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A PRELIMINARY INVESTIGATION OF THE POTENTIAL COSTS AND BENEFITS OF REHABILITATION OF THE NAKIVUBO WETLAND, KAMPALA

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PREFACE AND ACKNOWLEDGEMENTS

This study forms one of the case studies of a larger study on Green Urban Development commissioned by the World Bank and led by AECOM. Anchor Environmental Consultants (Anchor) was subcontracted by AECOM to undertake case studies in three cities: Kampala (Uganda), Dar es Salaam (Tanzania) and Durban (South Africa). Each city was consulted as to the focus of the case study. In the case of Kampala, the city requested a study to evaluate the potential costs and benefits of rehabilitating the Nakivubo wetland to enable the development of a recreational park.

The study was led by Dr Jane Turpie of Anchor Environmental Consultants (Anchor). Dr Liz Day of Freshwater Consulting Group undertook the ecological and restoration aspects of the study, assisted by Kat Forsythe of Anchor and by Chris Roed of West Coast Engineering on the engineering and costing aspects. Gwyn Letley of Anchor and Dr. Dambala Gelo Kutela of the University of Cape Town handled the econometric analyses of the water treatment costs and recreational valuation studies, respectively, while Gwyn Letley also undertook the cost-benefit analysis. Dr. David Kyamboto of Makere University and his graduate students assisted with the household survey.

We are grateful to Roland White and Chyi-Yun Huang of the World Bank, Diane Dale, Brian Goldberg and John Bachmann of AECOM, and Timm Kroeger of The Nature Conservancy for inputs and discussions during the project planning phase, as well as to the inputs received from reviewers Jeff Wielgus, Mike Toman, Urvashi Narain and Glen-Marie Lange of the World Bank.

We are also grateful to the Kampala Capital City Authority (KCCA) for their interest and support of this project - in particular to Najib Lukooya Bateganya for assistance with meetings and data collation. We are also grateful to Susan Namaalwa and Stephen Tumwebaze of the National Water and Sewerage Corporation (NWSC) for provision of water treatment works data and for a tour of the Ggaba water treatment works. Thanks also to the citizens of Kampala who willingly participated in the household survey.

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EXECUTIVE SUMMARY

Rapid urbanisation threatens existing natural areas within cities and the ecosystem services that they provide. This case study forms part of a broader study that investigates the benefits of investing in Green Urban Development in African cities. The Kampala case study focuses on the Nakivubo wetland, one of several large wetland systems that occur within and around the city. This wetland has become severely degraded by polluted water from the city that passes through the wetland before entering Inner Murchison Bay. In the late 1990s, it was ascertained that the water treatment service performed by the wetland yielded a significant cost saving for the nearby Ggaba Water Treatment Works. However, as the city has continued to grow, pollution flows into the wetland have increased significantly, the size and assimilative capacity of the wetland has decreased, and the costs of water treatment have increased. These concerns, as well as the increasing shortage of public open space areas in the city that are available for recreation, have led to the city's consideration of the rehabilitation of the Nakivubo wetland, both to restore its functioning and to create the opportunity for a recreational area with associated possibilities for economic development. This study provides a preliminary evaluation of the state of the Nakivubo wetland, the potential costs and benefits of its rehabilitation and the implications for the city's expansion plans.

Based on an analysis of the current functioning and capacity of the Nakivubo wetland, a set of interventions was identified that would be needed to restore the wetland to a level where economic benefits could be realised. The primary objectives were defined as (1) effecting a measurable improvement of water quality passing out of the Nakivubo wetland into Inner Murchison Bay, (2) ensuring sustainable management of the Nakivubo wetland, (3) reducing water quality impacts on human health and (4) opening up opportunities for safe recreational use of the lower wetland. A sequential set of interventions (treatment train) was recommended to achieve these objectives, and included both infrastructure upgrades and wetland rehabilitation and conservation measures, as well as investment in recreational facilities:

Step 1. Prevent pollution at source through improved sanitation infrastructure and measures;

Step 2. Prevent residual pollution entering the wetland;

Step 3. Improve Waste Water Treatment Works (WWTW) effluent quality;

Step 4. Rehabilitate the upper wetland for secondary waste water treatment / polishing;

Step 5. Restore and protect the lower wetland; and

Step 6. Establish recreational space and facilities.

An estimate was made of the design requirements and costs of the interventions outlined above in order to inform a high level cost-benefit analysis. These took existing commitments to sanitation infrastructure improvements into account. The overall estimated capital costs amounted to $53 million, with ongoing maintenance and operating costs of $3.6 million per annum. In addition, the cost of forgone agricultural production in the wetland area was estimated to be $141,500 per year.

The benefits associated with wetland restoration that were included in the cost-benefit analysis were water treatment cost savings and recreational benefits.
It was estimated that a reduction in phosphorous concentrations in the lower wetland as a result of the restoration interventions would have significant impacts on the chemical costs of water treatment, amounting to a saving of some $1.143 million per year. The overall recreational benefit was estimated using survey-based revealed- and stated-preference methods, which suggested that the welfare gains to households in Kampala would potentially amount to about $22.05 million per annum.

The estimates derived in this study suggest that the interventions would have an overall net benefit. Using a discount rate of 6%, the net present value of the project over 15 years was estimated to be $80 million (Table 1). This was further tested under varying assumptions of costs, benefits and discount rate. Under the worst case scenario (upper bound estimates of costs, lower bound estimates of benefits), the Net Present Value (NPV) was negative at discount rates of 6% and 9%. The internal rate of return (IRR) was estimated to be 20%, but sensitivity analysis yielded a range of 4 to 34%.

Table 1 Results of the cost-benefit analysis

Net present value (US $ millions)	Discount Rate		
	3%	6%	9%
Best	220	158	83
Base estimate	121	80	51
Worst	4	-13	-24

The following key messages emerge from the study:

1: Wetlands have limited capacity to solve urban pollution problems
Nakivubo wetland no longer has any positive impact on the ecological condition of Inner Murchison Bay, with the lower wetland and bay having reached a hypertrophic state that is characterised by frequent, often toxic, algal blooms, as well as being severely contaminated with pathogens that carry a risk to human health. Wetlands cannot substitute for wastewater treatment works and can only improve the quality of low volumes of moderately polluted water.

2: Rehabilitation will be costly but worthwhile
As is often the case in the rehabilitation of natural systems, the financial costs of the required interventions can be expected to be high. Many of these interventions could be regarded as obligations that should be met irrespective of the restoration of wetlands, for the mere purpose of providing essential services required for maintaining human health and dignity. While these investments would not be particularly cost-effective in terms of the impacts on water treatment costs alone (given the investment that has already been made in a new plant further afield), taken together with their potential recreational benefits, they are likely to be worthwhile. This is not surprising, given the dire lack of managed green open space available to Kampala residents for outdoor recreation. As the economy of Uganda continues to develop and incomes improve, the demand for these kinds of amenities is only set to increase. Such benefits would also potentially be reflected more tangibly in property values in the area. In addition, the restoration of wetlands and water quality in Inner Murchison Bay would be likely to have benefits for biodiversity and fisheries.

3: There are no shortcuts
For the rehabilitation effort to be successful, implementation of all the interventions outlined in this study is required. The order of implementation is not particularly important as long as they are all implemented. For example, Step 2 could be implemented as a stopgap while Step 1 is finalised. In addition, the sooner that work begins on the wetland-edge filter strips and on wetland rehabilitation, the lower the risk of further human encroachment into the wetland when it comes to the implementation of this step, because people will not be able to settle or carry out agriculture in the re-established permanently wet areas.

4: This will require fundraising and co-ordination
This study estimates that a total initial expenditure of at least $53 million is required in order to achieve the goals outlined, depending on the actual shortfall in sanitation infrastructure. Given recent and planned expenditure in the city, the Nakivubo rehabilitation may only be feasible with a significant contribution of donor funding. Separating the issues and addressing sanitation first will lower the risks and make funding for direct wetland rehabilitation work more accessible.

A detailed plan will need to be drawn up. The actions described in this report pertain to multiple government institutions. In order for effective action to take place, coordination between these bodies is necessary. It will also be necessary for one of them, probably the National Water and Sewerage Corporation, to take the lead in this co-ordination, with National Water and Sewerage Corporation focusing on the bulk of the investments required including treatment wetlands, Kampala Capital City Authority focusing on the investment in recreational facilities, and the Ministry of Natural Resources focusing on the management of the remaining natural wetlands. Similarly, there will need to be clarity regarding the responsibility and capacity of different institutions to undertake the ongoing oversight and management actions.

5: Avoid a repeat experience
There are important lessons to be learned from this study. Considerable environmental and economic costs have been incurred by delaying investments that are inevitably required. This potentially holds true for the many wetland areas that are about to become engulfed by the growing city of Kampala. Kampala is the second fastest growing city in Eastern Africa with an annual population growth rate of 3.9%. The population of the Greater Kampala Metropolitan Area (GKMA) is projected to grow from just over 3 million in 2012 to 13 million in 2040. Most wetlands within the existing urban area have already been effectively lost. Without proactive interventions, the wetlands outside of the present urban core will also be destroyed and the cumulative impacts on Murchison Bay and any economic activities around the bay, including the viability of a future waterfront development, could be significant.

Thus the following recommendations should be considered:

1. **Sanitation measures** need to keep ahead of the growing urban population, and until this is the case, runoff from areas that are not well serviced needs to be diverted to a WWTW;

2. **Water quality standards** for waste water treatment need to be increased and enforced, and investments need to be made in the technological innovation required to deal with this;

3. There needs to be stricter regulation and **control of industrial discharges**. This should form part of a review into industrial effluent guidelines and current practices;

4. **Legal protection of wetlands** needs to be strengthened, and tough and/or innovative measures need to be taken to prevent the reclamation, farming and settlement of wetland areas;

5. Construction of roads and railways through wetlands should be avoided, or at least be done in such a way as to **minimise impacts on hydro- and sediment dynamics** and aesthetics;

6. **Monitoring programmes** need to be established, including continuous monitoring of flows into the wetland, and monthly measures of water quality of inflows and within all wetland areas in and around Kampala. Water quality monitoring data should be made readily available on an online platform for potential use by academic institutions, consultants, civil society etc. in order to encourage transparency and accountability as well as facilitate ongoing analysis and adaptive management.

One of the main challenges in achieving the above would be institutional. Greater Kampala extends well beyond the boundaries of the KCCA, which originally encompassed the entire city, and unless the KCCA area is adjusted accordingly (as has been done in other countries), the problems that will arise in a growing city will be in areas under multiple other jurisdictions. Meanwhile, it may be more pragmatic for these issues to to be managed by the relevant national institutions such as NWSC.

ACRONYMS AND ABBREVIATIONS

B

BIC Bayesian Information Criterion

BOD Biological Oxygen Demand

BWWTW Bugolobi Waste Water Treatment Works

C

CBA Cost Benefit Analysis
CFU Colony-forming Units
CL Conditional Logit
COD Chemical Oxygen Demand
CV Compensation Variation
CVM Contingent Valuation Method

D

DO Dissolved Oxygen
DWAF Department of Water Affairs and Forestry

E

EAI Environmental Assessment Institute
EC Electrical Conductivity

F

FSTP Faecal Sludge Treatment Plant

G

GIS Geographic Information System
GUD Green Urban Development

I

IMB Inner Murchison Bay
IRR Internal Rate of Return

K

KCCA Kampala Capital City Authority
KSP Kampala Sanitation Programme

L

LCM Latent Class Model
LV WatSan Lake Victoria Water and Sanitation

M

ML Mega Litre
MWTP Marginal Willingness to Pay

N

NPV Net Present Value
NTU Nephelometric Turbidity Units
NWSC National Water and Sewerage Corporation

P

PAC Poly-aluminium Chloride
PES Present Ecological State

R

RPL Random Parameter Logit

S

SBDC Single Bounded Dichotomous Choice
SD Standard Deviation
SUDS Sustainable Urban Drainage System

T

TEEB The Economics of Ecosystems and Biodiversity
TP Total Phosphorous
TSS Total Suspended Solids

U

USh Ugandan Shillings

W

WHO World Health Organisation
WTP Willingness to Pay
WTW Water Treatment Works
WWTW Waste Water Treatment Works

CONTENTS

FIGURES

TABLES

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I. INTRODUCTION

Urbanisation is taking place at an unprecedented rate in Africa, with the rate of growth often outpacing plans and the capacity of city managers to provide the necessary services. As a result, existing natural areas within cities that provide a range of ecological, amenity and engineering benefits are becoming smaller and more degraded, and problems such as flooding, air pollution and water pollution are becoming worse. These problems are likely to escalate with continued movement of the poor into cities and will be exacerbated by climate change.

In Kampala, much of the remaining natural habitat comprises wetlands that have survived because of the high risk of flooding. However, these wetland areas have become increasingly degraded as a result of pollution, reclamation for agriculture, drying out and encroachment by human settlements. Wetlands are well known for their provision of valuable ecosystem services. In particular, the papyrus-dominated Nakivubo wetland in Kampala (Figure 1) has been shown in the past to provide an important function in the amelioration of water quality in Inner Murchison Bay. Polluted water from Kampala's city central district is channelled via the Nakivubo wetland into Inner Murchison Bay, which is also the main water supply area for the city, with water being treated for domestic consumption at the Ggaba Water Treatment Plant just 3km south of the wetland (Emerton et al. 1998).

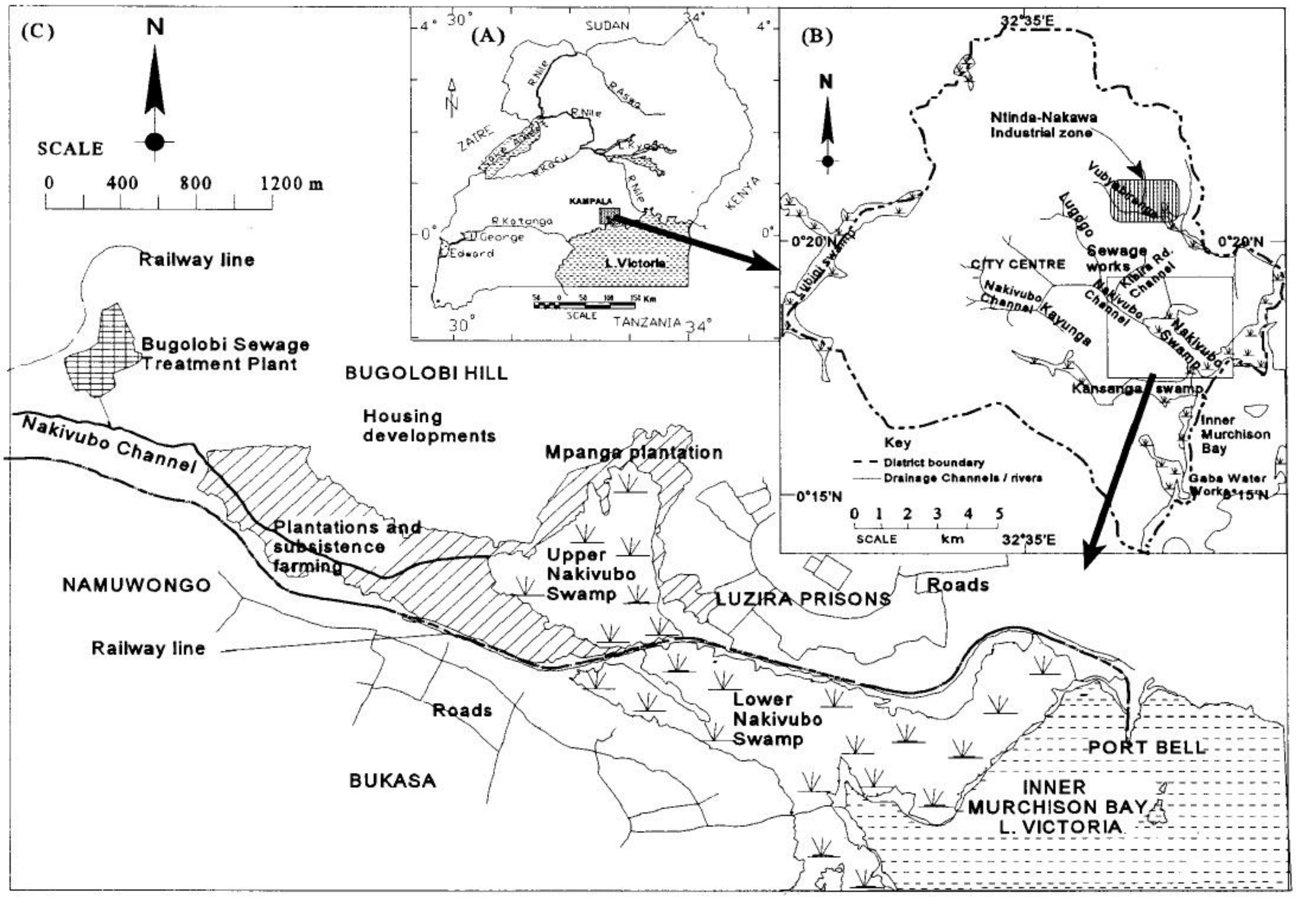

Figure 1 Map showing the location and extent (1996) of the Nakivubo wetland in Kampala
Redrawn from: Kansiime & Nalubega 1999

This polluted water comprises waste water runoff generated in residential and industrial areas, treated effluent from the main sewage treatment works, and raw sewage from slums within the catchment area (Emerton et al. 1998, Kayima et al. 2008). In the late 1990s, it was ascertained that the service performed by the wetland yielded a significant cost saving for the Ggaba Water Treatment Works (Emerton et al. 1998). However, as the city has continued to grow, waste water flows into the wetland have increased significantly, overwhelming the wetland's capacity to assimilate the excess pollutants before reaching Murchison Bay. This, as well as encroachment of informal settlements and agricultural activities in the wetland (Kansiime & Nalubega 1999) has led to increasing health risks (Stalder 2014), the deterioration of both the wetland and Inner Murchison Bay, and increasing costs of water treatment (Ooyo 2009).

These concerns, as well as the increasing shortage of public open space areas in the city that are suitable for recreation, have led to the city's consideration of a possibility of restoring some of the functions and economic value of its remaining natural assets, with a view to creating green urban recreational space and associated possibilities for economic development. One of the areas under consideration is the Nakivubo wetland, a papyrus dominated wetland system.

This study provides a preliminary ecological and economic evaluation of the potential for rehabilitation of the Nakivubo wetland system. Technical detail is provided in a series of appendices. The study provides an overview of the current status and functioning of the Nakivubo system and investigates the measures that would be required (a) to maximise its ecological capacity for removal of wastes, and (b) to restore the health of the system to the extent that would create the opportunity for the development of a recreational area in the lower wetland and adjacent lakeshore area. The indicative costs and benefits of these options are compared, and the policy implications of the findings are discussed.

II. PAPYRUS WETLANDS AND THEIR FUNCTIONING

Papyrus wetlands are associated with shallow, permanent and slow moving freshwater systems and occur extensively around the fringes of Lake Victoria (Kansiime *et al*. 2007, Van Dam *et al*. 2011). Their natural location and extent varies over time with changing lake levels (Morrison & Harper 2009). However, the papyrus wetlands around Lake Victoria are threatened by conversion to agriculture, grazing and human settlement, over harvesting and altered quantity and quality of freshwater inputs. In Kenya, iup to 50% of the papyrus wetlands along Lake Victoria have been cleared (Owino & Ryan 2007). These pressures are particularly intense in and around urban areas.

Papyrus grows in dense stands, either rooted to the substrate, or in the form of floating mats. The floating mats initially form as an extension of the rooted stands, but sections may break free to form floating papyrus rafts (Kansiime *et al*. 2007). Once these small sections are floating, they provide a nucleus for further growth and can lead to expansive vegetative mats, such as those found around Lake Victoria. Even within healthy papyrus swamps, sections of the mat will break off and float away. However, increased disturbance (for example through over-harvesting) can destabilise existing mats, leading to their more rapid fragmentation. The lower, floating portions of the wetlands have a high degree of exchange with the lake through seiches (regular, small rises in water level due to oscillations in broader lake water level) which occur on average every 135 minutes and have been estimated to exchange over 100 000 m3 of water per day in the Nakivubo wetland (Kansiime & Nalubega 1999).

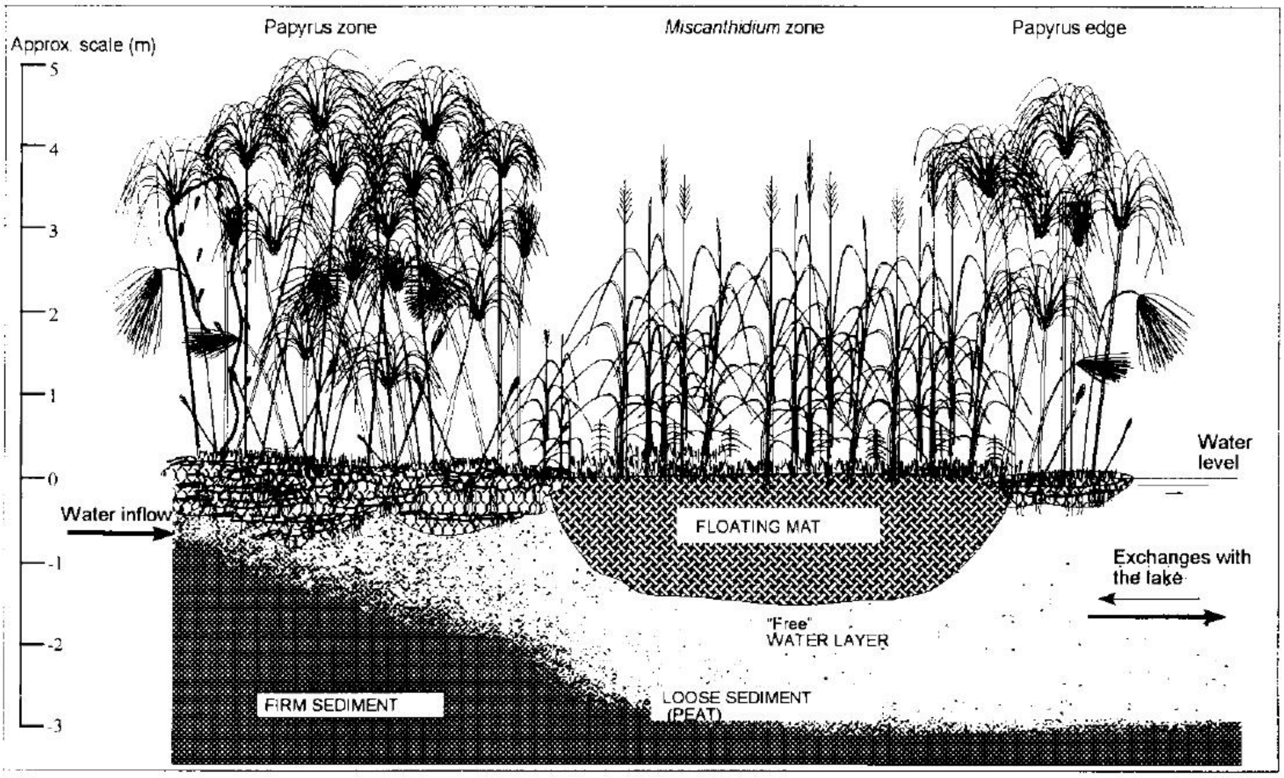

Figure 2 A typical longitudinal section of the lower Nakivubo swamps showing the dominant vegetation types and related morphological features, not to horizontal scale.

Source: Kansiime & Nalubega 1999

While papyrus wetlands are dominated by the large sedge species *Cyperus papyrus*, other species are often also present in particular zones of the wetland (Figure 2). Within Lake Victoria, the wetland grass *Miscanthidium violaceum*, is the next most abundant wetland plant species. While normally occurring on the fringes of wetlands, *Miscanthidium* can also form floating mats in deeper water.

The position of papyrus wetlands in the landscape means that they are important both in terms of their influence on water quality entering the lake, and as sheltered and productive refugia for aquatic biodiversity. Where they are adequately protected, papyrus wetlands are important for biodiversity and provide habitat for a suite of highly specialised and in many cases threatened species that are adapted to live within these unique environments. Such species include the sitatunga antelope *Tragelaphus spekei,* crested crane (Uganda's national bird), papyrus yellow warbler *Chlrorpeta gracilirostris* and papyrus gonolek *Laniarius mufumbiri* (Owino & Ryan 2007). The papyrus wetlands within the Lake Victoria system also provide important refugia for juvenile fish of species such as tilapia which constitute an important fishery within Lake Victoria (Balirwa 1995, Kiwango & Wolanski 2008).

While healthy wetlands are used to harvest papyrus and for fishing and hunting, the capacity of the wetlands to supply these resources and to provide a nursery service for lake fisheries is linked to their ecological condition. The most well-known ecosystem service provided by papyrus wetlands around Lake Victoria is "water quality amelioration", or "water treatment". This means that polluted water entering the wetlands is cleaned up to some extent before it passes into Lake Victoria.

Water entering wetlands from urbanised catchments in many African and other countries generally has elevated amounts of sediments, nutrients and pollutants from industrial effluents, as well as treated and, in many areas, untreated sewage and other wastes. Excess nutrients can stimulate algal and other plant growth in aquatic ecosystems, potentially leading to a deterioration in aquatic ecosystems (e.g. reduced biodiversity, possible toxicity, low concentrations of dissolved oxygen as a result of high levels of decomposition of plant material, poor habitat quality and the knock-on effects of these issues), while heavy metals and pathogens pose a risk to both natural wetland-associated fauna and flora and to human health. Polluted water flowing into wetlands is slowed down as it spreads out into the wetlands and passes between plants, allowing sediments to settle out, nutrients to be assimilated and pathogens to be destroyed by UV light (see Appendix 1 for more information on water quality measures and Appendix 2 for a detailed description of how wetlands improve water quality).

The ability of wetlands to perform water quality amelioration services depends on many factors, including the flow of water through them (hydraulic efficiency), their vegetation and management. It is very important to understand that there is an upper limit to the amount of pollution that a wetland can remove, as well as to the amount of pollution that can be added to a wetland without having a significant impact on its functioning and biodiversity.

III. THE DETERIORATION OF THE NAKIVUBO WETLAND

In its natural state, the Nakivubo wetland would have been dominated by perennial papyrus swamp, with the swamp area extending much further up the wetland than now. However, the wetland has undergone massive changes with the expansion and growth of Kampala. A railway line was constructed across the wetland from Port Bell to the city centre in 1923, resulting in the gradual infilling and drying out of the upper parts of the wetland. This process would have been accelerated by the construction of channels in the 1950s to carry waste water from the city, by the manipulation of the wetland drainage for small-scale farming, and the concentration of surface flows through a single culvert under the railway line. By the 1990s, the swamp vegetation was largely confined to the lower wetland (i.e. below the railway line)[1]. The drying of the upper wetland has probably also contributed to further degradation as a result of the establishment of unserviced informal settlements along its margins, and increasing cultivation (mainly cocoyams).

The original extent of the swamp area was estimated to be over 500 ha, but this had been reduced to about 400 ha by 1955. Taylor (1991) estimated the area of natural vegetation (the swamp) to be about 280 ha in 1990, while Kansiime & Nalubega (1999) estimated 190 ha less than a decade later. Based on Google Earth imagery, we estimated that the current (2015) functional area now only covers about 90 -91 ha (Figure 3; see Appendix 3 for time series). While there was a central section of wetland vegetation until the mid-1990s, the upper Nakivubo wetland was almost entirely under cultivation by 2000. A recently-published study by Isunju & Kemp (2016) which is based on more detailed satellite data analysis suggests that 62% of wetland vegetation was lost between 2002 and 2014, mostly attributable to crop cultivation. In recent years, the lower wetland has begun to break up, likely as a result of the intensive use of this area for agriculture. By mid-2015, a large section of *Miscanthidium* had broken away as a result of agricultural activities.

At the same time, increasing urbanisation has increased the volume of flows passing down the Nakivubo channel as a result of increased rate of runoff and generation of large volumes of waste water. Pollution enters the wetland mainly via the Nakivubo channel, which receives contaminated runoff and litter from poorly-serviced urban and industrial areas abutting the channel, and both treated and untreated sewage effluent from the Bugolobi Waste Water Treatment Works (WWTW). In addition, the wetland receives treated sewage effluent from the Luzira Prison and contaminated runoff from the settlements immediately around the wetland. During the rainy season, the channel blocks with litter and other waste and tends to spread widely across the surrounding area, comprising extant and former, now largely cultivated, portions of the Nakivubo wetland (Stalder 2014). More information on pollution inputs is given in Appendix 4.

Current levels of pollution in the wetland are hazardous for human health. The drainage channels have high levels of human excreta, and expose downstream users to large loads of parasitic nematodes and faecal bacteria. In addition they impact on wetland and lake ecological function. High loads of organic material, as well as contaminated sediments and nutrients, result in deteriorating ecological conditions (particularly reduced dissolved oxygen) in the lower Nakivubo wetland. This further impacts on lake biota, such as fish populations, while high concentrations of orthophosphates entering the Murchison Bay area further increase plant productivity, contributing to phytoplankton blooms and their associated aesthetic and human health effects and costs of treatment for water supply.

