,3	5E-08	18,7	61,5	8,1	128	74	68	0,8	1,7	7,5	36
er rehab KFBM4	3	Feb-20	7,3	5E-08	181	83,8	50	140	82	45	0,05	0,025	5,8	42

Appendix B: Field form

3. FIELD FORMS FOR THE WETLAND-IHI

Site name:	[illegible]
Location (GPS co-ordinates):	[illegible]
1:50 000 topo map reference :	
EcoRegion:	Highveld (8.12.B)
Geology (if available):	
Recorder:	[illegible]
Date:	27/11/2020

Notes and/or Sketch of the site

VEGETATION ALTERATION - the impacts of landuse activities within the wetland on the vegetation of the wetland

Estimate the impact RATING (0-5) and areal EXTENT (0-100 %) of the various landuse activities on the wetland system

Landuse Activities on the wetland	Ranking	Rating (0-5)	Extent (0-100%)	Confidence Rating (1-5)	Notes (describe the details of impacts here)
Mining/Excavation					
Infilling/Backfilling	1	5	20	4	
Vegetation Clearing/Loss/Alteration	2	5	20	4	
Weeds or invasive plants	3	5	20	4	
Percentage in Reference State	4	3	20	4	
	6	0	20	2	
		Total Extent: (MUST equal 100%)			

Reference State : this is what the site would have looked like without the landuse activities and without the on-site and catchment hydrology, geomorphology and water quality alterations/impacts which have occurred.

Description of the Reference State:

The clay bed has completly altered from reference. Vegetation and soil needs time to establish after the stream diversion and rehab process, although will never achieve natural state.

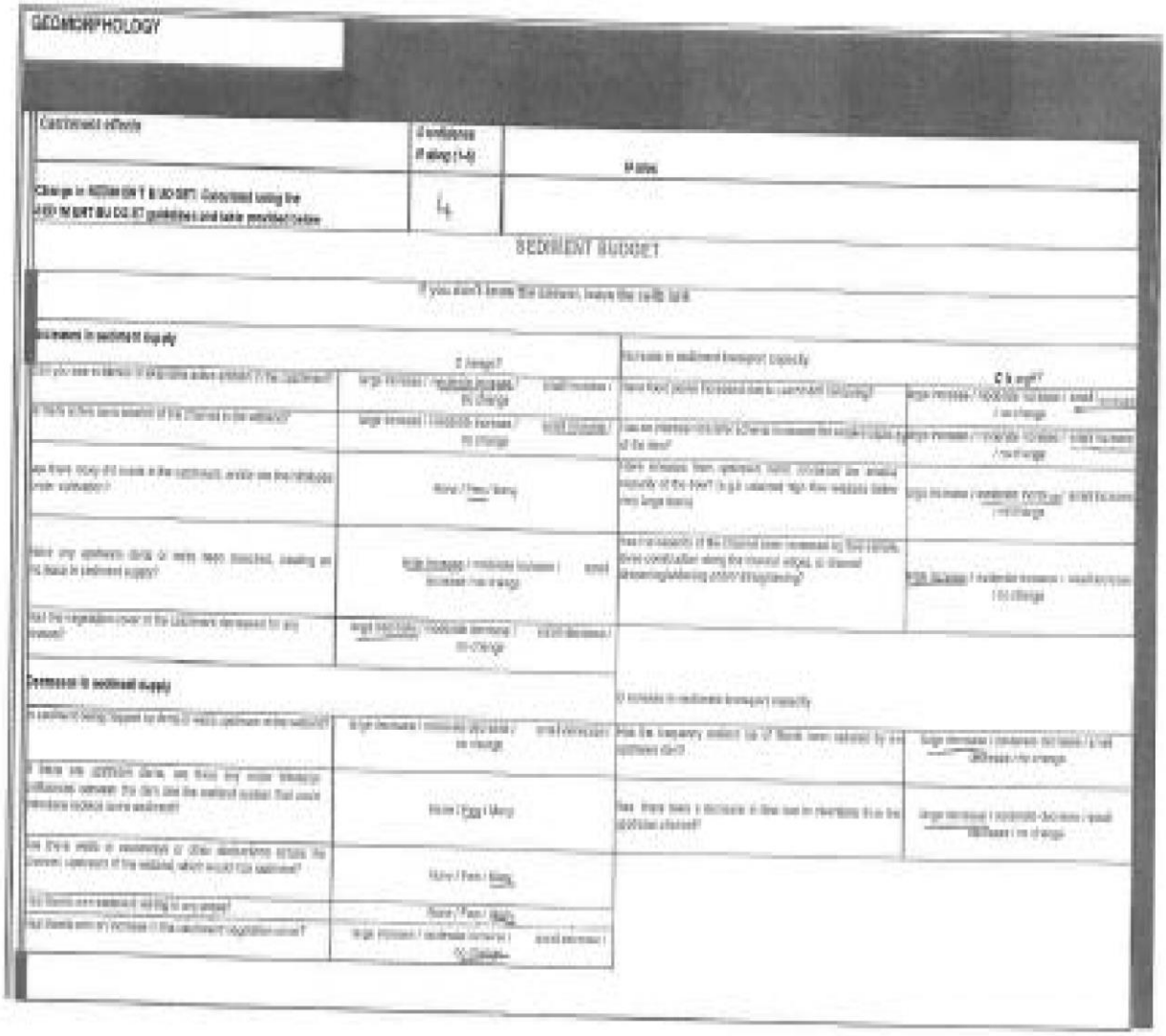
HYDROLOGY

Catchment Effects	Weighting (0-100%)	Rating	Confidence Rating (1-5)	Notes
Changes in flood peaks/frequencies	100	5	4	2 Large Dams Upstream
Changes in base flows	60	5	4	
Changes in seasonality	80	2	5	
Zero flows	10	5	3	

Within-wetland Effects	Rating	Extent (0-100%)	Confidence Rating (1-5)	Notes
Connectivity - altered channel size/competency	5	40	4	Dams with diversions downstream present.
Increased water retention on the floodplain	2	20	5	
Decreased water retention on the floodplain	5	40	4	
Reference State conditions		0.0		
		Total Extent (MUST equal 100%)		

Assessing Catchment Effects

Changes in flood peaks	
INCREASE? Is there catchment hardening (urbanisation) in the catchment?	large increase / moderate increase / small increase / no change
DECREASE? Are there many small dams, or a large/multi-dam upstream of the wetland?	None / Few / Many
Changes in base flow	
INCREASE: are there any interbasin transfers, or releases of elevated flows to cater for irrigation?	large increase / moderate increase / small increase / no change
DECREASE: is there extensive abstraction for irrigation, or extensively afforested areas, upstream of the wetland?	large decrease / moderate decrease / small decrease / no change



GEOMORPHOLOGY

Catchment effects	Confidence (High (1-4))	Notes
Change in RIVER DIRECTION AND SHIFT: Calculated using the RIVER MANAGEMENT CALCULATOR guidelines and table provided online	4	

SEDIMENT BUDGET

If you don't know the answer, leave the cells blank

Increases in sediment supply	If change?	Increase in sediment transport capacity	If change?
Are you near to failure or will some action protect it? Is the catchment	large increase / moderate increase / small increase / no change	Have flood banks increased due to catchment changes?	large increase / moderate increase / small increase / no change
Is there a new source of fine material in the catchment?	large increase / moderate increase / small increase / no change	Has the channel been straightened in the vicinity of the river?	large increase / moderate increase / small increase / no change
Are there many dirt roads in the catchment, and/or are they obviously under construction?	None / Few / Many	Have increases been upstream been considered the erosive capacity of the river? (e.g. steamed rigs flow velocities below very large dams)	large increase / moderate increase / small increase / no change
Have any sediment dams or weirs been breached, creating an influx in sediment supply?	large increase / moderate increase / small increase / no change	Has the capacity of the channel been increased by flow controls, dams constructed along the channel edges, or channel dredging/widening and/or straightening?	large increase / moderate increase / small increase / no change
Has the vegetation cover in the catchment decreased for any reason?	large increase / moderate increase / small increase / no change		
Decrease in sediment supply		If increase in sediment transport capacity	
Is sediment being trapped by dams in the catchment or the valley?	large decrease / moderate decrease / small decrease / no change	Has the capacity evident (or if there been reduced by in catchment dam?	large decrease / moderate decrease / small decrease / no change
Is there any artificial dams, are there any water diversion structures upstream (for dam use like wetland bodies that could reduce/stop sediment?	None / Few / Many	Has there been a decrease in flow due to diversions in to the artificial channel?	large decrease / moderate decrease / small decrease / no change
Are there weirs or reservoirs or other developments across the channel catchment of the wetland, which would trap sediment?	None / Few / Many		
Is channel ever dredged or mined for any purpose?	None / Few / Many		
Has there been any increase in the catchment vegetation cover?	large increase / moderate increase / small increase / no change		

Appendix C: wetland scoring results

HYDROLOGY	Ranking	Weighting	Weighted Rating
Catchment	1	100	-6,3
Within-wetland Effects	2	70	175,0
TOTAL HYDROLOGY PES		170	68,4

Catchment Effects	Ranking	Weighting	Rating	Impact Score
Changes in flood peaks/frequencies	1	100	-5,0	-5
Changes in annual volume (MAR)	2	60	-6,0	-3
Changes in seasonality	2	40	2,0	1,2
Zero flows	3	10	5,0	0,5
Sub-total		230		-6,3

Within-wetland Effects	Ranking	Weighting	Rating	Extent (0-100%)	Impact Score	Weighted Impact Score
Altered channel competency	1	100	5,0	50	250	125
Altered water retention on the floodplain	1	100	2,0	50	100	50
Sub-total		200				175

Recommended values, but can be altered by experts or when confidence for new value is high.
Data inputs required here

FLOODPLAIN LANDUSE

Estimate the area / Extent of the various landuse activities on the wetland system

Landuse Activities on the Floodplain	Ranking	Weighting	Rating (1-5)	Extent (0-100%)	Impact Score
Mining	1	100	5	20	1
Infilling/Backfilling	2	70	5	20	1
Alien plants	3	60	5	20	1
Vegetation Removal/Alteration	4	60	5	20	
Grazing	5	20	1	20	0,2
No change from Reference	6	0	0		0
TOTAL LANDUSE IMPACTS		300		100	3,2

To assess the REFERENCE CONDITION: consider the site without these impacts and without the on-site and catchment hydrology, geomorphology and water quality alterations/impacts.

Recommended values, but can be altered by experts or when confidence for new value is high.

Data inputs required here

GEOMORPHOLOGY			
Upstream of catchment vs on-site effects	Ranking	Weighting	Weighted Scores
Catchment	1	50	4.0
Within-wetland Effects	2	50	150.0
TOTAL GEOMORPHOLOGY PES		100	88.9

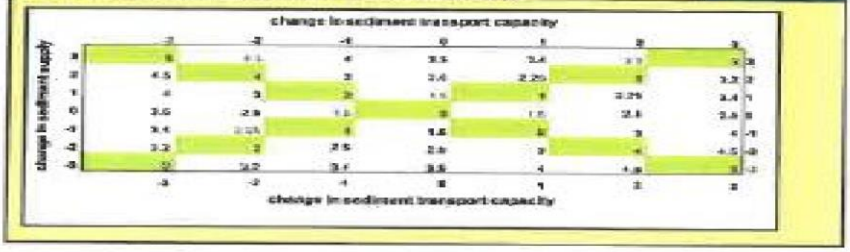
Catchment effects	Ranking	Weighted	Rating	Impact Score
Change in Sediment Budget (calculate below)	1	100	4.0	4
				4

Within-wetland Effects	Ranking	Weighting	Rating	Extent (0-100%)	Impact Score	Weighted Impact Score
Erosional processes	2	100	3.0	50	150	100
Depositional processes	3	50	3.0	50	150	50
Sub-total		150				150

SEDIMENT BUDGET (Increases or decreases in sediment)

Reach Assessment: Increase in sediment supply	Change?	Increase in transport capacity	Change?
Can you see evidence of active erosion in the catchment?	moderate increase	Have flood peaks increased due to catchment landuse?	small increase
Is there active bank erosion in the study section?	small increase	Has an instream barrier scheme increased the erosive capacity of the flow?	small increase
Are there many dirt roads in the catchment, and/or are the hills/ops under cultivation?	few	Have releases from upstream dams increased the erosive capacity of the flow? (e.g. sustained high flow releases below large dam)	large increase
Have any upstream dams or weirs been breached, causing an increase in sediment supply?	large increase		
Has the vegetation cover of the catchment decreased for any reason?	large decrease		
Decrease in sediment supply		**Decrease in transport capacity**	
Is sediment being trapped by dams or weirs upstream of the reach?	large decrease	Has the frequency of floods been reduced by an upstream dam?	large decrease
If there are upstream dams, are there any major tributary confluences between the dam and the wetland system that could introduce replace some sediment?	few	Has there been a decrease in flow due to diversions from the upstream channel?	large decrease
Are there weirs or causeways or other obstructions across the channel upstream of the reach?	many		
Has there been sediment mining in any areas?	many		
Has there been an increase in the catchment vegetation cover?	no change		

Catchment Assessment: Change in sediment supply	Change?	Change in transport capacity	Change?
Has there been an increase or decrease in sediment supply at the catchment scale?		Has there been an increase or decrease in sediment transport capacity (increase or decrease in high flows) at the catchment scale?	
Given the above, to what extent do you think the sediment supply to the wetland has changed? (-10 to +10)	-6	Given the above, to what extent do you think the transport capacity in the wetland has changed? (-10 to +10)	-6
Adjusted sediment supply index	-6.0	Adjusted transport capacity index	-6.0
Use the table below to assess the change in sediment budget (0-6)			2



WATER QUALITY

This won't be developed for this project, but assessors can assign a qualitative (A-F) judement for the site. This is down-weighted in the overall PES due to low confidence and general lower sensitivity of wetlands to water quality impacts (relative to riverine environments).

Water Quality Score:

3,5	
Category:	**Score:**
A =>	0,25
B =>	0,75
C =>	1,5
D =>	2,5
E =>	3,5
F =>	4,5

If available, substitute the upstream river site water quality scor

Appendix D: wetland assessment rating Evaluate vegetation alteration.

An assessment of the proportion of the extents of the land use activities/changes in the wetland, and a rating of their impacts was done under this section. Scoring was done according to the larger impact weighting. The following rating guidelines were used for the evaluation of the land use activities. The total of the extent of various landuse activities was equal to 100% **(**i.e. the wetland surface area that is: % mined/excavated + % infilled + % vegetation clearing + % invasive plants + % reference state = 100%) (DWAF, 2007).

Mining/Excavation:	
Rating Score	**Description of the type of impact at the site**
5:	Active Open Cast mining of the wetland
3:	Deep (>2m) sand mining or Peat mining
1:	Shallow sand mining
Infilling or backfilling in the wetland (platform construction):	
Rating Score	**Description of the type of impact at the site**
5:	Platform never flooded and platform developed (urbanisation)
3:	Infilling used for cultivation
2:	Isolated/sporadic infilling; natural vegetation persists
Vegetation Clearing/Loss/Alteration:	
Rating Score	**Description of the type of impact at the site**
5:	Dam
3:	Cropping - currently ploughed fields OR grassland to woodland transition
2:	Planted pastures
1:	Historical ploughing OR Heavy grazing
Invasive plants:	
Rating Score	**Description of the type of impact at the site**
5:	Highly invasive species; excludes native vegetation

3:	Competitive invasive species (including reeds and Typha) inhibits reference state vegetation. Terrestrialisation (encroachment of terrestrial species) can also be considered here.
1:	Invasive species have little perceptible effect on native vegetation (NOTE: remember to consider the effect of drying out the wetland in the case of exotic trees for instance).

Evaluate hydrological PES

Evaluation of the catchment scale and the changes on the water regime in the wetland was conducted. At the catchment level the following criteria was assessed and rated:

Changes in flood peaks and/or frequencies:

Changes in peak (flood) flows from the catchment i.e impacts of the large dams and farm dams. Changes in the catchment which might be affecting flood peaks was rated as follows: (DWAF, 2007).

Changes in flood peaks and/or frequencies:	
Rating Score	**Description of the type of impact at the site**
-5:	Large dam immediately upstream with no allowance for high flow releases; nor any tributaries between the dam and the wetland to reinstate some of the flows.
-2:	Numerous small (earthern) farm dams for irrigation, but no large dams
0:	No change from Reference
+1:	Heavy, extensive grazing in the catchment
+2:	Peri-urban catchment (smallholdings/plots) or small interbasin transfer scheme.
+5:	Entirely urbanized catchment, or large interbasin transfer scheme.

Changes in base flows:

Changes in the base flows from the catchment i.e. impacts of abstractions and interbasin transfer (sewage return flows; releases of elevated flows to cater for irrigation; suburban water contributions in the catchment? was conducted in this section. Rating of the changes in the catchment that are affecting base flows were dine as follows: (DWAF, 2007).

Changes in base flows:	
Rating Score	**Description of the type of impact at the site**
-5:	More than 50% reduction in baseflow (from abstractions/transfers)
-2:	Moderate levels of irrigation/abstraction
0:	No change from Reference
+2:	Introduction of indirect flows from upstream suburban areas
+5:	More than doubled the baseflow (e.g. large interbasin transfer; sewage return flows)

Changes in seasonality:

Changes in seasonality of flow as a result of upstream developments was evaluated. Effect of attenuation of early wet season flows as a result of dams upstream and any seasonality changes due to abstraction for irrigation or high flow releases during the dry season. Rating was conducted as follows. (DWAF, 2007).

Changes in seasonality:	
Rating Score	**Description of the type of impact at the site**
0:	No change from Reference
2:	Moderate alteration (e.g. delayed floods; higher base flows).
5:	Complete switch in seasonality of flows (can occur in highly regulated systems used for irrigation).

Change in the occurrence/duration of zero flow periods:

Assessment of changes in the occurrence and/or duration of zero flow periods as a result of any upstream activities such irrigation for farming and impacts of effects. Rating of the changes was done as follows: (DWAF, 2007).

Changes in occurrence/duration of zero flow periods:	
Rating Score	**Description of the type of impact at the site**
0:	No change from Reference
2:	Seasonal system with increased duration of zero flows
5:	Formerly perennial system with long zero flows

Connectivity - altered channel size/competency

Changes in terms of increase in the Channel competency was evaluated under this section. Changes in the channel competency are mostly as a result of erosion in the channel and this lead to high flows being contained in the channel and low flows onto the floodplain. These alterations must be assessed relative to the reference state of the system (DWAF, 2007). The following criteria was used for rating:

Connectivity - altered channel size/competency:	
Rating Score	**Description of the type of impact at the site**
0:	No change from Reference
3:	Channel competency (width and/or depth) has increased by 100%.
5:	Channel is so incised that no flows ever overtop.

Increased water retention on the floodplain:

Dams and other structures on the floodplain can, in the areas affected, increase the period of time that water remains on the floodplain. The extent of increased water retention was evaluated and rated as per the following guidelines (DWAF, 2007).

Increased water retention on the floodplain:	
Rating Score	**Description of the type of impact at the site**
0:	No change from Reference
2:	Shallow dam; emergent vegetation still present
5:	Dam >2m deep, no emergent vegetation possible

Decreased water retention on the floodplain:

Factors that contributes to decreased water retention were assessed and rated according to the following criteria: (DWAF, 2007).

Decreased water retention on the floodplain:	
Rating Score	**Description of the type of impact at the site**
0:	No change from Reference
2:	Some drains/ditches present, but flow capture and removal is ineffective
5:	Drains/ditches/dongas/erosional gullies have been constructed to capture most flows and remove water rapidly from the floodplain.

Evaluate geomorphological PES.

The geomorphological processes were evaluated at catchment level and as well as within the wetland itself. At the catchment scale changes to the balance between sediment deposition and sediment transportation were evaluated and the interaction between sediment deposition and transportation was evaluated and rated according to the following tables: (DWAF, 2007).

Changes in Sediment Supply:	
Rating Score	**Description of the type of impact at the site**
+10:	Most extreme increase possible - a burst sediment-laden dam immediately upstream of the wetland system.
+6:	Extensive catchment-wide degradation causing a more than 2x increase in sediment delivery to the wetland.
+3:	Moderate catchment degradation causing increased sediment delivery to the wetland.
+1	Low to moderate catchment degradation causing increased sediment delivery to the wetland (gullying/cattle paths/bank erosion in the upstream areas)
0	No change from Reference
-1:	Low to moderate reduction in sediment supply through sediment trapping in
	small weirs
-3:	Moderate reduction in sediment supply through sediment trapping in small dams (but upstream tributary influences ameliorates the impact)
-6:	Large reduction in sediment supply through sediment trapping in very large dams
-10:	Most extreme decrease possible - a large dam immediately upstream of the wetland with no tributaries to introduce sediment.

Sediment Transport Capacity:

Changes in Sediment Transport Capacity:	
Rating Score	**Description of the type of impact at the site**
+10:	Most extreme increase possible - interbasin transfers with sustained high flows and very large peak flow increases, or a very highly urbanised catchment with no flow attenuation abilities
+6:	Moderately urbanised, or moderate increase in peak flows.
+3:	Some urbanisation, or small interbasin transfer, or dam releasing higher frequency of high flows.
0	no change
-1:	Small-scale abstraction.
-3:	Moderate reduction due to dams, but tributary influences may restore some high flows.
-6:	Large reduction due to large dams and removal of peak flows
-10:	Most extreme decrease possible - large dam removes all high flows (e.g. flow diversion).

Erosional Processes:

The impact of erosional processes such as evidence of gullies occurrence and extent of overgrazing or ploughing on the floodplain were assessed as follows: (DWAF, 2007).

Erosional Processes:	
Rating Score	**Description of the type of impact at the site**
0:	No change from Reference
1:	Grazing but no erosional dongas/gullies; and/or Ploughing (<50% of the floodplain) but no erosional dongas/gullies
3:	Some erosion dongas; or incised main channel (cut/vertical banks on both sides of the channel for more than 80% of the length of the channel), but no other headcuts into the floodplain
5:	Extensive donga formation (>5m deep) and associated threat of erosion across the whole floodplain.

Depositional Processes:

The impact of depositional processes was evaluated by looking at evidence of new sediment deposition and it was rated as follows: (DWAF, 2007).

Depositional Processes:	
Rating Score	**Description of the type of impact at the site**
0:	No change from Reference
1:	Increased vegetation robustness (e.g. grassland to reeds/Typha); herbaceous to trees (score 1.5)
3:	Alluvial depositional features extend over more than 50% of the floodplain
5:	Recent deposition of more than 50 cm across most (>80%) of the floodplain (can be associated with European settlement and associated clearing of slopes and/or urbanization). Examine any cut banks for evidence of this process.

Appendix E: correlation test.

KFBM1 correlation test.

Summary statistics:											
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation				
H+	20	0	20	0,000	0,000	0,000	0,000				
TSS	20	0	20	1,300	156,000	28,625	35,282				
EC	20	0	20	51,100	456,000	110,015	89,683				
Turbidity	20	0	20	1,500	52,000	14,750	15,650				
Total Alkalinity	20	0	20	20,000	260,000	118,640	69,724				
Chloride	20	0	20	28,000	172,000	65,135	39,770				
Sulphate	20	0	20	142,000	754,000	264,700	165,120				
nitrate	20	0	20	0,050	1,200	0,190	0,258				
nitrite	20	0	20	0,005	0,025	0,023	0,006				
dissolved oxygen	20	0	20	4,670	9,400	7,334	1,113				
Sodium	20	0	20	28,000	129,000	57,395	25,773				
Results for group 1:											

Correlation matrix (Spearman) / Group 1:											

Variables	H+	TSS	EC	Turbity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	DO	Sodium
H+	**1**	0,353	-0,193	0,383	-0,267	-0,270	0,212	-0,107		-0,154	-0,175
TSS	0,353	**1**	0,182	**0,913**	0,413	0,078	0,159	-0,287		-0,422	0,164
EC	-0,193	0,182	**1**	0,100	0,588	**0,934**	**0,627**	0,235		**-0,738**	**0,955**
Turbidity	0,383	**0,913**	0,100	**1**	0,224	-0,005	0,182	-0,059		-0,393	0,091
Total Alkalinity	-0,267	0,413	0,588	0,224	**1**	**0,676**	0,109	0,059		-0,242	**0,633**
Chloride	-0,270	0,078	**0,934**	-0,005	**0,676**	**1**	0,524	0,247		-0,511	**0,980**
Sulphate	0,212	0,159	**0,627**	0,182	0,109	0,524	**1**	-0,225		**-0,793**	**0,645**
nitrate	-0,107	-0,287	0,235	-0,059	0,059	0,247	-0,225	**1**		0,042	0,169
nitrite											
dissolved oxygen	-0,154	-0,422	**-0,738**	-0,393	-0,242	-0,511	**-0,793**	0,042		**1**	-0,606

Sodium	-0,175	0,164	**0,955**	0,091	**0,633**	**0,980**	**0,64 5**	0,16 9		-0,606	**1**
Values in bold are different from 0 with a significance level alpha=0,05											

p-values (Spearman) / Group 1:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**0**	0,289	0,572	0,247	0,428	0,424	0,534	0,760		0,654	0,610
TSS	0,289	**0**	0,594	**<0,0001**	0,209	0,827	0,643	0,393		0,198	0,633
EC	0,572	0,594	**0**	0,775	0,062	**<0,0001**	**0,044**	0,488		**0,013**	**<0,0001**
Turbity	0,247	**<0,0001**	0,775	**0**	0,510	1,000	0,594	0,871		0,234	0,796
Total Alkalinity	0,428	0,209	0,062	0,510	**0**	**0,027**	0,754	0,871		0,475	**0,042**
Chloride	0,424	0,827	**<0,0001**	1,000	**0,027**	**0**	0,103	0,465		0,112	**<0,0001**
Sulphate	0,534	0,643	**0,044**	0,594	0,754	0,103	**0**	0,507		**0,006**	**0,037**
nitrate	0,760	0,393	0,488	0,871	0,871	0,465	0,507	**0**		0,910	0,622
nitrite											
disolved oxygen	0,654	0,198	**0,013**	0,234	0,475	0,112	**0,006**	0,910		**0**	0,053
Sodium	0,610	0,633	**<0,0001**	0,796	**0,042**	**<0,0001**	**0,037**	0,622		0,053	**0**
Coefficients of determination (Spearman) / Group 1:											

Variables	H+	TSS	EC	Turbity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	0,124	0,037	0,146	0,071	0,073	0,045	0,011		0,024	0,031
TSS	0,124	**1**	0,033	0,834	0,171	0,006	0,025	0,082		0,178	0,027
EC	0,037	0,033	**1**	0,010	0,345	0,872	0,393	0,055		0,545	0,911
Turbity	0,146	0,834	0,010	**1**	0,050	0,000	0,033	0,003		0,154	0,008
Total Alkalinity	0,071	0,171	0,345	0,050	**1**	0,457	0,012	0,003		0,059	0,401
Chloride	0,073	0,006	0,872	0,000	0,457	**1**	0,274	0,061		0,262	0,959
Sulphate	0,045	0,025	0,393	0,033	0,012	0,274	**1**	0,051		0,628	0,417
nitrate	0,011	0,082	0,055	0,003	0,003	0,061	0,051	**1**		0,002	0,029
nitrite											
dissolved oxygen	0,024	0,178	0,545	0,154	0,059	0,262	0,628	0,002		**1**	0,367
Sodium	0,031	0,027	0,911	0,008	0,401	0,959	0,417	0,029		0,367	**1**

Results for group 2:

Correlation matrix (Spearman) / Group 2:

Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium

H+	**1**	-0,800	-0,900	-0,900	-0,900	-0,900	-0,700	0,791		0,700	-0,900
TSS	-0,800	**1**	0,600	0,900	0,600	0,600	0,500	**-0,949**		-0,200	0,600
EC	-0,900	0,600	**1**	0,800	0,700	**1,000**	0,900	-0,580		-0,600	**1,000**
Turbidity	-0,900	0,900	0,800	**1**	0,700	0,800	0,600	**-0,949**		-0,400	0,800

Total Alkalinity	-0,900	0,600	0,700	0,700	**1**	0,700	0,400	-0,632		-0,900	0,700
Chloride	-0,900	0,600	**1,000**	0,800	0,700	**1**	0,900	-0,580		-0,600	**1,000**
Sulphate	-0,700	0,500	0,900	0,600	0,400	0,900	**1**	-0,369		-0,300	0,900
nitrate	0,79 1	**-0,949**	-0,580	**-0,949**	-0,632	-0,580	-0,369	**1**		0,26 4	-0,580
nitrite											
dissolved oxygen	0,700	-0,200	-0,600	-0,400	-0,900	-0,600	-0,300	0,264		**1**	-0,600
Sodium	-0,900	0,600	**1,000**	0,800	0,700	**1,000**	0,90 0	-0,580		-0,600	**1**
Values in bold are different from 0 with a significance level alpha=0,05											

p-values (Spearman) / Group 2:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**0,016667**	0,133	0,083	0,083	0,083	0,083	0,233	0,233		0,233	0,083
TSS	0,133	**0,016667**	0,350	0,083	0,350	0,350	0,450	**0,017**		0,783	0,350
EC	0,083	0,350	**0,016667**	0,133	0,233	**0,017**	0,083	0,350		0,350	**0,017**
Turbidity	0,083	0,083	0,133	**0,016667**	0,233	0,133	0,350	**0,017**		0,517	0,133
Total Alkalinity	0,083	0,350	0,233	0,233	**0,016667**	0,233	0,517	0,233		0,083	0,233
Chloride	0,083	0,350	**0,017**	0,133	0,233	**0,016667**	0,083	0,350		0,350	**0,017**
Sulphate	0,233	0,450	0,083	0,350	0,517	0,083	**0,016667**	0,517		0,683	0,083
nitrate	0,233	**0,017**	0,350	**0,017**	0,233	0,350	0,517	**0,016667**		0,783	0,350
nitrite											
dissolved oxygen	0,233	0,783	0,350	0,517	0,083	0,350	0,683	0,783		**0,016667**	0,350
Sodium	0,083	0,350	**0,017**	0,133	0,233	**0,017**	0,083	0,350		0,350	**0,016667**
Coefficients of determination (Spearman) / Group 2:											

Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	0,640	0,810	0,810	0,810	0,810	0,490	0,625		0,490	0,810
TSS	0,640	**1**	0,360	0,810	0,360	0,360	0,250	0,900		0,040	0,360
EC	0,810	0,360	**1**	0,640	0,490	1,000	0,810	0,336		0,360	1,000
Turbidity	0,810	0,810	0,640	**1**	0,490	0,640	0,360	0,900		0,160	0,640
Total Alkalinity	0,810	0,360	0,490	0,490	**1**	0,490	0,160	0,400		0,810	0,490
Chloride	0,810	0,360	1,000	0,640	0,490	**1**	0,810	0,336		0,360	1,000
Sulphate	0,490	0,250	0,810	0,360	0,160	0,810	**1**	0,136		0,090	0,810
nitrate	0,625	0,900	0,336	0,900	0,400	0,336	0,136	**1**		0,069	0,336
nitrite											
dissolved oxygen	0,490	0,040	0,360	0,160	0,810	0,360	0,090	0,069		**1**	0,360
Sodium	0,810	0,360	1,000	0,640	0,490	1,000	0,810	0,336		0,360	**1**
Results for group 3:											
Correlation matrix (Spearman) / Group 3:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium

H+	**1**	-0,949	-0,632	-0,632	-0,316	-0,632	-0,316	0,000	0,000	-0,316	-0,632
TSS	-0,949	**1**	0,800	0,800	0,600	0,800	0,400	0,316	0,000	0,400	0,800
EC	-0,632	0,800	**1**	1,000	0,800	1,000	0,800	0,632	-0,447	0,000	1,000
Turbidity	-0,632	0,800	1,000	**1**	0,800	1,000	0,800	0,632	-0,447	0,000	1,000
Total Alkalinity	-0,316	0,600	0,800	0,800	**1**	0,800	0,400	0,949	0,000	0,400	0,800
Chloride	-0,632	0,800	1,000	1,000	0,800	**1**	0,800	0,632	-0,447	0,000	1,000
Sulphate	-0,316	0,400	0,800	0,800	0,400	0,800	**1**	0,316	-0,894	-0,600	0,800
nitrate	0,000	0,316	0,632	0,632	0,949	0,632	0,316	**1**	0,000	0,316	0,632
nitrite	0,000	0,000	-0,447	-0,447	0,000	-0,447	-0,894	0,000	**1**	0,894	-0,447

dissolved oxygen	-0,316	0,400	0,000	0,000	0,400	0,000	-0,600	0,316	0,894	**1**	0,000
Sodium	-0,632	0,800	1,000	1,000	0,800	1,000	0,800	0,632	-0,447	0,000	**1**
Values in bold are different from 0 with a significance level alpha=0,05											

p-values (Spearman) / Group 3:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**0,083333**	0,083	0,333	0,333	0,750	0,333	0,750	1,000	1,000	0,750	0,333
TSS	0,083	**0,083333**	0,333	0,333	0,417	0,333	0,750	0,917	1,000	0,750	0,333
EC	0,333	0,333	**0,083333**	0,083	0,333	0,083	0,333	0,417	0,417	1,000	0,083
Turbidity	0,333	0,333	0,083	**0,083333**	0,333	0,083	0,333	0,417	0,417	1,000	0,083
Total Alkalinity	0,750	0,417	0,333	0,333	**0,083333**	0,333	0,750	0,333	1,000	0,750	0,333
Chloride	0,333	0,333	0,083	0,083	0,333	**0,083333**	0,333	0,417	0,417	1,000	0,083
Sulphate	0,750	0,750	0,333	0,333	0,750	0,333	**0,083333**	0,917	0,083	0,417	0,333
nitrate	1,000	0,917	0,417	0,417	0,333	0,417	0,917	**0,083333**	1,000	0,917	0,417
nitrite	1,000	1,000	0,417	0,417	1,000	0,417	0,083	1,000	**0,083333**	0,333	0,417
dissolved oxygen	0,750	0,750	1,000	1,000	0,750	1,000	0,417	0,917	0,333	**0,083333**	1,000
Sodium	0,333	0,333	0,083	0,083	0,333	0,083	0,333	0,417	0,417	1,000	**0,083333**
Coefficients of determination (Spearman) / Group 3:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium

H+	**1**	0,900	0,400	0,400	0,100	0,400	0,100	0,000	0,000	0,100	0,400
TSS	0,900	**1**	0,640	0,640	0,360	0,640	0,160	0,100	0,000	0,160	0,640
EC	0,400	0,640	**1**	1,000	0,640	1,000	0,640	0,400	0,200	0,000	1,000
Turbidity	0,400	0,640	1,000	**1**	0,640	1,000	0,640	0,400	0,200	0,000	1,000
Total Alkalinity	0,100	0,360	0,640	0,640	**1**	0,640	0,160	0,900	0,000	0,160	0,640
Chloride	0,400	0,640	1,000	1,000	0,640	**1**	0,640	0,400	0,200	0,000	1,000
Sulphate	0,100	0,160	0,640	0,640	0,160	0,640	**1**	0,100	0,800	0,360	0,640
nitrate	0,000	0,100	0,400	0,400	0,900	0,400	0,100	**1**	0,000	0,100	0,400
nitrite	0,000	0,000	0,200	0,200	0,000	0,200	0,800	0,000	**1**	0,800	0,200
dissolved oxygen	0,100	0,160	0,000	0,000	0,160	0,000	0,360	0,100	0,800	**1**	0,000
Sodium	0,400	0,640	1,000	1,000	0,640	1,000	0,640	0,400	0,200	0,000	**1**

KFBM2 correlation test.

Summary statistics:											
Variables	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation				
H+	13	0	13	0,000	0,000	0,000	0,000				
TSS	13	0	13	1,400	250,000	75,654	91,909				
EC	13	0	13	6,300	254,000	77,938	81,335				
Turbidity	13	0	13	1,000	584,000	132,322	213,321				
Total Alkalinity	13	0	13	2,500	212,000	79,346	66,578				
Chloride	13	0	13	6,000	114,000	29,662	27,162				
Sulphate	13	0	13	0,100	437,000	118,400	115,874				
nitrate	13	0	13	0,050	1,800	0,327	0,541				
nitrite	13	0	13	0,005	0,200	0,042	0,051				
dissolved oxygen	13	0	13	5,500	9,600	7,096	1,394				
Sodium	13	0	13	1,000	44,000	28,908	15,664				
Results for group 1:											
Correlation matrix (Spearman) / Group 1:											

Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	-0,353	-0,134	0,000	**-0,923**	-0,622	0,151	-0,304	0,140	0,105	0,161
TSS	-0,353	**1**	-0,483	**0,733**	0,305	-0,017	-0,383	**0,858**	0,653	-0,678	0,008
EC	-0,134	-0,483	**1**	**-0,850**	0,237	0,683	**0,883**	-0,237	-0,683	0,142	**0,723**
Turbidity	0,000	**0,733**	**-0,850**	**1**	-0,102	-0,483	-0,667	0,456	**0,762**	-0,351	0,420
Total Alkalinity	**-0,923**	0,305	0,237	-0,102	**1**	0,678	-0,119	0,167	-0,352	-0,034	0,222
Chloride	-0,622	-0,017	0,683	-0,483	0,678	**1**	0,500	-0,018	-0,505	-0,025	**0,740**
Sulphate	0,151	-0,383	**0,883**	-0,667	-0,119	0,500	**1**	-0,091	-0,416	0,008	**0,824**
nitrate	-0,304	**0,858**	-0,237	0,456	0,167	-0,018	-0,091	**1**	0,662	**-0,743**	0,083
nitrite	0,140	0,653	-0,683	**0,762**	-0,352	-0,505	-0,416	0,662	**1**	**-0,716**	0,369

dissolved oxygen	0,105	-0,678	0,142	-0,351	-0,034	-0,025	0,008	**-0,743**	**-0,716**	**1**	0,118

Sodium	-0,161	-0,008	**0,723**	-0,420	0,222	**0,740**	**0,824**	0,083	-0,369	-0,118	**1**
Values in bold are different from 0 with a significance level alpha=0,05											
p-values (Spearman) / Group 1:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**5,51146E-06**	0,336	0,708	1,000	**0,001**	0,076	0,708	0,410	0,744	0,810	0,678
TSS	0,336	**5,51146E-06**	0,194	**0,037**	0,437	0,982	0,313	**0,006**	0,067	0,050	0,982
EC	0,708	0,194	**5,51146E-06**	**0,006**	0,552	0,050	**0,005**	0,521	0,050	0,744	**0,037**
Turbidity	1,000	**0,037**	**0,006**	**5,51146E-06**	0,776	0,194	0,059	0,230	**0,025**	0,336	0,250
Total Alkalinity	**0,001**	0,437	0,552	0,776	**5,51146E-06**	0,059	0,744	0,678	0,336	0,912	0,581
Chloride	0,076	0,982	0,050	0,194	0,059	**5,51146E-06**	0,178	0,948	0,162	0,948	**0,031**

Sulphate	0,708	0,313	**0,005**	0,059	0,744	0,178	**5,51146E-06**	0,810	0,270	1,000	**0,011**
nitrate	0,410	**0,006**	0,521	0,230	0,678	0,948	0,810	**5,51146E-06**	0,067	**0,025**	0,880

nitrite	0,744	0,067	0,050	**0,025**	0,336	0,162	0,270	0,067	**5,51146E-06**	**0,037**	0,313
dissolved oxygen	0,810	0,050	0,744	0,336	0,912	0,948	1,000	**0,025**	**0,037**	**5,51146E-06**	0,744
Sodium	0,678	0,982	**0,037**	0,250	0,581	**0,031**	**0,011**	0,880	0,313	0,744	**5,51146E-06**

Coefficients of determination (Spearman) / Group 1:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	0,125	0,018	0,000	0,852	0,387	0,023	0,092	0,020	0,011	0,026
TSS	0,125	**1**	0,234	0,538	0,093	0,000	0,147	0,736	0,427	0,459	0,000
EC	0,018	0,234	**1**	0,723	0,056	0,467	0,780	0,056	0,467	0,020	0,522

Turbidity	0,000	0,538	0,723	**1**	0,010	0,234	0,444	0,208	0,581	0,124	0,177
Total Alkalinity	0,852	0,093	0,056	0,010	**1**	0,460	0,014	0,028	0,124	0,001	0,049
Chloride	0,387	0,000	0,467	0,234	0,460	**1**	0,250	0,000	0,255	0,001	0,547

Sulphate	0,023	0,147	0,780	0,444	0,014	0,250	**1**	0,008	0,173	0,000	0,678
nitrate	0,092	0,736	0,056	0,208	0,028	0,000	0,008	**1**	0,438	0,551	0,007
nitrite	0,020	0,427	0,467	0,581	0,124	0,255	0,173	0,438	**1**	0,513	0,136
dissolved oxygen	0,011	0,459	0,020	0,124	0,001	0,001	0,000	0,551	0,513	**1**	0,014
Sodium	0,026	0,000	0,522	0,177	0,049	0,547	0,678	0,007	0,136	0,014	**1**
Results for group 3:											
Correlation matrix (Spearman) / Group 3:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	-1,000	1,000	-1,000	0,200	0,800	0,400	-0,316	-0,894	-0,800	0,400

TSS	-1,000	**1**	-1,000	1,000	-0,200	-0,800	-0,400	0,316	0,894	0,800	0,400
EC	1,000	-1,000	**1**	-1,000	0,200	0,800	0,400	-0,316	-0,894	-0,800	0,400
Turbidity	-1,000	1,000	-1,000	**1**	-0,200	-0,800	-0,400	0,316	0,894	0,800	0,400

Total Alkalinity	0,200	-0,200	0,200	-0,200	**1**	0,400	-0,800	-0,949	0,000	0,400	0,800
Chloride	0,800	-0,800	0,800	-0,800	0,400	**1**	0,000	-0,316	-0,894	-0,600	0,200
Sulphate	0,400	-0,400	0,400	-0,400	-0,800	0,000	**1**	0,632	-0,447	-0,800	0,400
nitrate	-0,316	0,316	-0,316	0,316	-0,949	-0,316	0,632	**1**	0,000	-0,316	0,949
nitrite	-0,894	0,894	-0,894	0,894	0,000	-0,894	-0,447	0,000	**1**	0,894	0,000
dissolved oxygen	-0,800	0,800	-0,800	0,800	0,400	-0,600	-0,800	-0,316	0,894	**1**	0,200
Sodium	0,400	-0,400	0,400	-0,400	0,800	0,20 0	-0,400	-0,949	0,00 0	0,200	**1**

Values in bold are different from 0 with a significance level alpha=0,05											
p-values (Spearman) / Group 3:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**0,0833333333**	0,083	0,083	0,083	0,917	0,333	0,750	0,750	0,083	0,333	0,750
TSS	0,083	**0,0833333333**	0,083	0,083	0,917	0,333	0,750	0,917	0,333	0,333	0,750
EC	0,083	0,083	**0,0833333333**	0,083	0,917	0,333	0,750	0,750	0,083	0,333	0,750
Turbidity	0,083	0,083	0,083	**0,0833333333**	0,917	0,333	0,750	0,917	0,333	0,333	0,750
Total Alkalinity	0,917	0,917	0,917	0,917	**0,0833333333**	0,750	0,333	0,083	1,000	0,750	0,333
Chloride	0,333	0,333	0,333	0,333	0,750	**0,0833333333**	1,000	0,750	0,083	0,417	0,917
Sulphate	0,750	0,750	0,750	0,750	0,333	1,000	**0,0833333333**	0,417	0,417	0,333	0,750
nitrate	0,750	0,917	0,750	0,917	0,083	0,750	0,417	**0,0833333333**	1,000	0,750	0,083
nitrite	0,083	0,333	0,083	0,333	1,000	0,083	0,417	1,000	**0,0833333333**	0,333	1,000

dissolved oxygen	0,333	0,333	0,333	0,333	0,750	0,417	0,333	0,750	0,333	**0,0833333333**	0,917
Sodium	0,750	0,750	0,750	0,750	0,333	0,917	0,750	0,083	1,000	0,917	**0,0833333333**
Coefficients of determination (Spearman) / Group 3:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	1,000	1,000	1,000	0,040	0,640	0,160	0,100	0,800	0,640	0,160
TSS	1,000	**1**	1,000	1,000	0,040	0,640	0,160	0,100	0,800	0,640	0,160
EC	1,000	1,000	**1**	1,000	0,040	0,640	0,160	0,100	0,800	0,640	0,160
Turbidity	1,000	1,000	1,000	**1**	0,040	0,640	0,160	0,100	0,800	0,640	0,160
Total Alkalinity	0,040	0,040	0,040	0,040	**1**	0,160	0,640	0,900	0,000	0,160	0,640
Chloride	0,640	0,640	0,640	0,640	0,160	**1**	0,000	0,100	0,800	0,360	0,040
Sulphate	0,160	0,160	0,160	0,160	0,640	0,000	**1**	0,400	0,200	0,640	0,160

nitrate	0,100	0,100	0,100	0,100	0,900	0,100	0,400	**1**	0,000	0,100	0,900
nitrite	0,800	0,800	0,800	0,800	0,000	0,800	0,200	0,000	**1**	0,800	0,000
dissolved oxygen	0,640	0,640	0,640	0,640	0,160	0,360	0,640	0,100	0,800	**1**	0,040
Sodium	0,160	0,160	0,160	0,160	0,640	0,040	0,160	0,900	0,000	0,040	**1**

KFBM3 correlation test.