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[1] The only detailed studies of the vegetation of the wetland were carried out in the mid-1990s (Kansiime & Nalubega 1999). By then, only small areas of papyrus swamp were recorded in the upper wetland and the remaining lower wetland was dominated by papyrus (floating as well as rooted) and *Miscanthidium* grass.

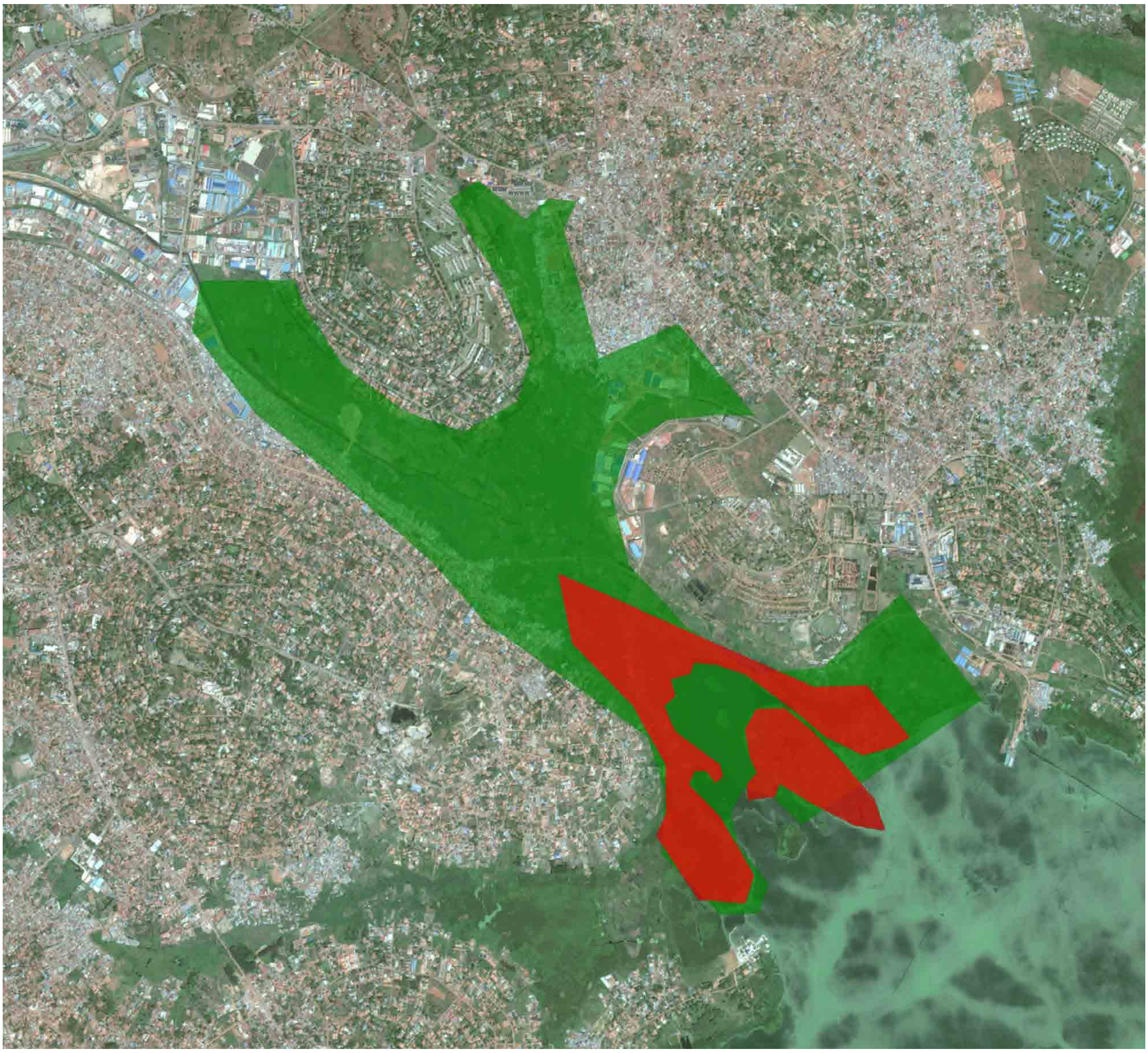

Figure 3 Estimated historical extent (green) and current (red) extent of mostly natural vegetation within the Nakivubo wetland.

IV. CURRENT CAPACITY FOR WATER TREATMENT

Emerton *et al*. (1998) suggested that the Nakivubo wetland treated almost all effluents entering the system and significantly improved the quality of water entering Inner Murchison Bay. However, the overall assimilative capacity of the wetland is assumed to have decreased substantially since then.

Kansiime & Nalubega (1999) showed that uptake rates of total nitrogen by the functional papyrus areas of the wetland were in the order of 475 kg N/ha/year, and total phosphorus reduction (through sedimentation and uptake) was in the order of 77 kg P/ha/year. *Miscanthidium violaceum* mats had lower rates of reduction of both phosphorus and nitrogen nutrients than C. papyrus.

About 70 ha of papyrus and 20 ha of *Miscanthidium* currently remains in the Nakivubo wetland, compared with about 91 ha and 23 ha respectively in 1996. Kansiime & Nalubega (1999) noted that more of the polluted inflows came into contact with the *Miscanthidium* than with papyrus, but papyrus is more efficient at nutrient removal and had higher overall removal rates. Based on their findings, it was estimated that the wetland removed about 15% of nitrogen and 20% of phosphorus inputs in 1996, but that this has now decreased to 8% and 10%, respectively, as a result of both increases in nutrient inputs and absolute decrease in the assimilative capacity of the wetland. Based on these findings, if the full extent of the wetland habitat was restored, it could hypothetically remove about 15% and 19% of current N and P inputs. If the restored areas were managed as treatment wetlands, this amount would be further increased (see Chapter 5 and Appendix 6).

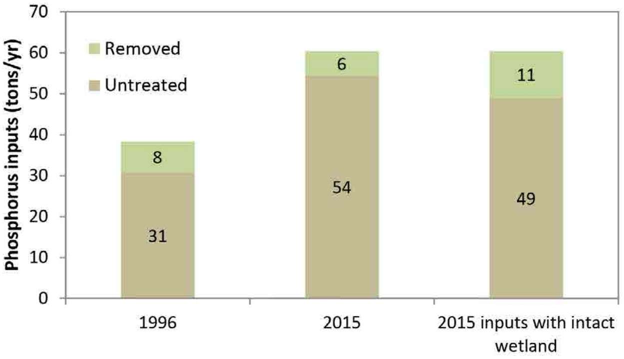

Figure 4 Estimated past and current capacity of the wetland for sedimentation /uptake of phosphorus, and estimated hypothetical removal if wetland habitats were still intact, with the volume of total phosphorus passing out of the system (i.e. "untreated" load)

V. INTERVENTIONS REQUIRED TO MEET WATER QUALITY AND RECREATIONAL OBJECTIVES

A. Objectives

One of the main objectives of this study was to identify the interventions that would be required to improve the quality of water passing from the Nakivubo wetland into Inner Murchison Bay, in order to address concerns about potable water supply for the city, to enable the potential development of recreational facilities in the Nakivubo wetland and Inner Murchison Bay, and to address other environmental problems such as the impact of water quality on biodiversity and fisheries.

The objectives were defined as

1. effecting a measurable improvement of water quality passing out of the Nakivubo wetland into Inner Murchison Bay;
2. to ensure sustainable management of the Nakivubo wetland;
3. reduce water quality impacts on human health; and
4. open up opportunities for safe recreational use of the lower wetland.

On the basis of the present condition and extent of the wetland and its current pollution load (see Appendices 2, 4 and 5), it must be stressed that the above objectives cannot be met simply by expanding the natural wetland treatment capacity of the lower Nakivubo wetland (see Figure 4). The volumes of waste water being produced in the upstream catchment and its quality are well beyond the capacity of the wetland in its current state or potential rehabilitated state (e.g. artificial wetlands) to effect adequate treatment on a long term basis. Indeed, while many wetlands are recognised as playing a valuable role in effecting the polishing of contaminated water passing through them, they do not provide effective mechanisms for the treatment of large volumes of highly contaminated waste with high loads of sediments and nutrients. Recognition of this point is a critical factor underpinning the approach recommended in this section to address water quality issues, and thereby drive other activities and/or opportunities such as the rehabilitation of parts of the Nakivubo wetlands and the development of recreational opportunities within the wetlands.

B. Proposed interventions

A sequential series of interventions, also known as a treatment train, is required to achieve the broad and ambitious objectives outlined in Figure 5. The interventions include both infrastructure upgrades and wetland rehabilitation and conservation measures. The six interventions are described briefly below, after which the high-level cost estimates are summarised and the cumulative impact of the interventions on water quality is discussed. A fuller description of the background, design and assumptions around each set of interventions is provided in Appendix 6.

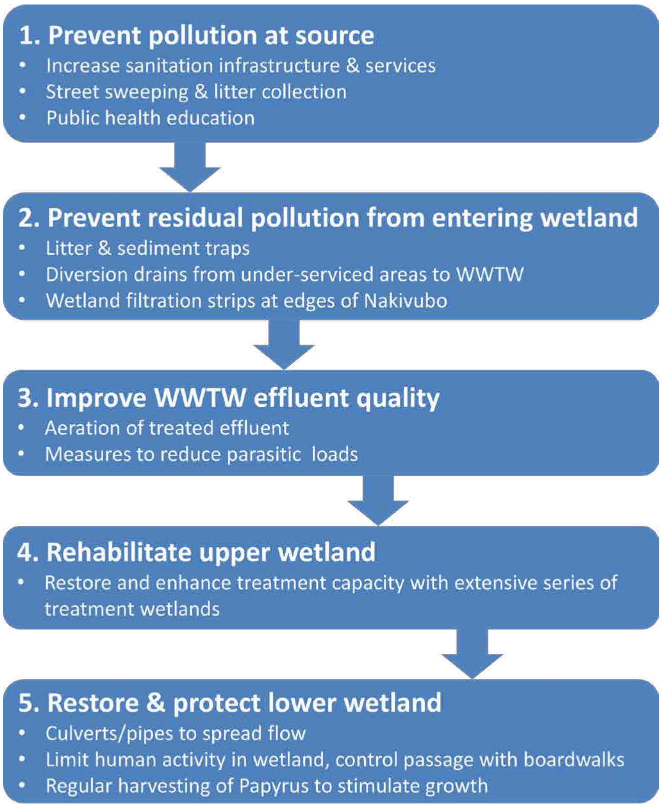

Figure 5 Treatment train required to achieve water quality objectives in the lower Nakivubo wetland and Inner Murchison Bay, with brief summary of actions required at each step. (Note: the sixth step, the establishment of recreational facilities, is not depicted here).

Step 1. Prevent pollution at source
Fewer than 10% of households in Kampala have piped sewage (NWSC Corporate Plan 2012), with the remaining population depending on various forms of on-site sanitation such as pit latrines, septic tanks, public toilets and open defecation. The collection and disposal of faecal sludge generated in the pit latrines is inadequate and sanitation in informal settlements is very poor.

In order to prevent raw sewage from entering the wetland and Inner Murchison Bay, both sanitation coverage and waste water treatment works (WWTW) capacity will need to be further increased by improving sanitation in areas not covered by water-borne sewage, expanding sewage systems, along with the provision of public health education. Sanitation measures ought to be in place as minimum standards in any high-density urban environment. These efforts should be complemented by improving sweeping and litter collection to reduce the amount of sediment and solid waste entering the wetland.

Some of these required improvements are already underway. New WWTW are under construction at Lubigi and Nakivubo, plus new sewers in Nakivubo and Kinawataka areas, which will increase the sanitation coverage to 30% of households in Kampala (NWSC 2014). The new 45 ML Nakivubo WWTW will replace the Bugolobi WWTW with its current design capacity of 12 ML and effective capacity of 6 ML. This will now deal with waste water from the Kinawataka catchment as well as the Nakivubo catchment, so there is some uncertainty as to how much of the Nakivubo and Kinawataka catchments respectively will be serviced. The total wastewater load from the Nakivubo catchment, if fully serviced, would be about 65 ML. Full coverage of waterborne sewage may not be feasible or desirable, however. It is probably more reasonable to aim for coverage of 60-70%, while implementing other measures such as VIP latrines in the remaining areas and having waste water treatment works that can handle waste water flows channelled from those areas as well as efficient sludge collection services and treatment facilities.

The Lake Victoria WatSan Project will address the water supply and sanitation situation for some of Kampala's informal settlements, including faecal sludge management, sewerage and building public toilets. About €3.41 million of the budget will be spent on upgrading sanitation within the Nakivubo catchment. (NWSC 2015). The project does not include the installation (or subsidisation) of pit latrines nor will it achieve full servicing of currently under-serviced areas in terms of sludge removal. This project will also cover public education, which is not considered further here.

While the ongoing projects are expected to greatly improve the situation, there is clearly still a shortfall in terms of sanitation. Given that the new Nakivubo WWTW will also have to handle waste from Kinawataka, it is likely that some further expansion of capacity will be required to adequately service the Nakivubo catchment. There is also still a need to install pit latrines, increase sludge treatment facilities, and to further increase WWTW capacity to deal with inputs from formal and informal areas. Based on the original plan to develop an 8ML WWTW in the Kinawataka catchment, it was assumed that the capacity of the Nakivubo WWTW needs to be increased by at least this amount in order to meet sewage treatment requirements in the catchment, at an estimated cost of $8.8 million. Based on available information (Ministry of Health 2010) we estimated that some 12.6% of the population in the catchment would still require pit latrines, and 40% of the existing latrines need access to proper servicing. Using data from Isunju et al. (2013), the costs of these were estimated to be about $1.15 million plus $0.67 million per year. Currently the collection and treatment of faecal sludge in Kampala is 43% or 390 m3 per day. Based on this information and the total number of households in the catchment area using pit latrines, it was also estimated that a 200 m3 faecal sludge treatment plant (FSTP) is needed to treat faecal sludge from pit latrines in the catchment adequately. The total construction cost of a new sludge treatment plant was estimated to be $1.44 million, with annual maintenance costs of around $0.07 million.

In addition to sanitation measures, it was also assumed that current levels of street sweeping and litter collection need to be improved at a cost of about $0.6 million per annum, to further prevent sediments and litter from entering the storm water system.

While implementation of these measures would require considerable capital expenditure of over $11 million, given the significant impact it would have on instream and downstream ecological function, as well as its implications for human health, and the opening up of opportunities for safe recreation downstream, it should be regarded as an essential medium-term rather than long-term objective.

Step 2. Prevent residual pollution from entering the wetland

It is recognised that the implementation of water-borne sewage is unlikely to be feasible for all households in the catchment, especially if there is further population growth in the catchment. Therefore alternative measures need to be put in place to address outstanding issues surrounding polluted runoff, such as the installation and management of litter and sediment traps, installation of diversion drains to convey waste water from informal settlements to the WWTW, and the creation of wetland filtration strips at the original wetland edges to filter overflows before they reach the main wetland. The combination of these measures with the above (Step 1) is considered the most effective, long-term approach to addressing the dire pollution levels passing into the Nakivubo channel.

To control and limit the amount of litter and sediment flowing into the Nakivubo channel an expanded channel litter trap, instream litter and sediment traps, about 12 hydraulic drops constructed from gabions to control for flow and particle transport, and continuous cleaning of the channel will be required, at a cost of about $1.75 million plus $0.95 million per year. Diversion drains are required to intercept dry season surface flows (i.e. flows not driven by rainfall events) and shallow seepage from unlined areas of informal settlements and would be routed to the nearest existing sewer and on to the WWTW for treatment. This would cost approximately $1 million. In addition, any excess runoff, most likely during wet conditions, should be diverted into sediment traps and through reed bed wetland filtration systems, established between diversion drain outlets and the main Nakivubo channel. The reed beds, which are necessary for filtering sediments and reducing the volume of organic waste should be designed as broad wetland filtration strips that run parallel with the channel. It is recommended that a linear series of papyrus wetlands should be installed along the wetland edge in the vicinity of the prison, occupying the eastern edge of the lower wetland, and along the wetland edge of the informal settlements occupying the western edge of the lower wetland (Figure 6). These wetlands would cost about $1.65 million to establish, and then would require maintenance on a cyclical basis, which would include the cutting and disposal of plant material, and the dredging and disposal to waste of contaminated sediment as necessary to restore wetland treatment capacity.

Step 3. Improve WWTW effluent quality

The new Nakivubo WWTW will include mechanical, biological and chemical treatment of municipal sewage and industrial effluent, sludge digestion and cogeneration using biogas. It is recommended that additional tertiary treatment measures such as filters to decrease nutrient concentration and maturation ponds to reduce pathogens are also added. This would cost about $22 million (Table 1).

Improving the aeration of treated effluent from the existing and planned WWTW, by installing aeration sprays within the final effluent maturation ponds, would increase dissolved oxygen concentrations to at least 4mg/L. Upgrading technology at the WWTW to allow for a final effluent concentration of 1.5 mg PO4-P /l (phosphorus in orthophosphate) instead of the current standard of 10 mg P/L (i.e. meeting effluent limits) would substantially reduce phosphorous loads entering the wetland, thereby improving conditions for aquatic ecosystems in Murchison Bay.

Step 4. Rehabilitate upper wetland for waste water treatment

Rehabilitating the wetland for waste water polishing (i.e. supplementary treatment of final effluent) requires installing and maintaining an extensive series of treatment wetlands throughout the upper Nakivubo wetland (Figure 6).

The area needs to be far more extensive than has been previously considered, because of the large volume of wastewater that has to be treated, and should ideally replace all of the upper wetland area that has been converted to agriculture. This would entail the construction of multiple shallow wetland cells separated by berms with controlled pipe outlets or multiple overflows linking each cell to downstream cells. Based on information from other areas and taking economies of scale into account, the cost of constructing these wetlands would be in the order of $2.3 million. As in Step 2, these wetlands would require maintenance on a cyclical basis, which would include the cutting and disposal of plant material, and the dredging of contaminated sediment to restore wetland treatment capacity.

Note that achieving required levels of tertiary polishing of effluent will be dependent on the size of the constructed wetland area and the concentration of the final effluent produced by the WWTW. Effluent concentrations need to be reduced significantly below those that are legally permissible in Uganda if specified volumes are to be treated effectively by rehabilitated wetland areas. Rehabilitated wetlands will therefore help to achieve downstream benefits in terms of resource quality, by helping to make the lower wetland safe for recreational purposes, improving fisheries, and potentially controlling the expansion of informal settlements into wetland areas.

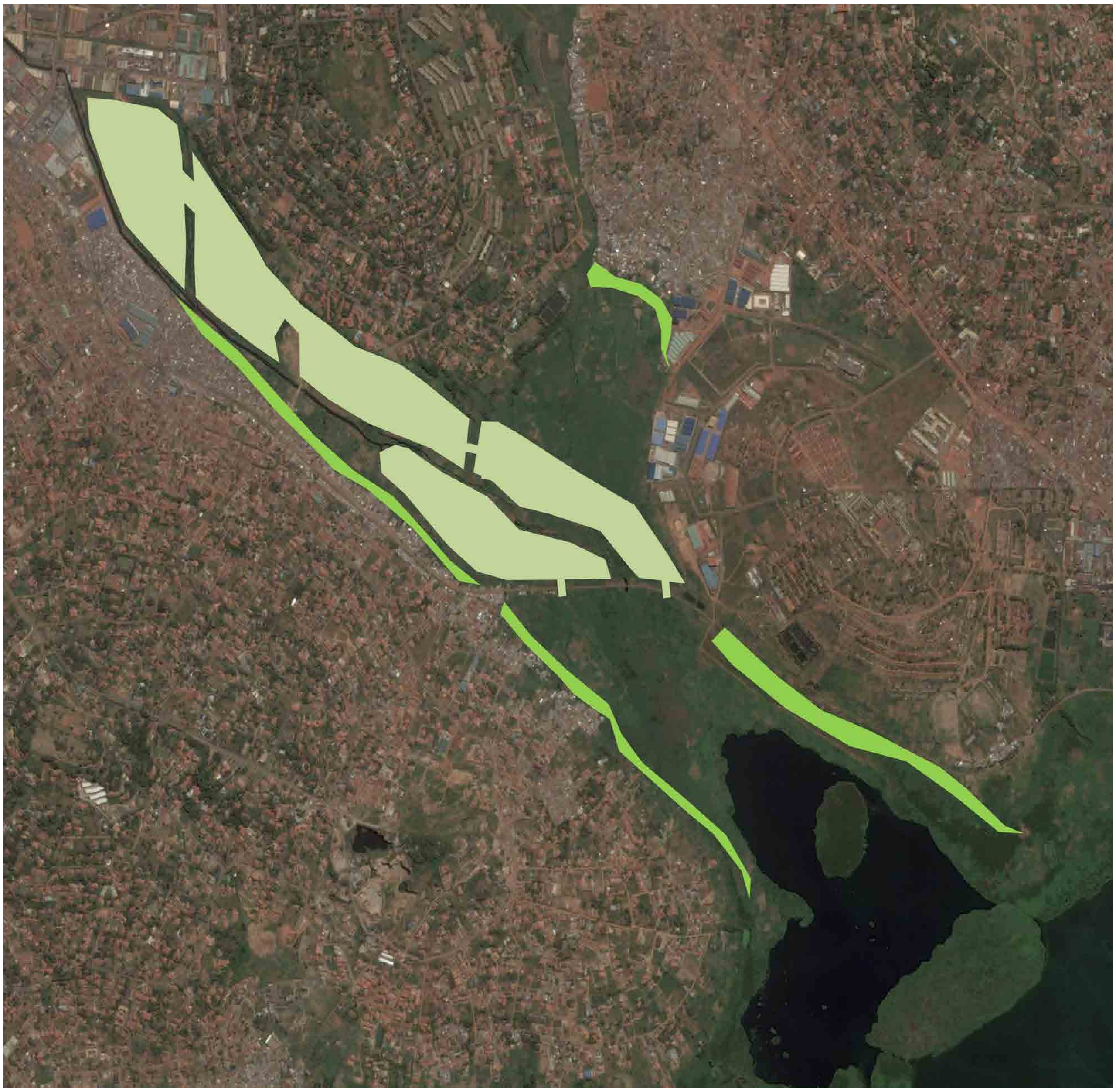

Figure 6 Areas for rehabilitation as filter strips (bright green areas) and treatment wetlands (light green areas) in the Nakivubo wetlands.

Source: Google Earth imagery

Step 5. Restore and protect lower wetland

Improving the functioning of the lower wetland requires improving the spread of flow into this area from upstream, reducing agricultural damage and encroachment, encouraging conservation and the regular harvesting of papyrus plant material to maintain wetland function.

It is recommended that at least three new channels are created via a series of pipes and culverts under the railway line in order to spread the flow effectively from the treatment wetlands along the width of the lower wetland. This would cost about $1.38 million. Flows from the Nakivubo channel should pass into the lower wetland as at present, with possible allowance for further spreading of flows into degraded Papyrus wetland.

To avoid further breaking up and loss of these wetlands, agricultural activities need to be managed to prevent cultivation and livestock grazing on the floating islands. Recommended measures include fencing where necessary, and signage and patrols to enforce these regulations. In order to promote nutrient storage within the wetland and to stimulate growth, papyrus needs to be harvested at certain times of the year and at different growth stages. A specific harvesting plan for papyrus plant material in the lower wetland should be initiated and this should focus on educating local people about how best to harvest the plant material. The ongoing costs would therefore include the managing and monitoring of the harvesting programme as part of the larger conservation effort in the lower wetland.

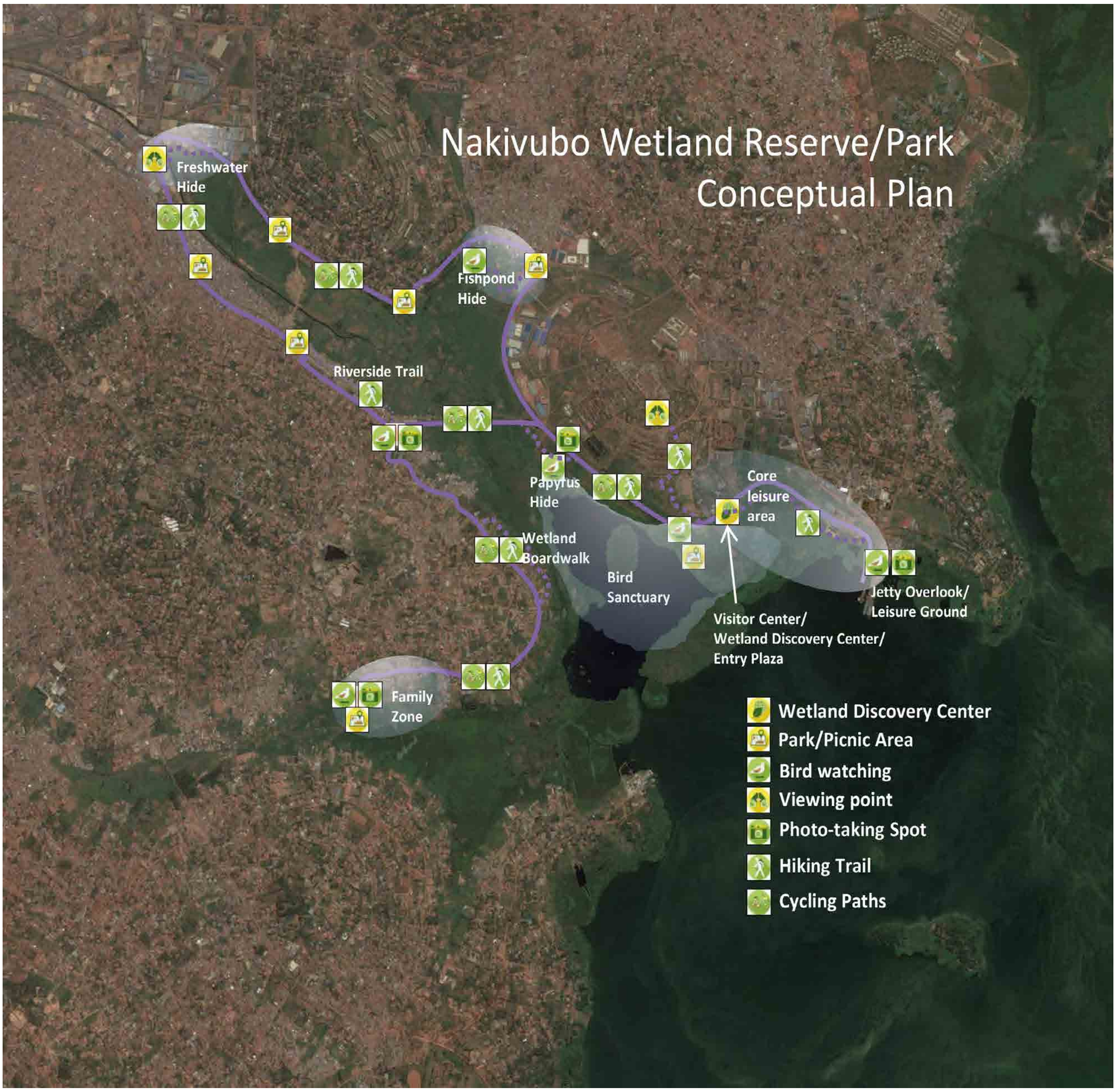

Figure 7 Concept vision for the Nakivubo Wetland Park used in this study

Step 6. Establish a recreational space with facilities
The development of a Nakivubo Wetland Park is envisaged to be integrally and physically linked to the planned waterfront area at Port Bell with the provision of a reasonably large park area adjacent to (not in) the wetland, with access to both the lake-front and vegetated wetlands, with picnic facilities and walking paths in and around the landscaped area and wetland (Figure 7). Therefore the main landscaped recreational area would be close to Port Bell, but smaller sites could also be set up at other locations around the wetland (See Appendix 6 for more detail).

It is envisioned that a central part of the wetland could be developed as a bird sanctuary which would retain its natural characteristics as far as possible. The sanctuary would contain rustic boardwalks and hides. If well managed, this in itself could provide tourism opportunities. The park would also contain a wetland visitor information centre located in between the landscaped areas and bird sanctuary to enhance visitor experience. The area in the vicinity of the prison site and Port Bell would be developed for retail and restaurants with some of these being on the waterfront. In addition to the central wetland recreational area at Port Bell it is also envisaged that landscaping of smaller areas on the opposite side of the lower wetland and the possible construction of wide paved walking and cycle routes along one or both banks of the wetland extending from the lake to 5th bridge. These walkways and cycle paths would provide a safe and pleasant passage into the city which would also encourage non-motorised commuting such as the use of bicycle taxis.

The costs of providing public amenities such as pathways, boardwalks, foot bridges, landscaped park space for picnic and leisure, bird hides, public toilet facilities, parking areas and a visitor centre are estimated to be about $11.5 million. This does not include private development costs associated with the development of restaurants and retail outlets.