Summary statistics:											
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation				
H+	9	0	9	0,000	0,000	0,000	0,000				
TSS	9	0	9	2,000	109360,000	12395,278	36367,693				
EC	9	0	9	49,700	104,000	77,333	21,315				
Turbidity	9	0	9	1,000	1875,000	226,811	618,284				
Total Alkalinity	9	0	9	2,500	316,000	101,611	96,227				
Chloride	9	0	9	8,000	211,000	75,333	74,873				

Sulphate	9	0	9	48,000	437,000	169,033	115,687				
nitrate	9	0	9	0,050	1,200	0,278	0,373				
nitrite	9	0	9	0,005	0,300	0,059	0,094				
dissolve d oxygen	9	0	9	0,200	8,300	6,078	2,369				
Sodium	9	0	9	28,000	52,000	37,333	7,794				
Results for group 1:											
Correlation matrix (Spearman) / Group 1:											

Variable s	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolve d oxygen	Sodium
H+	**1**	-0,771	-0,029	-0,771	**-0,886**	-0,429	0,371	-0,213	0,131	0,543	-0,116
TSS	-0,771	**1**	0,086	0,829	**0,943**	0,314	-0,600	-0,455	-0,393	-0,543	0,319
EC	-0,029	0,086	**1**	-0,086	0,143	-0,257	0,371	-0,030	-0,655	0,029	0,754
Turbidity	-0,771	0,829	-0,086	**1**	0,771	0,143	-0,257	-0,213	-0,393	-0,257	0,000
Total Alkalinity	**-0,886**	**0,943**	0,143	0,771	**1**	0,257	-0,486	-0,213	-0,393	-0,486	0,232

Chloride	-0,429	0,314	-0,257	0,143	0,257	**1**	-0,771	0,152	0,655	**-0,943**	0,348
Sulphate	0,371	-0,600	0,371	-0,257	-0,486	-0,771	**1**	0,395	-0,393	0,829	-0,232
nitrate	-0,213	-0,455	-0,030	-0,213	-0,213	0,152	0,395	**1**	0,417	0,030	-0,246
nitrite	0,131	-0,393	-0,655	-0,393	-0,393	0,655	-0,393	0,417	**1**	-0,393	-0,266
dissolve d oxygen	0,543	-0,543	0,029	-0,257	-0,486	**-0,943**	0,829	0,030	-0,393	**1**	-0,551
Sodium	-0,116	0,319	0,754	0,000	0,232	0,348	-0,232	-0,246	-0,266	-0,551	**1**

Values in bold are different from 0 with a significance level alpha=0,05											
p-values (Spearman) / Group 1:											
Variable s	H+	TSS	EC	Turbibity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolve d oxygen	Sodium
H+	**0,00277 8**	0,103	1,000	0,103	**0,033**	0,419	0,497	0,658	0,919	0,356	0,803
TSS	0,103	**0,00277 8**	0,919	0,058	**0,017**	0,564	0,242	0,356	0,419	0,297	0,564
EC	1,000	0,919	**0,00277 8**	0,919	0,803	0,658	0,497	0,919	0,175	1,000	0,136

Turbidity	0,103	0,058	0,919	**0,002778**	0,103	0,803	0,658	0,658	0,419	0,658	1,000
Total Alkalinity	**0,033**	**0,017**	0,803	0,103	**0,0027778**	0,658	0,356	0,658	0,419	0,356	0,714
Chloride	0,419	0,564	0,658	0,803	0,658	**0,002778**	0,103	0,803	0,242	**0,017**	0,564
Sulphate	0,497	0,242	0,497	0,658	0,356	0,103	**0,002778**	0,497	0,419	0,058	0,658
nitrate	0,658	0,356	0,919	0,658	0,658	0,803	0,497	**0,002778**	0,497	1,000	0,658
nitrite	0,919	0,419	0,175	0,419	0,419	0,242	0,419	0,497	**0,002778**	0,419	0,564
dissolve d oxygen	0,356	0,297	1,000	0,658	0,356	**0,017**	0,058	1,000	0,419	**0,002778**	0,242

Sodium	0,803	0,564	0,136	1,000	0,714	0,56 4	0,65 8	0,65 8	0,56 4	0,24 2	**0,002778**
Coefficients of determination (Spearman) / Group 1:											
Variable s	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolve d oxygen	Sodium
H+	**1**	0,595	0,001	0,595	0,784	0,184	0,138	0,045	0,017	0,295	0,013
TSS	0,595	**1**	0,007	0,687	0,889	0,099	0,360	0,207	0,154	0,295	0,102
EC	0,001	0,007	**1**	0,007	0,020	0,066	0,138	0,001	0,429	0,001	0,568
Turbidity	0,595	0,687	0,007	**1**	0,595	0,020	0,066	0,045	0,154	0,066	0,000

Total Alkalinity	0,784	0,889	0,020	0,595	**1**	0,066	0,236	0,045	0,154	0,236	0,054
Chloride	0,184	0,099	0,066	0,020	0,066	**1**	0,595	0,023	0,429	0,889	0,121
Sulphate	0,138	0,360	0,138	0,066	0,236	0,595	**1**	0,156	0,154	0,687	0,054
nitrate	0,045	0,207	0,001	0,045	0,045	0,023	0,156	**1**	0,174	0,001	0,061
nitrite	0,017	0,154	0,429	0,154	0,154	0,429	0,154	0,174	**1**	0,154	0,071
dissolve d oxygen	0,295	0,295	0,001	0,066	0,236	0,889	0,687	0,001	0,154	**1**	0,303
Sodium	0,013	0,102	0,568	0,000	0,054	0,121	0,054	0,061	0,071	0,303	**1**
Results for group 3:											
Correlation matrix (Spearman) / Group 3:											

Variable s	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolve d oxygen	Sodium
H+	**1**	-0,500	0,500	-0,500	-0,500	-0,500	0,500	0,000	0,000	-0,500	-0,500
TSS	-0,500	**1**	0,500	1,000	-0,500	1,000	0,500	-0,866	-0,866	-0,500	1,000
EC	0,500	0,500	**1**	0,500	-1,000	0,500	1,000	-0,866	-0,866	-1,000	0,500
Turbidity	-0,500	1,000	0,500	**1**	-0,500	1,000	0,500	-0,866	-0,866	-0,500	1,000

Total Alkalinity	-0,500	-0,500	-1,000	-0,500	**1**	-0,500	-1,000	0,866	0,866	1,000	-0,500
Chloride	-0,500	1,000	0,500	1,000	-0,500	**1**	0,500	-0,866	-0,866	-0,500	1,000
Sulphate	0,500	0,500	1,000	0,500	-1,000	0,500	**1**	-0,866	-0,866	-1,000	0,500
nitrate	0,000	-0,866	-0,866	-0,866	0,866	-0,866	-0,866	**1**	1,000	0,866	-0,866
nitrite	0,000	-0,866	-0,866	-0,866	0,866	-0,866	-0,866	1,000	**1**	0,866	-0,866
dissolve d oxygen	-0,500	-0,500	-1,000	-0,500	1,000	-0,500	-1,000	0,866	0,866	**1**	-0,500
Sodium	-0,500	1,000	0,500	1,000	-0,500	1,000	0,500	-0,866	-0,866	-0,500	**1**

Values in bold are different from 0 with a significance level alpha=0,05

p-values (Spearman) / Group 3:

Variable s	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**0,333333**	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000

TSS	1,000	**0,333333**	1,000	0,333	1,000	0,333	1,000	0,333	0,333	1,000	0,333
EC	1,000	1,000	**0,333333**	1,000	0,333	1,000	0,333	0,333	0,333	0,333	1,000
Turbidity	1,000	0,333	1,000	**0,333333**	1,000	0,333	1,000	0,333	0,333	1,000	0,333
Total Alkalinity	1,000	1,000	0,333	1,000	**0,333 3333**	1,000	0,333	1,000	1,000	0,333	1,000
Chloride	1,000	0,333	1,000	0,333	1,000	**0,333333**	1,000	0,333	0,333	1,000	0,333
Sulphate	1,000	1,000	0,333	1,000	0,333	1,000	**0,333333**	0,333	0,333	0,333	1,000
nitrate	1,000	0,333	0,333	0,333	1,000	0,333	0,333	**0,333333**	0,333	1,000	0,333
nitrite	1,000	0,333	0,333	0,333	1,000	0,333	0,333	0,333	**0,333333**	1,000	0,333
dissolve d oxygen	1,000	1,000	0,333	1,000	0,333	1,000	0,333	1,000	1,000	**0,333333**	1,000
Sodium	1,000	0,333	1,000	0,333	1,000	0,33 3	1,00 0	0,33 3	0,33 3	1,00 0	**0,333333**
Coefficients of determination (Spearman) / Group 3:											
Variable s	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolve d oxygen	Sodium

H+	**1**	0,250	0,250	0,250	0,250	0,250	0,250	0,000	0,000	0,250	0,250
TSS	0,250	**1**	0,250	1,000	0,250	1,000	0,250	0,750	0,750	0,250	1,000
EC	0,250	0,250	**1**	0,250	1,000	0,250	1,000	0,750	0,750	1,000	0,250
Turbidity	0,250	1,000	0,250	**1**	0,250	1,000	0,250	0,750	0,750	0,250	1,000
Total Alkalinity	0,250	0,250	1,000	0,250	**1**	0,250	1,000	0,750	0,750	1,000	0,250
Chloride	0,250	1,000	0,250	1,000	0,250	**1**	0,250	0,750	0,750	0,250	1,000
Sulphate	0,250	0,250	1,000	0,250	1,000	0,250	**1**	0,750	0,750	1,000	0,250
nitrate	0,000	0,750	0,750	0,750	0,750	0,750	0,750	**1**	1,000	0,750	0,750
nitrite	0,000	0,750	0,750	0,750	0,750	0,750	0,750	1,000	**1**	0,750	0,750
dissolve d oxygen	0,250	0,250	1,000	0,250	1,000	0,250	1,000	0,750	0,750	**1**	0,250
Sodium	0,250	1,000	0,250	1,000	0,250	1,000	0,250	0,750	0,750	0,250	**1**

KFBM4 correlation test.

Summary statistics:											
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation				
H+	14	0	14	0,000	0,002	0,000	0,000				
TSS	14	0	14	1,300	181,000	38,786	62,797				
EC	14	0	14	49,800	463,000	133,129	128,268				
Turbidity	14	0	14	0,300	109,000	25,529	37,364				
Total Alkalinity	14	0	14	2,500	228,000	57,429	79,237				
Chloride	14	0	14	24,000	158,000	84,286	38,643				
Sulphate	14	0	14	45,000	2486,000	529,857	810,436				
nitrate	14	0	14	0,050	0,600	0,100	0,149				
nitrite	14	0	14	0,025	1,700	0,145	0,448				
dissolved oxygen	14	0	14	1,300	8,500	6,386	2,378				
Sodium	14	0	14	30,000	149,000	62,786	37,444				

Results for group 1:										

Correlation matrix (Spearman) / Group 1:										
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	-0,100	**0,799**	0,059	**-0,778**	0,000	**0,877**			0,188	0,288
TSS	-0,100	**1**	0,200	**0,791**	0,364	**0,836**	0,018			-0,419	0,583
EC	**0,799**	0,200	**1**	0,291	**-0,665**	0,327	**0,927**			0,036	**0,647**
Turbidity	0,059	**0,791**	0,291	**1**	0,249	**0,855**	0,082			-0,583	0,501
Total Alkalinity	**-0,778**	0,364	**-0,665**	0,249	**1**	0,301	**-0,786**			**-0,626**	-0,191
Chloride	0,000	**0,836**	0,327	**0,855**	0,301	**1**	0,173			**-0,642**	**0,661**
Sulphate	**0,877**	0,018	**0,927**	0,082	**-0,786**	0,173	**1**			0,187	0,478
nitrate											
nitrite											
dissolved oxygen	0,188	-0,419	0,036	-0,583	**-0,626**	**-0,642**	0,187			**1**	-0,297
Sodium	0,288	0,583	**0,647**	0,501	-0,191	**0,661**	0,478			-0,297	**1**

Values in bold are different from 0 with a significance level alpha=0,05											
p-values (Spearman) / Group 1:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**0**	0,775	**0,005**	0,870	**0,007**	1,000	**0,001**			0,583	0,391
TSS	0,775	**0**	0,558	**0,006**	0,272	**0,003**	0,968			0,202	0,065
EC	**0,005**	0,558	**0**	0,386	**0,030**	0,327	**<0,001**			0,924	**0,036**
Turbidity	0,870	**0,006**	0,386	**0**	0,462	**0,002**	0,818			0,065	0,120
Total Alkalinity	**0,007**	0,272	**0,030**	0,462	**0**	0,370	**0,007**			**0,045**	0,576
Chloride	1,000	**0,003**	0,327	**0,002**	0,370	**0**	0,614			**0,038**	**0,032**
Sulphate	**0,001**	0,968	**<0,001**	0,818	**0,007**	0,614	**0**			0,585	0,140
nitrate											
nitrite											
dissolved oxygen	0,583	0,202	0,924	0,065	**0,045**	**0,038**	0,585			**0**	0,376
Sodium	0,391	0,065	**0,036**	0,120	0,576	**0,032**	0,140			0,376	**0**
Coefficients of determination (Spearman) / Group 1:											

Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	0,010	0,639	0,004	0,606	0,000	0,769			0,035	0,083
TSS	0,010	**1**	0,040	0,626	0,133	0,700	0,000			0,176	0,340
EC	0,639	0,040	**1**	0,085	0,442	0,107	0,860			0,001	0,419
Turbidity	0,004	0,626	0,085	**1**	0,062	0,730	0,007			0,340	0,251
Total Alkalinity	0,606	0,133	0,442	0,062	**1**	0,090	0,618			0,392	0,037
Chloride	0,000	0,700	0,107	0,730	0,090	**1**	0,030			0,413	0,436
Sulphate	0,769	0,000	0,860	0,007	0,618	0,030	**1**			0,035	0,229
nitrate											
nitrite											
dissolved oxygen	0,035	0,176	0,001	0,340	0,392	0,413	0,035			**1**	0,088
Sodium	0,083	0,340	0,419	0,251	0,037	0,436	0,229			0,088	**1**
Results for group 2:											
Correlation matrix (Spearman) / Group 2:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium

H+	**1**	-1,000	-1,000	-1,000	-1,000	-1,000	1,000	-1,000	-1,000	-1,000	-1,000
TSS	-1,000	**1**	1,000	1,000	1,000	1,000	-1,000	1,000	1,000	1,000	1,000
EC	-1,000	1,000	**1**	1,000	1,000	1,000	-1,000	1,000	1,000	1,000	1,000
Turbidity	-1,000	1,000	1,000	**1**	1,000	1,000	-1,000	1,000	1,000	1,000	1,000
Total Alkalinity	-1,000	1,000	1,000	1,000	**1**	1,000	-1,000	1,000	1,000	1,000	1,000
Chloride	-1,000	1,000	1,000	1,000	1,000	**1**	-1,000	1,000	1,000	1,000	1,000

Sulphate	1,000	-1,000	-1,000	-1,000	-1,000	-1,000	**1**	-1,000	-1,000	-1,000	-1,000
nitrate	-1,000	1,000	1,000	1,000	1,000	1,000	-1,000	**1**	1,000	1,000	1,000
nitrite	-1,000	1,000	1,000	1,000	1,000	1,000	-1,000	1,000	**1**	1,000	1,000
dissolved oxygen	-1,000	1,000	1,000	1,000	1,000	1,000	-1,000	1,000	1,000	**1**	1,000
Sodium	-1,000	1,000	1,000	1,000	1,000	1,000	-1,000	1,000	1,000	1,000	**1**

Values in bold are different from 0 with a significance level alpha=0,05											
p-values (Spearman) / Group 2:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
TSS	1,000	**1**	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
EC	1,000	1,000	**1**	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Turbidity	1,000	1,000	1,000	**1**	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Total Alkalinity	1,000	1,000	1,000	1,000	**1**	1,000	1,000	1,000	1,000	1,000	1,000
Chloride	1,000	1,000	1,000	1,000	1,000	**1**	1,000	1,000	1,000	1,000	1,000
Sulphate	1,000	1,000	1,000	1,000	1,000	1,000	**1**	1,000	1,000	1,000	1,000
nitrate	1,000	1,000	1,000	1,000	1,000	1,000	1,000	**1**	1,000	1,000	1,000
nitrite	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	**1**	1,000	1,000
dissolved oxygen	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	**1**	1,000
Sodium	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	**1**
Coefficients of determination (Spearman) / Group 2:											

Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+	**1**	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
TSS	1,000	**1**	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
EC	1,000	1,000	**1**	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Turbidity	1,000	1,000	1,000	**1**	1,000	1,000	1,000	1,000	1,000	1,000	1,000
Total Alkalinity	1,000	1,000	1,000	1,000	**1**	1,000	1,000	1,000	1,000	1,000	1,000
Chloride	1,000	1,000	1,000	1,000	1,000	**1**	1,000	1,000	1,000	1,000	1,000
Sulphate	1,000	1,000	1,000	1,000	1,000	1,000	**1**	1,000	1,000	1,000	1,000
nitrate	1,000	1,000	1,000	1,000	1,000	1,000	1,000	**1**	1,000	1,000	1,000
nitrite	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	**1**	1,000	1,000
dissolved oxygen	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	**1**	1,000

Sodium	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	**1**
Results for group 3:											
Correlation matrix (Spearman) / Group 3:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium

H+											
TSS											
EC											
Turbidity											
Total Alkalinity											
Chloride											
Sulphate											
nitrate											
nitrite											
dissolved oxygen											
Sodium											
Values in bold are different from 0 with a significance level alpha=0,05											
p-values (Spearman) / Group 3:											

Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+											
TSS											
EC											
Turbidity											
Total Alkalinity											
Chloride											
Sulphate											
nitrate											
nitrite											

dissolved oxygen											
Sodium											
Coefficients of determination (Spearman) / Group 3:											
Variables	H+	TSS	EC	Turbidity	Total Alkalinity	Chloride	Sulphate	nitrate	nitrite	dissolved oxygen	Sodium
H+											
TSS											
EC											
Turbidity											
Total Alkalinity											
Chloride											
Sulphate											
nitrate											

Insitu measurement correlation test.

Insitu1 correlation test

Summary statistics:								
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation	
Temperature (ºc)	7	0	7	13,400	25,500	19,171	5,094	
pH	7	0	7	6,680	8,510	7,716	0,900	
DO(mg/1)	7	0	7	1,620	9,200	5,276	3,721	
DO (%)	7	0	7	20,000	109,000	65,000	43,382	
EC(µS/cm)	7	0	7	732,000	2251,000	1248,714	655,674	
Results for group 2:								
Correlation matrix (Spearman) / Group 2:								
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)			
Temperature (ºc)	**1**	-0,200	0,029	0,086	0,600			
pH	-0,200	**1**	0,429	0,486	-0,486			
DO(mg/1)	0,029	0,429	**1**	**0,943**	-0,371			
DO (%)	0,086	0,486	**0,943**	**1**	-0,543			
EC(µS/cm)	0,600	-0,486	-0,371	-0,543	**1**			
Values in bold are different from 0 with a significance level alpha=0,05								
p-values (Spearman) / Group 2:								
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)			
Temperature (ºc)	**0,002778**	0,714	1,000	0,919	0,242			

pH	0,714	**0,002778**	0,419	0,356	0,356			
DO(mg/1)	1,000	0,419	**0,002778**	**0,017**	0,497			

DO (%)	0,919	0,356	**0,017**	**0,002778**	0,297			
EC(µS/cm)	0,242	0,356	0,497	0,297	**0,002778**			
Coefficients of determination (Spearman) / Group 2:								
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)			
Temperature (ºc)	**1**	0,040	0,001	0,007	0,360			
pH	0,040	**1**	0,184	0,236	0,236			
DO(mg/1)	0,001	0,184	**1**	0,889	0,138			
DO (%)	0,007	0,236	0,889	**1**	0,295			
EC(µS/cm)	0,360	0,236	0,138	0,295	**1**			
Results for group 3:								
Correlation matrix (Spearman) / Group 3:								
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)			
c)								
pH								
DO(mg/1)								
DO (%)								
EC(µS/cm)								
Values in bold are different from 0 with a significance level alpha=0,05								
p-values (Spearman) / Group 3:								
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)			

c)								
pH								
DO(mg/1)								
DO (%)								
EC(µS/cm)								
Coefficients of determination (Spearman) / Group 3:								
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)			
Temperature(ºc)								

pH								
DO(mg/1)								
DO (%)								

KFBM1 insitu correlation test.

Summary statistics:							
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Temperature (ºc)	7	0	7	13,500	26,200	19,829	5,457
pH	7	0	7	3,940	7,340	5,979	1,428
DO(mg/1)	7	0	7	2,250	11,650	6,274	3,829
DO (%)	7	0	7	30,600	135,000	82,971	39,011
EC(µS/cm)	7	0	7	654,000	5311,000	1780,571	1660,187
Results for group 2:							
Correlation matrix (Spearman) / Group 2:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature (ºc)	**1**	**0,943**	-0,771	-0,600	0,200		
pH	**0,943**	**1**	-0,714	-0,543	0,257		
DO(mg/1)	-0,771	-0,714	**1**	**0,943**	-0,314		
DO (%)	-0,600	-0,543	**0,943**	**1**	-0,086		
EC(µS/cm)	0,200	0,257	-0,314	-0,086	**1**		
Values in bold are different from 0 with a significance level alpha=0,05							
p-values (Spearman) / Group 2:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature (ºc)	**0,002778**	**0,017**	0,103	0,242	0,714		
pH	**0,017**	**0,002778**	0,136	0,297	0,658		

DO(mg/1)	0,103	0,136	**0,002778**	**0,017**	0,564		
DO (%)	0,242	0,297	**0,017**	**0,002778**	0,919		

EC(µS/cm)	0,714	0,658	0,564	0,919	**0,002778**		
Coefficients of determination (Spearman) / Group 2:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature (ºc)	**1**	0,889	0,595	0,360	0,040		
pH	0,889	**1**	0,510	0,295	0,066		
DO(mg/1)	0,595	0,510	**1**	0,889	0,099		
DO (%)	0,360	0,295	0,889	**1**	0,007		
EC(µS/cm)	0,040	0,066	0,099	0,007	**1**		
Results for group 3:							
Correlation matrix (Spearman) / Group 3:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)							
pH							
DO(mg/1)							
DO (%)							
EC(µS/cm)							
Values in bold are different from 0 with a significance level alpha=0,05							
p-values (Spearman) / Group 3:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)							
pH							

DO(mg/1)							
DO (%)							
EC(µS/cm)							
Coefficients of determination (Spearman) / Group 3:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)							
pH							
DO(mg/1)							

DO (%)							
EC(µS/cm)							

Dam insitu correlation test.

Summary statistics:							
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Temperature (ºc)	7	0	7	17,200	25,000	22,743	2,903
pH	7	0	7	6,810	8,610	7,784	0,891
DO(mg/1)	7	0	7	1,620	8,880	5,703	3,050
DO (%)	7	0	7	21,000	109,600	75,829	38,022
EC(µS/cm)	7	0	7	872,000	2410,000	1200,714	558,392
Results for group 2:							
Correlation matrix (Spearman) / Group 2:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature (ºc)	**1**	0,486	0,143	0,314	-0,371		
pH	0,486	**1**	0,543	0,771	0,086		
DO(mg/1)	0,143	0,543	**1**	**0,943**	-0,429		
DO (%)	0,314	0,771	**0,943**	**1**	-0,371		
EC(µS/cm)	-0,371	0,086	-0,429	-0,371	**1**		
Values in bold are different from 0 with a significance level alpha=0,05							
p-values (Spearman) / Group 2:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature (ºc)	**0,002778**	0,356	0,803	0,564	0,497		

pH	0,356	**0,002778**	0,356	0,103	0,919		
DO(mg/1)	0,803	0,356	**0,002778**	**0,017**	0,419		

DO (%)	0,564	0,103	**0,017**	**0,002778**	0,497		
EC(µS/cm)	0,497	0,919	0,419	0,497	**0,002778**		
Coefficients of determination (Spearman) / Group 2:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature (ºc)	**1**	0,236	0,020	0,099	0,138		
pH	0,236	**1**	0,295	0,595	0,007		
DO(mg/1)	0,020	0,295	**1**	0,889	0,184		
DO (%)	0,099	0,595	0,889	**1**	0,138		
EC(µS/cm)	0,138	0,007	0,184	0,138	**1**		
Results for group 3:							
Correlation matrix (Spearman) / Group 3:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)							
pH							
DO(mg/1)							
DO (%)							
EC(µS/cm)							
Values in bold are different from 0 with a significance level alpha=0,05							
p-values (Spearman) / Group 3:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		

Temperature(ºc)							
pH							
DO(mg/1)							
DO (%)							
EC(µS/cm)							
Coefficients of determination (Spearman) / Group 3:							
Variables	Temperature (ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)							

pH							
DO(mg/1)							
DO (%)							
EC(µS/cm)							

KFBM1 insitu correlation test.

Summary statistics:							
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Temperature(ºc)	3	0	3	21,100	25,800	24,067	2,581
pH	3	0	3	6,640	7,420	7,153	0,445
DO(mg/1)	3	0	3	4,660	7,950	5,767	1,891
DO (%)	3	0	3	70,000	107,000	83,000	20,809
EC(µS/cm)	3	0	3	751,000	758,000	754,333	3,512
Results for group 2:							
Correlation matrix (Spearman) / Group 2:							
Variables	Temperature(ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)	**1**	1,000	-1,000	-1,000	-1,000		
pH	1,000	**1**	-1,000	-1,000	-1,000		
DO(mg/1)	-1,000	-1,000	**1**	1,000	1,000		
DO (%)	-1,000	-1,000	1,000	**1**	1,000		
EC(µS/cm)	-1,000	-1,000	1,000	1,000	**1**		
Values in bold are different from 0 with a significance level alpha=0,05							
p-values (Spearman) / Group 2:							
Variables	Temperature(ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)	**1**	1,000	1,000	1,000	1,000		

pH	1,000	**1**	1,000	1,000	1,000		
DO(mg/1)	1,000	1,000	**1**	1,000	1,000		
DO (%)	1,000	1,000	1,000	**1**	1,000		

EC(µS/cm)	1,000	1,000	1,000	1,000	**1**		
Coefficients of determination (Spearman) / Group 2:							
Variables	Temperature(ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)	**1**	1,000	1,000	1,000	1,000		
pH	1,000	**1**	1,000	1,000	1,000		
DO(mg/1)	1,000	1,000	**1**	1,000	1,000		
DO (%)	1,000	1,000	1,000	**1**	1,000		
EC(µS/cm)	1,000	1,000	1,000	1,000	**1**		
Results for group 3:							
Correlation matrix (Spearman) / Group 3:							
Variables	Temperature(ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
)							
pH							
DO(mg/1)							
DO (%)							
EC(µS/cm)							
Values in bold are different from 0 with a significance level alpha=0,05							
p-values (Spearman) / Group 3:							
Variables	Temperature(ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
)							
pH							
DO(mg/1)							

DO (%)							
EC(µS/cm)							
Coefficients of determination (Spearman) / Group 3:							
Variables	Temperature(º c)	pH	DO(mg/ 1)	DO (%)	EC(µS/c m)		
)							
pH							
DO(mg/1)							
DO (%)							

EC(µS/cm)						

KFBM4 insitu correlation test.

Summary statistics:							
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Temperature(ºc)	3	0	3	20,100	23,000	21,900	1,572
pH	3	0	3	4,330	6,980	6,087	1,521
DO(mg/1)	3	0	3	1,910	8,260	4,037	3,658
DO (%)	3	0	3	27,000	110,000	55,500	47,215
EC(µS/cm)	3	0	3	717,000	1060,000	944,000	196,604
Results for group 2:							
Correlation matrix (Spearman) / Group 2:							
Variables	Temperature(ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)	**1**	1,000	-1,000	-1,000	1,000		
pH	1,000	**1**	-1,000	-1,000	1,000		
DO(mg/1)	-1,000	-1,000	**1**	1,000	-1,000		
DO (%)	-1,000	-1,000	1,000	**1**	-1,000		
EC(µS/cm)	1,000	1,000	-1,000	-1,000	**1**		
Values in bold are different from 0 with a significance level alpha=0,05							
p-values (Spearman) / Group 2:							
Variables	Temperature(ºc)	pH	DO(mg/1)	DO (%)	EC(µS/cm)		
Temperature(ºc)	**1**	1,000	1,000	1,000	1,000		

pH	1,000	**1**	1,000	1,000	1,000		
DO(mg/1)	1,000	1,000	**1**	1,000	1,000		
DO (%)	1,000	1,000	1,000	**1**	1,000		
EC(µS/cm)	1,000	1,000	1,000	1,000	**1**		

Coefficients of determination (Spearman) / Group 2:							
Variables	Temperature(º c)	pH	DO(mg/ 1)	DO (%)	EC(µS/c m)		
Temperature(º c)	**1**	1,000	1,000	1,000	1,000		
pH	1,000	**1**	1,000	1,000	1,000		
DO(mg/1)	1,000	1,000	**1**	1,000	1,000		
DO (%)	1,000	1,000	1,000	**1**	1,000		
EC(µS/cm)	1,000	1,000	1,000	1,000	**1**		
Results for group 3:							
Correlation matrix (Spearman) / Group 3:							
Variables	Temperature(º c)	pH	DO(mg/ 1)	DO (%)	EC(µS/c m)		
)							
pH							
DO(mg/1)							
DO (%)							
EC(µS/cm)							
Values in bold are different from 0 with a significance level alpha=0,05							
p-values (Spearman) / Group 3:							
Variables	Temperature(º c)	pH	DO(mg/ 1)	DO (%)	EC(µS/c m)		
)							
pH							
DO(mg/1)							

DO (%)							
EC(µS/cm)							
Coefficients of determination (Spearman) / Group 3:							
Variables	Temperature(º c)	pH	DO(mg/ 1)	DO (%)	EC(µS/c m)		
)							
pH							
DO(mg/1)							
DO (%)							
EC(µS/cm)							

Appendix F: Kruskal-wallis tests.

Kruskal-Wallis test for all variables at all sites for time periods 1, 2 and 3.

Table below shows Kruskal-Wallis test for sodium at KFMB1 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,998	0,079
2	0,998	**1**	0,306
3	0,079	0,306	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for sodium at Dam for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,773	0,302
2	0,773	**1**	0,837
3	0,302	0,837	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for sodium at KFBM1 for Period 1, 2 and 3.

Kruskal-Wallis test / Two-tailed test:	
K (Observed value)	0,862
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,353
alpha	0,050

Table below shows Kruskal-Wallis test for sodium at KFBM3 for Period 1, 2 and 3.

K (Observed value)	2,420
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,120
alpha	0,050

Table below shows Kruskal-Wallis test for sodium at KFBM4 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,076	0,392
2	0,076	**1**	0,438
3	0,392	0,438	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for DO at KFBM1 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,807	0,672
2	0,807	**1**	0,590
3	0,672	0,590	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Wallis test for DO at Dam for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	1,000	0,134
2	1,000	**1**	0,394
3	0,134	0,394	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for DO at KFBM2 for Period 1, 2 and 3.

K (Observed value)	0,054
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,816
alpha	0,050

Table below shows Kruskal-Wallis test for DO at KFBM4 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,995	0,901
2	0,995	**1**	0,438
3	0,901	0,438	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for Nitrite at Dam for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,071	1,000
2	0,071	**1**	0,728
3	1,000	0,728	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

K (Observed value)	4,473
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,034
alpha	0,050

Table below shows Kruskal-Wallis test for Nitrite at KFBM3 for Period 1, 2 and 3.

K (Observed value)	1,293
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,256
alpha	0,050

Table below shows Kruskal-Wallis test for Nitrate at KFBM1 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,825	0,940
2	0,825	**1**	0,574
3	0,940	0,574	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Wallis test for Nitrate at Dam for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,551	0,375
2	0,551	**1**	0,870
3	0,375	0,870	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for Nitrate at KFBM2 for Period 1, 2 and 3.

K (Observed value)	0,165
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,684
alpha	0,050

Table below shows Kruskal-Wallis test for Nitrate at KFBM3 for Period 1, 2 and 3.

K (Observed value)	0,626
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,429
alpha	0,050

Table below shows Kruskal-Wallis test for Nitrate at KFBM4 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	**0,002**	1,000
2	**0,002**	**1**	0,438
3	1,000	0,438	1
Significant differences:			
	1	2	3
1		**Yes**	No
2	**Yes**		No
3	No	No	

Table below shows Kruskal-Wallis test for sulphate at Dam for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,441	**0,006**
2	0,441	**1**	**0,012**
3	**0,006**	**0,012**	1
Significant differences:			
	1	2	3
1		No	**Yes**
2	No		**Yes**
3	**Yes**	**Yes**	

Table below shows Kruskal-Wallis test for sulphate at KFBM3 for Period 1, 2 and 3.

K (Observed value)	2,400
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,121
alpha	0,050

Table below shows Kruskal-Wallis test for chloride at KFBM1 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,672	0,260
2	0,672	**1**	0,300
3	0,260	0,300	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis Wallis test for chloride at Dam for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,591	**0,038**
2	0,591	**1**	0,350
3	**0,038**	0,350	1
Significant differences:			
	1	2	3
1		No	**Yes**
2	No		No
3	**Yes**	No	

Table below shows Kruskal-Wallis test for chloride at KFBM2 for Period 1, 2 and 3.

K (Observed value)	0,595
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,440
alpha	0,050

Table below shows Kruskal-Wallis Wallis test for chloride at KFBM3 for Period 1, 2 and 3.

K (Observed value)	5,400
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,020
alpha	0,050

Table below shows Kruskal-Wallis test for chloride at KFBM4 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,824	0,901
2	0,824	**1**	0,438
3	0,901	0,438	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for total alkalinity at KFBM1 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,332	**0,049**
2	0,332	**1**	0,967
3	**0,049**	0,967	1
Significant differences:			
	1	2	3
1		No	**Yes**
2	No		No
3	**Yes**	No	

Table below shows Kruskal-Wallis test for total alkalinity at Dam for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,077	1,000
2	0,077	**1**	**0,009**
3	1,000	**0,009**	1
Significant differences:			
	1	2	3
1		No	No
2	No		**Yes**
3	No	**Yes**	

-

Table below shows Kruskal-Wallis Wallis test for total alkalinity at KFBM2 for Period 1, 2 and 3.

K (Observed value)	2,913
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,088
alpha	0,050

Table below shows Kruskal-Wallis test for total alkalinity at KFBM3 for Period 1, 2 and 3.

K (Observed value)	0,067
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,796
alpha	0,050

-

Table below shows Kruskal Wallis test for turbidity at KFBM1 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,742	0,548
2	0,742	**1**	0,876
3	0,548	0,876	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for turbidity at Dam for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,359	0,967
2	0,359	**1**	0,203
3	0,967	0,203	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

-

Table below shows Kruskal Wallis test for turbidity at KFBM2 for Period 1, 2 and 3.

K (Observed value)	0
K (Critical value)	3,841
DF	1
p-value (one-tailed)	1,000
alpha	0,050

Table below shows Kruskal-Wallis test for turbidity at KFBM3 for Period 1, 2 and 3.

K (Observed value)	0,267
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,606
alpha	0,050

Table below shows Kruskal-Wallis Wallis test for turbidity at KFBM4 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,979	0,568
2	0,979	**1**	0,438
3	0,568	0,438	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for EC at KFBM1 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,998	0,549
2	0,998	**1**	0,743
3	0,549	0,743	1
Significant differences:			
	1	2	3
1		No	No
2	No		No

Table below shows Kruskal-Wallis test for EC at KFBM2 for Period 1, 2 and 3.

K (Observed value)	1,167
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,280
alpha	0,050

Table below shows Kruskal-Wallis Wallis test for EC at KFBM3 for Period 1, 2 and 3.

K (Observed value)	0,267
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,606
alpha	0,050

Table below shows Kruskal-Wallis test for EC at KFBM4 for Period 1, 2 and 3.

p-values:				
		1	2	3
1		**1**	0,119	0,393
2		0,119	**1**	0,438
3		0,393	0,438	1
	Significant differences:			
		1	2	3
1			No	No
2		No		No
3		No	No	

Table below shows Kruskal-Wallis test for TSS at Dam for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,471	0,513
2	0,471	**1**	0,234
3	0,513	0,234	1
Significant differences:			
	1	2	3
1		No	No
2	No		No

3	No	No	

Table below shows Kruskal Wallis test for TSS at KFBM2 for Period 1, 2 and 3.

K (Observed value)	1,167
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,280
alpha	0,050

Table below shows Kruskal-Wallis test for TSS at KFBM3 for Period 1, 2 and 3.

K (Observed value)	0,067
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,796
alpha	0,050

Table below shows Kruskal-Wallis test for hydrogen ion at KFBM1 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,916	0,464
2	0,916	**1**	0,579
3	0,464	0,579	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Table below shows Kruskal-Wallis test for hydrogen ion at KFBM2 for Period 1, 2 and 3.

K (Observed value)	1,749
K (Critical value)	3,841
DF	1
p-value (one-tailed)	0,186
alpha	0,050

Table below shows Kruskal-Wallis test for hydrogen ion at KFBM4 for Period 1, 2 and 3.

p-values:			
	1	2	3
1	**1**	0,583	0,748
2	0,583	**1**	0,759
3	0,748	0,759	1
Significant differences:			
	1	2	3
1		No	No
2	No		No
3	No	No	

Spatial comparison Kruskal wallis test.

Summary statistics:									
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation		
H+	78	0	78	0,000	0,002	0,000	0,000		
TSS	78	0	78	1,300	########	1464,738	12377,518		
EC	78	0	78	6,300	463,000	106,508	88,257		
Turbity	78	0	78	0,300	1875,000	63,237	229,208		
Total Alkalinity	78	0	78	2,500	316,000	88,485	77,874		
Chloride	78	0	78	6,000	211,000	59,240	43,874		
Sulphate	78	0	78	0,100	2486,000	322,201	445,495		
nitrate	78	0	78	0,050	1,800	0,213	0,344		
nitrite	78	0	78	0,005	1,700	0,059	0,195		
disolved oxygen	78	0	78	0,200	9,600	6,916	1,615		
Sodium	78	0	78	1,000	149,000	47,781	28,612		
Summary statistics (Subsamples):									
Variable	Categories	Counts	Frequencies	%					
ID No	Dam	22	22	28,205					
	KFBM1	20	20	25,641					
	KFBM2	13	13	16,667					

	KFBM3	9	9	11,538					
	KFBM4	14	14	17,949					
Summary statistics (Data / Subsamples):									
Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation		

H+ | ID No-Dam	22	0	22	0,000	0,001	0,000	0,000		
H+ | ID No-KFBM1	20	0	20	0,000	0,000	0,000	0,000		
H+ | ID No-KFBM2	13	0	13	0,000	0,000	0,000	0,000		
H+ | ID No-KFBM3	9	0	9	0,000	0,000	0,000	0,000		
H+ | ID No-KFBM4	14	0	14	0,000	0,002	0,000	0,000		
TSS | ID No-Dam	22	0	22	1,400	73,000	26,959	21,649		
TSS | ID No-KFBM1	20	0	20	1,300	156,000	28,625	35,282		
TSS | ID No-KFBM2	13	0	13	1,400	250,000	75,654	91,909		
TSS | ID No-KFBM3	9	0	9	2,000	########	12395,278	36367,693		
TSS | ID No-KFBM4	14	0	14	1,300	181,000	38,786	62,797		
EC | ID No-Dam	22	0	22	36,300	257,000	115,195	75,581		
EC | ID No-KFBM1	20	0	20	51,100	456,000	110,015	89,683		

EC | ID No-KFBM2	13	0	13	6,300	254,000	77,938	81,335		

EC | ID No-KFBM3	9	0	9	49,700	104,000	77,333	21,315		
EC | ID No-KFBM4	14	0	14	49,800	463,000	133,129	128,268		
Turbidity | ID No-Dam	22	0	22	2,900	102,000	23,573	25,651		
Turbidity | ID No-KFBM1	20	0	20	1,500	52,000	14,750	15,650		
Turbidity | ID No-KFBM2	13	0	13	1,000	584,000	132,322	213,321		
Turbidity | ID No-KFBM3	9	0	9	1,000	1875,000	226,811	618,284		
Turbidity | ID No-KFBM4	14	0	14	0,300	109,000	25,529	37,364		
Total Alkalinity | ID No-Dam	22	0	22	2,500	288,000	80,864	78,708		
Total Alkalinity | ID No-KFBM1	20	0	20	20,000	260,000	118,640	69,724		

Total Alkalinity | ID No-KFBM2	13	0	13	2,500	212,000	79,346	66,578		
Total Alkalinity | ID No-KFBM3	9	0	9	2,500	316,000	101,611	96,227		
Total Alkalinity | ID No-KFBM4	14	0	14	2,500	228,000	57,429	79,237		
Chloride | ID No-Dam	22	0	22	18,000	115,000	48,836	30,464		
Chloride | ID No-KFBM1	20	0	20	28,000	172,000	65,135	39,770		
Chloride | ID No-KFBM2	13	0	13	6,000	114,000	29,662	27,162		
Chloride | ID No-KFBM3	9	0	9	8,000	211,000	75,333	74,873		
Chloride | ID No-KFBM4	14	0	14	24,000	158,000	84,286	38,643		
Sulphate | ID No-Dam	22	0	22	38,000	1260,000	425,418	452,606		
Sulphate | ID No-KFBM1	20	0	20	142,000	754,000	264,700	165,120		

Sulphate | ID No-KFBM2	13	0	13	0,100	437,000	118,400	115,874		
Sulphate | ID No-KFBM3	9	0	9	48,000	437,000	169,033	115,687		
Sulphate | ID No-KFBM4	14	0	14	45,000	2486,000	529,857	810,436		

nitrate | ID No-Dam	22	0	22	0,050	1,300	0,213	0,348		
nitrate | ID No-KFBM1	20	0	20	0,050	1,200	0,190	0,258		
nitrate | ID No-KFBM2	13	0	13	0,050	1,800	0,327	0,541		
nitrate | ID No-KFBM3	9	0	9	0,050	1,200	0,278	0,373		
nitrate | ID No-KFBM4	14	0	14	0,050	0,600	0,100	0,149		
nitrite | ID No-Dam	22	0	22	0,005	0,300	0,048	0,065		
nitrite | ID No-KFBM1	20	0	20	0,005	0,025	0,023	0,006		
nitrite | ID No-KFBM2	13	0	13	0,005	0,200	0,042	0,051		

nitrite | ID No-KFBM3	9	0	9	0,005	0,300	0,059	0,094		
nitrite | ID No-KFBM4	14	0	14	0,025	1,700	0,145	0,448		
dissolved oxygen | ID No-Dam	22	0	22	5,100	9,500	7,109	0,993		
dissolved oxygen	20	0	20	4,670	9,400	7,334	1,113		

| ID No-KFBM1									
dissolved oxygen | ID No-KFBM2	13	0	13	5,500	9,600	7,096	1,394		
dissolved oxygen | ID No-KFBM3	9	0	9	0,200	8,300	6,078	2,369		
dissolved oxygen | ID No-KFBM4	14	0	14	1,300	8,500	6,386	2,378		
Sodium | ID No-Dam	22	0	22	5,000	124,000	44,918	29,249		
Sodium | ID No-KFBM1	20	0	20	28,000	129,000	57,395	25,773		
Sodium | ID No-KFBM2	13	0	13	1,000	44,000	28,908	15,664		

Sodium | ID No-KFBM3	9	0	9	28,000	52,000	37,333	7,794		
Sodium | ID No-KFBM4	14	0	14	30,000	149,000	62,786	37,444		
Results for variable H+:									
Kruskal-Wallis test / Two-tailed test (H+):									
K (Observed value)	11,889								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,018								
alpha	0,050								
An approximation has been used to compute the p-value.									
Test interpretation:									
H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									
As the computed p-value is lower than the significance level alpha=0,05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.									
Ties have been detected in the data and the appropriate corrections have been applied.									
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Two-tailed test:									
Sample	Frequency	Sum of ranks	Mean of ranks	Groups					

KFBM1	20	618,000	30,900	A					
KFBM2	13	454,500	34,962	A	B				
Dam	22	854,000	38,818	A	B				
KFBM3	9	355,000	39,444	A	B				
KFBM4	14	799,500	57,107		B				
Pairwise comparisons (H+):									
Wij:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		1,390	0,701	0,092	-3,214				

KFBM1	-1,390		-0,913	-1,537	**-4,588**				
KFBM2	-0,701	0,913		-0,899	-3,608				
KFBM3	-0,092	1,537	0,899		-2,812				
KFBM4	3,214	**4,588**	3,608	2,812					
p-values:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,863	0,988	1,000	0,154				
KFBM1	0,863	**1**	0,967	0,814	**0,010**				
KFBM2	0,988	0,967	**1**	0,969	0,080				
KFBM3	1,000	0,814	0,969	**1**	0,272				

KFBM4	0,154	**0,010**	0,080	0,272	1				
Significant differences:									
	Dam	KFBM 1	KFBM2	KFBM 3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		No	No	**Yes**				
KFBM2	No	No		No	No				
KFBM3	No	No	No		No				
KFBM4	No	**Yes**	No	No					
Results for variable TSS:									
Kruskal-Wallis test / Two-tailed test (TSS):									
K (Observed value)	2,324								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,676								

alpha	0,050								
An approximation has been used to compute the p-value.									
Test interpretation:									
H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									

As the computed p-value is greater than the significance level alpha=0,05, one cannot reject the null hypothesis H0.

Ties have been detected in the data and the appropriate corrections have been applied.

Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:

Sample	Frequency	Sum of ranks	Mean of ranks	Groups
KFBM4	14	468,000	33,429	A
KFBM1	20	762,000	38,100	A
Dam	22	880,500	40,023	A
KFBM2	13	544,000	41,846	A
KFBM3	9	426,500	47,389	A

Pairwise comparisons (TSS):

Wij:

	Dam	KFBM1	KFBM2	KFBM3	KFBM4
Dam		0,695	-0,652	-1,324	1,239
KFBM1	-0,695		-0,756	-1,167	1,163
KFBM2	0,652	0,756		-0,850	0,789

KFBM3	1,324	1,167	0,850		2,050				
KFBM4	-1,239	-1,163	-0,789	-2,050					

p-values:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,988	0,991	0,883	0,906				
KFBM1	0,988	**1**	0,984	0,923	0,924				
KFBM2	0,991	0,984	**1**	0,975	0,981				
KFBM3	0,883	0,923	0,975	**1**	0,595				
KFBM4	0,906	0,924	0,981	0,595	1				
Significant differences:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		No	No	No				
KFBM2	No	No		No	No				
KFBM3	No	No	No		No				
KFBM4	No	No	No	No					
Results for variable EC:									
Kruskal-Wallis test / Two-tailed test (EC):									

K (Observed value)	7,303								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,121								
alpha	0,050								
An approximation has been used to compute the p-value.									

Test interpretation:									
H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									
As the computed p-value is greater than the significance level alpha=0,05, one cannot reject the null hypothesis H0.									
Ties have been detected in the data and the appropriate corrections have been applied.									
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:									
Sample	Frequency	Sum of ranks	Mean of ranks	Groups					
KFBM2	13	328,000	25,231	A					

KFBM3	9	333,500	37,056	A					
Dam	22	891,000	40,500	A					
KFBM1	20	888,000	44,400	A					
KFBM4	14	640,500	45,750	A					
Pairwise comparisons (EC):									
Wij:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		-0,463	2,173	0,554	-0,872				
KFBM1	0,463		3,622	1,367	-0,247				
KFBM2	-2,173	-3,622		-2,173	-3,294				
KFBM3	-0,554	-1,367	2,173		-1,381				

KFBM4	0,872	0,247	3,294	1,381					
p-values:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,998	0,539	0,995	0,973				
KFBM1	0,998	**1**	0,078	0,870	1,000				
KFBM2	0,539	0,078	**1**	0,539	0,136				

KFBM3	0,995	0,870	0,539	**1**	0,866				
KFBM4	0,973	1,000	0,136	0,866	1				
Significant differences:									
	Dam	KFBM 1	KFBM2	KFBM 3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		No	No	No				
KFBM2	No	No		No	No				
KFBM3	No	No	No		No				
KFBM4	No	No	No	No					
Results for variable Turbity:									
Kruskal-Wallis test / Two-tailed test (Turbity):									
K (Observed value)	2,966								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,564								
alpha	0,050								

An approximation has been used to compute the p-value.				

Test interpretation:									
H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									
As the computed p-value is greater than the significance level alpha=0,05, one cannot reject the null hypothesis H0.									
Ties have been detected in the data and the appropriate corrections have been applied.									
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:									
Sample	Frequency	Sum of ranks	Mean of ranks	Groups					
KFBM1	20	690,500	34,525	A					
KFBM4	14	487,500	34,821	A					
Dam	22	930,000	42,273	A					
KFBM2	13	557,000	42,846	A					
KFBM3	9	416,000	46,222	A					
Pairwise comparisons (Turbity):									
Wij:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		2,030	-0,266	-0,769	1,010				

KFBM1	-2,030		-0,964	-1,834	0,173				
KFBM2	0,266	0,964		-0,331	1,578				
KFBM3	0,769	1,834	0,331		1,514				
KFBM4	-1,010	-0,173	-1,578	-1,514					

p-values:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,604	1,000	0,983	0,953				
KFBM1	0,604	**1**	0,960	0,693	1,000				
KFBM2	1,000	0,960	**1**	0,999	0,798				
KFBM3	0,983	0,693	0,999	**1**	0,822				
KFBM4	0,953	1,000	0,798	0,822	1				
Significant differences:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		No	No	No				
KFBM2	No	No		No	No				
KFBM3	No	No	No		No				
KFBM4	No	No	No	No					
Results for variable Total Alkalinity:									

Kruskal-Wallis test / Two-tailed test (Total Alkalinity):									
K (Observed value)	6,955								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,138								
alpha	0,050								
An approximation has been used to compute the p-value.									

Test interpretation:									
H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									
As the computed p-value is greater than the significance level alpha=0,05, one cannot reject the null hypothesis H0.									
Ties have been detected in the data and the appropriate corrections have been applied.									
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:									
Sample	Frequency	Sum of ranks	Mean of ranks	Groups					
KFBM4	14	415,000	29,643	A					

Dam	22	807,500	36,705	A					
KFBM2	13	493,500	37,962	A					
KFBM3	9	381,500	42,389	A					
KFBM1	20	983,500	49,175	A					
Pairwise comparisons (Total Alkalinity):									
Wij:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		-2,288	-0,270	-0,935	1,105				
KFBM1	2,288		2,085	1,268	3,512				
KFBM2	0,270	-2,085		-0,663	1,528				
KFBM3	0,935	-1,268	0,663		2,114				
KFBM4	-1,105	-3,512	-1,528	-2,114					
p-values:									

	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,486	1,000	0,965	0,936				
KFBM1	0,486	**1**	0,579	0,898	0,094				
KFBM2	1,000	0,579	**1**	0,990	0,817				
KFBM3	0,965	0,898	0,990	**1**	0,566				
KFBM4	0,936	0,094	0,817	0,566	1				

Significant differences:									
	Dam	KFBM 1	KFBM2	KFBM 3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		No	No	No				
KFBM2	No	No		No	No				
KFBM3	No	No	No		No				
KFBM4	No	No	No	No					
Results for variable Chloride:									
Kruskal-Wallis test / Two-tailed test (Chloride):									
K (Observed value)	19,358								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,001								
alpha	0,050								
An approximation has been used to compute the p-value.									