C. Overall costs

The overall estimated costs of the interventions are summarised in Table 2. These estimates are over and above the expenditure that has already been committed to in terms of sanitation upgrades.

Table 2 Estimated capital costs and ongoing maintenance and operating costs of the recommended interventions, broken into component costs. The minimum and maximum range for cost estimates are included in brackets adjacent to the estimated cost value for each intervention.

	Capital Costs (US $ Millions)	Maintenance and operating costs (US $ Millions per year)
1. Prevent pollution at source	11.39	1.78
Expand pit latrine access and servicing in Nakivubo catchment	1.15 (0.23 – 2.4)	0.67 (0.49 – 2.45)
Increase capacity of the Nakivubo WWTW by 8 ML	8.8 (6.6 – 11.0)	0.44 (0.33 – 0.55)
Construct a 200 m3/day Faecal Sludge Treatment Plant	1.44 (1.08 – 1.80)	0.07 (0.05 – 0.09)
Increased street sweeping and litter collection	-	0.60 (0.4 – 0.8)
2. Removal of pollution upstream of natural water resources	4.44	1.01
Installation and management of litter and sediment traps	1.75 (1.5 – 2.0)	0.95 (0.48 – 1.4)
Install diversion drains from informal settlements to WWTW	1.04 (0.3 – 1.77)	0.02 (0.006 – 0.04)
Installation and management of wetland filtration strips	1.65 (1.24 – 2.06)	0.03 (0.02 – 0.04)
3. Improvement in WWTW effluent quality	21.96	0.44
Filters to decrease nutrient concentrations	16.50 (12.4 – 20.6)	0.33 (0.25 -0.41)
Maturation ponds to reduce pathogens	5.46 (4.10 – 6.83)	0.11 (0.08 -0.14)
4. Rehabilitate parts of wetland for treatment	2.30	0.05
Installation and management of treatment wetlands	2.30 (1.73 – 2.88)	0.05 (0.03 – 0.06)
5. Improvement in function of the lower wetland	1.41	0.07
Pipes/culverts to improve hydraulic efficiency in lower wetlands	1.38 (1.04 – 1.72)	0.04 (0.03 – 0.05)
Measures to control agricultural activities	0.03 (0.02 – 0.04)	0.01 (0.005 – 0.01)
Harvesting of Papyrus plant material to stimulate growth	0.00	0.015 (0.01 – 0.02)
6. Recreational facilities	11.48	0.23
Boardwalks, signage etc. to control recreational impacts	2.52 (1.9 – 3.1)	0.05 (0.04 – 0.06)
Visitor centre, landscaping, picnic facilities, ablution facilities	8.96 (6.7 – 11.2)	0.18 (0.13 – 0.22)
TOTAL COSTS	52.98	3.57

D. Cumulative effect on water quality

While Steps 1 and 2 are likely to reduce nutrient levels significantly, these steps alone would not take the wetland out of its hypertrophic state. Adding Step 3 is likely to achieve eutrophic conditions. Implementation of Steps 1, 2 and 3 are considered an essential pre-requirement for achieving the outcomes of Steps 4 and 5, i.e. providing the opportunity for alternative beneficial uses of the lower wetland (e.g. recreation, tourism, fishing industry). Steps 4 and 5 are expected to bring the system close to its natural mesotrophic state. The cumulative modelled effect of the five intervention steps on the trophic state of the Nakivubo wetland is shown in Figure 8.

Note that the accuracy of predicted implementation effects, and in particular their knock-on downstream implications, is severely limited by poor data relating to water quality and hydrology in the catchment, and would be significantly improved by a structured flow and water quality monitoring programme, designed to improve decision-making around the short and long term benefits and costs likely to be associated with the recommended measures.

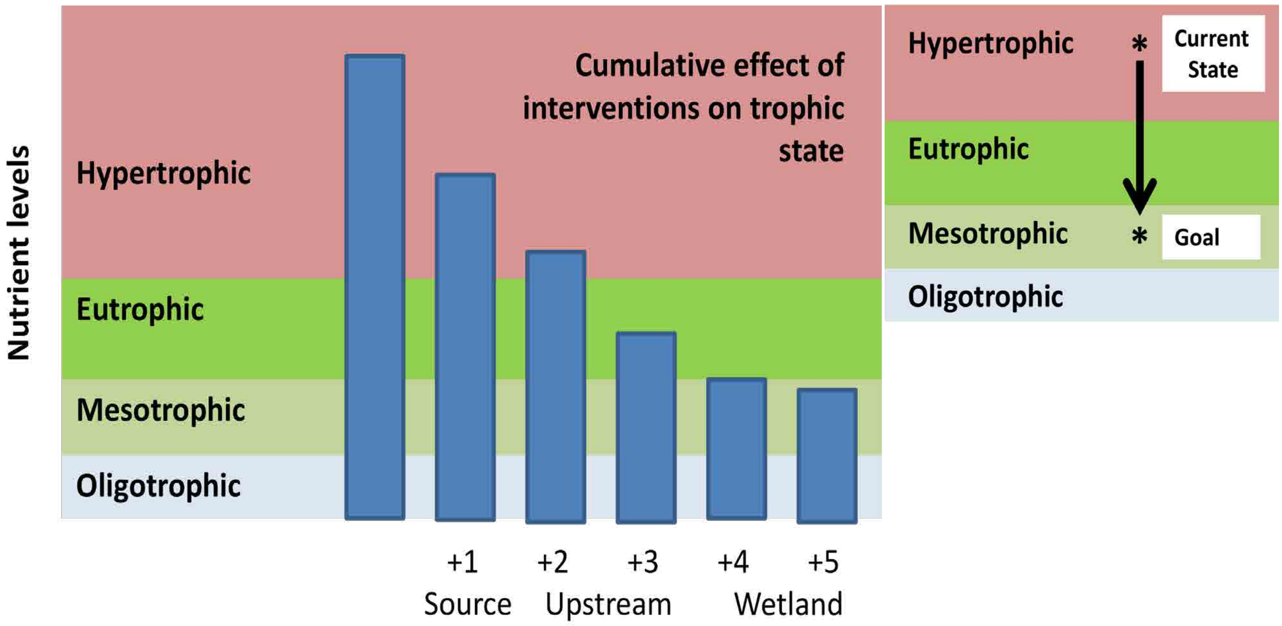

Figure 8 Schematic diagram of the cumulative effect of the five intervention steps on the trophic state of the lower wetland area.

VI. POTENTIAL WATER TREATMENT COST SAVINGS

The city of Kampala is supplied with drinking water from Lake Victoria, with the treatment and distribution being operated by the National Water and Sewerage Corporation (NWSC) and Kampala Water (KW) (NWSC 2014). The Ggaba Water Treatment Works (WTW) is located just 3 km south of the Nakivubo wetland, making it vulnerable to the impacts of urban activities on water quality in Inner Murchison Bay.

Both high sediment and nutrient loads typically lead to increased water treatment operation and maintenance costs. Increases in sedimentation and associated increases in turbidity in river and wetland systems have become a common challenge facing many cities worldwide (McDonald & Shemie 2014). In the context of treating water, the biggest effects of increased sediment and nutrient loads on the cost of treating water include increased use of coagulants, increased sludge output, increased occurrence of algal blooms, and clogging of reticulation systems (Graham 2004, McDonald & Shemie 2014, Rangeti 2014). It has previously been suggested that the Nakivubo wetland buffered these effects by significantly improving water quality before it reached Murchison Bay, leading to water treatment cost savings. However, more recently it has been suggested that water treatment costs have in fact been rising as a result of the subsequent deterioration of water quality in Inner Murchison Bay. In fact, Ooyo (2009) found intensive algal blooms to be particularly high, resulting from elevated phosphorous levels in Inner Murchison Bay. Between 1993 and 2007 the aluminium sulphate dosage, used during the treatment process to remove algae, increased significantly from 20 mg/l to almost 70 mg/l (Ooyo 2009). This effect has been sufficient to lead to various upgrades of the water treatment works, and finally to the planning of a new facility at some distance from the urban environment.

Ggaba Water Treatment Works comprises three treatment plants with a total water supply capacity of 170,000 m^3 per day (NWSC pers. comm. 2015). Upgrades have occurred in 1992 and in 2007 to make the plant fully automated (Ooyo 2009). In 2010, the intake pipeline at Ggaba III was extended further into Lake Victoria in an effort to extract water of a better quality for treatment. From October 2010, the new pipeline was in operation (NWSC pers. comm.).

Water treatment data from Ggaba WTW for the period February 2007 – May 2015 supplied by the NWSC were analysed. However, there were inconsistencies in some of the cost data and unexpected trends and results from the treatment analysis. As a result, we were not able to model costs using the local data provided. For the detailed analyses and more information about the empirical data see Appendix 7. Discussions with the NWSC confirmed that contrary to findings from the analysis, water quality deterioration still has a significant impact on costs and will continue to do so at the new plant. In the absence of a useable model for the Ggaba plant, it was decided to value the potential cost savings using a benefits transfer method. This is essentially the use of a model developed elsewhere, but with parameters adjusted as far as possible to correct for differences between the source and receiving valuation site. Therefore the potential cost savings were estimated using a model from a similar WTW in South Africa (see Appendix 7).

Based on existing data, and the assumption that the restoration interventions would achieve a mesotrophic state, the pre- and post-restoration phosphorous concentrations were estimated to be 2.5 mg/L and 0.047 mg/L, respectively. This would suggest a reduction in loads from over 8000 kg to about 150 kg. The model was updated using average values for water quality parameters found in the raw water in Inner Murchison Bay and it was estimated that the saving per ML of treated water would be almost half of the current day cost, amounting to some $845 000 per year.

The water currently being treated is much less than the quantity demanded, and there are several “dry zones” in Kampala. The city has planned for growth in capacity. Works are currently underway at the existing Ggaba site, which will increase the capacity of these works to some extent, and then a new treatment works will be constructed outside of Inner Murchison Bay, at some distance from the city, to meet future demands[2]. It is assumed that once these upgrades are completed, the Ggaba plants will be able to increase its outputs from 170 ML to the overall design capacity of about 230 ML. Thus the cost saving was estimated under full capacity, as **$1.143 million per annum**.

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[2] It should be noted that the extra cost of building the latter plant further away due to water quality issues is already a sunk cost. Although it is far away, the pollution inputs into IMB via the Nakivubo wetland will eventually have an effect on costs of water treatment at the new plant, but this is unlikely to be significant within the time frame of this analysis.

Not only is it expected that treatment costs will decrease, but associated costs such as sludge removal and backwashing are also expected to decrease with improved water quality. One assumes that the significant reduction in phosphorus and other nutrients as a result of restoration will decrease the frequency and intensity of algal blooms in Inner Murchison Bay and will decrease the need for continuous backwashing of filters at the Ggaba WTW. Sludge dewatering and sludge removal can be very expensive and it is assumed that the improved water quality will decrease the amount of sludge produced during the water treatment process and will therefore reduce the time and costs involved in having it removed. In the Rio Camboriu watershed in Brazil, preliminary results have shown that a significant part of the cost saving associated with improved water quality was in the savings associated with sludge disposal (Timm Kroeger, TNC, in *litt*.)

VII. POTENTIAL RECREATIONAL BENEFITS

A study was undertaken to estimate the possible welfare gains from the creation of a Nakivubo Wetland Park, using both revealed preference methods (analysis of the use of existing sites to infer the willingness to pay for the proposed site) and stated preference methods (asking people to state their willingness to pay to use a proposed site). Data were collected by means of a survey of over 600 households in a representative set of parishes in all five divisions of Kampala. Respondents were asked to answer questions about their socio-economic circumstances, about household use of multiple outdoor recreational sites during the last 12 months and about how they felt about the restoration of the Nakivubo wetland for its development as a recreational park. These included questions about their current expenditure and how much they would be willing to pay to use a park at Nakivubo. Data were analysed using a range of econometric models (for the full study, see Appendix 8).

Based on different models, the revealed preference analysis suggested that the compensating variation (CV) or total willingness to pay (WTP) for the Nakivubo Wetland Park would be from $18 (on average) to $75 (for one sector of the population) per household per year, suggesting a substantial welfare gain of designing a new site that involves such changes. The stated preference analysis suggested that households were willing to pay between $5.64 and $6.11 per adult, and anticipated visiting the park on average 2.3 times per year.

Given a total of over 400 000 households in Kampala City, the results of the revealed preference analysis suggest a potential overall net benefit to Kampalans of some **$17.0 - $29.4 million** per annum. Using the mean household size, mean adult:child ratio, and mean expected level of use per household (2.3 times), the results of the stated preference analysis yield a slightly lower overall estimate of **$14.7 - $15.9 million** per annum. Nevertheless the estimates are relatively close. These minimum and maximum estimations were used to determine an average estimate of $22.05 million in overall recreational benefit (Table 3). These results highlight the demand for outdoor recreational opportunities in Kampala and the associated welfare gains with improving current outdoor open green spaces.

Table 3 Results of the cost-benefit analysis

	Revealed Preference	Stated Preference
Willingness to Pay ($/hh/year)	40 -70	35 – 38
Aggregate benefit (US $ millions)	17 – 29.4	14.7 – 15.9
Average estimate used in CBA (US $ millions)		22.05

VIII. COST-BENEFIT ANALYSIS

Cost-benefit analysis is a conceptual framework and tool used to evaluate the viability and desirability of projects and policies based on costs and benefits accumulating over time (Hanley & Spash 1993, Pearce *et al*. 2006). Cost-benefit analysis involves the adjustment of future values to their present value equivalent through the process of discounting at a rate which reflects the potential rate of return on alternative investments or the rate of time preference. For a project to be considered viable, the net present value (NPV) must be positive. This places greater weight on values occurring closer to the present, which means that the future benefits of restoration projects will be down-weighted compared with the upfront investment costs, and have to be substantial in order for a project to be viewed positively. Projects can also be evaluated by estimating the internal rate of return (IRR), which is the discount rate at which the total net present value of the project falls to zero.

The implicit assumption of the above is that the costs and benefits of a project can be determined with certainty. In reality however, accurately estimating all variables in a cost-benefit analysis becomes a challenge as a result of the way in which estimates are assessed and forecast (EAI 2006). Studies are limited by availability of data and resources, as well as uncertainty in the consideration of changes in factors such as land use, climate, household incomes and urbanisation (EAI 2006). It is therefore important to incorporate some form of sensitivity analysis so as to adequately assess the reliability of the estimates.

In addition to the costs of the interventions and the water treatment and recreational benefits described above, the opportunity costs associated with the loss of agricultural land were also taken into account. It is estimated that there are currently 135 ha of agricultural land within the wetland that need to be rehabilitated. The value added by the past conversion of wetland to crop farming was estimated to be between $91 000 to $192 000 (average $141 500) per year, based on Emerton et al. (1998) and Kakuru *et al*. (2013), respectively.

Note that the time for recovery of the lake system is unknown. This is difficult to estimate since nutrient cycling is a complex process. Phosphorous has been accumulating in Inner Murchison Bay for decades. The nutrient fluxes and transportation are not well understood in this system. To some extent there is exchange with the rest of Lake Victoria, but the nature of Inner Murchison Bay is that water is retained within the bay for long periods, and sediments and nutrients accumulate in this area. The phosphorous that has accumulated in the system will take some years to be depleted and/or flushed from the system, and will continue to become available for plant uptake during periods of disturbance (e.g. by wind). Therefore, even if nutrient inputs into Inner Murchison Bay were to be reduced to very low levels by the interventions described in this report, it may take years before this has an impact on the trophic status of the lower wetland and Inner Murchison Bay. Thus we have incorporated a time delay of 5 years before the benefits of the project are felt.

The estimates derived in this study suggest that the interventions would have a net benefit. Using a discount rate of 6%, the net present value of the project over 15 years was estimated to be $80 million (Table 4). This was further tested under varying assumptions of costs, benefits and discount rate. Under the worst case scenario (upper bound estimates of costs, lower bound estimates of benefits), the NPV was negative at discount rates of 6% and 9%, which suggests there is some risk of the project costs outweighing the benefits (Table 5). The internal rate of return (IRR) was estimated to be 20%, but sensitivity analysis yielded a range of 4 to 34%. Monte Carlo Simulations were conducted using 10 000 runs on the base, best and worst NPV estimates using a triangular distribution for 3%, 6% and 9% discount rates. The results suggest that the probability of a negative outcome is 0%, 2% and 7% for these three discount rates, respectively.

Table 4 Present value of costs and benefits under expected best case, base estimate and worst case scenarios (2015 US Dollars, 6% discount rate, 15 years)

	Present Value (US $ millions)		
	Best	Base Estimate	Worst
Costs			
Restoration	35.6	48.6	62.0
Maintenance	21.1	32.1	57.6
Loss of agricultural land	0.83	1.30	1.76
Total present value of costs	57.6	82.0	121.3
Benefits			
Recreation	206.9	155.2	103.4
Water treatment Savings	8.7	7.0	5.2
Total present value of benefits	215.6	162.1	108.7
Net Present Value	158.0	80.1	-12.6
Internal Rate of Return (IRR, %)	34%	20%	4%

Table 5 NPV Sensitivity Analysis using discount rates of 3%, 6%, 9%

Net present value (US $ millions)	Discount Rate		
	3%	6%	9%
Best	220	158	83
Base estimate	121	80	51
Worst	4	-13	-24

It should be noted that the estimate of benefits are highly conservative. Firstly, the recreational benefits associated with the restoration today are likely to understate future values of these benefits, which are expected to increase as the city becomes larger and incomes rise. Secondly, the cost-benefit analysis does not take into account a range of other potential benefits of the restoration interventions. These include improvements in human health, property value and fisheries, as well as intangible benefits that may arise from restoring the biodiversity of the area.

Human health is strongly related to access to water and sanitation (Alexander & McInnes 2012, Wetlands International 2010). Many people living within the Nakivubo catchment are exposed to poor sanitation conditions. In addition, the people living along the edge of the Nakivubo wetland and those using the wetland for farming have direct contact with the water (and parasites) and are exposed to considerable risk. An improvement in sanitation and the disposal and treatment of waste water will have a significant positive influence on human health and welfare in Kampala, with further benefits in terms of reduced pressure on health services and avoided loss of productivity.

An improved local environment is also likely to be reflected in property prices in the area. It is well known that well-managed green open space areas lead to higher property prices, whereas degraded environments lower property prices (Behrer 2010, Letley & Turpie 2015). In brief discussions with property agents in Kampala, it was suggested that property values are positively influenced by altitude, with hilltop homes having better views, whereas the properties in the valley areas close to the wetlands had lower value, and this tended to be very strongly negatively influenced by the fact that the wetland areas are the areas available for informal settlement and the development of slums. Where slums do occur, it is likely to be this factor, rather than the state of the wetland, that drives property prices. However, away from slums, the health of wetlands is more likely to have an impact. In the Nakivubo wetland area, while some of the wetland is fringed with slums, there are areas where property values may potentially benefit from wetland restoration. If residents do value open space and associated amenities then it would be expected that the willingness to pay for these amenities should be revealed in property prices[3].

The restoration of water quality in Nakivubo wetland may also be beneficial to fisheries, but this is dependent on a number of factors. Habitat degradation and poor water quality has led to the movement of fishermen out of Inner Murchison Bay to more productive fishing areas in Lake Victoria. Fish communities have been impacted by low levels of oxygen as a result of the eutrophication of wetland areas and the increased nutrients in the lake resulting in excessive algal and plankton growth (Muyodi et al. 2011). It is expected that with improved effluent control, siltation control and restored riparian habitat within the Nakivubo wetland and along the lake shore, fish stocks will start to increase in Inner Murchison Bay and this would have a positive influence on local fisheries. Studies elsewhere have shown that wetland restoration can curtail the decline and loss of local fisheries (Alexander & McInnes 2012). However, this is dependent on how the other catchments and wetlands around Inner Murchison Bay are managed, the time taken for lake water quality to change, and the way in which the fisheries are managed.

Finally, the restoration of the wetland would lead to an improvement in its flora and fauna, which is something that many members of society, even beyond Kampala or Uganda, would value. These kinds of values, referred to in the literature as non-use or existence values, are intangible and difficult to quantify, even with best-practice stated preference methods (Dubgaard 2003, Olsen & Shannon 2010). While the study area is not particularly important from a conservation perspective, e.g. as a habitat for rare and endangered species, its conservation is likely to play a role in the overall health and viability of aquatic ecosystems in and around Murchison Bay, and thus the overall levels and diversity of flora and fauna that can be supported in the area. While this study has not attempted to estimate existence value, this benefit should be acknowledged.

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[3] This could be captured through land value capture initiatives in the areas where there is planned development. Instruments such as tax increment financing (TIF), joint development agreements and betterment tax could be used to capitalise on these benefits. Tax increment financing, for example, uses property tax increases to repay public infrastructure investment required by a project. It encourages investment in deteriorating areas by allowing local governments to use future property tax revenues to finance the current infrastructure costs needed to attract development. Local government could also levy a betterment tax against real estate in the area, which is a tax that is dedicated to a specific project that helps to improve an area.

IX. CONCLUSIONS AND POLICY IMPLICATIONS

Key message 1: Wetlands have limited capacity to solve urban pollution problems

The Nakivubo wetland has deteriorated significantly since the 1990s, when it was believed to perform a valuable service in ameliorating the quality of water passing though it into Inner Murchison Bay, even though at that stage the system was already impacted by structures and human activities. The pressures on the wetland, including pollution inflows, agriculture and settlement, have increased markedly, and the functional part of the wetland is now less than a quarter of its original extent. The wetland no longer has any positive impact on the trophic status of Inner Murchison Bay, with the lower wetland and bay having reached a hypertrophic state that is characterised by frequent, often toxic, algal blooms, as well as being severely contaminated with pathogens that carry a risk to human health.

Timely interventions to keep pace with the city's growing sanitation needs would have prevented the deterioration of water quality in Nakivubo and Inner Murchison Bay. Waste water treatment standards are also a contributing factor. The lack of urgency in dealing with these issues may have been partly due to the assumption that the environment would be able to deal with the remainder of the pollution load without any significant impact on human welfare. This is a myth that needs to be quickly dispelled. Wetlands cannot substitute wastewater treatment works and can only improve the quality of limited volumes of moderately polluted water.

Key message 2: Rehabilitation will be costly but worthwhile

As is often the case in the restoration of natural systems, the estimated costs of the required interventions can be expected to be high. Many of these interventions could be regarded as obligations that should be met irrespective of the restoration of wetlands, for the mere purpose of providing essential services required for maintaining human health and dignity. While these investments would not be particularly cost effective in terms of the impacts on water treatment costs alone (given the investment that has already been made in a new plant further afield), taken together with their potential recreational benefits, they are likely to be worthwhile. This is not surprising given the dire lack of managed green open space available to Kampala residents for outdoor recreation. As the economy of Uganda continues to develop and incomes improve, the demand for these kinds of amenities is likely to increase. Such benefits would also potentially be reflected more tangibly in property values in the area. In addition, the restoration of the wetlands and water quality in Inner Murchison Bay would be likely to have benefits for biodiversity and fisheries.

Key message 3: There are no shortcuts

For restoration to be successful, implementation of all the interventions outlined in this study is required. *Ad hoc* investments not driven by detailed plans will fail to deliver the outcomes required, resulting in both wasted money and time. The order of implementation is not particularly important as long as they are all implemented. For example, Step 2 could be implemented as a stopgap while Step 1 is finalised. In addition, the sooner that work begins on the wetland-edge filter strips and on wetland rehabilitation, the lower the risk of further human encroachment into the wetland when it comes to the implementation of this step, because people will not be able to settle or carry out agriculture in the re-established permanently wet areas.

Key message 4: This will need fundraising and co-ordination

In order for the restoration interventions to be successfully realised, the city will need to carry out a suite of actions relating to sourcing and management of funds, sorting out responsibilities and co-ordinating the efforts required.

This study estimates that a total initial expenditure of at least $53 million is required in order to achieve the goals outlined, depending on the actual shortfall in sanitation infrastructure. If, for example, the total Nakivubo restoration took place over four years, this would entail an average annual capital expenditure of 13.25 per year, which is equal to 39-74% of the city's capital budget in the last three financial years up to 2014/15 ($18, $25 and $34 million, respectively) and 11-23% of planned annual capital expenditures over the next two years ($57 and $123 million, respectively, which is largely donor-funded). This suggests that the Nakivubo restoration is only feasible with a significant contribution of donor funding. The challenge this represents may look different depending on the potential funding sources and whether these are fungible (i.e. interchangeable). For example there may be an opportunity to use a donor source that has a pre-determined preference to spend on these issues. Raising funds for further sanitation investments does not necessarily have to be linked to wetland restoration. Separating the issues and addressing sanitation first will lower the risks and make funding for the direct wetland rehabilitation work more accessible.

A detailed plan will need to be drawn up. The actions described in this report pertain to multiple government institutions, particularly the KCCA, the NWSC, the Ministry of Lands, Housing and Urban Development, and the Ministry of Natural Resources. In order for effective action to take place, coordination between these bodies is necessary. It will also be necessary for one of these bodies, probably the NWSC to take the lead in this co-ordination, with NWSC focusing on the bulk of the investments required including treatment wetlands, KCCA focusing on the investment in recreational facilities, and the Ministry of Natural Resources focusing on the management of the remaining natural wetlands. Similarly, there will need to be clarity regarding the responsibility and capacity of different institutions to undertake the ongoing oversight management actions.

Key message 5: Avoid a repeat experience

There are important lessons to be learned from this study. Wetland function has been detrimentally impacted by direct and indirect interventions that have in many cases wasted opportunities to reap benefits that might be associated with a healthy wetland. For example, increasing the spread of flows under the railway line would have retained a much larger area of functional wetland downstream, and thus increased wetland services. Given the pollution loading into and through the wetland, even such measures would not however have protected the wetland adequately, or allowed it to address its present pollution load to any significant level. Considerable environmental and economic costs have thus been incurred by delaying investments that are inevitably required, including the additional costs that have been sunk into water treatment facility modifications and the location of new treatment works at distant sites. This potentially holds true for the many wetland areas that are about to become engulfed by the growing city of Kampala. Kampala is the second fastest growing city in Eastern Africa with an annual population growth rate of 3.9% (KCCA 2012). In 2012 the population of the Greater Kampala Metropolitan Area (GKMA) was just over 3 million and was projected to reach 5 million in 2020 and 13 million in 2040 (KCCA 2012). The area of developed land within the GKMA increased from 27% in 1989 to 78% in 2010 (KCCA 2012). Land conversion has already resulted in the substantial loss of wetland area in Kampala with almost 50% of the original wetland areas within Kampala’s core city area (KCCA) having been converted by 1999, and only about 8% remaining highly functioning (KCCA 2014b). Without proactive interventions, the wetlands outside of the present urban core will also be destroyed and the cumulative impacts on Murchison Bay and any economic activities around the bay, including the viability of a future waterfront development, could be significant.

Thus the following recommendations should be considered:

1. **Sanitation measures** need to keep ahead of the growing urban population, and until this is the case, runoff from areas that are not well serviced needs to be diverted to a WWTW;
2. **Water quality standards** for waste water treatment need to be made more stringent, particularly with regards to phosporus, and enforced, and investments need to be made in the technological innovation needed to deal with this;
3. There needs to be stricter regulation and **control of industrial discharges.** This should form part of a review into industrial effluent guidelines and current practices;
4. **Legal protection of wetlands** needs to be strengthened, and tough and/or innovative measures need to be taken to prevent the reclamation, farming and settlement of wetland areas;
5. Construction of roads and railways through wetlands should be avoided, or at least be done in such a way as to **minimise impacts on hydro- and sediment dynamics** and aesthetics;
6. **Monitoring programmes** need to be established, including continuous monitoring of flows into the wetland, and monthly measures of water quality of inflows and within all wetland areas in and around Kampala. Water quality monitoring data should be made readily available in an online platform for potential use by academic institutions, consultants, civil society etc. in order to encourage transparency and accountability as well as facilitate ongoing analysis and adaptive management.

One of the main challenges in achieving the above will be institutional. Greater Kampala extends well beyond the boundaries of the KCCA, which originally encompassed the entire city, and unless the KCCA area is adjusted accordingly (as has been done in other countries), the problems that will arise in a growing city will be in areas under multiple other jurisdictions. Meanwhile, it may be more pragmatic for these issues t to be managed by the relevant national institutions such as NWSC.

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APPENDIX 1. SELECTED WATER QUALITY MEASURES AND THEIR INTERPRETATION

A. General Measures

pH

- **Definition:** This is the measurement of the hydrogen-ion concentration in the water. A pH below 7 is acidic (the lower the number, the more acidic the water, with a decrease of one full unit representing an increase in acidity of ten times) and a pH above 7 (to a maximum of 14) is basic (the higher the number, the more basic the water).
- **Importance:** High pH values tend to facilitate the solubilisation of ammonia, heavy metals and salts. The precipitation of carbonate salts (marl) is encouraged when pH levels are high. Low pH levels tend to increase carbon dioxide and carbonic acid concentrations. Lethal effects of pH on aquatic life may occur below pH 4.5 and above pH 9.5, although it is noted that some aquatic ecosystems are naturally within these ranges and their fauna and flora have adaptations that allow them to withstand these conditions.