Test interpretation:									
H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									
As the computed p-value is lower than the significance level alpha=0,05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.									
Ties have been detected in the data and the appropriate corrections have been applied.									
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:									
Sample	Frequency	Sum of ranks	Mean of ranks	Groups					
KFBM2	13	241,500	18,577	A					
Dam	22	799,500	36,341						
KFBM3	9	356,000	39,556						
KFBM1	20	920,000	46,000						
KFBM4	14	764,000	54,571						
Groupings could not be properly performed because the significance of differences is not transitive in this particular case.									
Pairwise comparisons (Chloride):									
Wij:									

	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		-2,281	**3,864**	-0,369	-3,649				
KFBM1	2,281		**4,979**	0,667	-1,955				
KFBM2	**-3,864**	**-4,979**		-2,315	**-4,941**				
KFBM3	0,369	-0,667	2,315		-1,782				
KFBM4	3,649	1,955	**4,941**	1,782					

p-values:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,489	**0,049**	0,999	0,074				
KFBM1	0,489	**1**	**0,004**	0,990	0,639				
KFBM2	**0,049**	**0,004**	**1**	0,474	**0,004**				
KFBM3	0,999	0,990	0,474	**1**	0,716				
KFBM4	0,074	0,639	**0,004**	0,716	1				
Significant differences:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		No	**Yes**	No	No				
KFBM1	No		**Yes**	No	No				
KFBM2	**Yes**	**Yes**		No	**Yes**				
KFBM3	No	No	No		No				
KFBM4	No	No	**Yes**	No					
Results for variable Sulphate:									

Kruskal-Wallis test / Two-tailed test (Sulphate):									
K (Observed value)	9,148								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,058								
alpha	0,050								

An approximation has been used to compute the p-value.									
Test interpretation:									
H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									
As the computed p-value is greater than the significance level alpha=0,05, one cannot reject the null hypothesis H0.									
Ties have been detected in the data and the appropriate corrections have been applied.									
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:									

Sample	Frequency	Sum of ranks	Mean of ranks	Groups					
KFBM2	13	318,500	24,500	A					
KFBM3	9	316,000	35,111	A	B				
Dam	22	901,000	40,955	A	B				
KFBM4	14	583,000	41,643	A	B				
KFBM1	20	962,500	48,125		B				
Pairwise comparisons (Sulphate):									
Wij:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		-1,354	2,414	0,677	0,413				
KFBM1	1,354		**4,716**	2,667	0,198				
KFBM2	-2,414	**-4,716**		-1,937	-2,334				
KFBM3	-0,677	-2,667	1,937		-0,802				
KFBM4	-0,413	-0,198	2,334	0,802					
pvalues:									

	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,874	0,429	0,989	0,998				
KFBM1	0,874	**1**	**0,008**	0,325	1,000				

KFBM2	0,429	**0,008**	**1**	0,647	0,465				
KFBM3	0,989	0,325	0,647	**1**	0,980				
KFBM4	0,998	1,000	0,465	0,980	1				
Significant differences:									
	Dam	KFBM 1	KFBM2	KFBM 3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		**Yes**	No	No				
KFBM2	No	**Yes**		No	No				
KFBM3	No	No	No		No				
KFBM4	No	No	No	No					
Results for variable nitrate:									
Kruskal-Wallis test / Two-tailed test (nitrate):									
K (Observed value)	7,404								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,116								
alpha	0,050								
An approximation has been used to compute the p-value.									

Test interpretation:									

H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									
As the computed p-value is greater than the significance level alpha=0,05, one cannot reject the null hypothesis H0.									
Ties have been detected in the data and the appropriate corrections have been applied.									
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:									
Sample	Frequency	Sum of ranks	Mean of ranks	Groups					
KFBM4	14	374,000	26,714	A					
Dam	22	852,500	38,750	A					
KFBM2	13	556,000	42,769	A					
KFBM1	20	876,000	43,800	A					
KFBM3	9	422,500	46,944	A					
Pairwise comparisons (nitrate):									
Wij:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				

Dam		-1,102	-0,772	-1,427	2,672				
KFBM1	1,102		0,108	-0,651	3,494				
KFBM2	0,772	-0,108		-0,491	2,823				
KFBM3	1,427	0,651	0,491		3,197				
KFBM4	-2,672	-3,494	-2,823	-3,197					
p-values:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				

Dam	**1**	0,937	0,982	0,851	0,323				
KFBM1	0,937	**1**	1,000	0,991	0,097				
KFBM2	0,982	1,000	**1**	0,997	0,268				
KFBM3	0,851	0,991	0,997	**1**	0,158				
KFBM4	0,323	0,097	0,268	0,158	1				
Significant differences:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		No	No	No				
KFBM2	No	No		No	No				
KFBM3	No	No	No		No				
KFBM4	No	No	No	No					
Results for variable nitrite:									
Kruskal-Wallis test / Two-tailed test (nitrite):									

K (Observed value)	2,572								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,632								
alpha	0,050								
An approximation has been used to compute the p-value.									
Test interpretation:									
H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									

As the computed p-value is greater than the significance level alpha=0,05, one cannot reject the null hypothesis H0.

Ties have been detected in the data and the appropriate corrections have been applied.									
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:									
Sample	Frequency	Sum of ranks	Mean of ranks	Groups					

KFBM1	20	693,000	34,650	A					
KFBM3	9	348,000	38,667	A					
KFBM2	13	528,000	40,615	A					
KFBM4	14	572,000	40,857	A					
Dam	22	940,000	42,727	A					
Pairwise comparisons (nitrite):									
Wij:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		2,334	0,400	0,613	0,536				
KFBM1	-2,334		-1,460	-0,661	-2,314				
KFBM2	-0,400	1,460		0,159	0,000				
KFBM3	-0,613	0,661	-0,159		-0,556				
KFBM4	-0,536	2,314	0,000	0,556					
p-values:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,465	0,999	0,993	0,996				
KFBM1	0,465	**1**	0,840	0,990	0,474				
KFBM2	0,999	0,840	**1**	1,000	1,000				

KFBM3	0,993	0,990	1,000	**1**	0,995				
KFBM4	0,996	0,474	1,000	0,995	1				
Significant differences:									
	Dam	KFBM 1	KFBM2	KFBM 3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		No	No	No				
KFBM2	No	No		No	No				
KFBM3	No	No	No		No				
KFBM4	No	No	No	No					
Results for variable disolved oxygen:									
Kruskal-Wallis test / Two-tailed test (disolved oxygen):									
K (Observed value)	3,681								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,451								
alpha	0,050								
An approximation has been used to compute the p-value.									

Test interpretation:								
H0: The samples come from the same population.								
Ha: The samples do not come from the same population.								
As the computed p-value is greater than the significance level alpha=0,05, one cannot reject the null hypothesis H0.								

Ties have been detected in the data and the appropriate corrections have been applied.								
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:								
Sample	Frequency	Sum of ranks	Mean of ranks	Groups				
KFBM3	9	254,500	28,278	A				
KFBM4	14	534,000	38,143	A				
Dam	22	859,000	39,045	A				
KFBM2	13	524,000	40,308	A				
KFBM1	20	909,500	45,475	A				
Pairwise comparisons (disolved oxygen):								
Wij:								
	Dam	KFBM1	KFBM2	KFBM3	KFBM4			
Dam		-1,499	0,073	1,636	0,184			

KFBM1	1,499		0,782	2,839	0,991				
KFBM2	-0,073	-0,782		1,466	0,790				
KFBM3	-1,636	-2,839	-1,466		-1,474				
KFBM4	-0,184	-0,991	-0,790	1,474					
p-values:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,827	1,000	0,776	1,000				
KFBM1	0,827	**1**	0,982	0,262	0,956				
KFBM2	1,000	0,982	**1**	0,838	0,981				
KFBM3	0,776	0,262	0,838	**1**	0,836				

KFBM4	1,000	0,956	0,981	0,836	1				
Significant differences:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		No	No	No				
KFBM2	No	No		No	No				
KFBM3	No	No	No		No				
KFBM4	No	No	No	No					
Results for variable Sodium:									
Kruskal-Wallis test / Two-tailed test (Sodium):									

K (Observed value)	17,905								
K (Critical value)	9,488								
DF	4								
p-value (one-tailed)	0,001								
alpha	0,050								
An approximation has been used to compute the p-value.									
Test interpretation:									
H0: The samples come from the same population.									
Ha: The samples do not come from the same population.									
As the computed p-value is lower than the significance level alpha=0,05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.									
Ties have been detected in the data and the appropriate corrections have been applied.									

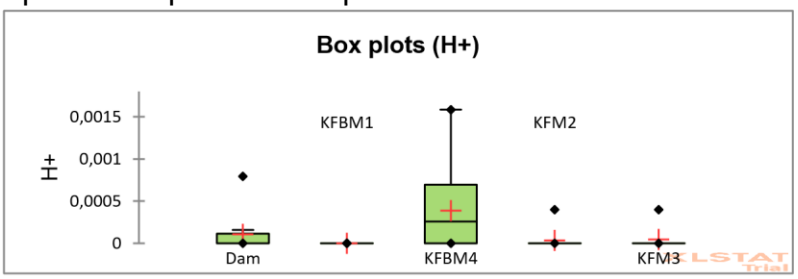
Multiple pairwise comparisons using the Steel-Dwass-Critchlow-Fligner procedure / Twotailed test:									
Sample	Frequency	Sum of ranks	Mean of ranks	Groups					
KFBM2	13	285,000	21,923	A					

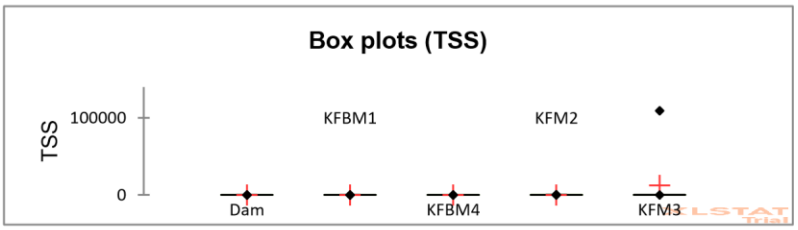
KFBM3	9	270,500	30,056	A	B				
Dam	22	807,500	36,705	A	B				
KFBM1	20	988,500	49,425		B				
KFBM4	14	729,500	52,107		B				
Pairwise comparisons (Sodium):									
Wij:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam		-2,441	2,634	0,770	-2,756				
KFBM1	2,441		**4,535**	3,269	-0,297				
KFBM2	-2,634	**-4,535**		-1,609	**-4,810**				
KFBM3	-0,770	-3,269	1,609		-3,611				
KFBM4	2,756	0,297	**4,810**	3,611					
p-values:									
	Dam	KFBM1	KFBM2	KFBM3	KFBM4				
Dam	**1**	0,418	0,338	0,983	0,291				
KFBM1	0,418	**1**	**0,012**	0,141	1,000				
KFBM2	0,338	**0,012**	**1**	0,787	**0,006**				
KFBM3	0,983	0,141	0,787	**1**	0,079				
KFBM4	0,291	1,000	**0,006**	0,079	1				

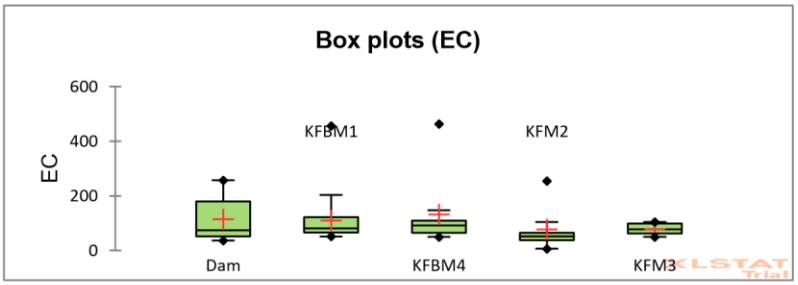
Significant differences:									
	Dam	KFBM 1	KFBM2	KFBM 3	KFBM4				
Dam		No	No	No	No				
KFBM1	No		**Yes**	No	No				
KFBM2	No	**Yes**		No	**Yes**				
KFBM3	No	No	No		No				
KFBM4	No	No	**Yes**	No					
Summary (p-values):									
Variable	Kruskal-Wallis								
H+	**0,018**								
TSS	0,676								
EC	0,121								
Turbity	0,564								
Total Alkalinity	0,138								
Chloride	**0,001**								
Sulphate	0,058								
nitrate	0,116								
nitrite	0,632								
disolved oxygen	0,451								
Sodium	**0,001**								

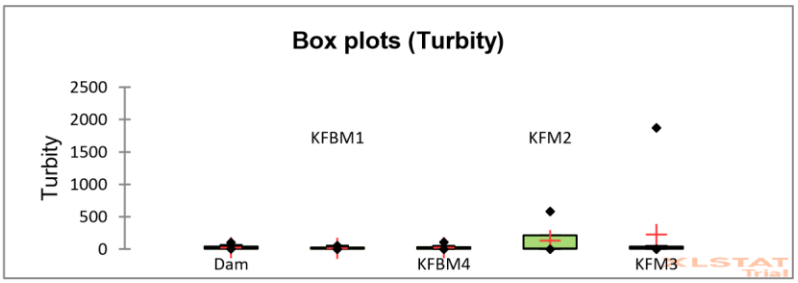
Appendix G: box plots

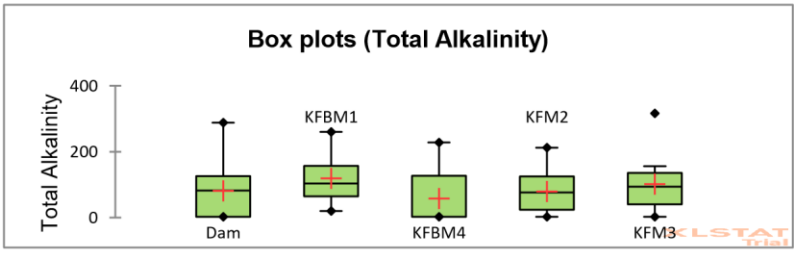
Spatial comparison box plots.

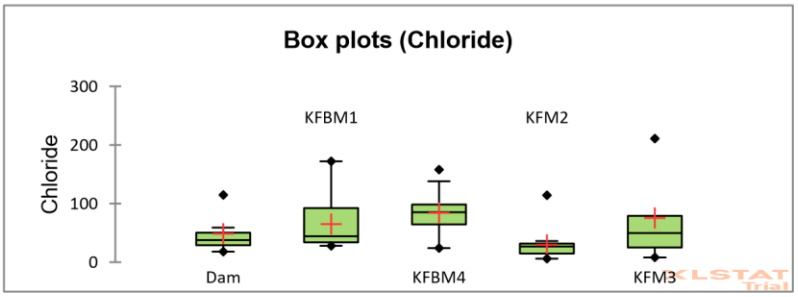


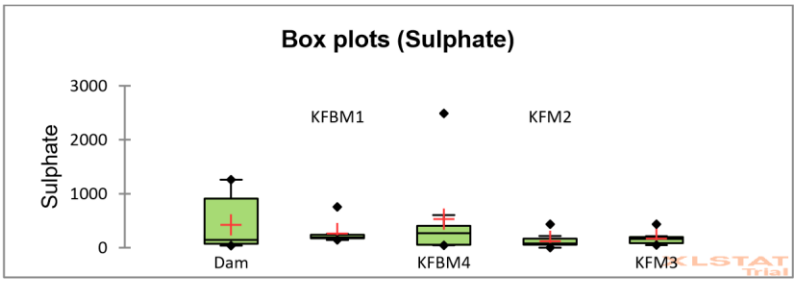


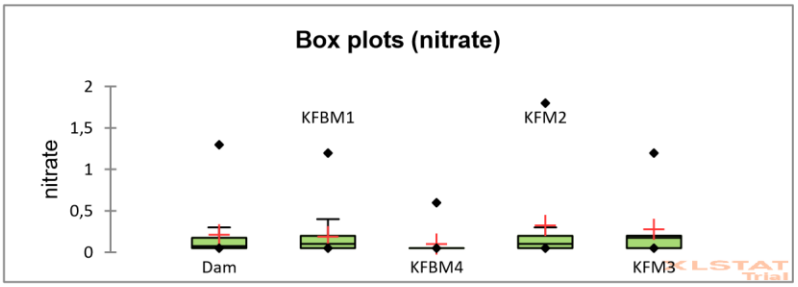


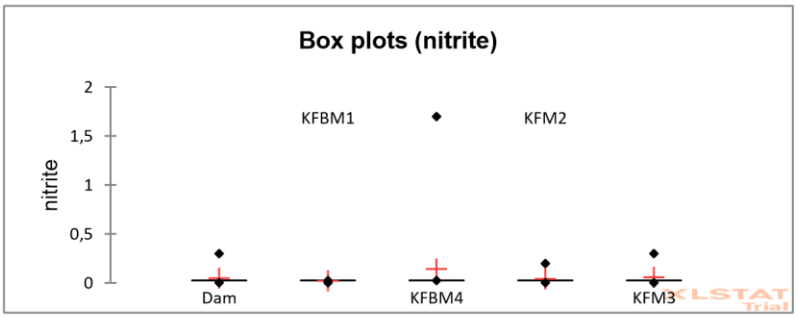


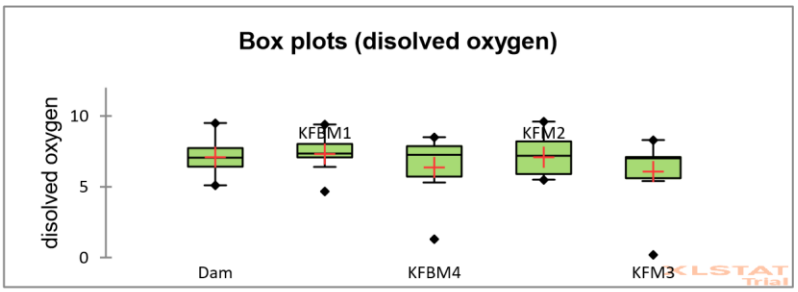


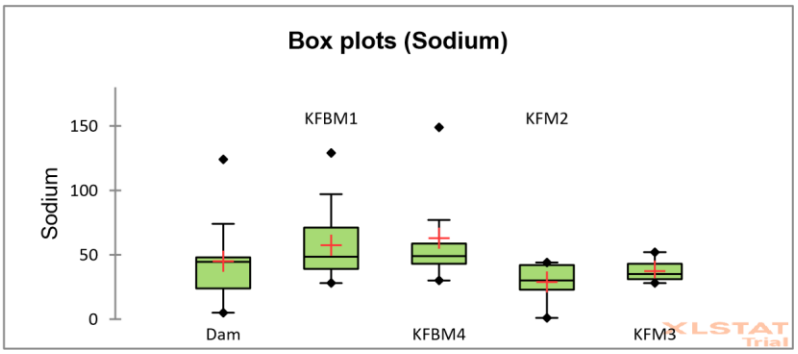



Box plots (Sulphate)
Sulphate
3000
2000
1000
0
KFBM1
KFM2
Dam
KFBM4
KFM3
XLSTAT Trial

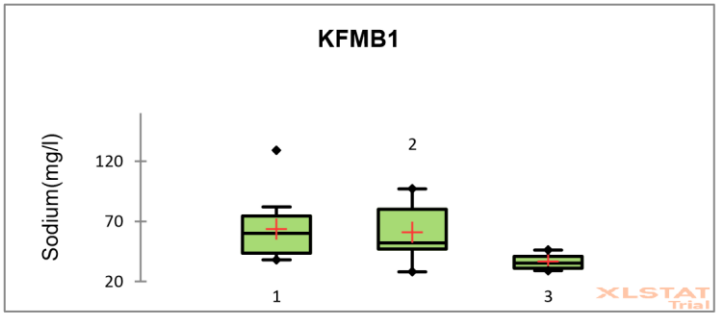

Box plots (nitrate)
nitrate
2
1,5
1
0,5
0
KFBM1
KFM2
Dam
KFBM4
KFM3
XLSTAT Trial

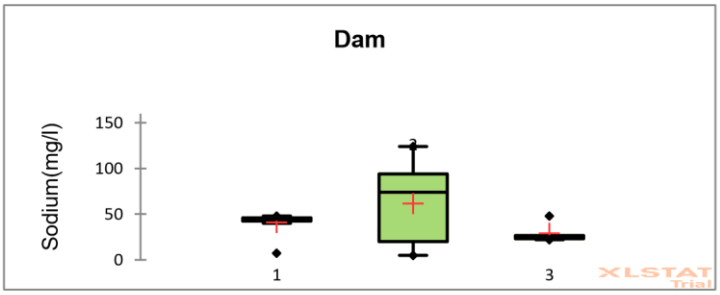

Box plots (nitrite)
nitrite
2
1,5
1
0,5
0
KFBM1
KFM2
Dam
KFBM4
KFM3
XLSTAT Trial

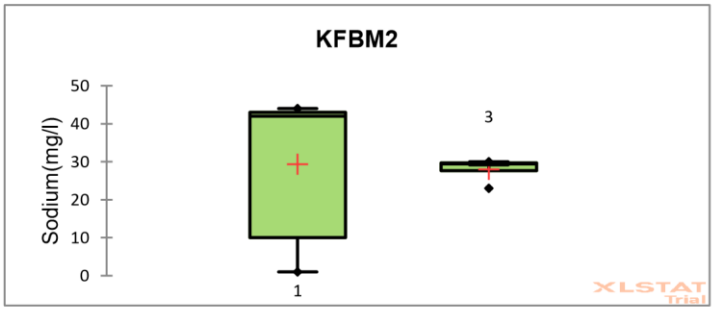

Box plots (disolved oxygen)
disolved oxygen
10
5
0
KFBM1
KFM2
Dam
KFBM4
KFM3
XLSTAT Trial

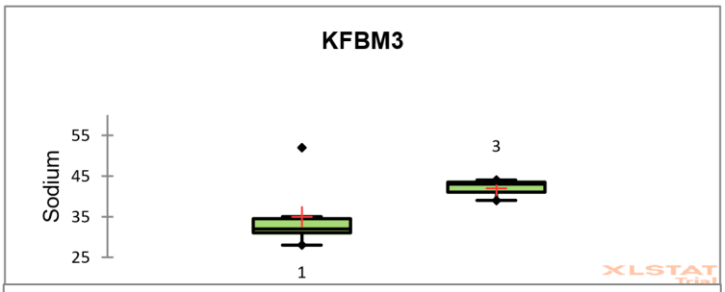

Box plots (Sodium)
Sodium
150
100
50
0
KFBM1
KFM2
Dam
KFBM4
KFM3
XLSTAT Trial

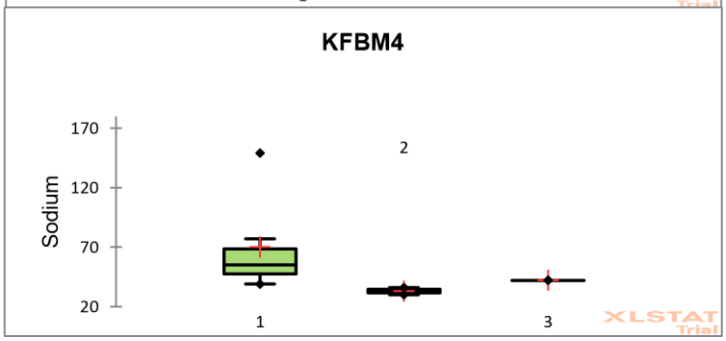
Box plots for sodium at different sampling sites.



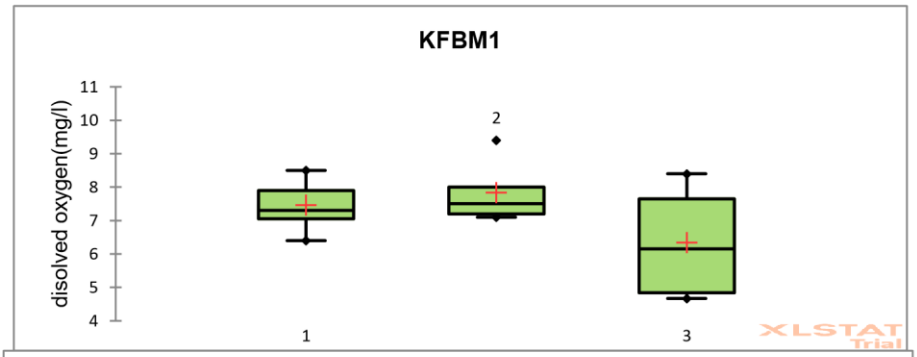


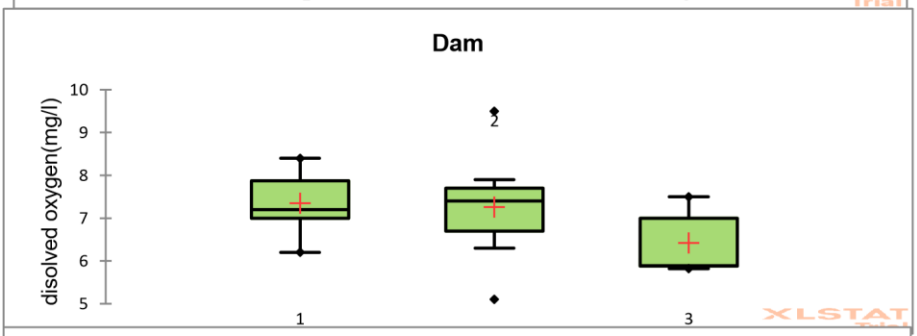


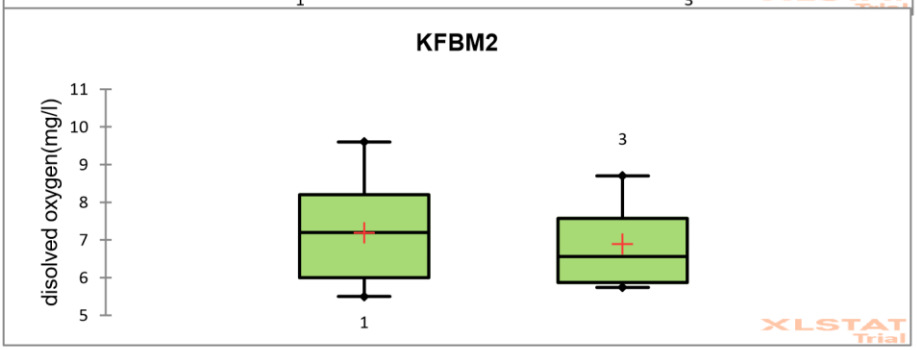


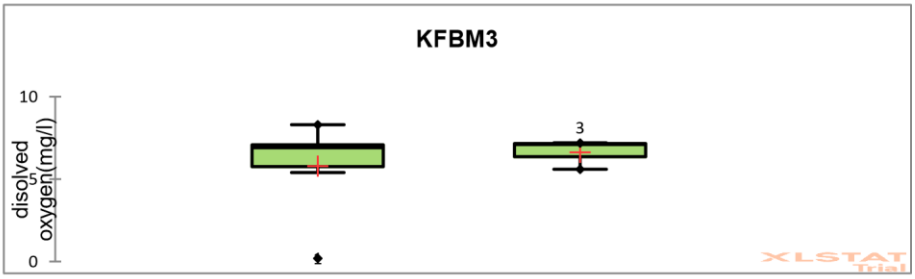


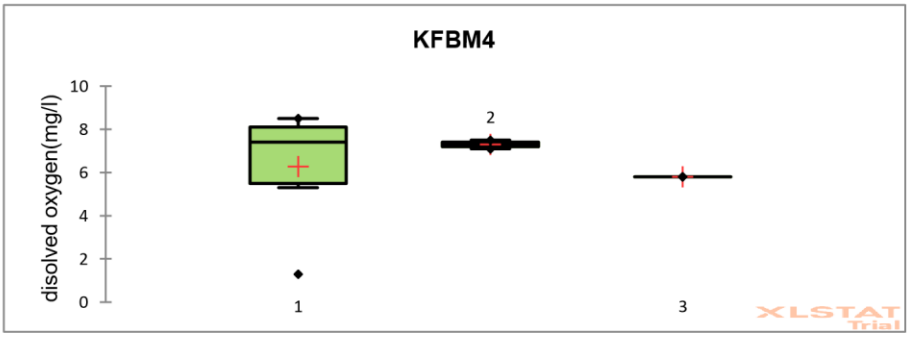
Box plots for DO at different sampling sites.



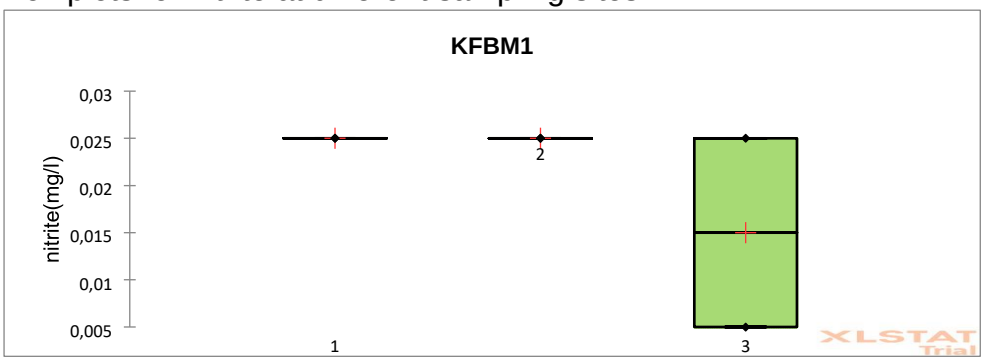


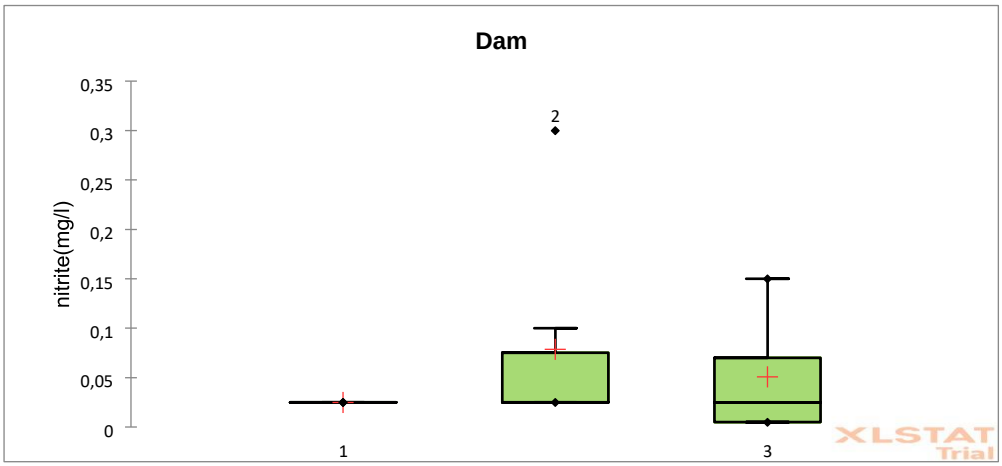


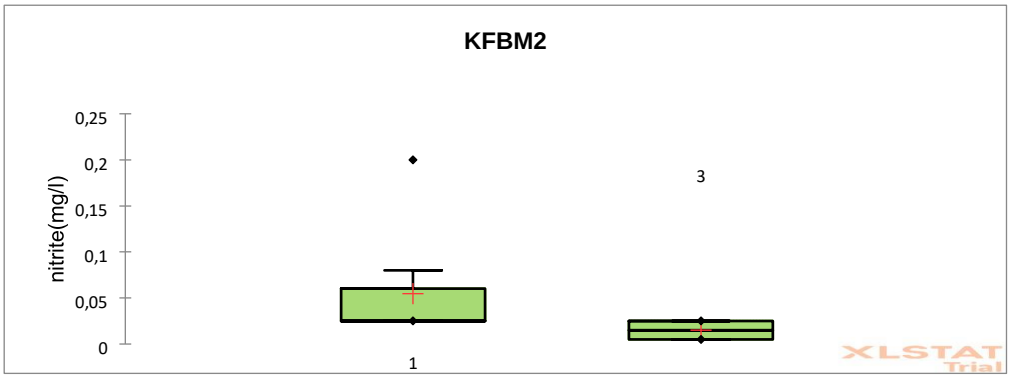


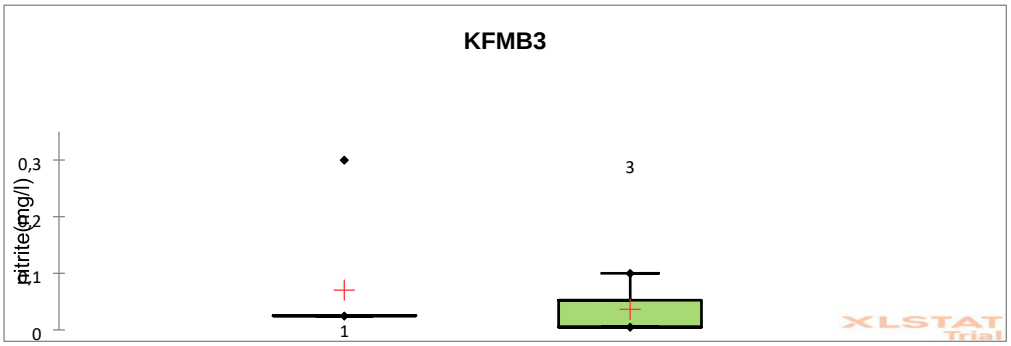


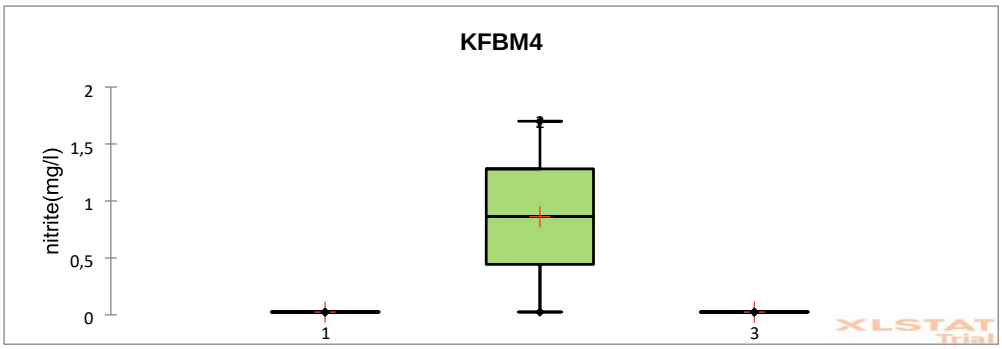
Box plots for nitrite at different sampling sites.



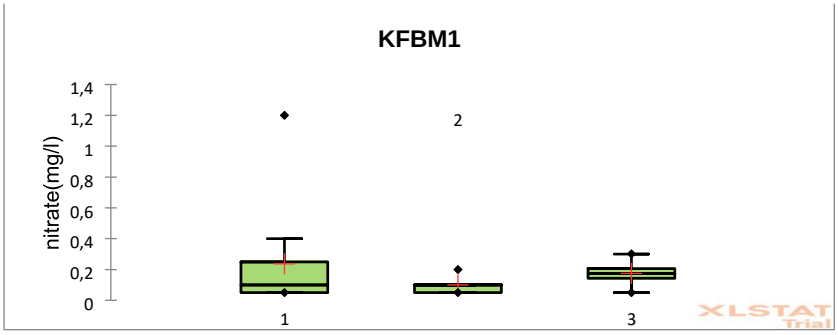


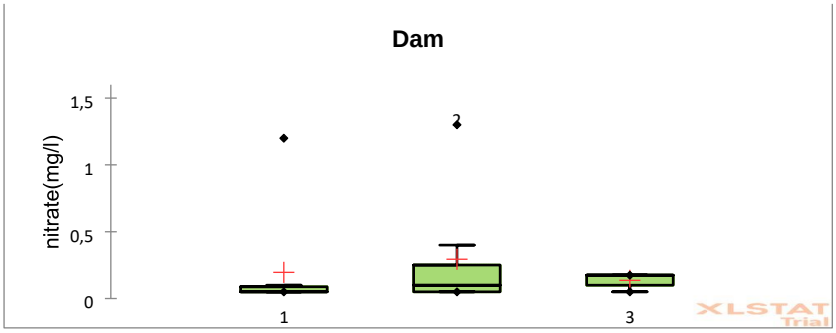


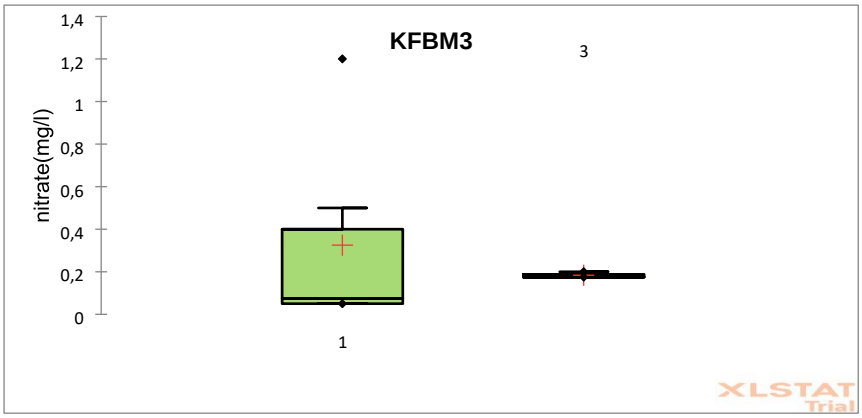


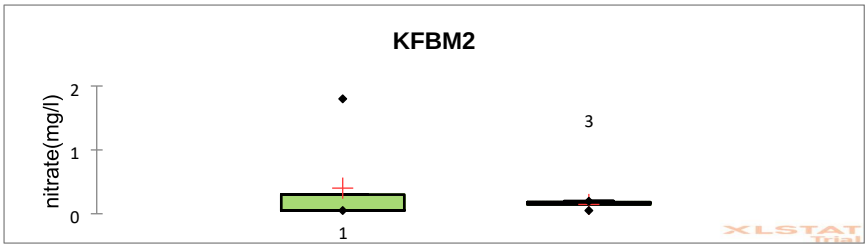


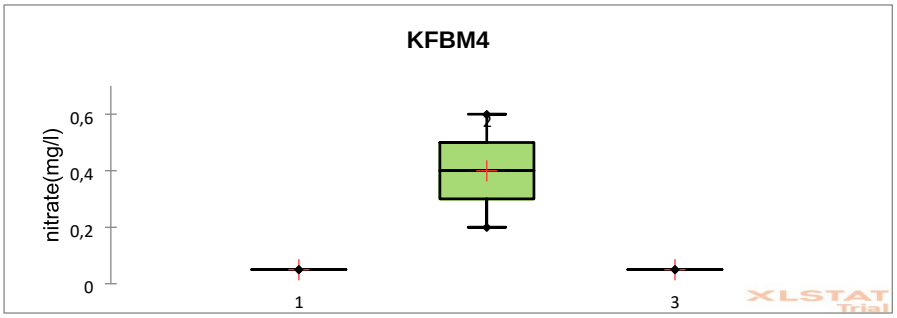
Box plots for nitrate at different sampling sites.



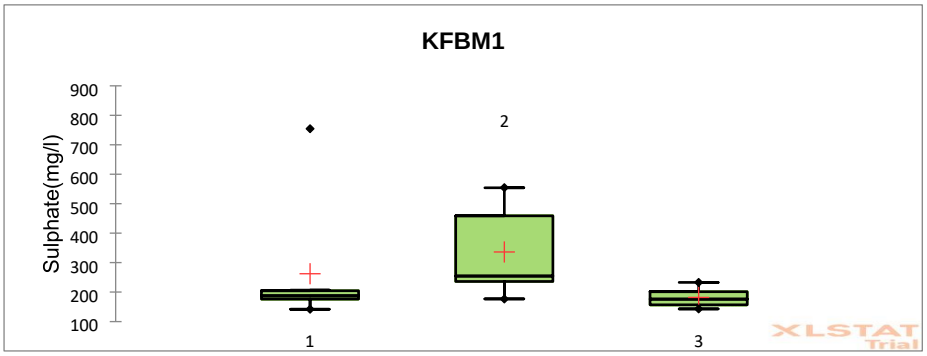


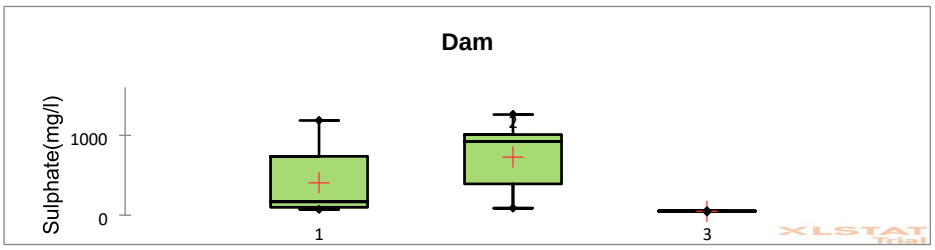


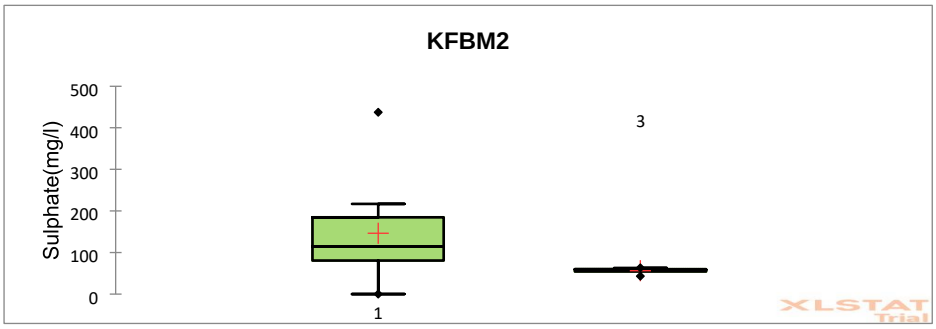


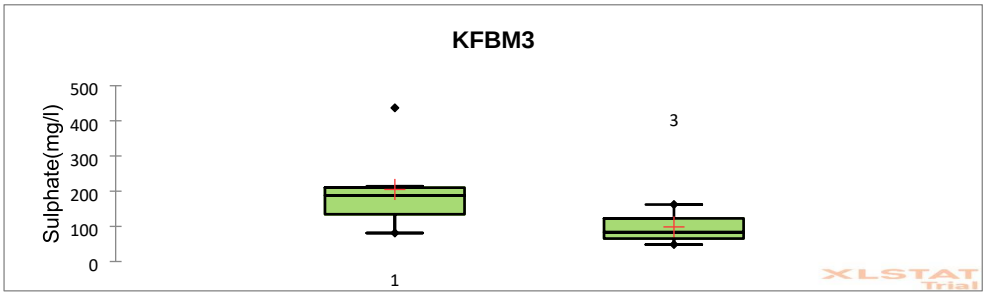


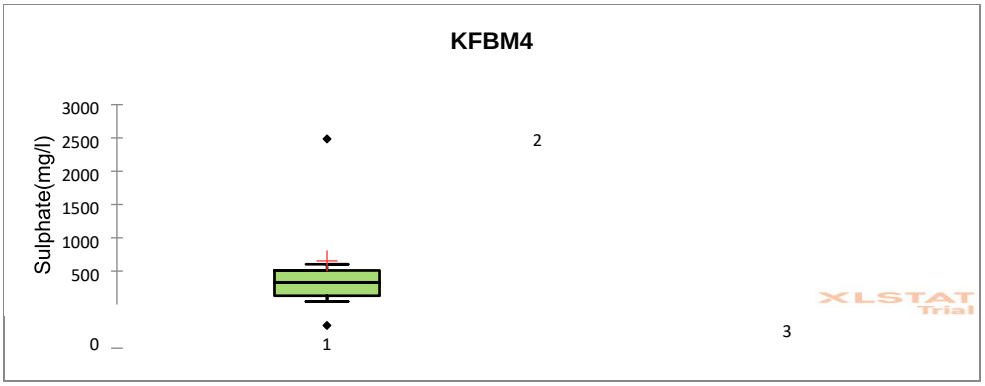
Box plots for sulphate at different sampling sites.



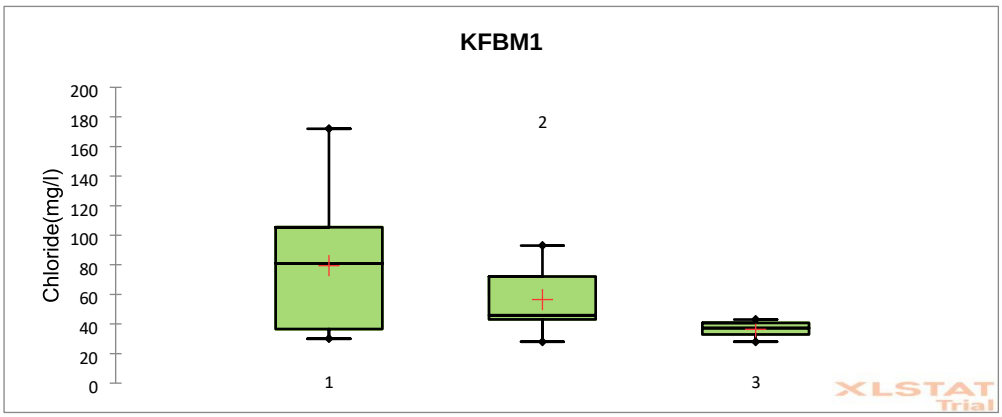


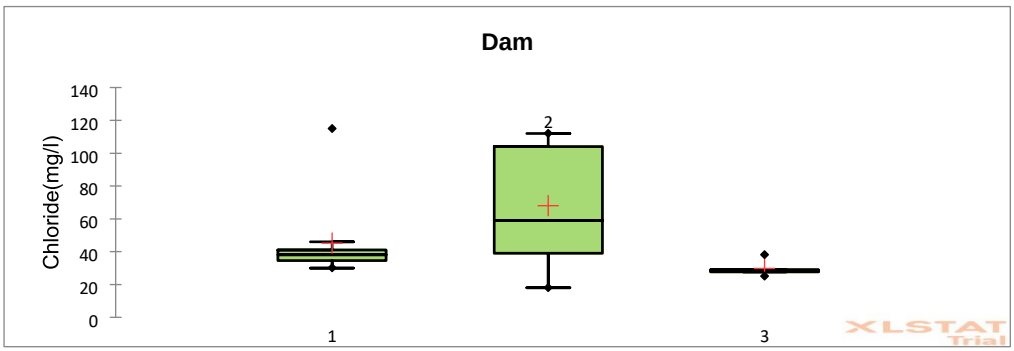


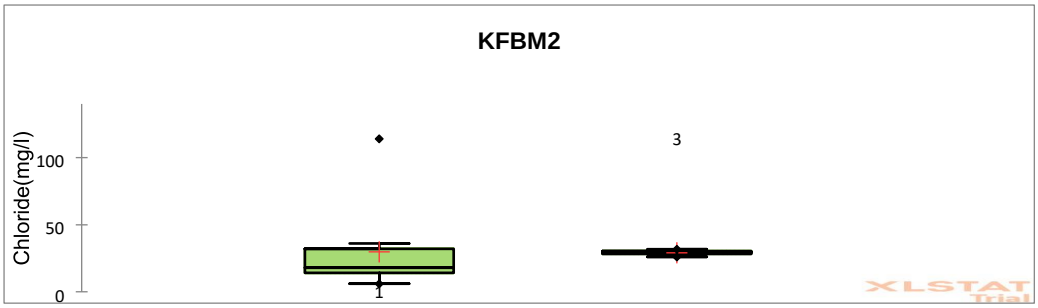


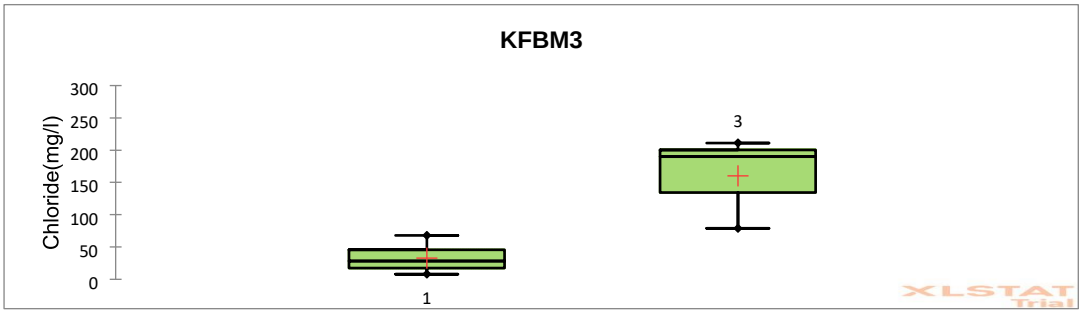


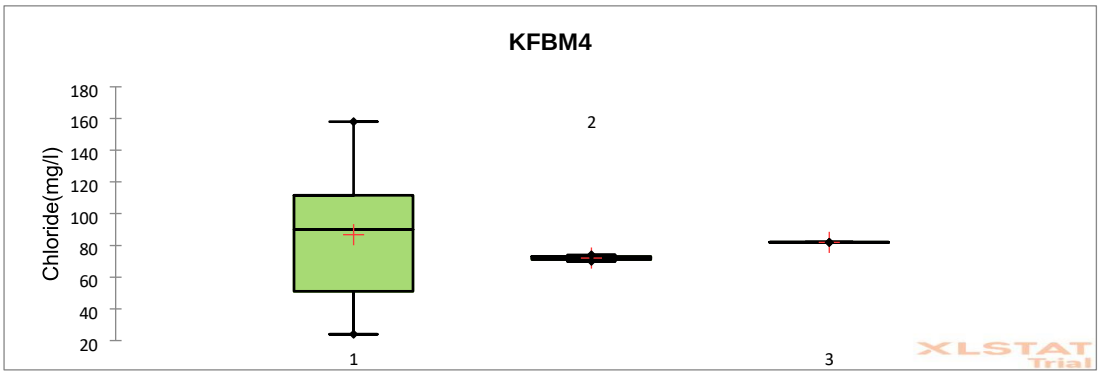
Box plots for chloride at different sampling sites.