Dissolved Oxygen (DO)

- **Definition:** This is a measure of the amount of oxygen dissolved in water. Typically the concentration of dissolved oxygen in surface water is less than 10 mg/L. The DO concentration is subject to diurnal and seasonal fluctuations that are due, in part, to variations in temperature, photosynthetic activity and river discharge. The maximum solubility of oxygen (fully saturated) ranges from approximately 15 mg/L at 0°C to 8 mg/L at 25°C (at sea level). Natural sources of dissolved oxygen are derived from the atmosphere or through photosynthetic production by aquatic plants. Natural re-aeration of streams can take place in areas of waterfalls and rapids.
- **Importance:** Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. It affects the solubility and availability of nutrients, and therefore the productivity of aquatic ecosystems. Low levels of dissolved oxygen facilitate the release of nutrients from the sediments. Oligotrophic (low nutrient) lakes tend to have increased concentrations of dissolved oxygen in the hypolimnion (deeper waters) relative to the epilimnion (defined as orthograde oxygen profiles). Eutrophic (high nutrient) lakes tend to have decreased concentrations of dissolved oxygen in the hypolimnion relative to the epilimnion (defined as clinograde oxygen profiles).

Specific Conductivity

- **Definition:** This is the measurement of the ability of water to conduct an electric current - the greater the content of ions in the water, the more current the water can carry. Ions are dissolved metals and other dissolved materials. Conductivity is reported in terms of microsiemens per centimetre (µS/cm). Natural waters tend to vary between 50 and 1500 µS/cm.
- **Importance:** Specific Conductivity may be used to estimate the total ion concentration of the water, and is often used as an alternative measure of dissolved solids. It is often possible to establish a correlation between conductivity and dissolved solids for a specific body of water

Turbidity

- **Definition:** This is a measurement of the suspended particulate matter in a water body which interferes with the passage of a beam of light through the water. Materials that contribute to turbidity are silt, clay, organic material, or micro-organisms. Turbidity values are generally reported in Nephelometric Turbidity Units (NTU). Pure distilled water would have non-detectable turbidity (0 NTU). The extinction depth (for lakes), measured with a Secchi disc, is an alternative means of expressing turbidity.
- **Importance:** High levels of turbidity increase the total available surface area of solids in suspension upon which bacteria can grow. High turbidity reduces light penetration; therefore, it impairs photosynthesis of submerged vegetation and algae. In turn, the reduced plant growth may suppress fish productivity. Turbidity interferes with the disinfection of drinking water and is aesthetically unpleasant. Drinking water should be < 1 NTU.

Suspended Solids (Residue, Non-filterable)

- **Definition:** This is a measure of the particulate matter that is suspended within the water column. Non-filterable residue values are reported in mg/L.
- **Importance:** High concentrations of non-filterable residue increases turbidity, thereby restricting light penetration (hindering photosynthetic activity). Suspended material can result in damage to fish gills. Settling suspended solids can cause impairment to spawning habitat by smothering fish eggs. Suspended solids interfere with water treatment processes.

Total Dissolved Solids - TDS (Residue, Filterable)

- **Definition:** This is a measure of the amount of dissolved material in the water column. It is reported in mg/L with values in fresh water naturally ranging from 0-1000 mg/L. Dissolved salts such as sodium, chloride, magnesium and sulphate contribute to elevated filterable residue values.
- **Importance:** High concentrations of TDS limit the suitability of water as a drinking source and irrigation supply. High TDS waters may interfere with the clarity, colour and taste of manufactured products. Drinking water should have <500 mg/L.

Colour, true

- **Definition:** This is a measure of the dissolved colouring compounds in water. The colour of water is attributed to the presence of organic and inorganic materials; different materials absorb different light frequencies. Colour is expressed as Pt-Co units according to the platinum-cobalt scale. Water colour can naturally range from 0-300 Pt-Co. Higher values are associated with swamps and bogs.
- **Importance:** Colour is regarded as a pollution problem in terms aesthetics, but is not generally considered a detriment to aquatic life. Increased colour may interfere with the passage of light, thereby impeding photosynthesis.

B. Nutrients (Nitrogen and Phosphorus)

The sources of the following nutrients include sewage treatment plant effluents, agriculture, urban developments, recreation, industrial effluents and mining

Total Ammonia (NH_3 & NH^4+)

- **Definition:** This is a measure of the most reduced inorganic form of nitrogen in water and includes dissolved ammonia (NH_3) and the ammonium ion (NH_4+). Nitrogen is an essential plant nutrient and although ammonia is only a small component of the nitrogen cycle, it contributes to the trophic status of a body of water. Ammonia is generally reported in either µg/L or mg/L. Natural waters typically have ammonia concentrations less than 0.1 mg/L.
- **Importance:** Excess ammonia contributes to eutrophication of water bodies. This results in prolific algal growths that have deleterious impacts on other aquatic life, drinking water supplies, and recreation. Ammonia at high concentrations is toxic to aquatic life.

Nitrite (NO_2-)

- **Definition:** This is a measure of a form of nitrogen that occurs as an intermediate in the nitrogen cycle. It is an unstable form that is either rapidly oxidized to nitrate (nitrification) or reduced to nitrogen gas (de-nitrification). This form of nitrogen can also be used as a source of nutrients for plants. Nitrite is generally reported in either µg/L or mg/L. It is normally present in only minute quantities in surface waters (<0.001 mg/L).
- **Importance:** Since nitrite is also a source of nutrients for plants its presence encourages plant proliferation. Nitrite is toxic to aquatic life at relatively low concentrations. Drinking water limits tend to be about 1 mg/L.

Nitrate (NO_3-)

- **Definition:** This is the measurement of the most oxidized and stable form of nitrogen in a water body. Nitrate is the principle form of combined nitrogen found in natural waters. It results from the complete oxidation of nitrogen compounds. It is generally reported in µg/L or mg/L. Without anthropogenic inputs, most surface waters have less than 0.3 mg/L of nitrate.
- **Importance:** Nitrate is the primary form of nitrogen used by plants as a nutrient to stimulate growth. Excessive amounts of nitrogen may result in phytoplankton or macrophyte proliferations. At high levels it is toxic to infants. Drinking water limits tend to be about 10 mg/L.

Total Organic Nitrogen

- **Definition:** This is a measure of that portion of nitrogen that is organically bound. Organic nitrogen includes all organic compounds such as proteins, polypeptides, amino acids, and urea. It is reported as mg/L. Dissolved organic nitrogen can often constitute over 50% of the total soluble nitrogen in fresh water.
- **Importance:** Organic nitrogen is not immediately available for biological activity. Therefore, it does not contribute to furthering plant proliferation until decomposition to the inorganic forms of nitrogen occurs.

Total Nitrogen

- **Definition:** This is a measure of all forms of nitrogen (organic and inorganic). Nitrogen is an essential plant element and is often the limiting nutrient in marine waters.
- **Importance:** The importance of nitrogen in the aquatic environment varies according to the relative amounts of the forms of nitrogen present, be it ammonia, nitrite, nitrate, or organic nitrogen (each of which are discussed in detail above).

Total Phosphorus

- **Definition:** This is a measure of both inorganic and organic forms of phosphorus. Phosphorus can be present as dissolved or particulate matter. It is an essential plant nutrient and is often the most limiting nutrient to plant growth in fresh water. It is rarely found in significant concentrations in surface waters. It is generally reported in µg/L or mg/L. The total phosphorus concentrations in most lakes not affected by anthropogenic inputs is generally less than 0.01 mg/L (10 µg/L).
- **Importance:** Since phosphorus is generally the most limiting nutrient, its input to fresh water systems can cause extreme proliferations of algal growth. Inputs of phosphorus are the prime contributing factors to eutrophication in most fresh water systems. A general guideline regarding phosphorus and lake productivity is: <10 µg/L phosphorus yields is considered oligotrophic, 10-25 µg/L P will be found in lakes considered mesotrophic, and >25 µg/L P will be found in lakes considered eutrophic. Drinking water limits tend to be 10 µg/L.

Orthophosphate (PO_4^{-3})

- **Definition:** This is a measure of the inorganic oxidized form of soluble phosphorus. It is generally reported in µg/L or mg/L.
- **Importance:** This form of phosphorus is the most readily available for uptake during photosynthesis. High concentrations of orthophosphate generally occur in conjunction with algal blooms.

Source: https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/interp/index.htm

APPENDIX 2. WATER QUALITY AMELIORATION BY WETLANDS

Water entering wetlands from developed catchments generally has elevated amounts of sediments, nutrients and pollutants from catchment activities, industrial effluents, treated and untreated sewage and other wastes. Excess nutrients can stimulate algal growth, leading to deterioration in aquatic ecosystems, with a whole suite of knock-on effects, while other heavy metals and pathogens pose a risk to human health.

There are a number of different process through which wetlands remove sediments, nutrients and pollutants from the inflowing water (Figure A2.1). Nutrients that are introduced in dissolved form can be taken up directly by plants and incorporated into plant tissue as they grow. Most of the phosphorous that is introduced to wetlands is attached to sediment and settles to the bottom, where it can remain inactive (Brinson 2000). However, if sediments are stirred up then some of this phosphorous can go back into solution and become available for use by plants. The uptake of dissolved phosphorous will continue as long as there is room for further plant growth (in terms of space, oxygen or plant size limits), after which the system will reach some kind of equilibrium in which the uptake is balanced by the senescence, death and rotting of plant material which reintroduces nutrients into the water column (remineralisation). At this point there would be no further net uptake of nutrients by the wetland unless nutrients are being exported out of the system (e.g. by harvesting plants or dredging and removal of sediments), or unless there is a natural process of peat formation, which does occur in Nakivubo wetland (Kansiime & Nalubega 1999).

Nitrogen is removed in wetlands mainly by the nitrification–denitrification process (Saunders & Kalff 2001). Nitrification is the microbially-mediated oxidation of ammonium (NH_4) to nitrite (NO_2) and then nitrate (NO_3). This process consumes oxygen and thus occurs in aerobic areas of the wetland. Nitrate then diffuses to anaerobic areas of the wetland where it may be denitrified. This is the rate-limiting step in the removal of nitrogen from flooded systems. In the denitrification process nitrate (NO_3) is reduced to gaseous nitrous oxide (N_2O) and nitrogen gas (N_2), which are then released to the atmosphere (Mitsch & Gosselink 1993). This occurs mainly in sediments with abundant organic matter that provides a carbon source for denitrifying bacteria.

Bacteria concentrations are reduced in wetlands by exposure to UV-light. The degree to which this occurs is linked to the duration of water retention within the system. In the Nakivubo wetland, the concentrations of pollutants are also decreased in the lower part of the wetland by dilution with lake waters.

The ability of wetlands to perform water quality amelioration services depends on their area and type of vegetation as well as to their overall health and management. Hydraulic efficiency, which is the degree to which a wetland disperses inflow over its area, is also important (Jordan *et al*. 2003). This maximizes contact area and it can be assumed that it serves to increase detention time as well. There is an upper limit to the amount of pollution that a wetland can remove, as well as to the amount of pollution that can be added to a wetland without having a significant impact on its functioning and biodiversity. At high phosphorus loading rates wetlands may eventually become a phosphorus source rather than a sink (Tilton & Kadlec 1979, Forbes et al. 2004). This also varies seasonally. Wetlands are thought to be better at removing total suspended solids, phosphorus and ammonia during high flow periods (when sediment loads entering the wetland increase), but better at removing nitrates during low flow periods (Johnston *et al*. 1990, McKee et al. 2000).

APPENDIX 3. RECENT CHANGES TO NAKIVUBO WETLAND

From the satellite images taken in 2000 and 2015 it can be seen that there has been extensive encroachment around the sides of the Nakivubo wetland (Figure A3.1). These mostly consist of informal dwellings as well as expansion of industrial areas. There is also evidence for sediment being dumped in the upper sections alongside the canal (possible dredge spoils from the canal itself).

The upper Nakivubo wetland was almost entirely under cultivation already by the year 2000 (Figure A3.2). This is in contrast to the maps in Kansiime & Nalubega (1999), which indicated a remaining central section of wetland vegetation in the mid-1990s. The channel is also much less defined in 2000 and is further north than that in 2015.

The lower sections of the wetland in the most recent picture have changed quite dramatically from that in 2000 (Figure A3.3). It is clear that some of the papyrus floating islands are breaking apart and seem to have decreased in size. The exact cause of these changes is unknown, however, degradation of the papyrus through cutting, burning or replacing with agriculture could be leading to these patterns observed. On close inspection of the island in the southern end in the 2015 image, extensive agriculture can be seen. This area was identified as a thick *Miscanthiduim violaceum* mat in Kansiime & Nalubega (1999) and appears mainly intact in the 2000 image.

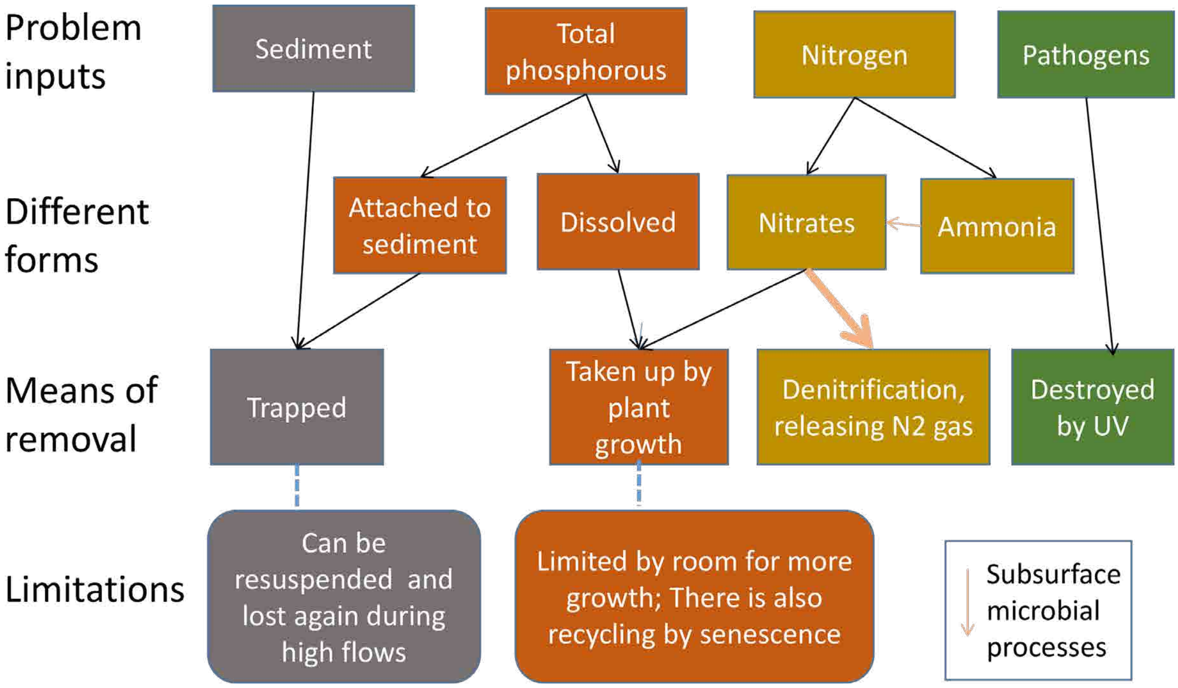

Figure A2.1 Summary of water quality amelioration services by natural systems
Source: Turpie, 2015

Figure A3.1 Changes in Nakivubo wetland between 2000 (top picture) and 2015 (bottom picture) from satellite pictures (Google Earth). Red outline indicates soil dumping, blue indicates informal encroachment and yellow indicates industrial expansion.

Figure A3.2 Changes in upper Nakivubo wetland between 2000 (top picture) and 2015 (bottom picture) from satellite pictures (Google Earth).

Figure A3.3 Changes in lower Nakivubo wetland between 2000 (top picture) and 2015 (bottom picture) from satellite pictures (Google Earth).

APPENDIX 4. POLLUTION INPUTS

Sources of pollution affecting the wetland are routed primarily along the Nakivubo channel, which receives contaminated runoff and litter from poorly-serviced urban areas abutting the channel, treated sewage effluent from the Bugolobi Waste Water Treatment Works (WWTW), and treated sewage from the Luzira Prison.

Flows have been recorded in various parts of the catchment in the 1990s (Kansiime & Nalubega 1999, COWI 1998) as well as in a recent study (Tebandeke 2013; Table A4.1). These data suggest that flows entering the wetland may have increased from about 73 000 m^3 per day in the 1990s (COWI 1998) to about 106 000 m^3 per day in 2013 (based on Tebandeke 2013). If this is the case, the increase (4% per year) is in line with population increase in the catchment over the same period. Households within the catchment receive water from outside the catchment (piped in to houses and water points), and runoff is increased as a result of hardened surfaces. About 92% of the flow into the wetland reaches the railway culvert and flows into the lower part of the wetland (COWI 1998).

The nutrient loading into the wetland has been described in a number of studies. Of these, three estimate the total daily loading into the wetland. Kansiime & Nalubega (1999) estimated that 365 000 kg of total N and 28 288 kg of total P were deposited into the wetland annually during the mid-1990s. Estimates from COWI (1998) which was conducted during a similar period were not vastly different (Table A4.2). More recent estimates from Tebandeke (2013) give an average and a range of estimates; however these are from smaller streams as well as the Nakivubo Channel. We therefore assume that the Nakivubo is the highest estimates as we know it contributes the most into the wetland. These upper limits were about a 50% increase in terms of N and P loads from 1998 to 2013. This seems feasible in terms of the increased population of Kampala over this period.

Water quality and sediment data collected by Stalder (2014) & Fuhrimann et al. (2015) showed that:

- Bacterial contamination decreased along the Nakivubo channel with distance from Kampala City;

Table A4.1 Flow data for different sites upstream of the Nakivubo wetland from available literature sources. Flow is expressed in m^3/day and for some data sources was separated into average flows for dry and wet seasons.

Study	Sampling Location	Dry Season Flow (m^3/day)	Wet Season Flow (m^3/day)	Average Flow (m^3/day)
Kansiime & Nalubega 1999	Railway culvert	50 000-60 000	~500 000	101 575
COWI 1998	Fire Station			22 464
	Kayuanga drainage area			6 048
	Kitante drainage area			9 504
	Bugolobi WWTW			5 184
	Nakivubo Channel (5th street)			72 576
	Railway Culvert			66 528
Tebandeke 2013	Kayuanga drainage area	2 851	12 787	
	Kitante drainage area	3 024	18 317	
	City Abattoir	778	864	
	Nakivubo Channel	42 509	170 208	

Table A4.2 Nutrient loadings (total nitrogen and total phosphorous) for the Nakivubo wetland (kg/y) from available literature sources.

Time of sampling	Annual loading N (kg/y)	Annual loading P (kg/y)	Reference
Mid 1990s	365 000	28 288	Kansiime & Nalubega 1999
1997	310 980	38 325	COWI 1998
Nov 2010-May 2012	457 544*	60 366*	Tebandeke 2013

** Individual values not given for sampling sites, however assuming highest values correspond to the Nakivubo Channel entering the wetland.*

- With distance further downstream, high levels of point-source contamination of faecal coliform bacteria were however associated with inflows from the BWWTW (final effluent *E. coli* and *Salmonella* spp. counts ranged from 3×10^6 to 9.7×10^7 (mean 2.5×10^7) and $1 \times 10^2 – 3.6 \times 10^4$ (mean 1.5×10^3) respectively);
- Point source inflows of water contaminated with Salmonella bacteria strains appeared in samples from sites further downstream from the BWWTW outlet, and were assumed to be sourced from informal settlements to the west of the wetland (Kasanvu, Namuwongo A and B and Yoka zones);
- Bacterial contamination decreased with distance into Lake Victoria, and with depth from the surface.

Kansiime & Nalubega (1999) showed that waste water is not evenly distributed through the Nakivubo swamp, with the bulk of water from the Nakivubo channel funnelling through the central portion of the swamp, while the edges of the swamp receive low volumes of waste water, or none at all – this is attributed to the fact that the edges of the swamp are emergent and attached, whereas the lake-side (downstream) portions of the swamp are floating, and result in channelization of water and (effective) short-circuiting of effluent flows.

APPENDIX 5. CURRENT CONDITION OF AQUATIC ECOSYSTEMS IN TERMS OF WATER QUALITY

This section describes the quality of various sources of water considered in this study, in terms of its human health and/or ecological effects, using the guidelines/criteria presented below.

A5.1 Water quality limits and guidelines used

Interpretation of water quality in the Nakivubo Channel, wetlands and Inner Murchison Bay area was informed by existing guidelines relating to both human and ecological health. From an ecological perspective, these hinged mainly on water quality guidelines relating to trophic (nutrient) condition, since this is the key area of ecosystem response to nutrients, considered in the present study to comprise one of the main impacts affecting the Nakivubo wetland and its potential for future development/beneficial use. The trophic status of freshwater ecosystems allows them to be broadly classified into one of four trophic categories associated with different levels of nutrients (mainly phosphorus and nitrogen; Table A5.1). The ranges of key nutrients (phosphorus and nitrogen nutrients) as well as of chlorophyll-a (a measure of phytoplankton (green algae) in the water) that are (broadly) associated with different trophic states in open water systems are provided in Table A5.2. An explanation of water quality variables is given in Appendix 1.

Table A5.1 Broad classification of trophic condition (based on DWAF 1996)

Trophic status	Level of nutrients	Generic description	Typical situation for lakes
Oligotrophic	Low	Systems with moderate species diversity; usually low productivity systems with rapid nutrient cycling and no nuisance growth of algae or aquatic plants	Clear waters and a rocky or sandy shoreline. Both planktonic and rooted plant growth are sparse
Mesotrophic	Moderate	Systems that usually exhibit high species diversity; productive systems, prone to nuisance growths of aquatic plants and blooms of (seldom toxic) blue-green algae	Shallow with a soft, silty bottom. Rooted plant growth is abundant along the shores and out into the lake, and algal blooms are not unusual. Water clarity is usually poor. If deep enough to thermally stratify, the bottom waters are often devoid of or low in oxygen.
Eutrophic	High	Systems associated with low species diversity, highly productive systems, prone to nuisance growths of aquatic plants and blooms of (sometimes toxic) blue-green algae	Characteristics between meso- and hypertrophic
Hypertrophic	Extremely high	Systems that usually exhibit very low species diversity; very highly productive; prone to nuisance growths of aquatic plants and blooms of (sometimes toxic) blue-green algae	Bottom level anoxia is common and the systems are prone to blooms of blue-green as well as green algae

The ecological condition of a wetland can also be assessed in terms of its similarity to the natural condition. A set of guidelines has been devised to determine the health of southern African systems, expressed in terms of classes A (natural) to F (very highly degraded), based on ranges of concentrations for key water quality variables (Table A5.3). Present Ecological State (PES) categories reflect assumed deviation in water quality from natural / reference conditions. The thresholds in Table A5.3 are based on data for open water systems in southern Africa (DWAF 2008). While these have not been tested in East African lakes such as Lake Victoria, it is probable that the ranges at least at the degraded end of the scale (that is, in the range D to F) apply to most open water bodies. For the purposes of broadly defining target management objectives for treating urban runoff, the values in Table A5.3 should be adequate.

From a human health perspective, WHO (2006) guidelines ought ideally to be used with regard to the identification of risk thresholds associated with different concentrations of bacterial contamination. However, WHO (2006) guidelines are based on concentrations of intestinal Enterococci bacteria in water. These data were not available for any of the aquatic ecosystems addressed in this study, and as a result, human health guidelines that covered available data (e.g. South African Water Quality Guidelines for Recreational Use (DWAF 1996b) were used in this study. These guidelines, developed for application in freshwater environments are based on concentrations of faecal coliform bacteria. Such data are also available for the freshwater ecosystems included in the present study area. The DWAF (1996b) water quality guidelines are thus considered realistically applicable to the present study, and are summarised in Table A5.4, with categories of recreational exposure to water as defined/described in Table A5.5.

Table A5.2 Summary of ranges of phosphorus and/or nitrogen based nutrients associated with different trophic conditions in in-lake aquatic ecosystems

Trophic state	Average summer inorganic nitrogen concentrations (mg/l) (DWAF 1996a)	Average summer inorganic phosphorus concentrations (mg/l) (DWAF 2002)	Chlorophyll-a (ug/l)
Oligotrophic	<0.5	< 0.015	< 3.5
Mesotrophic	0.5-2.5	> 0.015-0.047	3.5- 9
Eutrophic	2.5-10	>0.047-0.130	9-25
Hypertrophic	>10	> 0.130	>25

Table A5.3 Threshold values for key water quality variables for determining Present Ecological State (PES) after Day & Clark (2012) – For all variables except Dissolved oxygen (DO), listed values represent the upper threshold for each PES Category. For DO, values shown represent the lower threshold for each PES Category. TIN is Total Inorganic Nitrogen

PES Category	PES description (based on deviation from assumed reference condition)	Chl-a	TOTAL P	NH3-N	DO	TIN
A	No change	5	0.005	0.015	>8	0.25
B	Small change	10	0.015	0.04375	>7	0.7
C	Moderate change	20	0.047	0.0725	>6	1
D	Large change	30	0.13	0.1	>4	4
E	Serious change	40	1	0.12875	>2	10
F	Extreme change	>40	> 1	>0.5	>0	>20

Interpretation of effluent quality data from the BWWTW has been carried out with reference to effluent limits as cited in the (Ugandan) National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations (S.I. No 5/1999) (Under section 26 and 107 of the National Environment Act, Cap 153). Data relevant to this study are summarised in Table A5.6.

It should be noted upfront, however, that while adequate guidelines exist for the interpretation of data, the water quality data for the effluent, channelled, wetland and in-lake environments considered in this study are limited to the results of a few discrete studies, the data for which have seldom been presented in a manner that permits easy dissemination or application to other questions/ research areas, and flow data from which loading could be calculated were limited and unreliable.

Table A5.4 South African DWAF (2005b) water quality limits for the use of water for recreational purposes.

Description of effect	Faecal coliform bacteria (#cfu)	
	Full contact range	Intermediate contact range
Target water quality range Some risk of gastrointestinal effects	0-130	0-1000
Moderate risk of gastrointestinal effects	130-600	1000-4000
Noticeable health effects expected in swimmer and bather population, especially if such events occur frequently	600-2000	
Increasing levels of risk of gastrointestinal illness, with only small volumes of water needed to be ingested to be associated with human health impacts	> 2000	>4000

 # The concentrations of bacteria in water is usually expressed as numbers of colony-forming units (CFU) per 100 ml, which is a measure of the number of viable cells in a particular sample, where a colony represents an aggregate of cells derived from a single progenitor cell

Table A5.5 Categories of recreational use of a water body (DWAF 1996b)

Category	**Description**
Full contact recreation	Full-body water contact, and includes full immersion activities such as swimming and diving.
Intermediate contact recreation	All forms of contact recreation excluding those listed under full contact recreation. Includes some activities which involve a high degree of water contact (e.g. water-skiing, wading and wind-surfing) as well as those which involve relatively little water contact (e.g. canoeing and angling). Compared with the above, full immersion is likely to occur only occasionally and among novices of a water sport in respect of the latter category, the age of users (water sports such as water-skiing and windsurfing are usually practised by adults rather than by young children), and health status of users (strenuous water sports are generally practised by water users in a fairly good state of health).
Non-contact recreation	All forms of recreation which do not involve direct contact with water such as picnicking and hiking alongside water bodies, and scenic appreciation of water by those residing or holidaying on the shores of a water body. These activities are primarily concerned with the scenic and aesthetic appreciation of water.

Table A5.6 Effluent Limits as cited in the Ugandan National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations, S.I. No 5/1999 (Under section 26 and 107 of the National Environment Act, Cap 153). Only variables referred to in this study are included

Variable	Concentration	Variable	Concentration
Biological Oxygen Demand (BOD)	50 (mg/L)	Total phosphate (mg/L)	10
Chemical Oxygen Demand (COD)	100 (mg/L)	Orthophosphate (PO4-P) (mg/L)	5.0
Total nitrogen	10 (mg/L)	Total suspended solids (TSS) (mg/L)	100
Coliform organisms	10 000 counts/100 ml		

A5.2 Water from the BWWTW

Water quality data for the first six months of 2015 only were available for BWWTW final effluent, and are presented graphically in Figure A5.1. No reliable water flow data were available, although it is understood that the works when upgraded would treat up to 45 ML/day. The effluent quality data, interpreted with reference to Table A5.6, suggest that:

- Out of the 24 samples analysed, total phosphorus concentrations fell within legal effluent discharge limits only seven times;
- COD concentrations were also problematic, only complying in six samples, although BOD showed better compliance, with nine samples only exceeding legal limits;
- Total suspended solids complied with legal limits in just eight samples;
- Effluent data generally showed a reduction in concentrations of TSS, faecal coliforms and orthophosphate in April / May samples, assumed to reflect a dilution effect of rainfall on effluent streams.

In the event that effluent data comprised the full stream of water in the channel, it would be associated with the following aquatic ecosystem attributes (interpreted from Table A5.2 and with reference to DWAF 1996a):

- Orthophosphate concentrations were always at least an order of magnitude greater than the threshold for hypertrophic conditions and if this water comprised in-lake water, it would fall within the range of a Category F, as described in Table A5.3;
- Orthophosphate usually comprised more than 50% of total phosphorus, indicating that removal efforts would need to allow for large levels of uptake by plants, rather than focus only on sedimentation of particulate material;
- Faecal coliform data were always in excess of safe limits for even intermediate contact recreation;

Dissolved oxygen data, although limited to two samples, showed levels that were critically low (as per DWAF 1996a), and likely to pose acute threats to non air-breathing aquatic life. They fell within the PES range for a Category F for this variable (Table A5.3).

A5.3 The Nakivubo channel

Useful data for the channel are limited, and the most recent, useable data that could be sourced are presented in Table A5.7 and Table A5.8, with assumed site locations as shown in Figure A5.3.

These data suggested that:

- Concentrations of both orthophosphate (PO4-P) (the dissolved, biologically available part of total phosphorus) and total nitrogen fell well within the range considered associated with hypertrophic conditions in aquatic ecosystems, as outlined in Table A5.2.
- Concentrations of orthophosphate were variable, but increased substantially overall with distance downstream, as did loading of total phosphorus (TP), suggesting that additional sources of this nutrient entered the channel along its length at least as far as the railway line culvert;
- Total ammonium nitrogen concentrations were elevated well above target concentrations for this variable (e.g. DWAF 1996) but, assuming pH <7 and temperatures < 20°C, were all still below the range at which concentrations of un-ionised ammonia (NH_3) would reach assumed "chronic toxicity" concentrations for aquatic ecosystems. However, given that high rates of photosynthesis may increase pH, at least during the day, high concentrations of total ammonia in association with orthophosphate (which increases algal productivity) should still be viewed with concern;
- Biological Oxygen Demand was relatively high in the channel (nearly double the maximum legal limit for waste water effluent at the two upstream sites; see Table A5.6) and reflected high levels of organic material in the channel;
- Suspended sediment concentrations were highest in the upstream channel sites, but dropped substantially (by an order of magnitude) with distance downstream. Sediment loading increased at the 5th Street site, reflecting large volumes of diluted inflows from the BWWTW upstream of this site. The fact that there was a substantial reduction in TSS load by the railway line site is indicative of high levels of sedimentation in the channel upstream. Such sedimentation, along with some degree of instream biological processes, is assumed to account also for the reduction in BOD loading by the railway culvert;

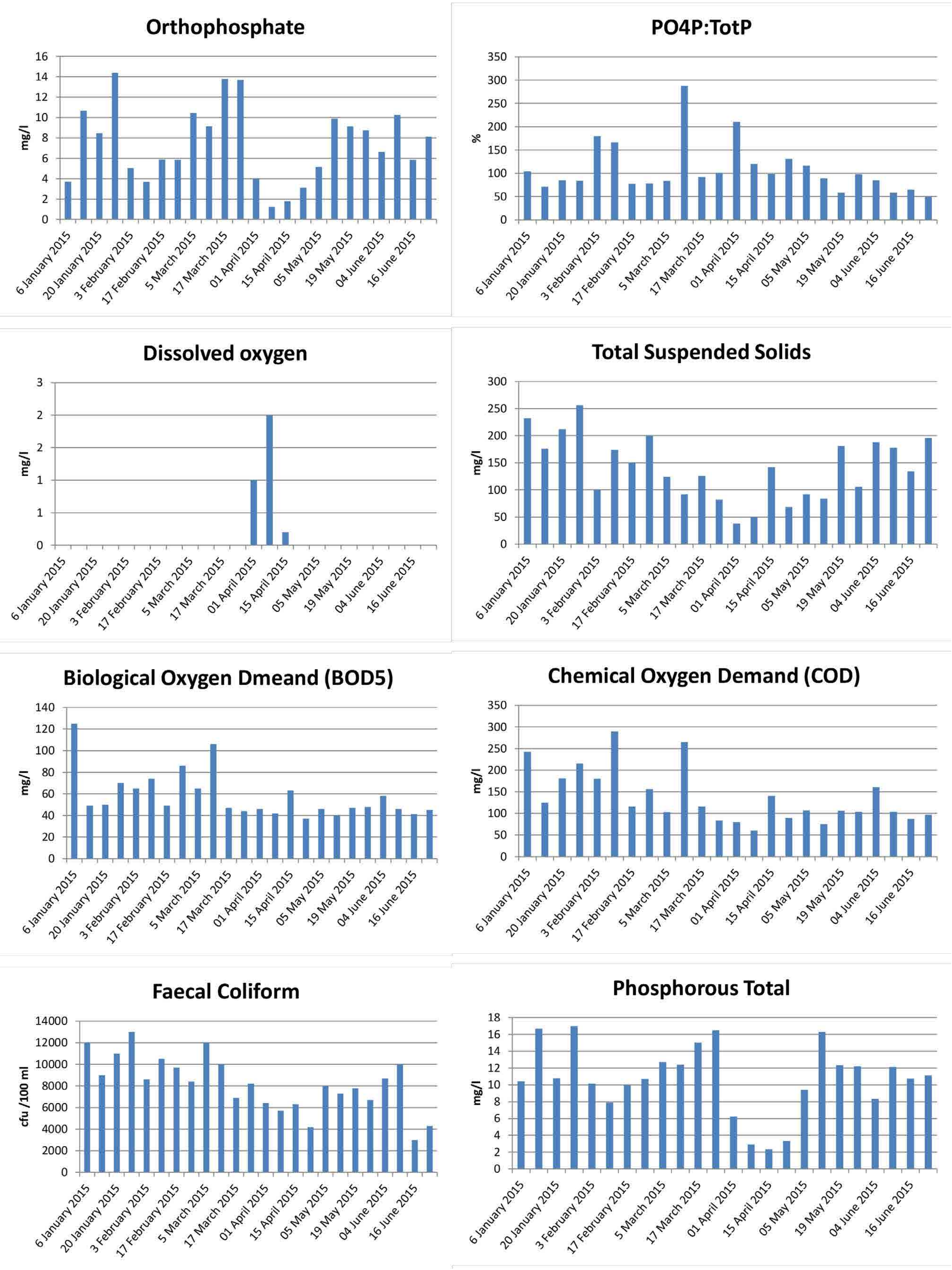

Figure A5.1 Water quality data for final effluent from the BWWTW

Table A5.7 Undated water quality data for the Nakivubo channel after COWI (1998)

Station	pH	EC	TN (mg/l)	TP (mg/l)	NO3 (mg/l)	NH4 (mg/l)	PO4 (mg/l)	BOD (mg/l)	TSS (mg/l)	TN (kg/ day)	TP (kg/ day)	PO4 (kg/ day)	BOD (kg/ day)	TSS (kg/ day)	Flow (m3 day)
Fire Station	6.7	456	11.54	2.03	0.13	3.09	0.4	98.3	260	239	42	13	2.038	5 840	22464
5th street	6.89	497	11.99	1.69	0.11	2.58	0.13	98.6	172	852	105	67	10.195	12 483	72576
Railway Culvert	6.79	429	8.88	1.67	0.05	3.45	0.68	44.1	26	755	112	39	3.274	1 729	66528

Figure A5.2 Nakivubo channel at 5th Street Bridge

- The substantial increase in loading of total phosphorus with distance downstream reflects both the fact that additional sources of phosphorus enter the channel from informal settlements between the 5th Street site and the railway, and that the proportion of total phosphorus that was dissolved rather than in particulate form increased with distance downstream as well, thus reducing the efficiency of sedimentation as a process for phosphorus removal.

The data described above do not reflect any seasonal trends. Descriptive data presented in Kansiime & Nalubega (1999) suggest, however, that water quality may deteriorate in the channel as a result of runoff – this scenario is typical of many urban catchments with poor servicing and high levels of informal settlement (e.g. Cerfonteyn & Day 2012), because instead of diluting pollution streams, rainwater may simply wash contaminants from the broader catchment into the watercourse. Even if there is some dilution impact, net pollutant loading increases. No data indicating this process were available for the study area.

Table A5.8 Effluent Limits as cited in the Ugandan National Environment (Standards for Discharge of Effluent into Water or on Land) Regulations, S.I. No 5/1999 (Under section 26 and 107 of the National Environment Act, Cap 153). Only variables referred to in this study are included

Concentrations (all streams and channels)	Value Range	Variance Range	Value Range	Variance Range
pH	6.3-7.6		6.6-8.4	
DO (mg/l)	0.0-3.0	0.1	0.0-2.2	1.2
EC (uS/cm)	215-1597	100-523	252-2028	60-897
TSS (mg/l)	61-877	12-350	25-514	10-44
Temp (°C)	23-25.5	1-0.9	24.9-28.9	0.3-0.9
TN (mg/l)	2.28-164.07	0.31-22.85	3.49-173	0.84-3.1
TP (mg/l)	0.77-23.33	0.24-11.55	0.94-38.18	0.51-9.71
COD (mg/l)	100.7-1480.5	5.58-582.4	96.19-1352.48	31.44-880
BOD (mg/l)	82.28-839.4	18.36-372.4	69.31-1108.05	34.01-333.16
FC (cFu/100ml)	$3.8*10^6$-$2.1*10^7$	$3.5*10^5$-$1.3*10^7$	$2.6*10^6$-$5.4*10^7$	$1.5*10^6$-$4.8*10^7$

Figure A5.3 2015 Google Earth Image showing main features referred to in this section. Yellow labels indicate assumed locations of water quality sites referred to in the text and Table A5.7 and Table A5.8.

A5.4 The Nakivubo wetlands

Data collected by Stalder (2014) showed that both the upper and lower portions of the wetland are affected by:

- Elevated faecal coliform bacteria, including Escherichia coli, as well as Salmonella as a result of receipt of contaminated water from the Nakivubo channel;
- Parasitic nematode eggs and larvae, assumed to derive from raw and treated waste water - hookworm and several other nematode species were detected in the channel, the lower wetland and its Murchison Bay outlet at concentrations above the safe limits recommended by WHO (2006), while Ascaris lumbricoides (giant roundworm) were present in the channel, but not in the lower wetland;
- Heavy metal contamination of both water and sediments as a result of industrial pollution, with copper, iron and cadmium all occurring at concentrations that exceeded cited NEMA (1999) maximum acceptable concentrations in the channel, the lower wetland / swamp and the lake shores,
- Elevated suspended solids, orthophosphate and total ammonia concentrations, as well as high levels of both Biological and Chemical Oxygen Demand (BOD and COD), associated with organic waste – the study did not however indicate the degree of spatial variability in concentrations of these variables in the channel, lower wetland and lake environments.

Water passing along the Nakivubo channel at least as far as the railway line generally carries high loads of phosphorus and nitrogen nutrients, as well as sediments. The high chemical and biological oxygen demands (COD and BOD) of this waste stream are likely to contribute to downstream effects in the lower wetland, including reduced levels of dissolved oxygen and high levels of plant productivity (Kansiime & Nalubega 1999).

The dataset presented in Table A5.7 does not include bacterial data. Data in Table A5.8 are of limited value, in that they do not allow differentiation between sites, but they do indicate extremely high counts of faecal bacteria in the samples, with even minimum values being well above high risk thresholds for intermediate contact recreation, suggesting that at all times during the period sampled by Tebandeke (2013), contact with water in the channel would have been a potentially high risk activity from a human health perspective. This interpretation is supported by (again, non-site-specific) data from Stalder (2014) for both bacterial and human parasite data.

The condition of the lower Nakivubo wetland is considered to be deteriorating, with shrinkage of areas dominated by indigenous wetland plant communities (e.g. Cyperus papyrus community), as well as the detachment of substantial portions of floating *Miscanthidium violaceum* islands and their passage into the greater Murchison Bay area, as described above.

Figure A5.4 View of the Nakivubo wetlands

Figure A5.5 View across the lower wetland towards Murchison Bay.

A5.5 Murchison Bay

Between the edge of the Nakivubo wetland and the Ggaba intake, any pollution undergoes dilution through mixing with the lake water. The levels of BOD, TP, EC and Ammonium decreased by 51%, 96%, 67% and 98% respectively (Ooyo 2009). However, there are other potential sources of pollution within Inner Murchinson Bay that will also contribute to the levels of pollution encountered at the Ggaba water intake plant. In 2001, levels of NH4+ detected in the Inner Murchinson Bay were isolated to the area at the edge of the Nakivubo wetland with values measuring 2-3 mg/l (Table A5.6). By 2010, most of the northern section of the Inner Murchison Bay measured at least 5 mg/l, and in 2014, around the edge of Nakivubo wetland and around Port Bell these measurements were about 10 mg/l. Levels of total Phosphorous were quite evenly distributed across the Inner Murchison Bay during 2001, however by 2011 high values (1mg/l) were concentrated in the northern half of the bay (Table A5.6).

The only apparent source of Total Suspended Solids (TSS) in 2001 were coming from a source near to the Ggaba intake, which measured less that 100mg/l (Figure A5. 8). There were no detectable TSS coming from the edge of Nakivubo wetland. By 2010 this pattern had however completely shifted and the highest levels in the Inner Murchison Bay came from the edge of the Nakivubo wetland measuring up to 400mg/l.

Measurements of Biological Oxygen Demand were low during 2001 (less than 5 mg/l) (Figure A5. 9). Measurements in 2014 indicated that comparatively much higher levels of BOD were encountered across the Bay with measurements highest (over 20 mg/l) around the Nakivubo wetland edge, Kasanga wetland immediately south of Nakivubo and Wankolokolo wetland to the east of Port Bell.

No useful recent water quality data for Murchison Bay at the outlet of the Nakivubo channel were sourced in this study. Although water quality data were available for the Ggaba Water Treatment Plant in the bay, even these did not include nutrient or oxygen data. Visual evidence from Google Earth imagery (e.g. Figure A5. 2) suggests however that water in the bay is affected by periodic algal blooms, consistent with hypertrophic in-lake conditions, as described in Table A5.2, and it is assumed on this basis that the bay is subject to substantially elevated concentrations of at least phosphorus nutrients.

Kansiime & Nalubega (1999) did measure water quality in the bay, with distance from the lower Nakivubo wetland. Although this study did not provide raw data, they noted the following:

- Temperature, pH and Dissolved Oxygen increased with passage from the wetland interface to the open waters of the bay;
- Water was still hypoxic at 750 m offshore from the wetland interface;
- Conductivity, ammonium-nitrogen and total phosphorus concentrations sharply decreased in the open waters of the bay, just 1 km offshore, presumably as a result of dilution – the graph provided by these authors appears to indicate a range of approximately 1.0 to 1.5 mg P/l for samples taken 750m from the shore, reducing to a range of approximately 0.1-0.6 mg/l for samples 2.5 km from the shore. Interpreting these data in terms of the ranges presented in Table A5.2, even the latter are however still clearly in the hypertrophic zone for orthophosphate, noting however that the above authors presented data for total phosphorus only and not orthophosphate;
- On the basis of Table A5.3, the above data would all place Murchison Bay in a Category F in terms of phosphorus, and a Category B in terms of un-ionised ammonia. Data for the other variables considered in Table A5.3 were not available.

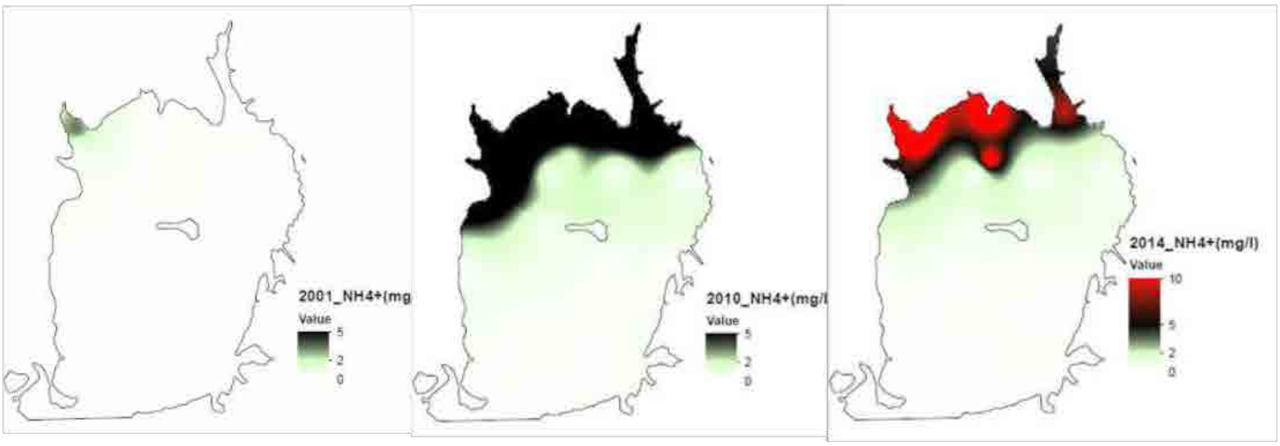

Figure A5.6 Ammonium measurements in 2001, 2010 and 2014 across Inner Murchison Bay (WSS Services 2015).

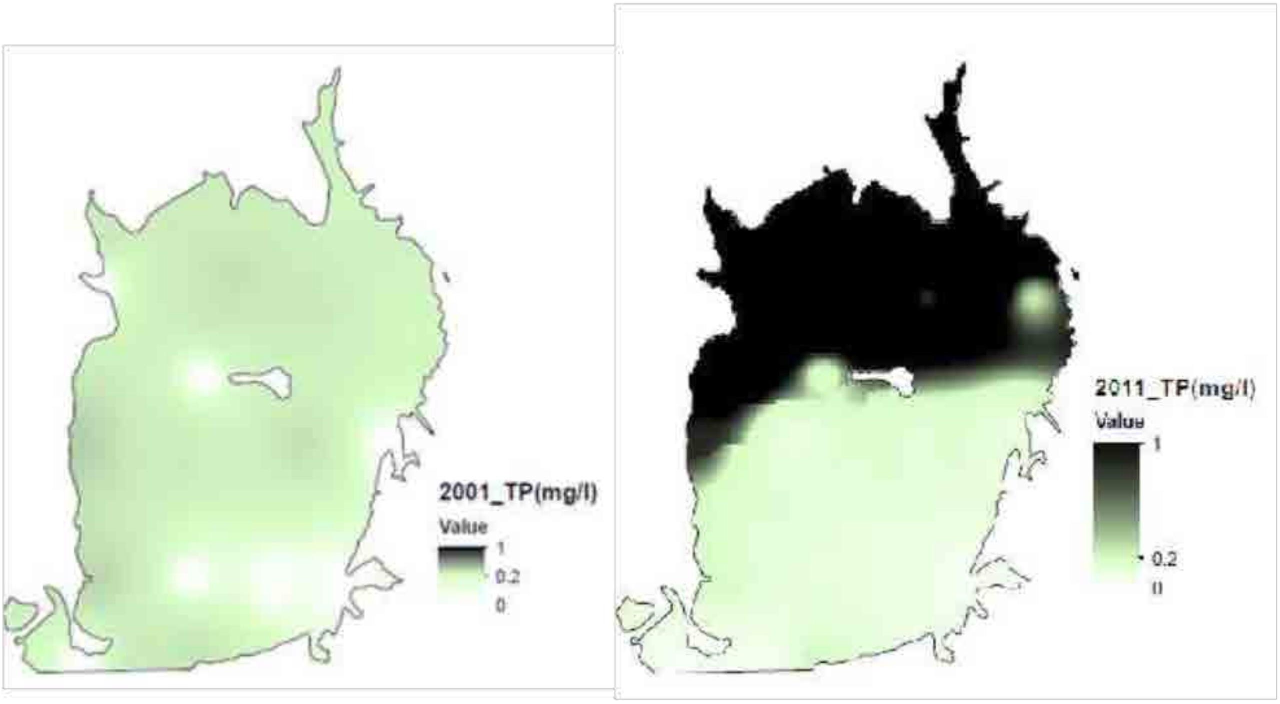

Figure A5.7 Total Phosphorous measurements in 2001 and 2011 across Inner Murchison Bay (WSS Services 2015).

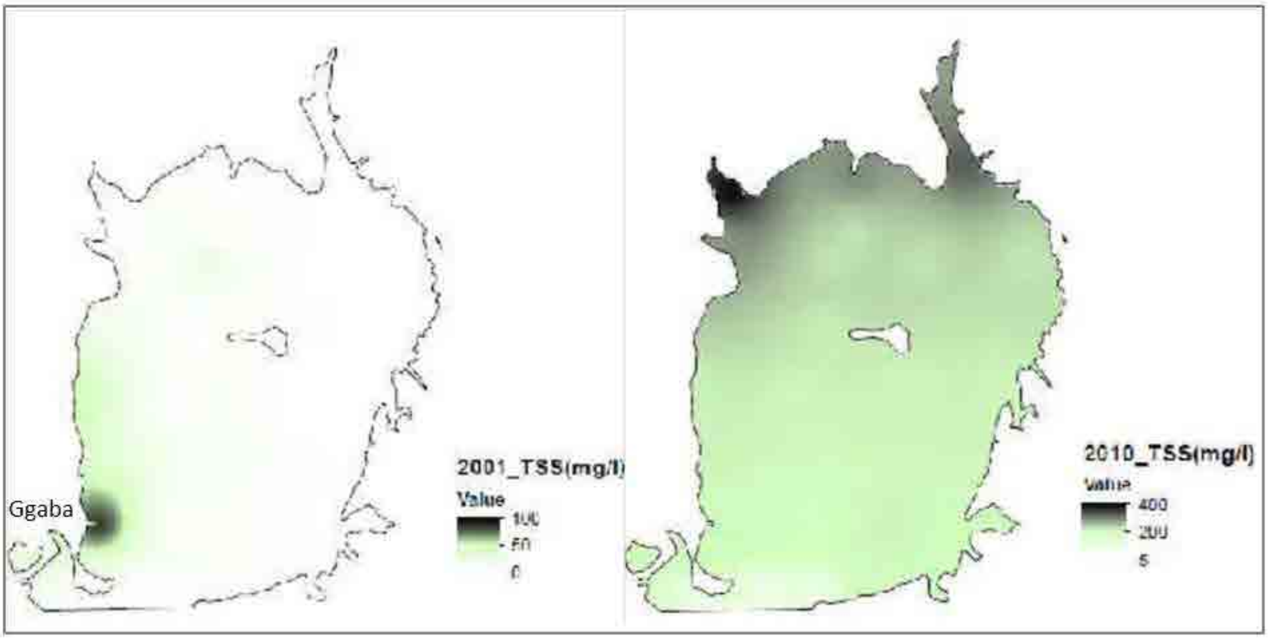

Figure A5.8 Total Suspended Solids measurements in 2001 and 2011 across Inner Murchison Bay (WSS Services 2015).

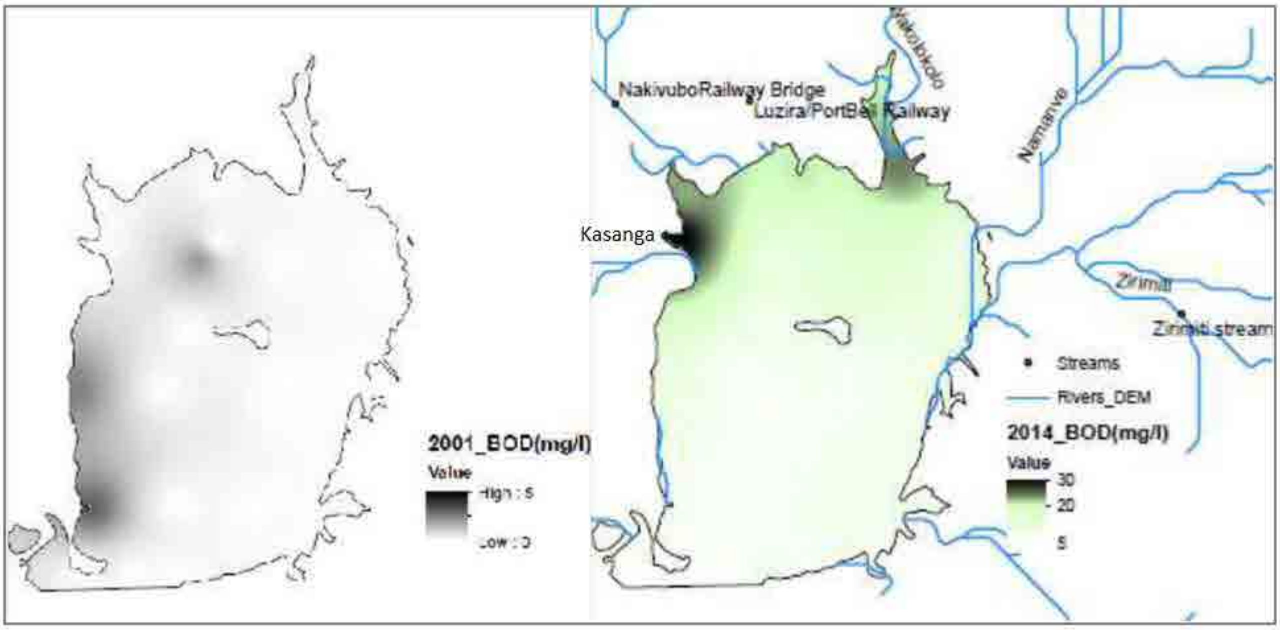

Figure A5.9 Biological Oxygen Demand measurements in 2001 and 2014 across Inner Murchison Bay (WSS Services 2015).

APPENDIX 6. ASSESSMENT OF INTERVENTIONS REQUIRED TO MEET WATER QUALITY AND RECREATIONAL OBJECTIVES

The objectives of the rehabilitation measures were assumed to be as follows:

1. Effect a measurable improvement in the quality of water passing out of the Nakivubo wetland into Murchison Bay
   a. Improvement of water quality to a Category D or better (Table A5.3) would be recommended for all ecological variables,
   b. The "low risk" category for at least intermediate contact recreational use of water (see Table A5. 4) is assumed to be a necessary target in terms of faecal bacteria counts;
2. Ensure sustainable management of the existing Nakivubo wetland;
3. Reduce impacts on human health as a result of exposure to
   a. faecal bacteria, parasitic nematodes and other pests associated with exposure to human faecal waste;
   b. blooms of algae including blue-green algae (Murchison Bay);
4. Open up opportunities for the safe recreational use of the lower wetland.

Each intervention in the treatment train is presented in detail below (Step 1 – 6). Information about the measures required, design specifications and costs, and the expected outcomes for each intervention are described. The approaches are presented here in the order in which they need to be implemented if there is to be any chance of achieving these objectives.

Step 1. Prevent pollution from catchment area

Existing sanitation systems and projects

Currently the piped sewerage coverage is only between 6.5 and 10% of households in Kampala (NWSC Corporate Plan 2012). The remaining population depends on various forms of on-site sanitation: pit latrines (55-65%), improved (VIP) pit latrines (27.5%), septic tanks (20%), public toilets (1%), and open defecation (African Development Fund 2008, KCCA 2012, 2014a). There is inadequate collection and disposal of faecal sludge that is generated in pit latrines, with only 43% (390m3 per day) of the faecal sludge generated being collected for proper disposal. Statistics for the population living within the catchment area of the Nakivubo wetland are unknown, however. Based on 2014 census data, an estimated 324 000 people live in about 77 100 households within the catchment, which if serviced would generate about 65 ML[4] of sewage per day (assuming 200 litres/person/day). This does not include the effluent generated by industry.

The National Water and Sewerage Corporation (NWSC) in Kampala currently operates two waste water treatment works in the form of the conventional sewage treatment works at Bugolobi with a capacity to treat up to 12 ML per day and waste water stabilisation ponds at Lubigi (outside the Nakivubo catchment area) that have a combined capacity of 5.4 ML per day. The Bugolobi WWTW currently receives piped sewage predominantly from the central business district in Kampala and extends to areas of Old Kampala, Mengo, Katwe, Nsambya, Kibuli, Mbuya, Nakawa, Naguru, Bukoto and Kamwokya (NWSC website, accessed 2015), as well as from medium and large industrial facilities (COWI 1998).

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[4] 1 ML = 1000 m3 = 1 million litres

During the period 2009 - 2012 funding was secured for the Kampala Sanitation Programme (KSP) which forms part of the larger Lake Victoria Protection Project (LVP; NWSC Annual Activity Report 2013). The LVP was to be implemented in two separate phases. LVP Phase 1 reportedly included the completion of the Lubigi Sewage and Faecal Sludge Plant and the upgrading of the Bugolobi WWTW, at a total cost of about €15 million (NWSC Annual Activity Report 2013), although the latter had not occurred by the time of this study, possibly due to a change in plan (see below). The LVP Phase 2 incorporates major works to construct and operate a new Nakivubo Waste Water Treatment Plant (WWTP), construct a Kinawataka WWTW, rehabilitate and extend the Nakivubo Sewer Network and construct the Kinawataka Sewer Network (NWSC Annual Activity Report 2013). Kinawataka is to the north of the Nakivubo catchment area, and drains into the Murchison Bay to the east of Nakivubo and Port Bell. The cost of this phase of the project was reported to be €84 million with the funding coming from KfW (€10 million), African Development Bank (AfDB; €38 million) and the Government of Uganda/NWSC (€36 million; NWSC Annual Activity Report 2013).