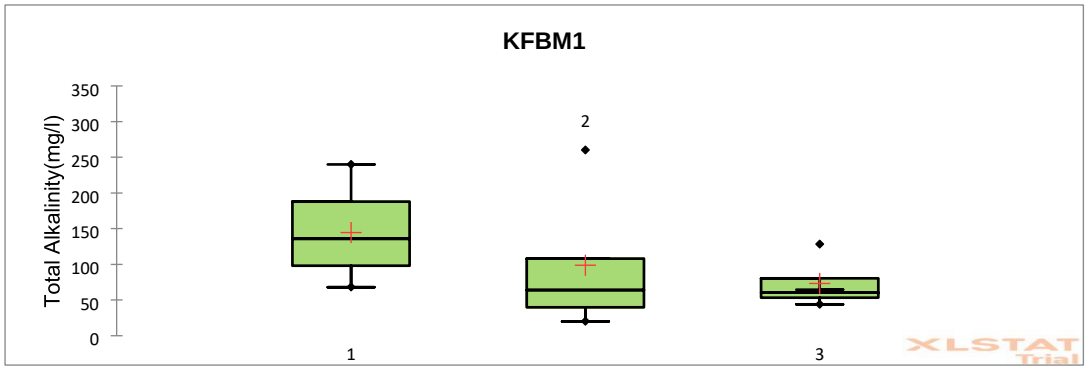

Dam
Chloride(mg/l)
140
120
100
80
60
40
20
0
1
2
3
XLSTAT
Trial

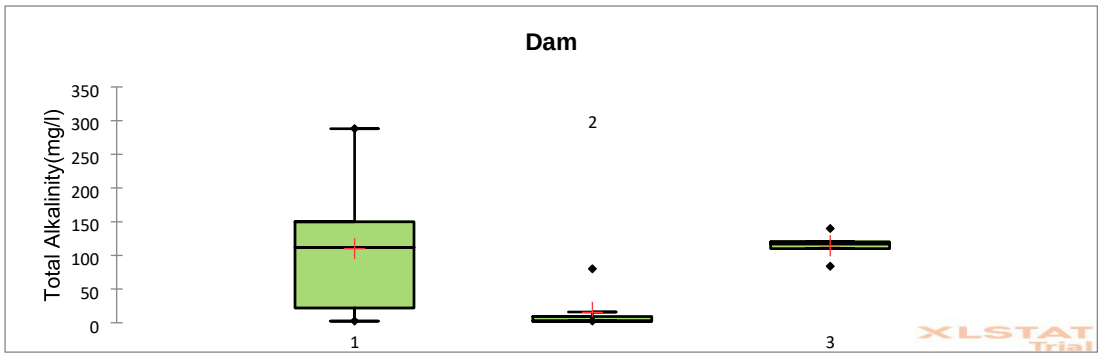

KFBM2
Chloride(mg/l)
100
50
0
1
3
XLSTAT
Trial

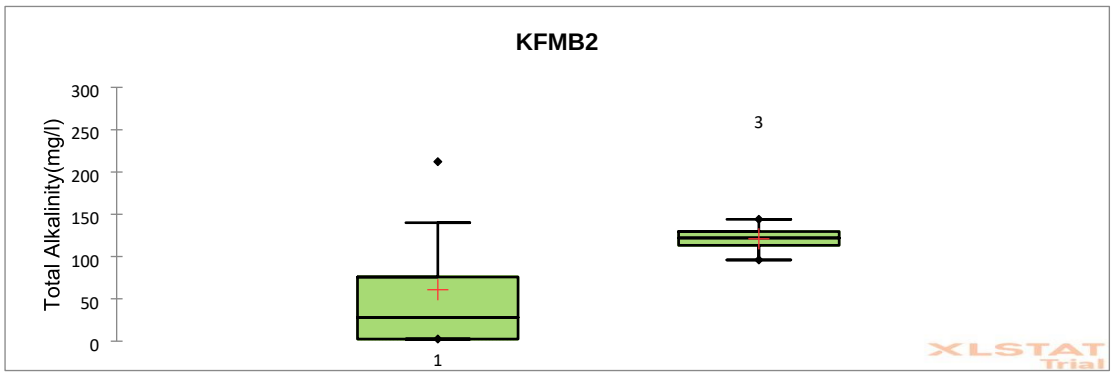

KFBM3
Chloride(mg/l)
300
250
200
150
100
50
0
1
3
XLSTAT
Trial

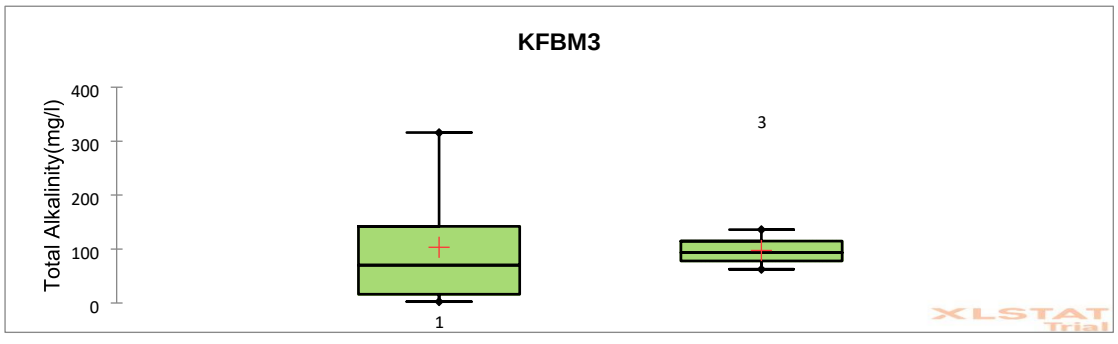

KFBM4
Chloride(mg/l)
180
160
140
120
100
80
60
40
20
1
2
3
XLSTAT
Trial

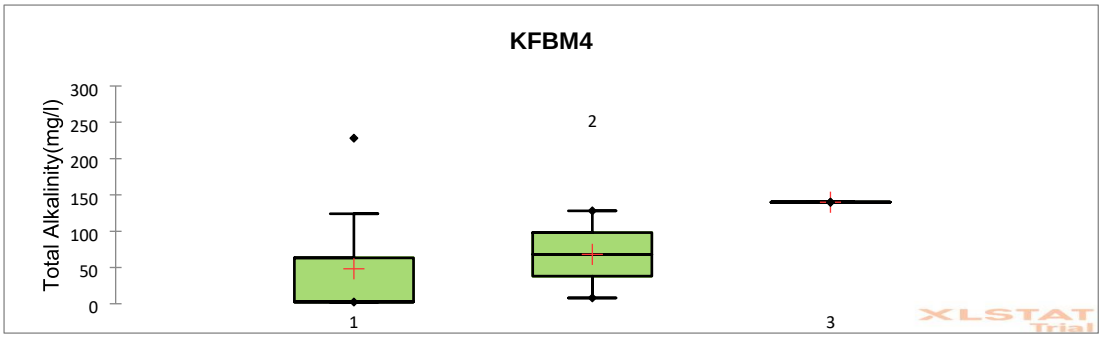
Box plots for total alkalinity at different sampling sites.



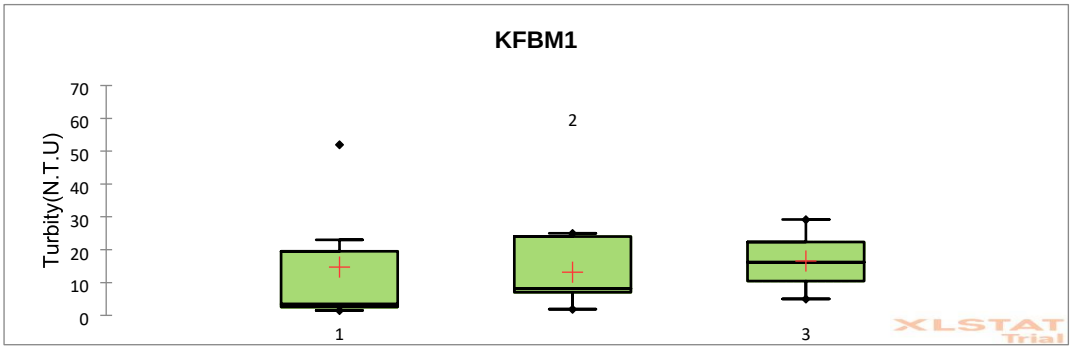


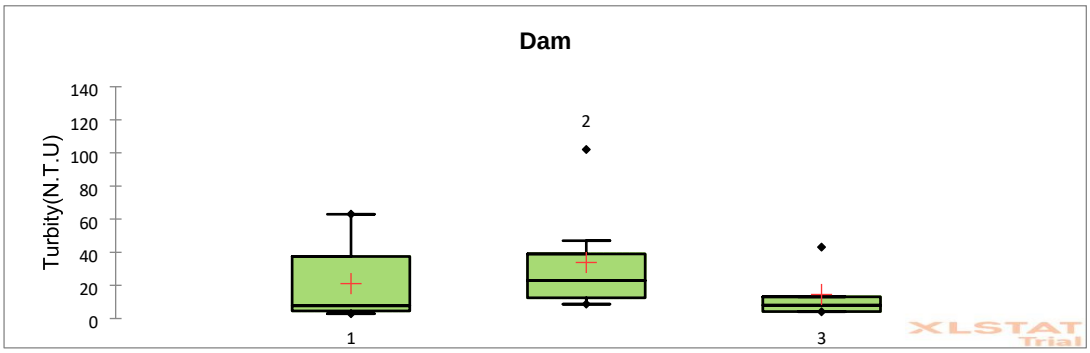


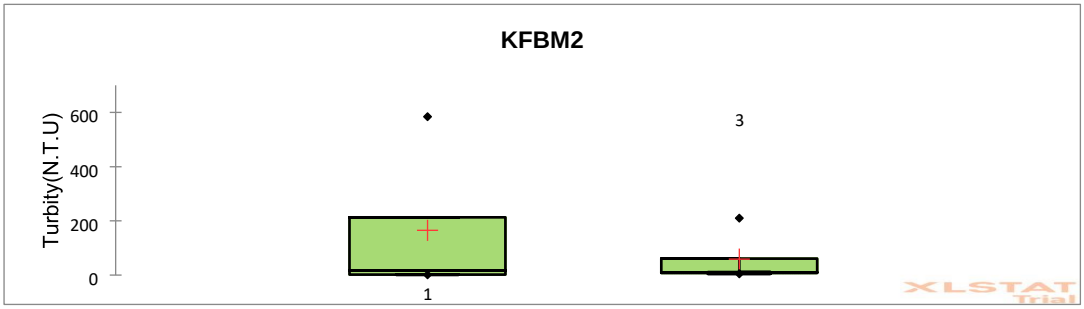


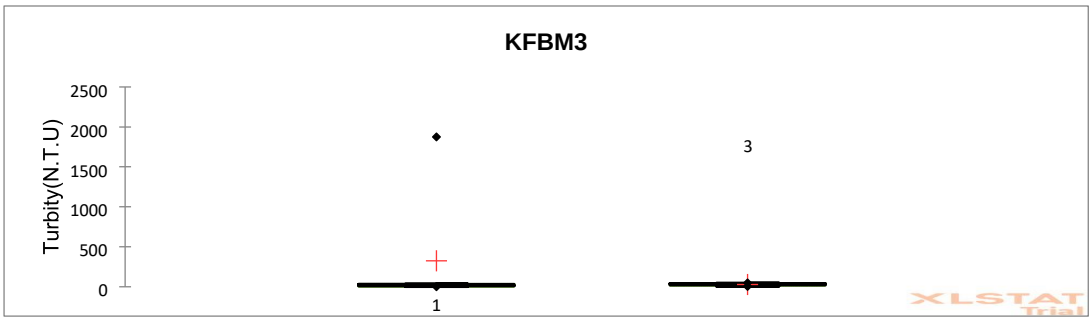


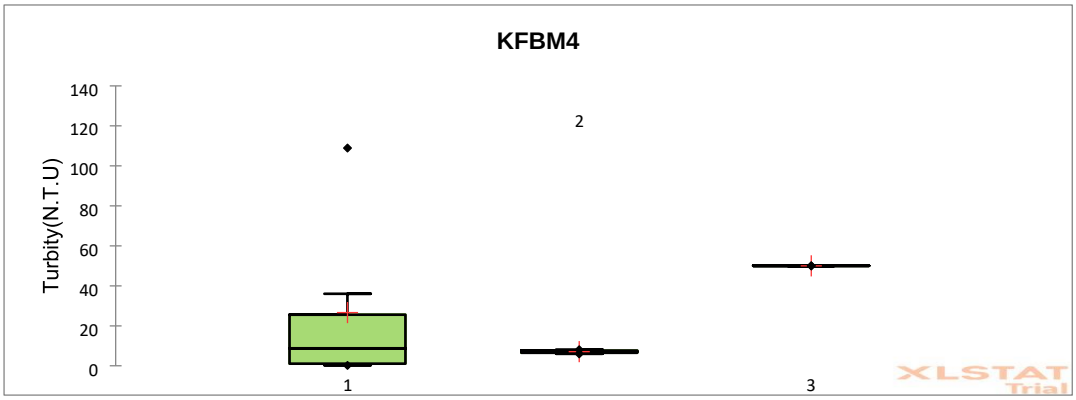
Box plots for turbidity at different sampling sites.



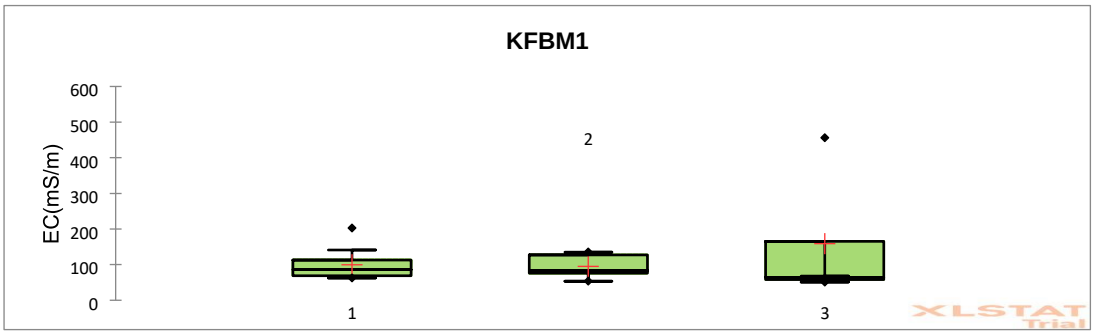


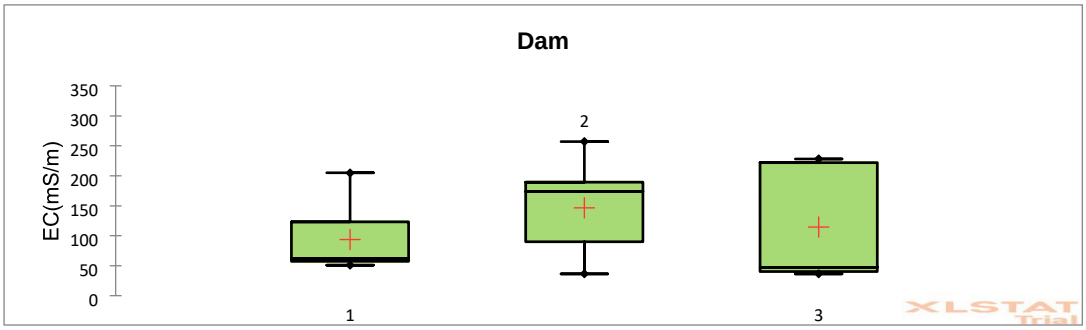


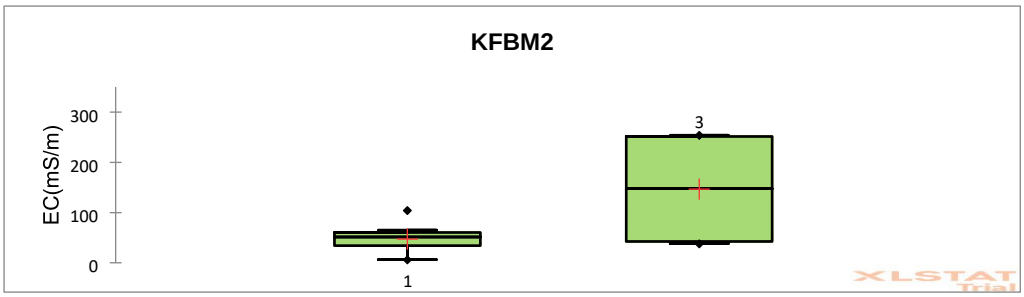


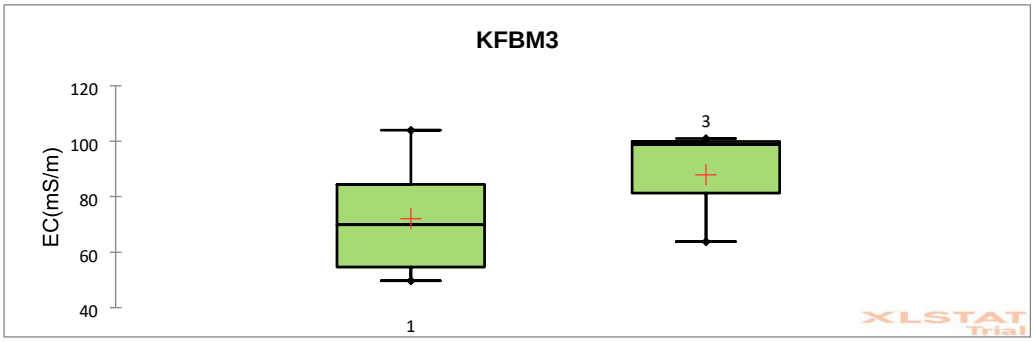


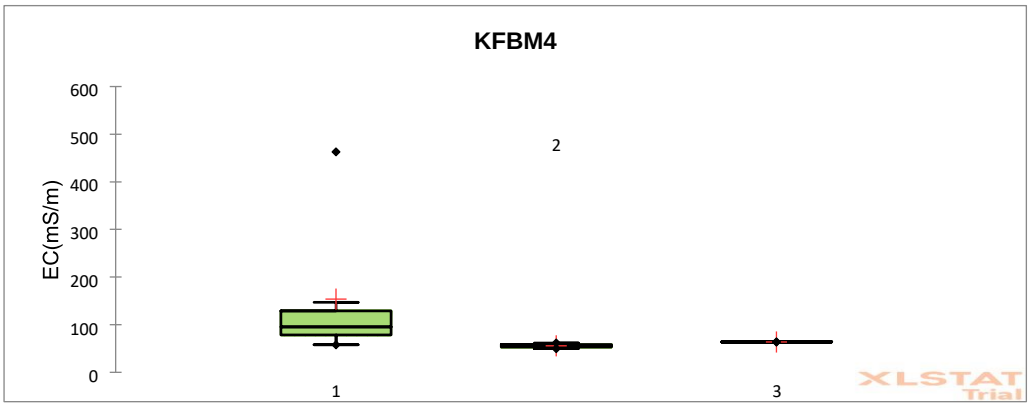
Box plots for EC at different sampling sites.



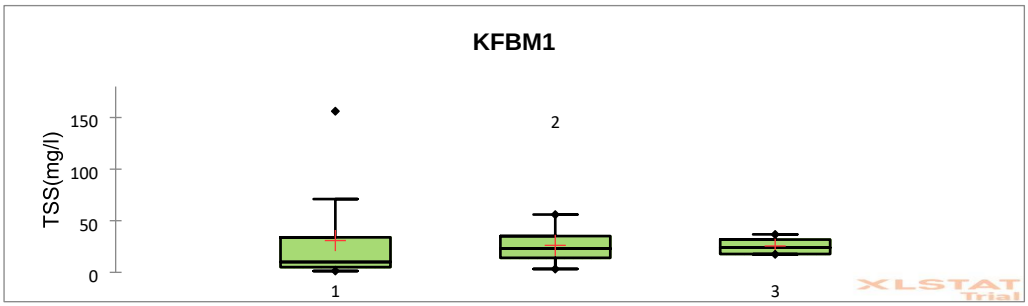


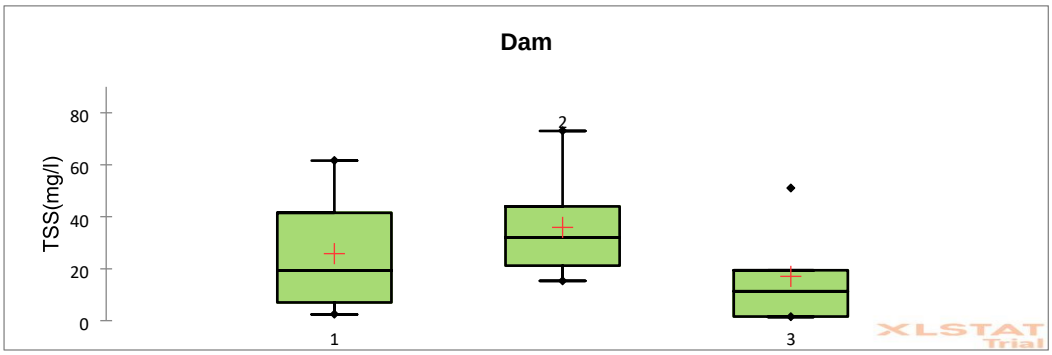


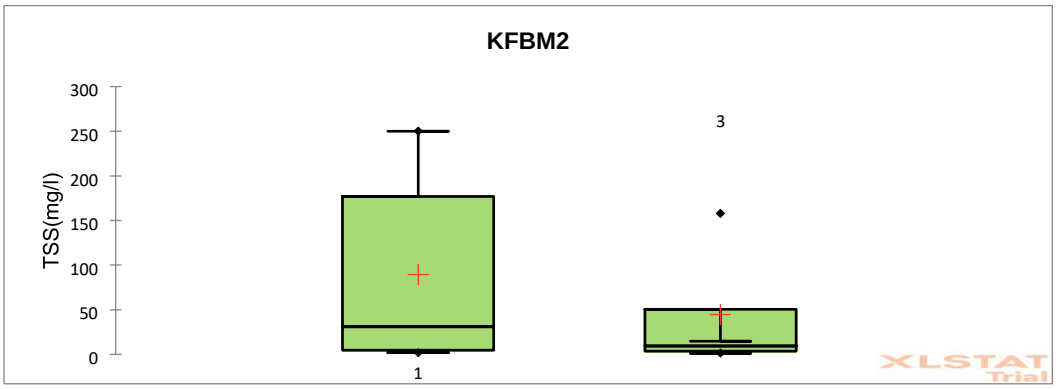


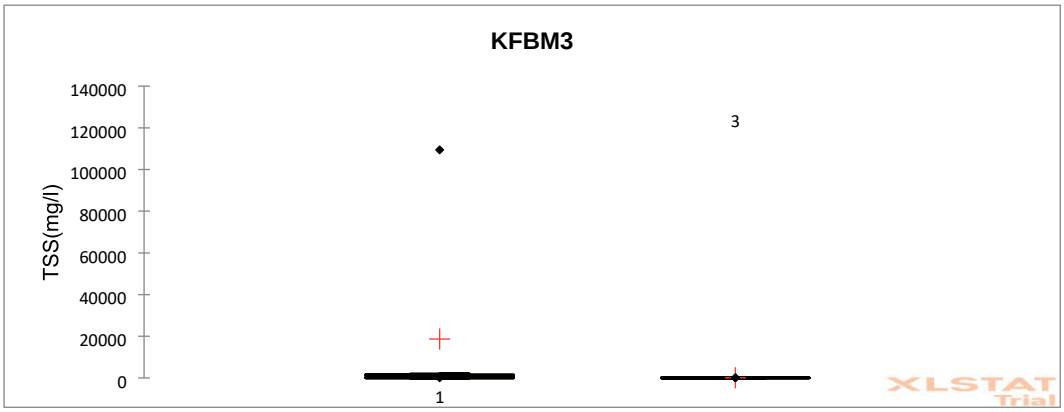


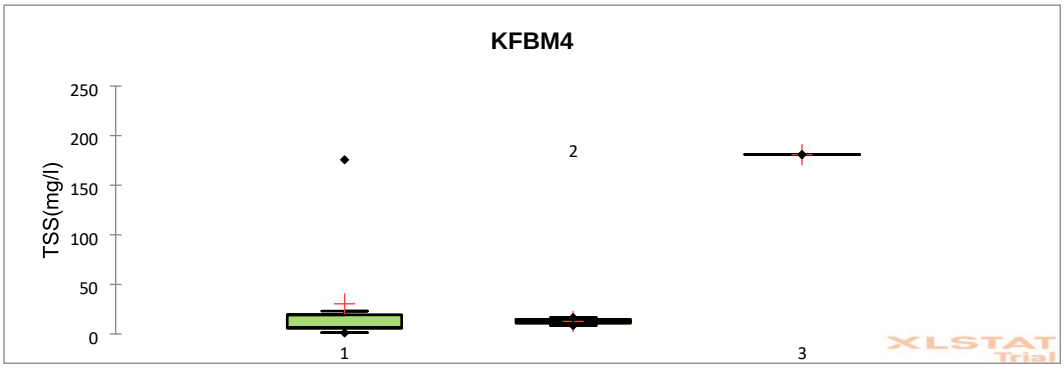
Box plots for TSS at different sampling sites.