Due to soil conditions, the plans for construction of the new Nakivubo WWTW had to be moved from the original site near the lower reaches of the Nakivubo wetland to Bugolobi, at the site of the existing WWTW. The construction of the Kinawataka WWTW was put on hold and the scope scaled down as it extended beyond the available budget (NWSC Annual Activity Report 2013). The LV WatSan Sanitation Plan states that the original Kinawataka WWTW would not be constructed due to limited investment costs but would be replaced by a pre-treatment facility and pumping station which will transport sewage to the new Nakivubo WWTW at the Bugolobi site (NWSC 2014). The new Nakivubo and Kinawataka Sewers are reported to be under construction with one third of the pipes having been laid. Phase 2 of the LVP was due to be completed towards the end of 2015. However, construction had just begun at the Bugolobi WWTW at the time of a site visit (October 2015), and will probably take another two years.

With the construction of new WWTW at Lubigi and Nakivubo, plus new sewers in Nakivubo and Kinawataka areas, the sanitation coverage is expected to rise to 30% of households in Kampala (NWSC 2014). The new Nakivubo WWTW is planned to increase overall capacity to 45 ML per day. If this serviced the Nakivubo catchment only, this could meet two-thirds of demand. However, this needs to deal with waste water from the Kinawataka catchment as well.

Another major project is underway to address the water supply and sanitation situation for Kampala's informal settlements. This project, the Lake Victoria WatSan Project (NWSC 2015) has identified six different aspects that should be addressed: 1) water supply, 2) sanitation and hygiene marketing, 3) faecal sludge management, 4) sewerage, 5) schools and 6) public toilets. The project does not go as far as to install pit latrines for households, but does market them. The faecal sludge management aspect includes a collection service, transfer stations and treatment plants. While the project is for Kampala as a whole, based on the percentage of the area of each of the parishes inside the Nakivubo catchment, we estimate that approximately €1.16 million will be spent on upgrading water supply and €3.41 million on upgrading sanitation within the informal areas within the Nakivubo catchment. Estimates for improving sewerage were only given for two parishes, only one of which, Kibuli, was within our catchment.

Further measures required

In order to prevent raw sewage from entering the wetland and Murchison Bay, both sanitation coverage and WWTW capacity will need to be further increased. Sanitation measures ought to be in place as minimum standards in any high density urban environment. For a situation such as currently found in Kampala, there is an urgent requirement for improving sanitation through:

a. Retrofitting unserviced areas with appropriate infrastructure to allow for the conveyance and treatment of waste water including sewage generated in developed areas of the upstream catchment;

b. Expansion of existing sewage works capacity as required to accommodate the additional sewage volume generated by; and

c. Effective long-term maintenance of new and existing sewage collection, conveyance and treatment facilities, including long-term policing and pollution tracking.

It is however recognised that the financial costs of retrofitting unserviced areas will be high, though noting that such cost analyses often ignore hidden cost offsets such as human health benefits. The planned interventions described above will substantially increase sanitation coverage and WWTW capacity, but will still only meet a fraction of what is needed from a human health, let alone environmental, perspective for Kampala as a whole. While full coverage is not likely to be feasible, it is more reasonable to aim for waterborne sanitation coverage of 60-70%, while implementing cheaper measures such as VIP latrines in the remaining areas and having waste water treatment works that can handle waste water flows channelled from those areas.

While the WatSan Project aims to improve sanitation in these areas, it does not include the installation (or subsidisation) of pit latrines nor will it achieve full servicing of currently under-serviced areas in terms of sludge removal. These measures generally need to go hand in hand with a comprehensive public health education campaign. Such sanitation measures are being addressed by the WatSan Project and are not considered further here.

The planned capacity of the Nakivubo WWTW could provide an acceptable level of service for the Nakivubo catchment. However, because the Nakivubo WWTW will have to deal with waste water from Kinawataka, the combined treatment capacity for these two catchments will need to be increased in order to meet this level.

In addition, attention needs to be paid to catchment management functions such as street sweeping and litter collection, to prevent sediments and litter from entering the storm water system. It is therefore estimated that the following additional measures would be required in order to significantly reduce polluted inflows into the Nakivubo wetland from the catchment:

a. Improve sanitation in areas that are not serviced by water borne sewage

b. Further expand WWTW capacity

c. Street sweeping and litter collection

Design and costs

Improve sanitation

The additional investment required for installation and servicing of pit latrines and the costs associated with the construction of a new faecal sludge treatment facility in the catchment were estimated. Emerton et al. (1998) had estimated that the cost of improving sewerage and sanitation facilities in low-cost areas adjacent to Nakivubo would be in the order of 97.59 USh million/year. That study assumed that about one third of the population of each of the directly surrounding parishes were considered low-income; that population and number of households in each parish had increased since the 1991 census data at the average population growth rate; that elevated pit latrines would need to be constructed at a 1999 price of USh 625 000 each; that each pit latrine is shared between five households; and that the lifespan of each pit latrine is approximately 10 years.

Using a similar approach, we derived an estimate which included the whole catchment area rather than only the directly neighbouring parishes, based on GIS data of the catchment and parishes and 2014 census data. It was assumed that 87.4% of the population had pit latrine access (Ministry of Health 2010) and only the remaining 12.6% required new pit latrines. Updated prices for construction were obtained from Isunju et al. (2013), and the cost of having the sludge removed from the pit latrines twice a year (Isunju et al. 2013) was included for the new latrines as well as for the estimated 40% of the existing latrines that are not regularly serviced (KCCA 2012). This yielded an estimated capital cost of $1.15 million and additional annual costs of $0.67 million (Table A6.1).

The study by Isunju *et al*. (2013) suggested that although the willingness to pay for operations and maintenance of public sanitation facilities was high (61.2% of respondents in a Kampalan slum), this was also very dependent on level of awareness, costs of visits and the management of the facility. Due to the high costs involved in setting up new facilities, the transient residence of people in slums and the socioeconomic status of most people in these areas, the overall willingness to pay fell short of the funds required to maintain the infrastructure. This is evident in the low level of maintenance of existing latrines. There is thus a need for public funding to extend to the financing of these. This is considered crucial to prevent the high loads of pollution that are washed into the Nakivubo system during the rainy season.

In Kampala, there is inadequate collection and disposal of faecal sludge generated by pit latrines, and existing faecal sludge treatment plants (FSTP) across the city are overwhelmed. With the increase in pit latrine access and additional servicing in the Nakivubo catchment, it is deemed essential that a new FSTP be constructed to deal with increased outputs of sludge from informal areas. Approximately only 43% (390 m^3 per day) of faecal sludge generated in Kampala is being collected and disposed of properly (KCCA 2014a). This suggests that if sludge from pit latrines was collected with a 100% coverage, the total amount generated per day and needing disposal would be 907 m^3 . Based on this information and the total number of households in the catchment area using pit latrines, it was estimated that a 200 m^3 FSTP would be needed to adequately address the treatment of sludge from pit latrines in the catchment. Cost estimates from the LV WatSan Project (NWSC 2014, Annex 11) for the construction of a 400m^3 per day FSTP were used to determine the costs associated with a FSTP of half that size (200 m^3 per day). The total construction cost was estimated to be $1.44 million, with annual maintenance costs of around $0.07 million.

Table A6.1 Estimated costs of improving pit toilet access and servicing within the Nakivubo catchment area based on method from Emerton *et al.* (1998).

Total # households	77 102
% without sanitation	12.6%
Additional % unserviced	40%
Installation ratio (hh: pit latrines)	5
Average cost of installation per latrine (range)	$598 ($125-1250)
Average cost of biannual sludge removal per latrine (range)	$23.58 ($17-85.8)
Initial installation costs (based on average prices)	$1 152 000
Annual maintenance cost (based on average prices)	$675 000

Waste water treatment capacity

Given that the new Nakivubo 45 ML WWTW will be receiving sewage from both the Nakivubo and Kinawataka catchments, it is assumed that the capacity of the new plant may not be sufficient. It is difficult to estimate exactly how much sewage will be pumped to the WWTW from these areas as there is little information about the exact number of sewer connections in either of these catchments or the extent and location of the sewer network. Based on census data it is estimated that the Nakivubo catchment alone generates around 65ML per day. If we assume a long term target of 70% coverage in the Nakivubo catchment whilst implementing other sanitation measures such as increased pit latrine access and servicing, and improved sludge treatment facilities, then the design capacity of 45 ML is expected to be sufficient. However, due to changes in the planned Sanitation Program, and the now increased flow of sewage from adjacent catchments to the Nakivubo WWTW via pumping stations, it is assumed that the overall capacity of the plant may be exceeded. The original Sanitation Plan included a new WWTW in the Kinawataka catchment with a design capacity of 8 ML. If one assumes that this WWTW was designed based on the catchment population size and sanitation targets then it is expected that an extra 8 ML of sewage will be required.

Based on a database of capital costs of WWTW constructed throughout Africa maintained by GIBB Consulting Engineers in Cape Town, the cost of constructing a new WWTW is expected to be in the order of $1.1 million per ML of works constructed. Ongoing maintenance of the plants are estimated at 2% of the total capital portion of the WWTW for civil and building works, and 3% for the mechanical and electrical portions of the WWTW. Therefore increasing the capacity of the Nakivubo WWTW is estimated to cost approximately $8.8 million, with maintenance required for this increase in plant capacity estimated at $0.44 per annum.

Street sweeping and litter collection

Sediments and litter are ubiquitous problems in urban environments. They accumulate until they are either manually removed or are transported by the wind and/or stormwater runoff into the drainage system. Once in the drainage system, they can contribute to blockages and increased flood risk, as well as providing health risks. These problems should ideally be managed as part of an integrated catchment management strategy which includes planning controls (e.g. restrict use of certain areas), source controls (e.g. education programmes, litter bins), and structural controls (stormwater treatment and litter traps).

In South Africa, studies indicate that sweeping once a day removes about 83% of litter, whereas sweeping three times a day can remove as much as 99% (Armitage et al. 1998, Marais & Armitage 2004). The efficiency is strongly linked to the frequency of sweeping relative to the frequency of stormwater-producing rainfall events (greater than about 5mm rainfall). This means that effort could vary seasonally, but must prepare for the “first flush” after the dry season. The method is also important. Use of street flushing, for example, would exacerbate the problem. Numerous studies have been undertaken on litter generated in urban environments. Based on these, Wise & Armitage (2002) estimated litter loads generated by a variety of residential, industrial, retail and other urban typologies. These estimates, together with generalised costs in Armitage (2004) suggest that as much as 3800 tonnes of litter may be generated annually in the Nakivubo catchment (Table A6. 2).

In order to achieve a street sweeping efficiency of 60%, this would incur an annual cost of about $2.4-4.8 million per year. Assuming that no litter traps are in place in the catchment, and that street sweeping currently achieves an efficiency of 50%, the residual requirement for sweeping would be approximately $0.4 – 0.8 million per annum.

Expected outcome

The outcome of these measures along with the already planned improvements in sanitation would be to significantly improve the quality of water entering the wetlands via the Nakivubo Channel. In addition, dry season runoff would be reduced, and reflect genuine stormwater flows, and not dry weather pollution streams. Further polishing of stormwater would be possible in the lower Nakivubo wetland as outlined for Step 4.

In order to quantify changes in loading of major water quality variables into the lower wetland and Murchison Bay as a result of implementation of this activity, a TSS removal efficiency of 80% is considered a reasonable target objective. This target is in line with typical Sustainable Urban Drainage System (SUDS) approaches to urban stormwater management (e.g. Debo & Reese 2003), with the latter demonstrating treatment train efficiencies of 61-95% for TSS removal. An important component of TSS removal from stormwater in the Kampala area is the assumed corresponding removal of particulate phosphorus- and nitrogen-enriched organic sediments, thus addressing in part nutrient enrichment and chemical and biological oxygen demand issues. Debo & Reese (2003) also demonstrated total phosphorus removal rates of up to 89% (group median 34 ± 33%) for different treatment options and removal of 45% total phosphorus is a standard requirement in the stormwater management policies of some cities (e.g. City of Cape Town 2009: Management of Urban Stormwater Impacts Policy).

The (albeit very limited) water quality and flow data available for the Nakivubo Channel in the present project were used to estimate possible outcomes in terms of stormwater quality, assuming implementation of this treatment option. Estimated wet- and dry-season [5] discharge data were based on summary data presented by Tebandeke (2013) for the Nakivubo Channel (position undefined), and loading rates calculated for these discharges were calculated for Total Nitrogen (TN), Total Phosphorus (TP), BOD and TSS, using water quality data provided in Table A5. 7 for the Railway Culvert. The proportions of TP and TN comprising orthophosphate, and [6] ammonium and nitrate nitrogen, respectively, were also calculated and used to derive broad estimates (by difference) of the proportion of phosphorus and nitrogen nutrients that could be expected to be removed as particulate matter in sediments. 40% of both TP and TN was thus calculated to be the proportion likely to be available in particulate form, and these values were included in calculations of removal rates if 80% TSS was removed. The data, though of low confidence, do not seem unreasonable - 45% removal rates of total phosphorus are the standard requirement for management of stormwater runoff in the previously cited City of Cape Town stormwater management policy.

It should be emphasised, however, that all of these data provide broad comparisons only, and moreover do not allow for the change in discharge that would be associated with diversion of effluent to the sewers, which would mainly affect low flow data. The results of these comparisons are provided in Table A6. 3 in terms of both loading and stormwater concentrations, and presented graphically in Figure A6. 1. The latter shows the data as concentrations, in relation to the trophic state guidelines presented in Table A5.2.

Data in Table A6. 3 indicate that an assumed 80% TSS removal rate upstream would have a significant effect on instream water quality (concentration) – this positive outcome would be passed on to the downstream environment of the lower Nakivubo wetland and Murchison Bay (loading). The most useful representation of the outcome of this measure is indicated in Figure A6. 1, which shows the current highly eutrophic status of water in the channel. This would conceivably be reduced to mesotrophic conditions in the case of nitrogen nutrients and, in the case of the more problematic phosphorus nutrients associated with phytoplankton blooms in the downstream environment, from strongly hypertrophic to near-eutrophic levels. Such changes would be considered of significant magnitude to have a good likelihood of resulting in measurable change in terms of downstream plant production, although phosphorus concentrations would remain high. Dilution effects from lake water and lake water seiches would moreover also be likely in the bay and lower wetland respectively, and would further improve water quality if not nutrient loading.

Reduced organic loading, reflected in assumed significant reductions in BOD and COD in downstream water, would be assumed to be of benefit to general aquatic ecosystem function downstream. For example, it would be likely to improve the availability of habitat of suitable quality for fish, thus potentially improving the downstream *Tilapia* fishery. Such knock-on effects have not been quantified in this study.

An unquantified reduction in bacterial contamination of downstream water bodies would also be assumed as a result of implementation of these measures. However, given the high rates of *Salmonella* and parasitic nematodes associated at present with even treated sewage effluent, alternative approaches to the treatment of these pests would need to be found in addition to those outlined above.

Implementation of this measure would require considerable capital expenditure and political will. Given the significant impact it would have on instream and downstream ecological function, as well as its implications for human health and dignity, and the opening up of opportunities for safe recreation downstream, it should be regarded as an essential medium-term rather than long-term objective in urban centres.

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[5] Tebaneke (2013) presented mean wet and dry season discharge data of 1.97m3/s and 0.492 m3/s respectively

[6] Note that nitrite nitrogen data were missing from datasets – this component of total nitrogen was assumed to be very low

Table A6.2 Estimate of annual litter loads generated in the Nakivubo wetland catchment, based on preliminary estimates of land cover and litter generation values given in Armitage (2004)

Sub catchment	Kayunga	Kitante	5th Str	Lower	TOTAL
Area (ha)	170	420	1370	830	
Land-use - approx. %					
Low Density Res		40%	10%	20%	
Med Density Res	25%	5%	5%	5%	
High Density Res	40%		10%	10%	
Informal Res	40%	5%	10%	20%	
Industrial			15%	5%	
Retail	5%	15%	15%		
Offices			10%		
Halls, Stadiums and Entertainment Facilities			5%		
Taxi Ranks	5%	5%	5%		
Schools	5%	10%	10%	5%	
Hospitals			5%		
Golf course		20%			
Wetland/ fields				35%	
Litter Load (kg/year)	491 938	414 267	1 828 402	1 016 792	3 751 398
Vegetation load (kg/year)	4 760	10 290	27 058	20 543	62 650
Total load (kg/year)	496 698	424 557	1 855 460	1 037 334	3 814 048

Table A6.3 Preliminary estimates of changes in loading of key variables before and after treatment step 1, based on assumptions of 80% TSS removal.

LOADING	Total nitrogen (kg / month)		Total Phosphorus loading (kg / month)		Total suspended sediment (TSS) (kg / month)		Biological Oxygen Demand (BOD) (kg / month)	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Pre implementation	11 482	45 973	2 159	8 646	33 617	134 606	57 020	228 313
After implementation	1 378	5 517	259	1 038	6 724	26 921	No conversion data	No conversion data
CONCENTRATION	Total nitrogen (mg/l)		Total Phosphorus (mg/l)		Total suspended sediment (TSS) (mg/l)		Biological Oxygen Demand (BOD) (mg/l)	
Pre implementation	8.88		1.67		26.0		44.1	
After implementation	1.07		0.20		5.2		No conversion	

Wet and dry flow data derived from estimates in Tebandeke (2013) for the Nakivubo Channel, and reflected as loading per month, noting that wet and dry seasons span approximately six months of the year each.

Note however that water quality data do not reflect seasonal variation, so wet and dry season data should be considered as ranges in loading.

Water quality data used to calculate loading and to depict concentrations for the pre- and post-implementation scenarios based on Table A1 data for the Railway Culvert (after COWI 1998). Data for the Railway culvert used because this point includes most of the significant current sources of contamination into the Nakivubo channel that have been targeted by Steps 1 and 2.

Concentrations calculated as a percentage of existing concentrations, assuming 80% TSS removal.

80% TSS reduction assumed, and 40% TP and TN reduction allowed for, on the 80% removed through TSS. These proportions calculated from proportion of TP and TN respectively comprising (NH4 +NO3)/TN and PO4-P/ TP – the limited data indicate 40% for both variables. Data shown in table reflect nutrients and sediments left in the system – hence 60% of 20% remaining TSS, if 80% TSS removed and 40% Nitrogen and phosphorus nutrients removed.

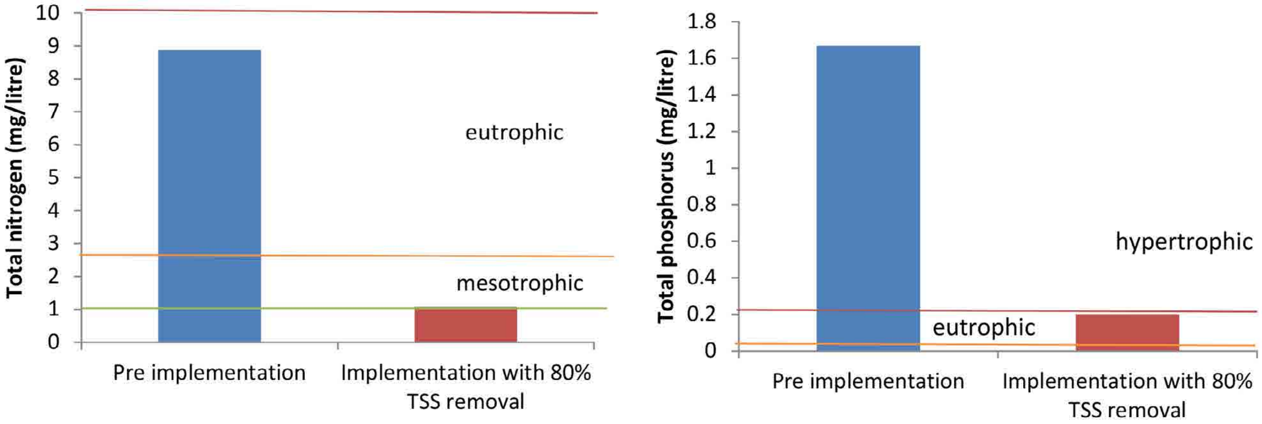


Figure A6.1 Changes in concentrations of total nitrogen and total phosphorus compared to assumed current conditions if sediment removal rates of 80% are achieved. Coloured horizontal bars indicate trophic state at different nutrient concentrations, using data from Table A5.2 after DWAF (1996a and 2002).

Step 2. Prevent residual pollution entering Nakivubo wetland

Measures required

While it might be reasonable to aim for waterborne sanitation coverage of 60%, we recognise that implementation of water-borne sewage is unlikely to be feasible for all households for a number of reasons. Therefore alternative measures will need to be put in place to address the residual problems of polluted runoff, which include installation and servicing of litter and sediment traps, diversion of waste water flows to the waste water treatment works, and filtration strips to help deal with wet season overflows from these systems. The latter measures will also provide some level of pollution control during the interim period during which the sewage systems are expanded. This combination of measures is considered the most effective, long-term approach to addressing the dire pollution levels passing into the Nakivubo channel.

The main objective of this set of measures is to minimise the volume of polluted waste, including sediment, heavy metals, solid waste and (particularly) organic waste in the form of untreated sewage, domestic grey water, and urban detritus, entering the Nakivubo wetland, and thus becoming part of the catchment drainage system. The following measures must be included in this activity:

a. Installation and management of litter and sediment traps

b. Install diversion drains to convey waste water from informal settlements to WWTW

c. Create wetland filtration strips to filter drain overflows before reaching main wetland

Design and costs

Sediment and litter traps

This would require:

i) Installation of litter and sediment traps on inflows into the Nakivubo channel – this would apply to catch pits, drains and minor channels leading into the main channel

ii) Design and installation of an instream litter and sediment trap in the Nakivubo channel in the vicinity of the 5th Street channel crossing – this would aim to remove sediment and solid waste in a reach affected by high TSS loading, and would reduce the requirement for channel dredging downstream;

iii) A second in-channel litter and sediment trap should be installed in the channel immediately upstream of the railway culvert, and downstream of the informal settlements abutting the channel in this area;

iv) Allowance would need to be made for the ongoing maintenance (dredging) of the above facility, and for the disposal at an appropriate waste disposal site of spoil thus generated;

To control and limit the amount of sediment flowing into the Nakivubo wetland, the flow of any rivers and channels should be controlled to prevent particle sizes larger than the selected size from flowing into the wetland (see Box 1). Normal practice would be to prevent particles of say 0.5mm or 1mm from being transported. Typically the flow speed should be limited. To control the gradient it is normal practice to install hydraulic drops along the river or channel

To install an expanded channel litter trap and to control the flow of the Nakivubo channel from the Olde Timey Railway crossing to 5th Street to the Nakivubo channel, a distance of approximately 5km to the Nakivubo railway crossing, is estimated to cost between $1.5m to $2.0m. This includes 12 hydraulic drops constructed from gabions, a litter trap, and cleaning of the channel.

Box 1. The sediment trapping process

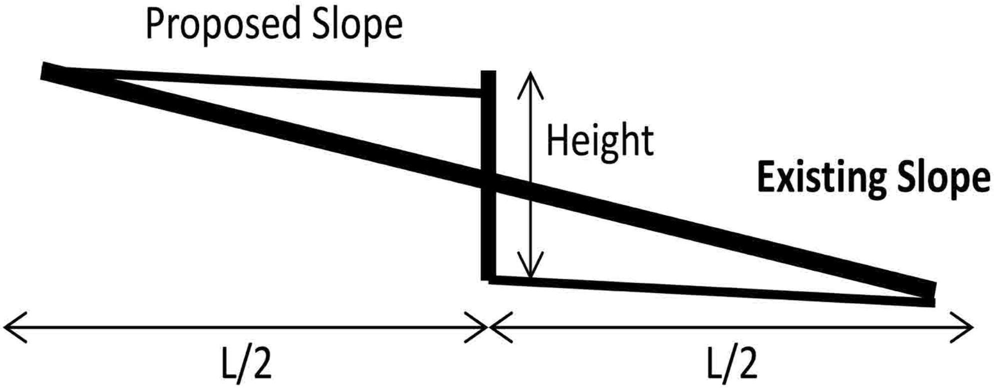
Deposition of transported sediments happens when a river loses energy, e.g. when a river enters a wetland or lake. To control and limit the amount of sediment flowing into the Nakivubo wetland, the flow of any rivers and channels should be controlled so that they are deposited before entering the wetland. Normal practice would be to prevent particles of say 0.5mm or 1mm from being transported.

Using the Manning equation, $Q = [A.R^{2/3}.i^{1/2}] / n$, for channels and assuming a channel width of 4m, a Manning coefficient of 0.048, and a depth of between 25mm to 100mm, the flow velocities can be controlled as follows:

For a gradient of 1:50 (assumed existing gradient)

Water depth [mm]	Flow velocity [cm/s]	Flow [m^3/hr]	Maximum Particle Size that can be transported [mm]
8	11.9	14	2
16	19.0	45	6
25	24.7	87	8
33	29.8	140	11

For a gradient of 1:2000 (proposed new gradient)



Water depth [mm]	Flow velocity [cm/s]	Flow [m^3/hr]	Maximum Particle Size that can be transported [mm]
25	4.0	14	0.6
50	6.2	45	1.0
75	8.1	87	1.1
100	9.7	140	1.1

By controlling the gradient of the Nakivubo channel, the particle sizes being transported would be greatly reduced, reducing the sediments and nutrients entering the Nakivubo wetland. To control the gradient it is normal practice to install hydraulic drops along the river or channel as shown below. The installation is considered relatively inexpensive and will achieve immediate results.

Example of a hydraulic drop installed along a river to control the river's gradient and the carrying velocity of particles.

Even with source measures in place, there will be transfer of sediment and litter into the drainage system. In areas that have combined sewer systems (e.g. Europe, North America) removal can be achieved at the sewage works, as well as at overflows in very wet weather.

Where stormwater drainage is separate from the sewage system, the sediments and litter must be trapped and removed along the watercourse. A range of designs exist that are applicable to different circumstances, from concrete structures within canalised reaches to in-channel excavated depressions.

Sediment traps in particular will retard velocities to facilitate settling out of sediments. Litter traps work best when they incorporate some form of screen (Armitage et al. 1998). Of the different designs of litter traps, two patented designs were highlighted by Armitage et al. (1998) as being the most effective – the Stormwater Cleaning Systems (SCS) structure (similar to the Baramy Gross Pollutant Trap in Australia), and the Urban Water Environmental Management (UWEM) concept. The advantage of the latter is that it can trap silt and sewage as well as litter, and can be deigned to handle very large flows.

While this was all technology that was developed around the 1990s there has not been much more done to advance this. The success of these measures depends on the ongoing maintenance of the traps.

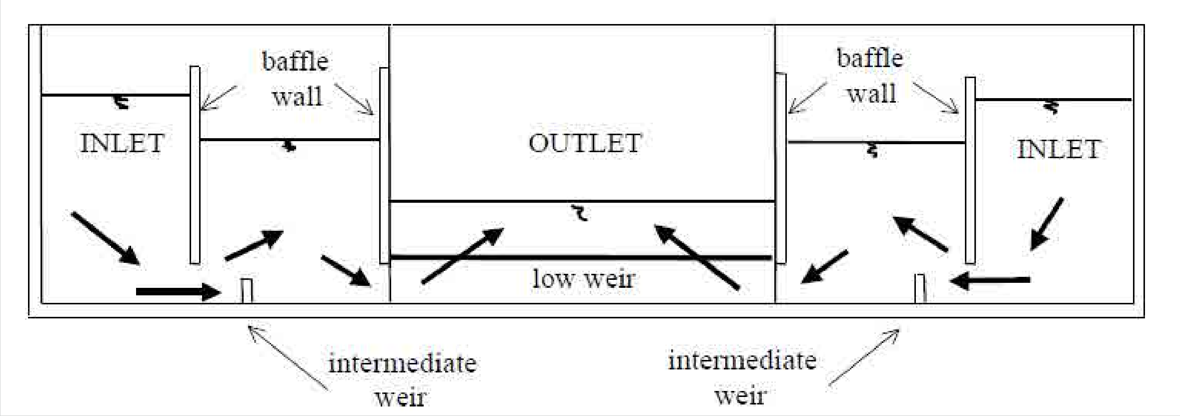
Below are examples of sediment and grit traps developed by Armitage et al. (1998).

Enviroscreen installed at the Vygekraal Canal (Armitage et al. 1998)

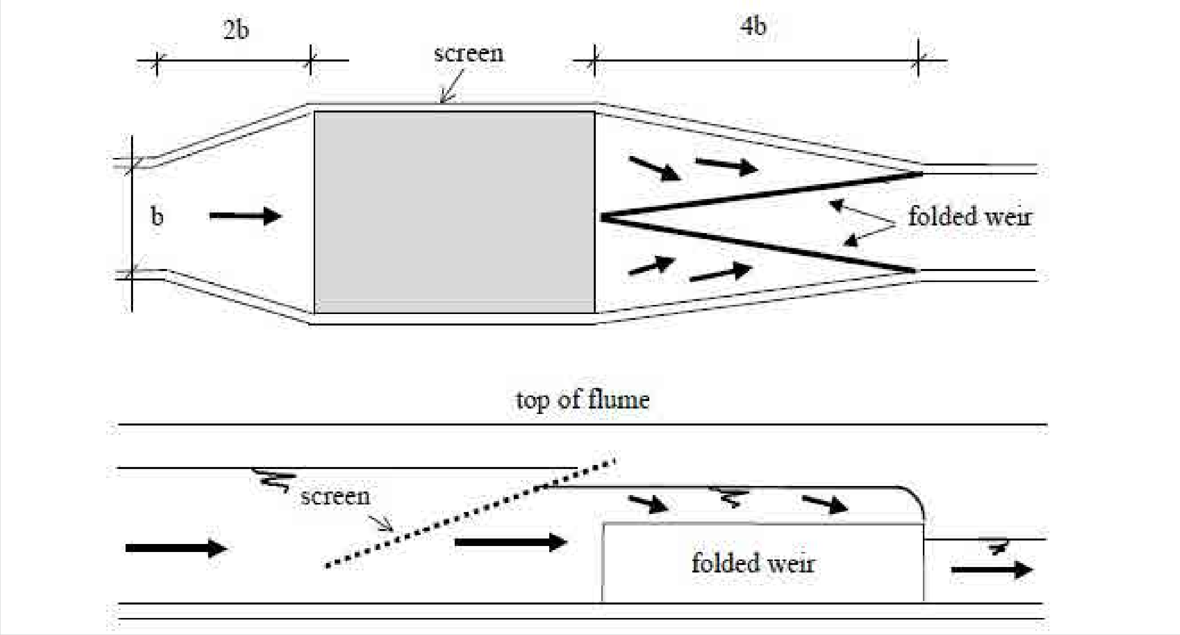
The Enviroscreen model

The improved Uyse model

View of the expanded channel model



Cross section through the improved Uys structure.



Plan and long section through the expanded channel litter channel.

Diversion drains

Installation of diversion drains would be required to intercept surface flows and shallow seepage from unlined areas of informal settlements, where there is a high likelihood that such water comprises untreated sewage and grey water runoff, with high bacterial, parasite, nutrient and general organic waste content. Diversion drains would need to be routed into the nearest existing sewer with capacity, and routed to the WWTW for treatment. Alternatively, new sewers would need to be laid to cater for this waste stream. The diversion of such waste is usually effective only in dry flow scenarios, as it is likely to be practically limited to a low volume only. This could require further expansion of existing sewage works capacity to accommodate the additional sewage volumes created. Assuming that the planned capacity of the sewage works will accommodate this, the costs of the drains themselves are estimated to be in the region of $1.04 million.

Figure A6.2 Proposed location of linear series of Cyperus papyrus wetland strip filters

Wetland filtration strips

Excess runoff (e.g. in wet conditions) from diversion drains should be diverted into sediment traps and through reed bed filtration systems, established between diversion drain outlets and the main Nakivubo channel. Such reed beds, which should be designed as broad wetland filtration strips running parallel with the channel, would be required to filter sediment and reduce the volume of organic waste in particular that passes into the channel.

A linear series of *Cyperus papyrus* wetlands should be designed and installed along the wetland edge of the prison, occupying the eastern edge of the lower wetland, and along the wetland edge of the informal settlements occupying the western edge of the lower wetland (Figure A6. 2). These would help to delineate the wetland edge, preventing further encroachment, although it is likely that the wetlands would be crossed to access the agricultural areas within the wetland.

These wetlands and/or traps should be maintained on a cyclical basis, with the following measures being required (exact frequency would need to be determined in detailed design and operational phases):

- Cutting of plant material and disposal as a means of nutrient removal: at least annually to stimulate growth; and
- Dredging of contaminated sediment to restore wetland treatment capacity – this activity would be required more frequently in upslope wetlands and those associated with the treatment of seepage from informal settlements and the Luzira Prison (see iii and iv above).

Dredged sediment would need to be disposed of appropriately – disinfection and beneficial use in fertiliser or manure pellets could be considered.

Based on the costs of developing and maintaining treatment wetlands (described under Step 4), it was estimated that the construction of the filter strips would cost in the order of $1.65 million, and maintenance costs thereafter would be roughly $300 000 per year.

Expected outcome

This step serves to complement the activities in Step 1, providing a second sweep to remove any remaining pollutants as far as possible just before they enter the wetland. Nevertheless, thorough implementation of this approach in all identified areas of concern is likely to result in significant downstream improvement from both a human health and ecosystem function perspective.

While this step could be implemented independently of Step 1 as an alternative set of measures, it would not achieve the same degree of pollution abatement. However, these measures can make a short-term difference, since they are faster to implement than those in Step 1.

Step 3. Improve WWTW effluent quality

Existing technology and capacity

The Bugolobi WWTW uses conventional sewage treatment technology involving trickling filters (Box 2). Trickling filters are a well proven and documented method of treating sewage with the earliest trickling filters constructed in the early twentieth century. They are a low energy and effective means of treating sewage, require relatively little maintenance and are easy to maintain with parts being readily available. Trickling filters are therefore ideally suited for Kampala.

Box 2. Current treatment of sewage through the Bugolobi WWTW (Source: NWSC)

Preliminary Treatment: The inlet filter removes debris, large suspended solids and organic matter using metallic bar screens, sand traps and grit removal. The waste water then flows into grit chambers where heavy solids sink to the bottom and are removed. These chambers remove solids >0.3mm in diameter.

Primary Treatment: Organic solids are separated from the liquid in the first sludge sedimentation tank (primary clarifier). Offensive solids removed through settling and floating materials (scum, oils, grease) are removed through skimming in circular sedimentation basins. Removes on average 45-50% of suspended solids and 25-30% of the BOD in the incoming waste water. Settled sludge is collected and transported to a sludge thickener.

Secondary Treatment: This purification stage involves treatment by means of biological trickling filter where waste water flowing over the surface of a well aerated stone bed where bacteria remove any organic matter, commonly known as bio-filters or aeration tanks. After this any excess sediments, suspended matter and break-off bacterial film is removed as sludge through a secondary clarifier. The final treated sewage effluent is tested and must comply with the national environmental standards before being discharged into the receiving environment (Nakivubo) through an artificial wetland. Sludge is moved to anaerobic sludge digester beds and then onto sand drying beds. Dried sludge is sold to farmers to use as fertiliser.

Additional Treatment: Vegetation in the Nakivubo wetland provides final "tertiary treatment", i.e. the removal of excess inorganic nutrients.

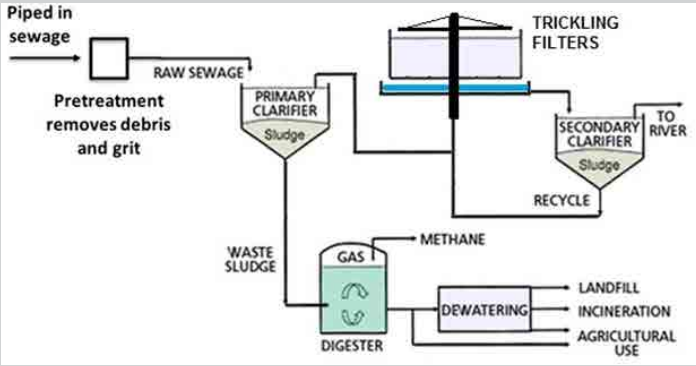


Illustration of the conventional sewage treatment process

Figure A6.3 Bugolobi WWTW from Google Earth on 18 July 2015. The various unit processes indicated are as follows: (1) Primary Settling Tanks, (2) Digesters, (3) Large Trickling Filters, (4) Small Trickling Filters, (5) Secondary Settling Tanks, (6) Sludge Drying Beds, (7) Demolished structures, most probably old trickling filters.

The capacity of the BWWTW was estimated based on the size of the trickling filters in operation. From Figure A6. 3 taken in 2015, it appears that about half of the trickling filters have been demolished. Using the measurement tool in Google Earth, the diameter of each of the existing large trickling filters are 32m, and each of the small trickling filters are 12m.

According to Metcalfe & Eddie (2004), stone media will have a surface area of about 70 m2 per cubic metre of filter media. Using a total surface area for all trickling filters of 7100 m2 and a filter media depth of 4.0 m deep, the flow capacity of the trickling filters would be 12 463 m3/day. With a shallower filter media depth of 3.5m the flow capacity of the trickling filters would be 10 905 m3/day. These estimates are more or less in line with the influent flow as stated by Nansubuga *et al*. (2013) that the WWTW is receiving an average inflow of 12 000 m3 per day. However, the inflows are likely to have increased, which means that the capacity of the plant can be considered to be exceeded at this stage, even if all the trickling filters were working and if the WWTW was running at full capacity.

Indeed, the Bugolobi WWTW is not currently used to its full capacity and does not operate efficiently. It relies on a system of siphons and pumping stations to deliver more than half of its sewage. Frequent operational problems results in untreated sewage being discharged into the environment. When treatment occurs, the facility does not comply with nutrient and coliform removal standards (African Development Fund 2008).

For trickling filters to work effectively, they require continuous wetting of the substrate media otherwise the organic matter attached to the media will die. Re-commissioning a trickling filter to its design capacity generally takes two to three months to develop effective organic matter on the substrate media. It is therefore important to ensure that there is always electrical power to supply pumping equipment and also that there is standby equipment should a pump fail or be in the process of being serviced.

The most recent Google Earth image (July 2015) shows that only four of the eight large trickling filters are working. This can be seen from their darker colour, indicating that the filters are wet. Thus the Bugolobi WWTW is running at about 50% of its capacity which is the same as having at least 50% of the raw sewage enter the Nakivubo wetland untreated (or more than 50% if input has increased).

The new Nakivubo WWTW will replace the Bugolobi WWTW and is planned to increase overall capacity to 45 ML per day. The treatment process will include mechanical, biological and chemical treatment of municipal sewage and industrial effluent, sludge digestion and cogeneration using biogas (NWSC). The biogas will be captured during the anaerobic processes and will be converted into electricity using combined biogas heat and power systems.

Further measures required

The following measures are included in this step:

a. Improve aeration of treated effluent from the existing and planned WWTW, by the installation of aeration sprays within final effluent maturation ponds – this would have the aim of increasing DO concentrations to at least 4mg/l;

b. Improve effluent standards with regard to phosphorus, by upgrading technology at the WWTW to allow for final effluent with concentrations of 1.5 mg orthophosphate/litre instead of the current standard of 10mg/l; and

c. Include measures to reduce parasitic nematode infection of final effluent.

Design and costs

Given that work has already commenced on the new 45 ML plant, the only additional interventions required are the tertiary treatment facilities (sand filters and maturation ponds).

The tertiary treatment for phosphate removal is achieved using sand filters. The cost of this is estimated at about a third of the capital cost of a plant up to the secondary settling tanks. Therefore the construction of sand filters was estimated to be $16.5 million (Table A6. 4).

Pathogens can be reduced using chemical treatment or exposure to sunlight in maturation ponds. The latter is recommended here. Assuming that there is no disinfection happening at the WWTW such as chlorination of the final effluent, the ponds should be designed with a surface area large enough to reduce the faecal coliform loading. The maturation ponds act as solar ponds where the sun's ultra violet rays destroy pathogens. Maturation ponds also provide a buffer between the WWTW and the environment should any major spills at the plant occur. Maturation ponds are generally designed as flat shallow ponds with a depth of one metre (to prevent reeds and other aquatic plants taking root. There need to be a minimum of three ponds in series. For a flow of 12 ML per day, and allowing for a 99.8% reduction in faecal coliforms, three maturations ponds, the surface area required for each pond needs to be 4800m2 (about 0.5 ha) To cater for a flow of 45 ML/day, 13 ponds would be required (7.5 ha). Note that these ponds are not the same as the waste water treatment wetlands described further below.

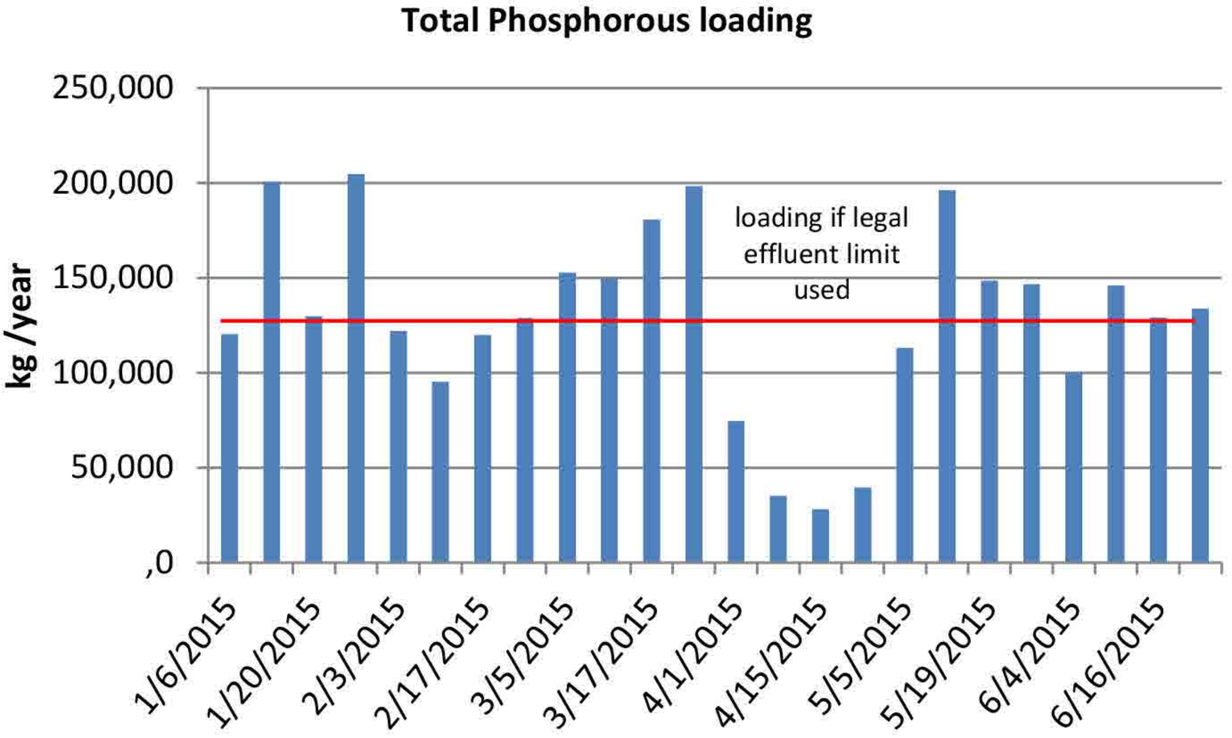
To construct maturation ponds below the existing BWWTW, a cost of $420 000 per pond is estimated. Thus three ponds is estimated at $1.26 million and a further seven ponds are estimated at $2.94 million. Maintenance is estimated at 2% per annum of the construction costs (Table A6. 4).

Expected outcome

Consideration of treated effluent volumes and quality provides an interesting picture in relation to proposed efforts to address water quality issues in the Nakivubo wetlands and associated Murchison Bay areas. The limited 2015 dataset for the Bugolobi WWTW suggest that current effluent treatment does not meet legal effluent limits outlined in Table A5. 6. Figure A6. 4 illustrates effluent loading on receiving water bodies for the 2015 dataset for Total phosphorus and TSS data only, assuming actual water quality at the time, but projecting the planned future design effluent volume onto these data. The calculated total phosphorus and TSS loads are compared in the figure against loads that would be achieved if legal effluent limits were met, and the figures show that substantially reduced loads would occur, if effluent limits were met.

Table A6.4 Estimated capital and operating costs of upgrading the WWTW to improve water quality standards in Nakivubo wetland

Intervention	Initial cost $ million	Operating and maintenance costs $ million per annum
Further improvements to decrease nutrient concentrations (sand filters)	16.5	0.33
Further improvements to reduce pathogens		
(maturation ponds for 45 ML output)	5.46	0.11



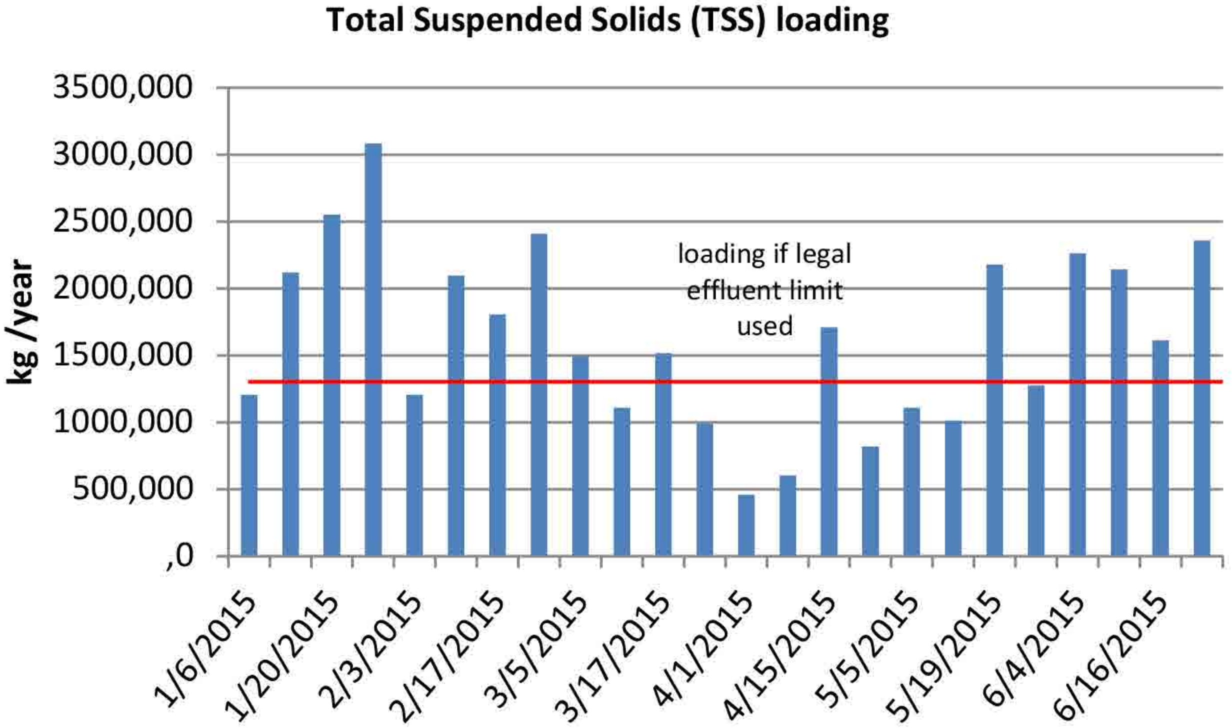


Figure A6.4 Total phosphorus and TSS loading estimates in BWWTW final effluent assuming treatment volumes of 33 000m3/d. Loading based on 2015 data, with red line showing loading if legal effluent limits shown in Table A5. 6 are achieved.

Figure A6.5 Bioballs are light and easy to handle.
Source Broadreach (Pty) Ltd

Bioballs are easily transported, unloaded and packed due to their lightness and robustness.

Organically loaded (dirty) water being sprinkled over the bioballs in a trickling filter.

In fact, an upgrading of the BWWTW is already planned. An important assumption of this study is that the new plant will be required to be designed so as to meet at least the legal limits for effluent discharge, as required by Uganda's own legislation.

Aeration of final effluent is recommended, with a view to increasing Dissolved Oxygen Concentrations in final effluent to > 4mg/l. This is because 4mg/l is believed to be a threshold below which non air breathing aquatic fauna may be critically affected (DWAF 2008). The reason for the low current dissolved oxygen concentrations in water in the lower wetland and zone of discharge into Murchison Bay is primarily due to the high biological and chemical oxygen demands (BOD and COD) of the combined effluent and stormwater. Oxygen is required for process such nitrification (that is, the oxidation of ammonia or ammonium to nitrite, followed by the oxidation of nitrite to nitrate) and is generally required in the decomposition of organic material. Aeration of effluent water is one manner in which additional dissolved oxygen can be made available for such processes, with the intended outcome that more of the BOD and COD can thus be met, resulting in higher concentrations in dissolved oxygen passing into the lower wetland and Murchison Bay, thus improving conditions for aquatic ecosystems including the Murchison Bay fishery.

Potential rapid intervention to improve capacity of Bugolobi WWTW

With the BWWTW running at 50% capacity and being overloaded and with the time for the new proposed works coming on line, a contingency plan is needed urgently to alleviate the pollution into the Nakivubo wetlands and into Lake Victoria.

The capacity of the existing trickling filters can be almost instantly increased replacing the stone media with high surface area packing or bioballs (Figure A6. 5). Whereas the existing stone media has a surface area of between 65 to 75 m^2 per cubic metre of stone, proprietary packing and bioballs typically have a surface area ranging from 175 m^2 to 300 m^2 per cubic metre of media. This equates to an increase in area of up to 3.5 to 4 times. This alone would increase the capacity of the treatment works considerably. It is recommended that this is done in stages over the period of a year, to accommodate the time for the bioballs to become colonised and fully functional.

It is assumed that the already-planned expansion of the WWTW is designed to meet legal effluent standards. Therefore, additional measures would have to be installed in order to reduce the nutrient loads and pathogens beyond that required by national policy, in order to achieve the goals of wetland rehabilitation and downstream water quality fit for recreational use.

Tertiary filtration aided by chemical addition can reduce total phosphorus concentrations in the final effluent to very low levels. To achieve very low phosphorus concentrations, chemicals must be added to waste water to associate phosphorus with solids that can then be successfully removed through filtration. Aluminum- or iron-based coagulants and polymer are the chemicals most commonly used for this purpose.

Traveling sand bed filters, mixed- media gravity filters, and variations of these filtration technologies as well as membrane filters are commonly used. Filtration has been employed for many years to treat drinking water and more recently applied to treat waste water. Selection of a filtration technology includes the usual considerations such as: desired effluent quality; reliability of treatment equipment; capital, operating and maintenance costs; equipment footprint, and future expandability.

A two-stage filtration process generally produces the lowest phosphorus levels. Two-stage treatment may be achieved through use of a first and second stage filter or by providing tertiary clarification prior to filtration. Excellent treatment results have been obtained by using a two-stage treatment process consisting of chemical addition with tertiary settling in advance of their sand bed filters.

The treatment provided also removes other pollutants which commonly affect water quality to very low levels. COD and TSS are routinely less than 2 mg/l and fecal coliform bacteria less than 10fcu/100 ml. Turbidity of the final effluent is very low which allows for effective disinfection using ultraviolet light (by means of maturation ponds), rather than chlorination.

The amount of bioballs or packing media required to replace the stone media in, say, four trickling filters would be 12 900 m3. Assuming a material cost of $270 per cubic metre and allowing for transportation, removal of the existing media, and placement costs is estimated at $7m.

Step 4. Rehabilitation of upper wetland for waste water treatment

Note that unless the measures outlined in Steps 1 - 3 above can be achieved, it is unlikely that the measures outlined in the following section will have any measurable effect on wetland function or fitness of water quality from an aesthetic or human heath perspective.

Measures required

The following measure is required to improve the supplementary treatment for final treated effluent. The extent depends on the extent to which final effluent is treated (Step 3).

Design and costs

This step involves the creation of multiple shallow wetland cells (standing water depth 300-500mm or less), separated by berms and with controlled pipe outlets or multiple overflows linking each cell to downstream cells (Figure A6. 6). The excavated spoil could be used in part for the creation of berms, and should ideally be treated initially to remove parasite loads. Excess fill would need to be disposed of outside of the wetland areas.

Allowance needs to be made for maintenance of the treatment wetlands on a cyclical basis, with the following measures being required (exact frequency would need to be determined in detailed design and operational phases):

1. Cutting of plant material and disposal as a means of nutrient removal: at least annually to stimulate growth;
2. Dredging of contaminated sediment to restore wetland treatment capacity; and
3. Disposing of dredged sediment appropriately – disinfection and beneficial use in fertiliser or manure pellets could be considered.

Figure A6.6 Indicative areas for rehabilitation as treatment wetlands in the Nakivubo wetlands. The proposed location of filters are also shown (darker green) for reference.

Constructed wetlands require extensive landscaping and excavation work and should be designed with careful consideration for factors such as access, prevention of litter and debris entering the inlet zone, and regulation of the water level within the constructed wetlands (Armitage *et al*. 2013). The following cost estimates are based on information collated from the literature (Table A6. 5.

4. (Table A6. 6) that focused on best management practices for sustainable drainage systems. Costs vary significantly from country to country. The main expenses involved in construction wetlands include acquiring land, excavation, planting soil, pipelines, vegetation and on-site work (Kadlec & Wallace 2009, Gunes *et al*. 2011).

Table A6. 7 includes an estimate for a hypothetical 1 ha constructed wetland system as described by Kadlec & Wallace (2009).

Maintenance of the constructed wetland systems include inspections and monitoring of mosquitos, algae and sediment build up (Armitage *et al*. 2013) and the frequency of such is dependent on the individual system. In the UK, low frequency monitoring is every 12 months and high frequency is every month (Armitage *et al*. 2013). The routine maintenance of constructed wetlands include the removal of litter, the cutting of grass banks and general management of the vegetation and should include the inspection and cleaning of inlet and outlet pipes (Armitage *et al*. 2013). The following table represents typical maintenance rates (Table A6. 8, based on 2010 Rands, Armitage *et al*. 2013).

Taylor's (2005) review of Australian best management practices in this field reported that annual maintenance costs for constructed wetlands are 2% of the construction costs (cited CWP 1998, Weber 2001, U.S. EPA 2001). In the same review it is reported that the macrophyte zone should be replaced every 20-50 years at a cost of 50% of the initial construction cost (cited Fletcher *et al*. 2003). In Taylor (2005), it was reported that Lloyd *et al*. (2002) estimated the following equation that could be used for estimating the landscaping maintenance costs: Maintenance Costs (Aus $) = 9842.20*(surface treatment area in ha)^0.4303.

Given that the study area is likely to require maximal rehabilitation of the upper wetland, of about 75 ha, there are likely to be economies of scale when it comes to labour and construction of the treatment wetlands. Thus we applied the equations of Lloyd *et al*. (2002), which takes into consideration economies of scale, to estimate the construction costs. These were adjusted to 2015 US $ values. Based on this the design and construction costs could be expected to be in the order of **$2.287 million**, with an annual maintenance cost (estimated to be 2% of this), of about **$45 700 per year.**

Table A6.5 Estimated construction and design costs for constructed treatment wetlands typically treating municipal waste water (extracted from reviews by Taylor 2005, Silva & Bragga 2006, Gunes et al. 2011, La Notte *et al.* 2012).