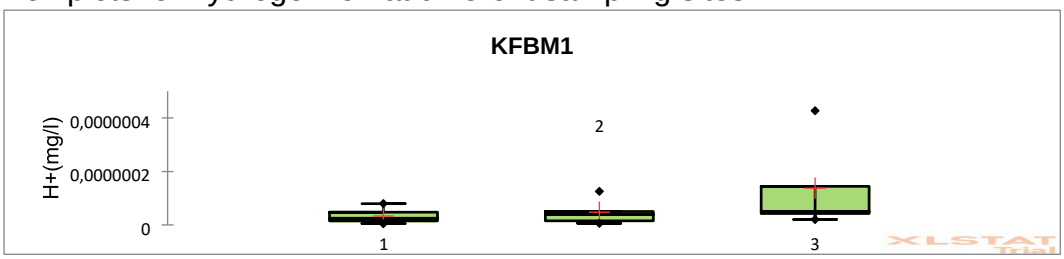

Dam
TSS(mg/l)
80
60
40
20
0
1
2
3
XLSTAT
Trial

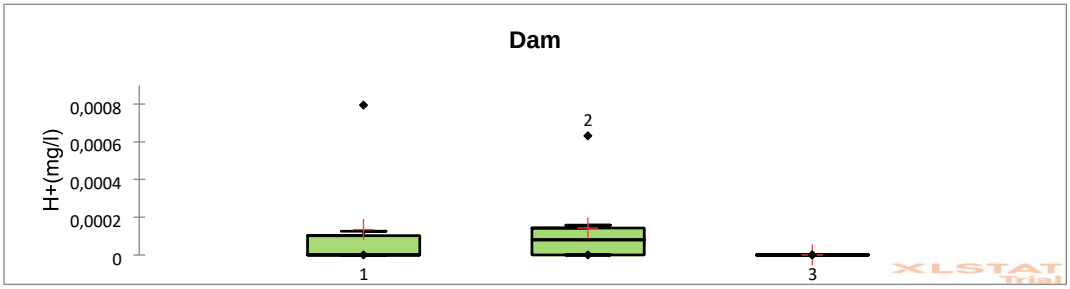

KFBM2
TSS(mg/l)
300
250
200
150
100
50
0
1
3
XLSTAT
Trial

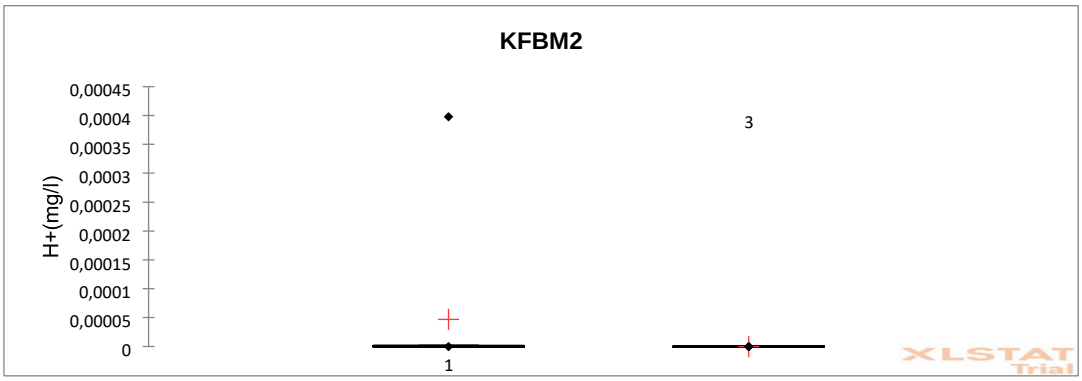

KFBM3
TSS(mg/l)
140000
120000
100000
80000
60000
40000
20000
0
1
3
XLSTAT
Trial

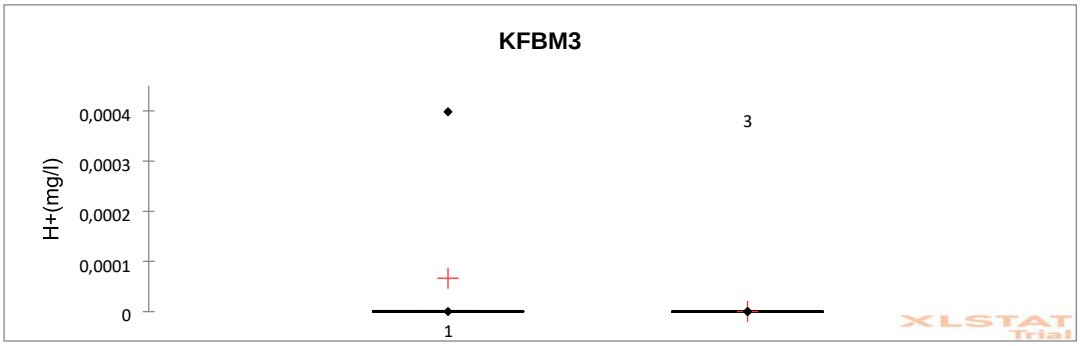

KFBM4
TSS(mg/l)
250
200
150
100
50
0
1
2
3
XLSTAT
Trial

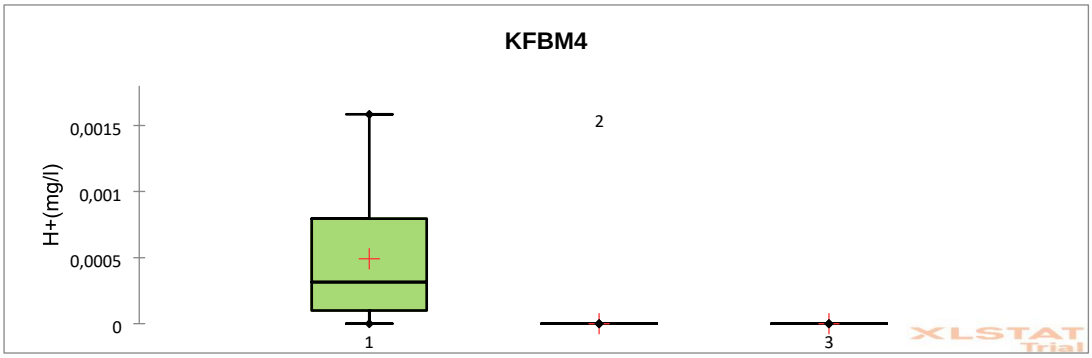
Box plots for hydrogen ion at different sampling sites.





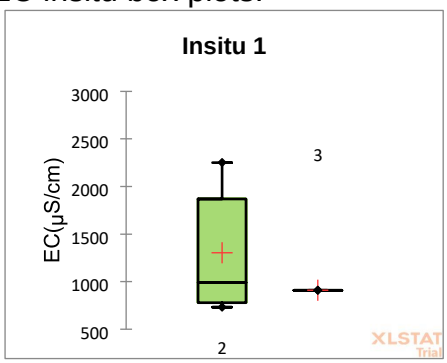


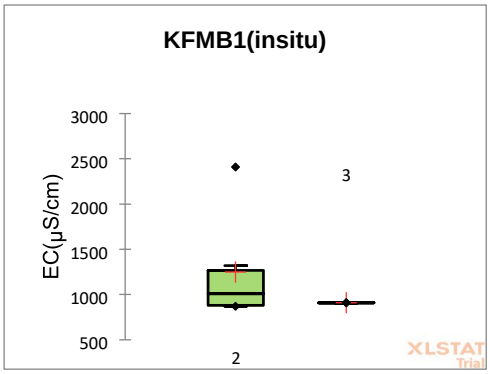


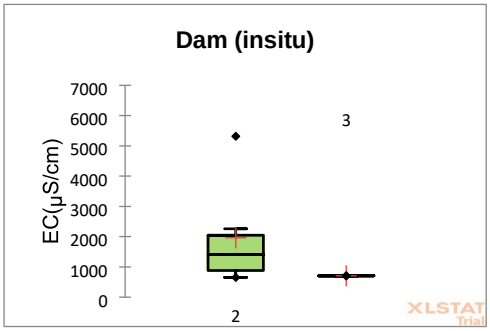

KFBM4
H+(mg/l)
0,0015
0,001
0,0005
0
1
2
3
XLSTAT
Trial

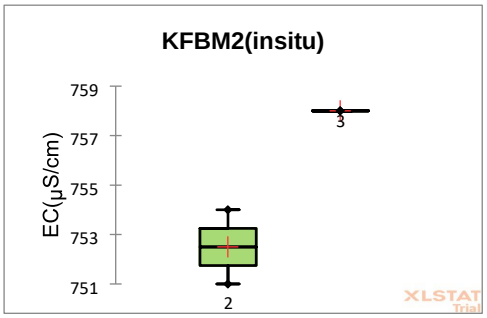
In situ Box plots insitu box plots for different insitu measurements.

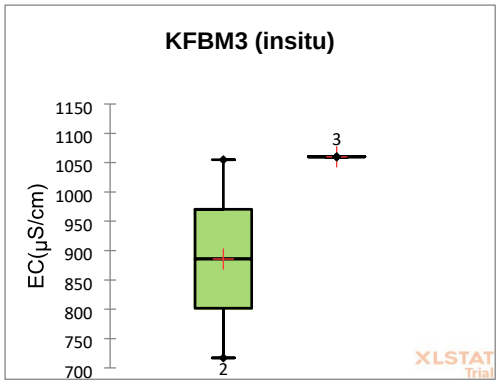
EC insitu box plots.



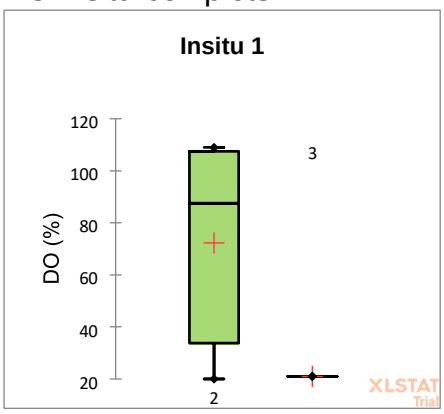


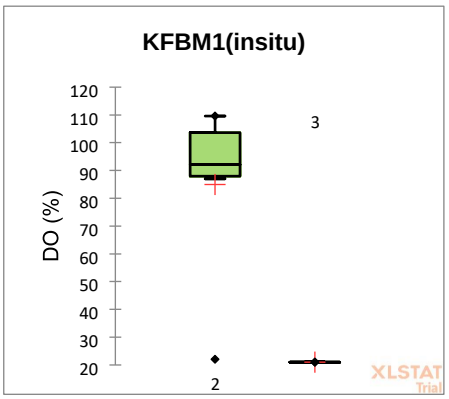


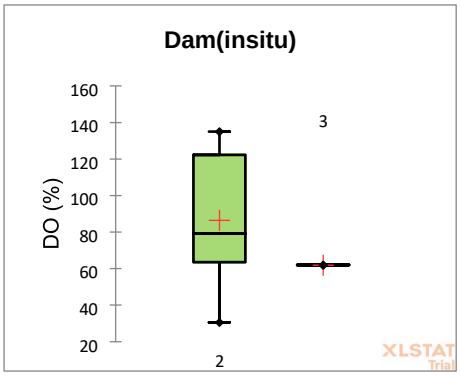


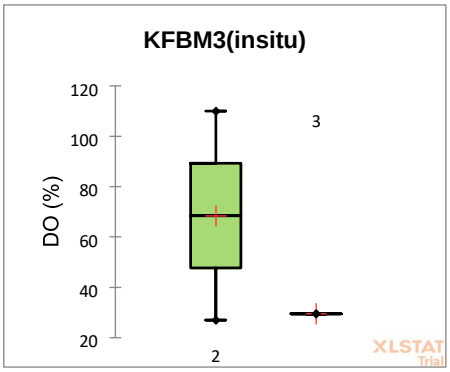


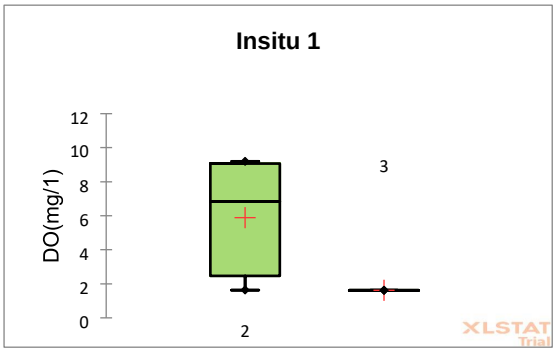
DO insitu box plots

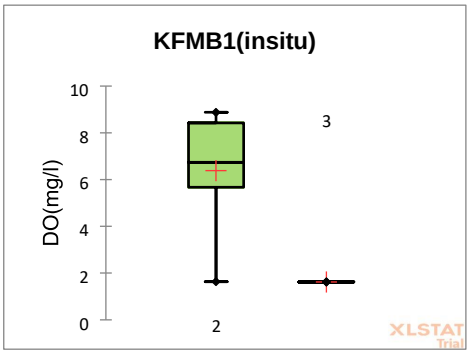


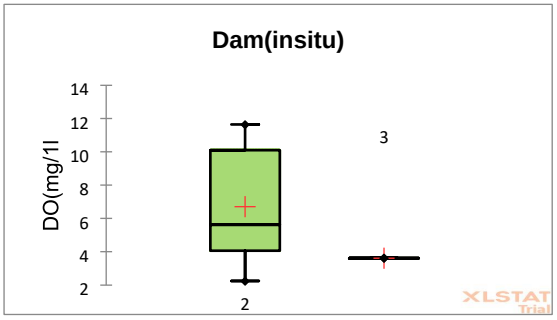


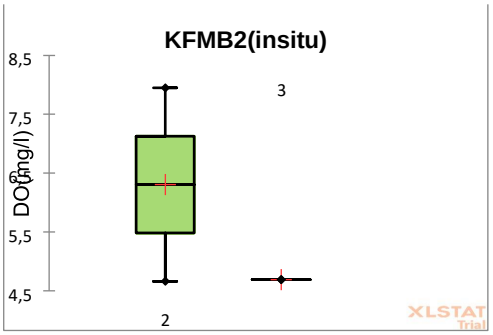


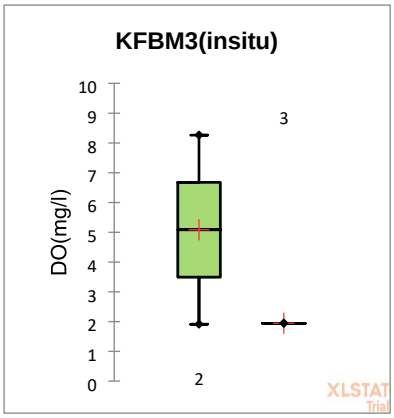




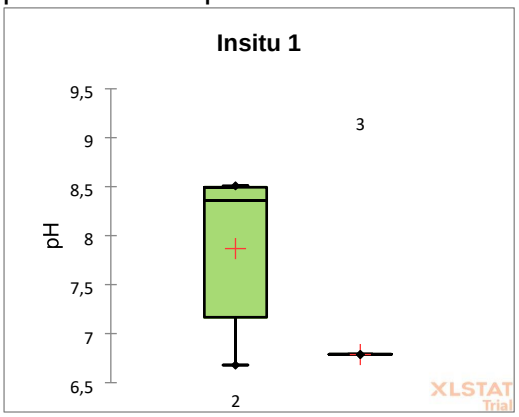


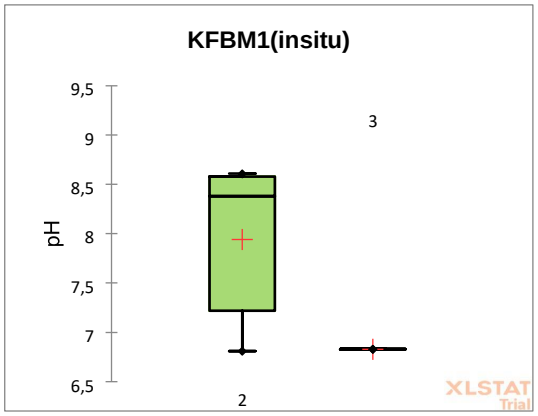


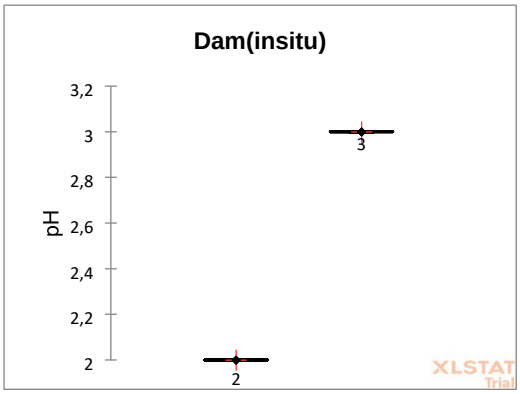


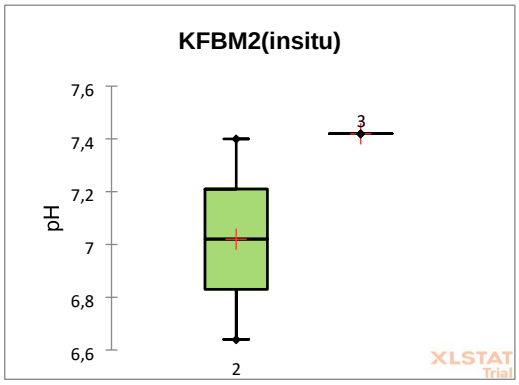


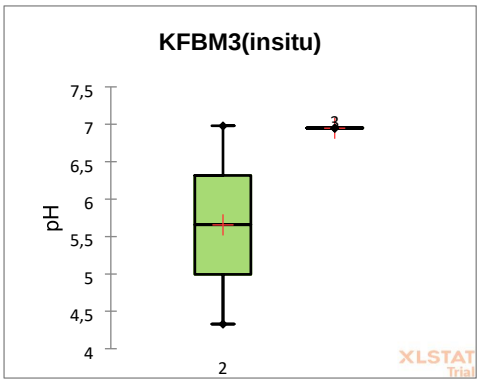
pH insiitu box plots



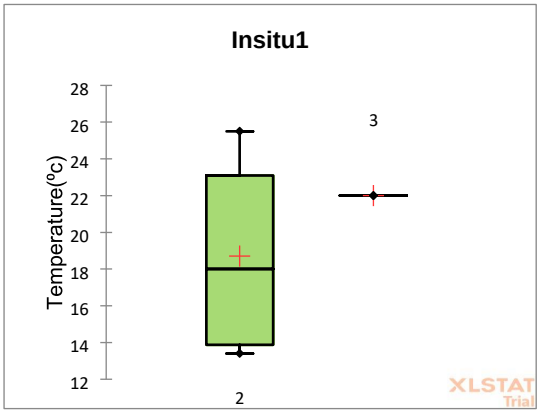


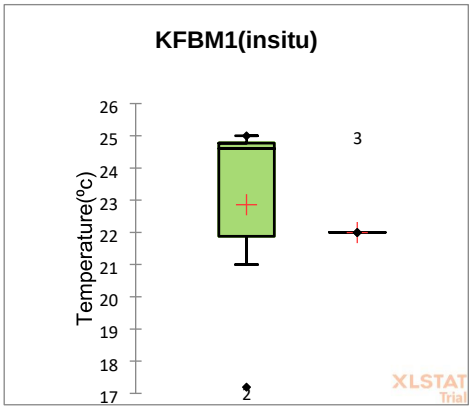


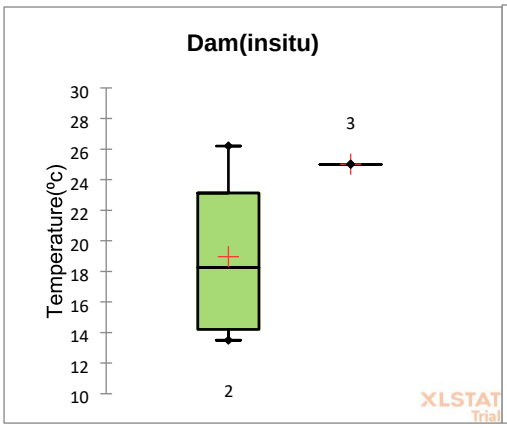


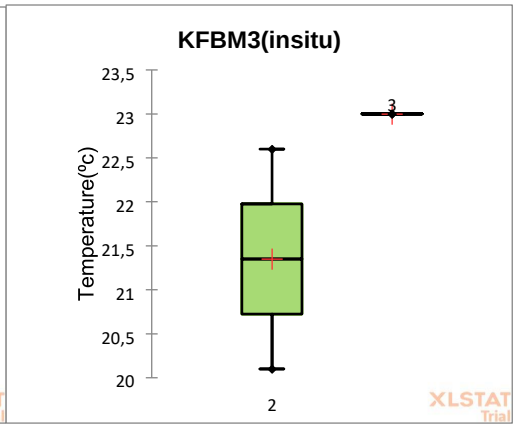


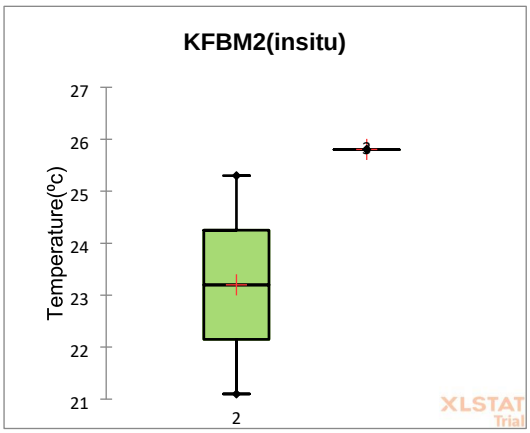
Temperature insitu box plots











Appendix H: Rainfall data

date	rainfall	date	rainfall	date	rainfall
January	39	Jan-19	148	Jan-20	128
February	60	Feb-19	136	Feb-20	64,9
March	107	Mar-19	0	Mar-20	12,8
April	22	Apr-19	0	Apr-20	103,5
May	18	May-19	0	May-20	0
June	0	Jun-19	0	Jun-20	4,6
July	0	Jul-19	0	Jul-20	0
August	14	Aug-19	0	Aug-20	0
Septemberer	0	Sep-19	0	Sep-20	0
October	85	Oct-19	19,2	Oct-20	91,8
Novemberer	63	Nov-19	266	Nov-20	137,8
Decemberer	88	Dec-19	261,1	Dec-20	558,2