Reference	Wetland type/size	Cost per unit	Currency
Leinster 2004	Small-scale wetland	\$90 - \$100 per m^2	Australian $
Leinster 2004	Large-scale wetland (reticulated lake)	\$65 per m^2	Australian $
Hunter 2003	Large wetland	$500,000 per ha	Australian $
Weber 2002	Standard constructed wetland	$3400 – $17,900 per ha of area treated or $730,000 per ha of total wetland area	Australian $
Walsh 2001	Greenfields wetland	$120,000 per ha of area treated	Australian $
Lloyd et al. 2002			
(equation)	Greenfields wetland	Construction cost ($) = 343,913 x Ln * (surface treatment area in ha) + 738,607	Australian $
Lane 2004	Standard constructed wetland	\$16 000 for outlet and CDS unit plus the costs of \$75 per m^2	Australian $
Stewart 2005	Horizontal Flow (HF) wetland	\$86 per m^2 (\$74 -97)	US $
Dzikiewicz 1996	Horizontal Flow (HF) wetland	€31 per m^2 (€10 – 83)	Euro
Rousseau et al. 2004	Horizontal Flow (HF) wetland	€257 per m^2 (€237 – 277)	Euro
IRIDRA 2002	Horizontal Flow (HF) wetland	€125 per m^2 (€38 – 247)	Euro
Masi et al. 2006	Horizontal Flow (HF) wetland	€115 per m^2 (€101 – 129)	Euro
Steiner & Combs 1993	Horizontal Flow (HF) wetland	€74 per m^2 (€27 - 144)	Euro
Billore et al. 1999	Horizontal Flow (HF) wetland	€29 per m^2	Euro
Platzer et al. 2002	Horizontal Flow (HF) wetland	\$61 per m^2 (\$22 - 229)	US $
U.S. EPA 2000	Horizontal Flow (HF) wetland	\$67 per m^2 (\$32 - 125)	US $
Dallas et al. 2004	Horizontal Flow (HF) wetland	\$33 per m^2	US $
De Morais et al. 2003	Horizontal Flow (HF) wetland	€96 per m^2	Euro
Shrestha et al. 2001	Horizontal Flow (HF) wetland	\$31 – 72 per m^2	US $

Table A6.6 Percentage breakdown of capital costs for the construction of the treatment wetland beds

Country example	Excavation	Gravel	Liner	Vegetation	Plumbing (Pipes)	Control Structures	Other
Spain	15	27	33	2	6	5	12
Czech Republic	7	53	13	7	12	-	8
Portugal	12.5	37.5	25	5	-	11	9

Source: La Notte et al. 2012

Table A6.7 Estimated capital costs for a hypothetical 1 ha wetland system, in 2009 US $

Component	**Unit**	**Quantity**	**Unit Cost ($)**	**Total Cost ($)**
Land acquisition	ha	1	10,000	10 000
Site evaluation	Lump sum	1	2,000	2,000
Clear & grub	ha	1	8,000	8,000
Earthworks	m^3	10,000	7	70,000
Liner	m^2	12,000	8	96,000
Planting soil	m^2	3,000	10	30,000
Plants & planting	plant	20,000	3	60,000
Structures	Lump sum	5	2,000	10,000
Conveyance	m	400	35	14,000
Site Work	Lump sum	1	20,000	20,000
Total direct cost				320,000
Engineering	15%			48,000
Construction & observation	5%			16,000
Start-up service	5%			16,000
Non-construction costs	5%			16,000
Contingency	20%			64,000
Total indirect cost				160,000
Total Cost				480,000

Source: Kadlec & Wallace 2009

Table A6.8 Typical routine inspection and monitoring rates for constructed wetlands based on data provided in Armitage et al. (2013)

Description	Unit	Rate (Rands)
Inspections	Visit	210
Vegetation management (large)	Visit.m^2	0.60
Vegetation management (pocket wetlands)	Visit.m^2	2.00-2.40
Sediment removal (standard wetland)	m^3	Site dependent, > 160

Source: 2010 Rands

Expected outcome

The following factors and assumptions have a bearing on the calculations and approaches informing this section:

- Groundwater influence – this is assumed to be negligible, with much of the swamp underlain by clays (Kansiime & Nalubega 1999);
- Channel length and inflows:
  - Kansiime & Nalubega (1999) estimate the total length of the Nakivubo channel as 12.3km, with the upper swamp zone (upstream of the railway line) comprising 1.1km and the lower swamp zone being a further 1.2km
- Influence of seiches: these affect in-swamp retention time, and flush sediments into Lake Victoria (Kansiime & Nalubega 1999) – however, they affect the middle portions of the swamp (along the main flow path) and the lakeward side, and do not result in flushing of the whole swamp, with thick peat and areas with high levels of suspended solids having a "dampening" effect on flushing (Kansiime & Nalubega 1999);
- Swamp-lake exchange: this increases longitudinally with distance from the railway towards the lake shore (also see above regarding seiche effects) – swamp lake exchange has been discounted in this assessment;
- Waste water influences:
  - Waste water flow is not well distributed throughout the swamp – Kansiime & Nalubega (1999) show that the area of the swamp exposed at the time of their (1999) study to waste water effluent was some 785 000 m^2 out of a total area of 1 150 000 m^2 – by the time of the present project, this area had decreased considerably (see Chapter 4 and Appendix 3);
  - Water depth, vegetation type and density and flow depth are the main reasons affecting preferential flow in the wetland (Kansiime & Nalubega 1999), with data from the above authors as well as Kyambadde *et al*. (2004) suggesting:
    - *Cyperus papyrus* wetland allows for higher rates of both nitrogen and phosphorus removal than *Miscanthidium violaceum*, with plant uptake and storage being the main factors accounting for nitrogen and phosphorus removal in the former,
    - *Miscanthidium violaceum* mats provided a barrier between underlying swamp waters, which were poorly treated as a result of passage through the mats; however, the efficacy of use of *Miscanthidium* as a treatment for irrigated waste water was not investigated in any of the above studies, and may have yielded different results to testing of its role in an in situ flow-through system;
- Hydraulic retention time: 5 days has been assumed (based on Kyambadde *et al*. 2004), noting again that no allowance for seiche effects has been made. This time is however likely to have been reduced, as a result of more recent detachment of large portions of the floating island of the wetland (see Appendix 3);
- Seasonality (after Stalder 2014):
  - Wet seasons: March to May and October to November (152 mm maximum)
  - Dry Seasons: July (driest month), and December to February

Even if the water treatment regulations are met for all the WWTW discharging into the Nakivubo wetland, these standards will not be enough (in conjunction with Steps 1 – 2) to bring about the targeted trophic condition of the lower wetland and Inner Murchison Bay, or fulfil the objective of improving wetland quality and recreational and opportunities in the lower wetland. Objectives for achieving such measures should be based on the passage of water that is not enriched beyond eutrophic levels, as outlined in Table A5.2. In terms of the Condition categories outlined in Table A5.3, this would equate to conditions that were not worse than Category D.

Given that reduction in phosphorus concentrations is considered the most challenging of the variables to address, and that achieving these requirements for phosphorus means that there is a high likelihood that these would also be achieved for other variables, calculations around the effect of wetlands and other measures on WWTW effluent quality have focused on total phosphorus. Achieving a PES Category D for phosphorus means that a target concentration of no higher than 0.15 mg/L total phosphorus would be required at the railway culvert, noting that even this value lies just above the eutrophic /hypertrophic threshold.

With treatment wetlands being suggested as a potentially useful tertiary polishing mechanism to improve effluent quality, data from Kyambadde *et al*. (2005) for total phosphorus removal rates were used to calculate approximate areas required to achieve the target water quality concentrations with regard to total phosphorus. These authors assessed performance efficiencies in constructed *Cyperus papyrus* wetlands in Uganda, and their data are therefore considered appropriate to the current circumstances. They estimated total phosphorus removal rates by treatment wetlands of 191 ± 9 kg/ha/year. These data were used to inform the graphs shown in Figure A6. 4.

Figure A6. 7 shows the areas of treatment wetland that would be required to treat effluent to the target value of 0.15 mg/L total phosphorus, assuming different concentrations of total phosphorus in final effluent, starting from the legal limit of 10 mg/l, and reducing to much lower concentrations. Actual areas of nominal parts of the Nakivubo wetland are shown in Figure A6. 6 to illustrate the implications of the areas shown in Figure A6. 7. A total of 134 ha is illustrated in the figure as the maximum area for rehabilitation as treatment wetlands.

The following conclusions can be drawn regarding the use of treatment wetlands in achieving tertiary polishing of effluent:

- If effluent is produced to the legal limits for total phosphorus of 10mg/l, there is not sufficient area in the wetland to be able to further treat it to its required standard of 0.15 mg P/l. In the event that effluent remains in the high hypertrophic zone, even if its concentrations have reduced considerably, it is unlikely that there will be a measurable reduction in symptoms of hypertrophic conditions, such as phytoplankton blooms, low oxygenation of bottom waters, affecting aquatic habitat quality (e.g. for fish);
- In order to achieve the required levels of tertiary polishing of effluent, the final effluent itself needs to be produced with substantially lower concentrations of total phosphorus than those that are legally permissible in Uganda. In fact, a final effluent of 1.5 mg/L would be required if a treatment wetland of 85 ha was utilised, while an area of 117 ha would be required for final effluent quality of 2 mg/l for total phosphorus;
- If lower volumes of effluent were produced (e.g. if the improved quality of effluent generated in the new works allowed for its beneficial reuse in industry or agriculture elsewhere), then smaller wetland areas would be required, as also indicated in Figure A6. 7 (e.g. a reduction in wetland area from 85ha to 65 ha to achieve the same final water quality, if the volume was reduced to 25 000 m3/d);
- Such low concentrations are achievable in WWTWs – but would need to be included in the design of the planned new facility.

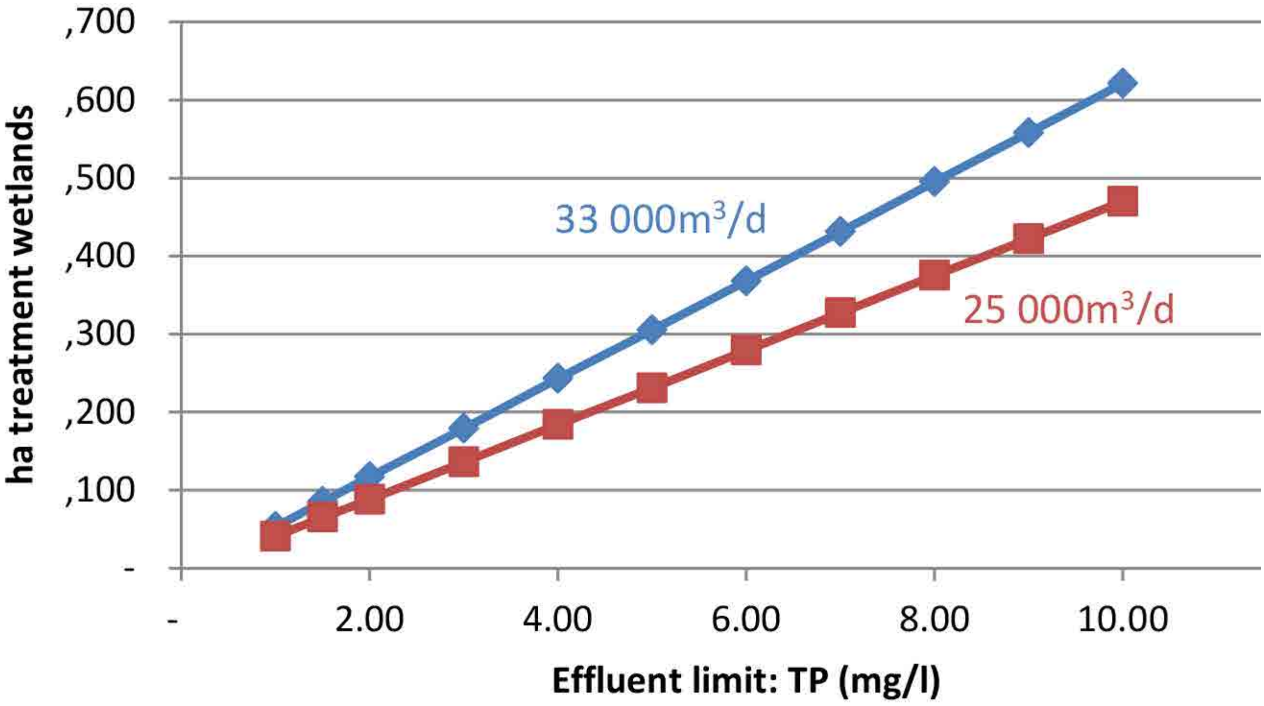


Figure A6.7 Estimated wetland area required to treat effluent to a fixed target of 0.15 mg/L, for two different final effluent volumes, when different final effluent concentrations are achieved.

In addition to achieving downstream benefits in terms of resource quality, opening the lower wetland for safe recreational purposes, likely improvements in fisheries and other benefits discussed in terms of Step 4, rehabilitated wetlands would also be likely to control the expansion of informal settlement into the wetlands.

There are caveats to the above discussion. Hydrological data for the Nakivubo channel are very limited, and calculations of loading in the channel (presented for Step 1) use single values for assumed wet and dry channel flows. The calculation of required wetland area to address effluent of a known quantity and assumed quality ignores the fact that during high flows, if Step 1 only is pursued, then there would be a substantial improvement in the quality of outflows from the channel, which in wet conditions might exceed treated effluent volumes by more than fourfold (data from Tebandeke (2013) suggest that wet season flows are in the order of 170 000 m³/d). If these flows took place in the context of full implementation of Step 1, then considerable wet season dilution of effluent flows would occur. In the event that Step 1 was not implemented and only Step 2 was followed, this argument would not apply, as the latter is based primarily on dry season diversion of contaminated flows, and these would be largely ineffectual in the wet season.

Step 5. Improve the functioning of the lower wetland

Measures required

The following measures are included in this step:

a. Improve the spread of flow into the lower wetlands;

b. Prevent further damage from agriculture;

c. Encourage regular harvesting of Papyrus plant material to stimulate growth; and

d. In the event that recreational use of the island occurs, control the effects of increased human passage by:

    i) Creating boardwalks to avoid where possible sensitive floating wetland areas;

    ii) Ensure that adequate provision is made for litter collection; and

    iii) Ensure that sewage and grey waste water are disposed of into the sewerage and do not pass into the water body.

The last measures are necessary for both the protection of the wetland and as facilities for visitors, and are thus incorporated into Step 6.

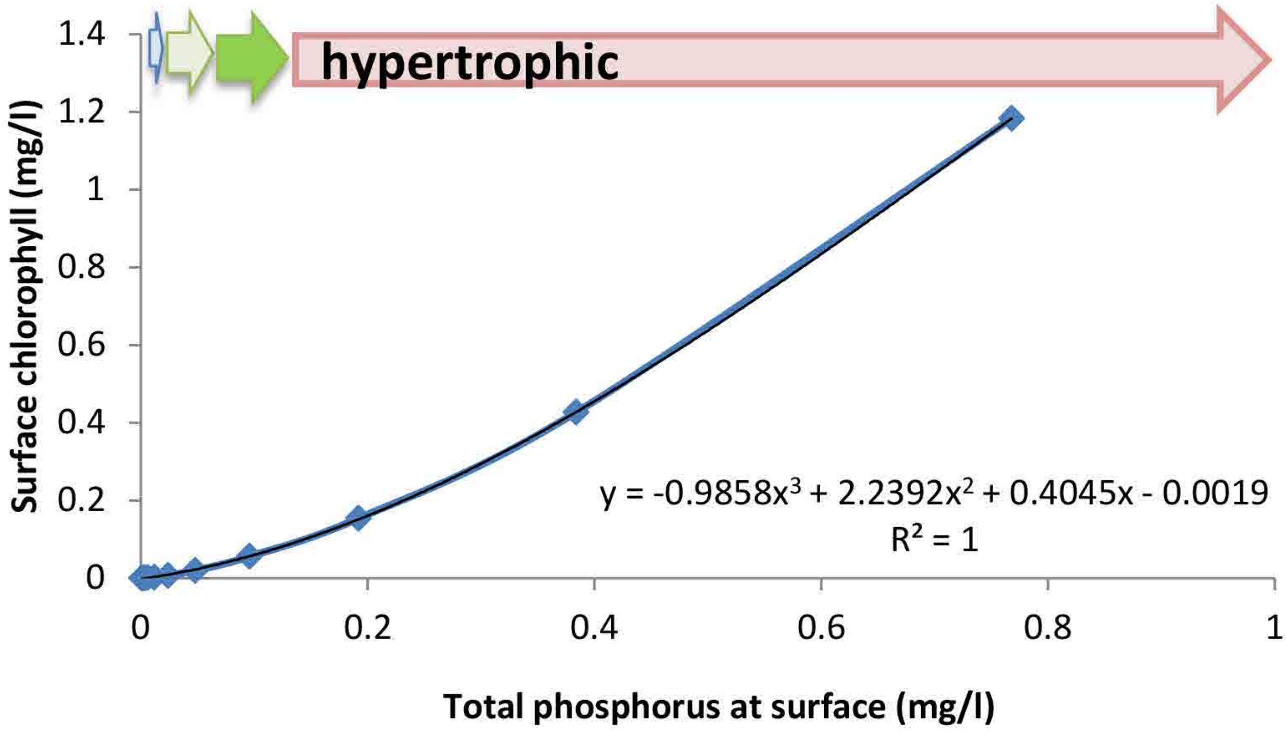


Figure A6.8 Relationship between surface phosphorus and surface chlorophyll in lakes. Data sourced from Cooke et al. (2005) after Carlson (1977). Equation for relationship (3rd order polynomial) calculated in present study.

Design and costs

Improve the spread of flow

The treatment wetlands and filtration strip wetlands (Step 3) should be connected to the lower wetland via a series of pipe or other culverts created at intervals along the railway line. At least three new drainage lines are envisaged. It was assumed that three new drainage lines would be needed to spread the flow effectively from the treatment wetlands through to the lower wetland via a series of pipes and/or culverts. Typical capital and maintenance costs for conventional drainage design were taken from Armitage *et al*. (2013) and inflated to 2015 US $. These costs were based on estimates for constructing unlined channels, using pipe culverts 600mm in diameter and dewatering subsoil to fit the drainage lines.

Flows from the Nakivubo channel should pass into the lower wetland as at present, with possible allowance for further spreading of flows into degraded Papyrus wetland, if there is sufficient water flow.

Prevent further damage from agriculture

Agricultural activities need to be managed to prevent cultivation and livestock grazing in the floating *Cyperus papyrus or M. violaceum* islands, to prevent further breaking up and loss of these wetlands.

Measures to control agricultural activities include fencing where necessary around the lower wetland to prevent agriculture within the designated wetland area, and signage and patrols to enforce these regulations. It was assumed that approximately 2 km of fencing would be needed and that patrolling the wetland would require full time staff at a cost of $6000 per year (updated from Kakuru *et al*. 2013 who estimated wetland management costs including salaries of staff).

Harvest wetland vegetation

Papyrus needs to be harvested at certain times of the year and at different growth stages to stimulate growth and promote nutrient storage within the wetland. A specific harvesting plan for papyrus plant material in the lower wetland should be initiated and this should focus on educating local people about how best to harvest the plant material. The ongoing costs would therefore include the managing and monitoring of the harvesting programme as part of the larger conservation effort in the lower wetland. This was based on estimates taken from Kakuru *et al*. (2013) for wetland management and conservation.

The estimated capital and maintenance costs involved in protecting the lower section of the wetland are summarised in Table A6. 9.

Expected outcome

Achievement of this objective is contingent on implementation of Steps 1 to 3. The resultant improved water quality flowing into the lower wetland and more particularly into the Murchison Bay area would be associated with the following impacts:

- Improved oxygenation of wetland waters, improving wetland / lake habitat for aquatic organisms including fish, reported in some studies (e.g. Stalder 2014) to be limited by the build-up of anoxic sludge on the lake bottoms and poor water quality;
- Improved growth of *Cyperus papyrus* wetland vegetation throughout the Nakivubo wetlands (as a result of establishment of extensive treatment wetlands (Step 4)) but particularly in the lower wetlands, where reduced sediment would allow improved uptake of orthophosphate by this species in water channelled into degraded areas from upstream;

Table A6.9 Estimated capital and ongoing maintenance costs associated with interventions to conserve the lower wetlands (2015 US $ millions)

Intervention	Initial cost $ million	Operating and maintenance costs $ million per annum
Pipes/culverts to improve the spread of flow into the lower wetlands.	1.38	0.04
Measures to control agricultural activities	0.03	0.007
Encourage regular harvesting of Papyrus plant material to stimulate growth	0.00	0.02
Total costs: conservation of lower wetland	1.41	0.07

- Improved aesthetic conditions, as a result of reduced litter and sedimentation (Steps 1 and 2), as well as substantially reduced human health risks for intermediate contact recreation, allowing opportunities for the use of the lower wetland for safe recreational / tourism opportunities to be explored; and
- Decreased plant production in Murchison Bay, potentially:
    - improving its aesthetic qualities if decreased production rates result in measurable improvement in water clarity and decreased phytoplankton blooms; and
    - potentially reducing purification costs.

It should, however, be noted that these impacts are only likely to be measurable / visually apparent if Steps 1 to 3 have been rigorously implemented. Figure A6. 8 plots values from Cooke *et al*. (2005) that are applicable to all lake conditions, and were derived from Carlson (1977). The graph shown in Figure A6. 8 shows that, once in-lake water is in a hypertrophic state, substantial reduction in total phosphorus concentration needs to be achieved to show a reduction in surface chlorophyll concentrations. Other data from the same sources (not shown in this figure) highlight the related fact that improved water clarity as a result of nutrient reduction also requires the water body to be shifted towards mesotrophic conditions, and achieving major reductions in surface phosphorus concentrations may have little visible effect unless actual trophic state thresholds can be crossed.

No quantification of the effects of reduced phosphorus concentrations on in-lake chlorophyll concentrations, particularly in the vicinity of the Ggaba water inlet have been made in this study. Water quality data for the latter include TSS concentrations, but no nutrient data. Although it is assumed that the measured TSS comprised wholly of phytoplankton, the data themselves are not transposable to any of the variables included in the Carlson (1977) relationships.

Step 6. Establish a recreational space with facilities

Vision for the Nakivubo Wetland Park

The KCCA envisages a future development path in which wetlands areas are enhanced as recreational green open space areas to be enjoyed by the city's inhabitants. This has been recently reinforced by a directive from the Ministry of Environment to restore the city's wetlands. In addition, the city envisages a lakefront development in the vicinity of Port Bell in which there will be various attractions such as waterside restaurants (Figure A6. 9). Such waterside developments within or alongside working harbours have been very successful in other cities, such as Cape Town.

The extent and details of the envisaged Nakivubo Wetland Park have not been developed. For this study it was necessary to articulate what this might mean. We envisage that this will be integrally and physically linked to the planned waterfront area at Port Bell.

What we have envisaged for the Nakivubo-Wetland recreational area is the provision of a reasonably large parkscape area adjacent to the wetland, with access to both lakefront and the vegetated wetlands, with picnic facilities and walking paths in and around the landscaped area and wetland (Figure A6. 10). The main landscaped recreational area would thus be close to Port Bell, but smaller sites could also be set up at other locations around the wetland.

A core part of the wetland could be set up as a bird sanctuary which retains its natural characteristics as far as possible and into which access would require a bit more effort in order to keep human disturbance to a low level. The bird sanctuary would contain rustic boardwalks and hides (of a design that would not encourage unintended uses. This in itself could provide tourism opportunities if well managed. The park would also contain a wetlands information centre located in between the landscaped areas and bird sanctuary to enhance the visitor experience.

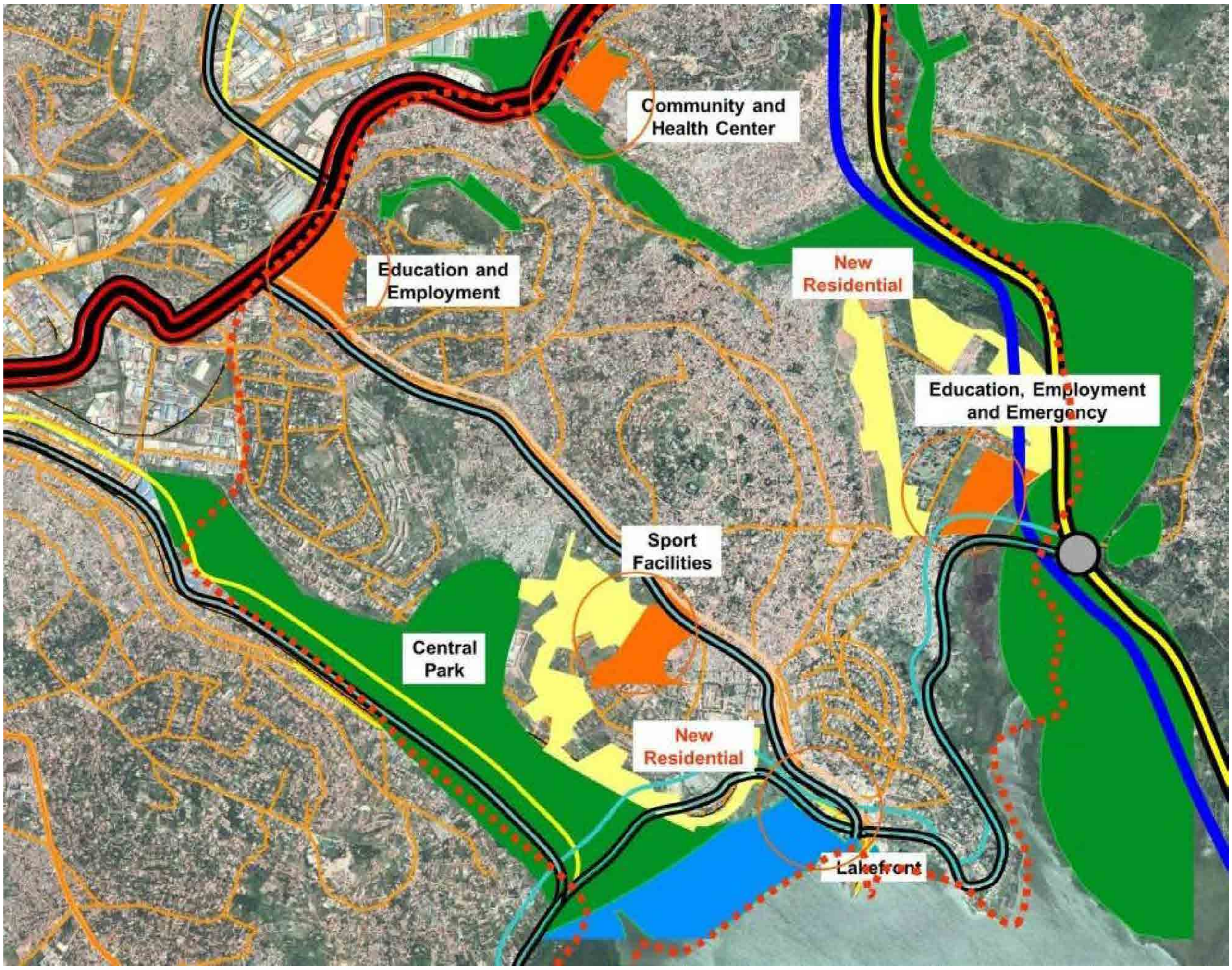


Figure A6.9 Concept plan for the study area taken from the Kampala Physical Development Plan

Various other facilities (e.g. sporting facilities) could be included depending on the space available. It is envisaged that the immediate surrounding area in the vicinity of the current prison site and Port Bell would be developed for retail, restaurants or kiosks with some of this being on the waterfront. We do not envisage any further transport routes across the wetland however, as this would likely be counter to the objectives of wetland restoration, conservation and aesthetic improvement of the area.

In addition to a core recreational area in the vicinity of the Prison site to Port Bell area we also envisage landscaping of smaller areas on the opposite side of the lower wetland, and the possible creation of a wide paved walking/cycle way along one or both banks of the wetland extending over parts or all of the way from the lake to 5th bridge. Such a pathway would be on the inside of the wetland buffer strips described in the previous chapter and could potentially create a safe and pleasant passage into town which encourages non-motorised commuting and the use of cycle taxis rather than the highly polluting boda-boda's. Extending this idea to the whole length of the wetland would, however, require the relocation of houses from the informal slum areas. Should this be feasible, its proper construction would discourage the return of these informal dwellings. In this study, we have not considered the addition of this feature due to the difficulty of estimating the relocation costs. However, it is recommended that this be considered in the future.

Table A6.10 Estimated capital and maintenance costs for the proposed Nakivubo Wetland Park based on the concept vision used for this study

Work/Amenity	Initial cost $ million	Operating and maintenance costs $ million per annum
Vegetation clearing	0.12	0.002
Boardwalk & foot bridges	0.65	0.013
Fencing	0.08	0.002
Pathways (walkways, cycle paths etc.) including amenities such as benches, litter bins and lighting	1.54	0.031
Landscaping of park area for picnic and leisure activities	2.59	0.052
Public toilets	0.43	0.009
Parking areas	1.62	0.032
Visitor centre	4.32	0.086
Hides/resting pavilions	0.12	0.002
TOTAL	11.48	0.230

Estimated costs of recreational facilities

A high level estimate was made of the costs of developing the recreational park. This does not include the private development costs that would be anticipated, such as the development of restaurant, entertainment and retail outlets, but only the cost of providing public amenities. These were estimated to include the following:

- 13 km main paths around the wetland area of at least 2 m width, designed for walking and cycling, with amenities such as benches, bins and lighting;
- 5 km of board walks within the wetland, and 5 foot bridges;
- 15 ha of landscaped park space for picnic and leisure activities;
- 8 resting pavilions/bird hides;
- 10 public toilet blocks;
- 5 parking/access areas of 0.5 ha; and
- 1 single-storey visitor centre of about 0.5 ha in size.

Costs associated with constructing the wetland park and associated amenities, and measures to control the effects of increased human recreational use within the wetland park were estimated using costs available in the literature on similar projects based elsewhere in the world combined with costings provided by an industry professional in South Africa. All values were converted to 2015 US $. South African cost estimates were multiplied by a factor of 1.5 as it was assumed that the associated costs in Kampala would be higher due to influences such as fewer suppliers and imported materials. Maintaining and servicing these amenities was assumed to be 2% of capital costs. Some of the ongoing servicing and maintenance costs for the public restrooms could possibly be covered by a pay-per-use initiative.

It is estimated that the total capital costs involved in constructing the wetland park will be approximately $11.5 million, with annual maintenance and operating costs of $0.23 million per annum (Table A6. 10). The largest cost being the construction of parking areas, a visitor centre and the landscaping of 15ha of park area.

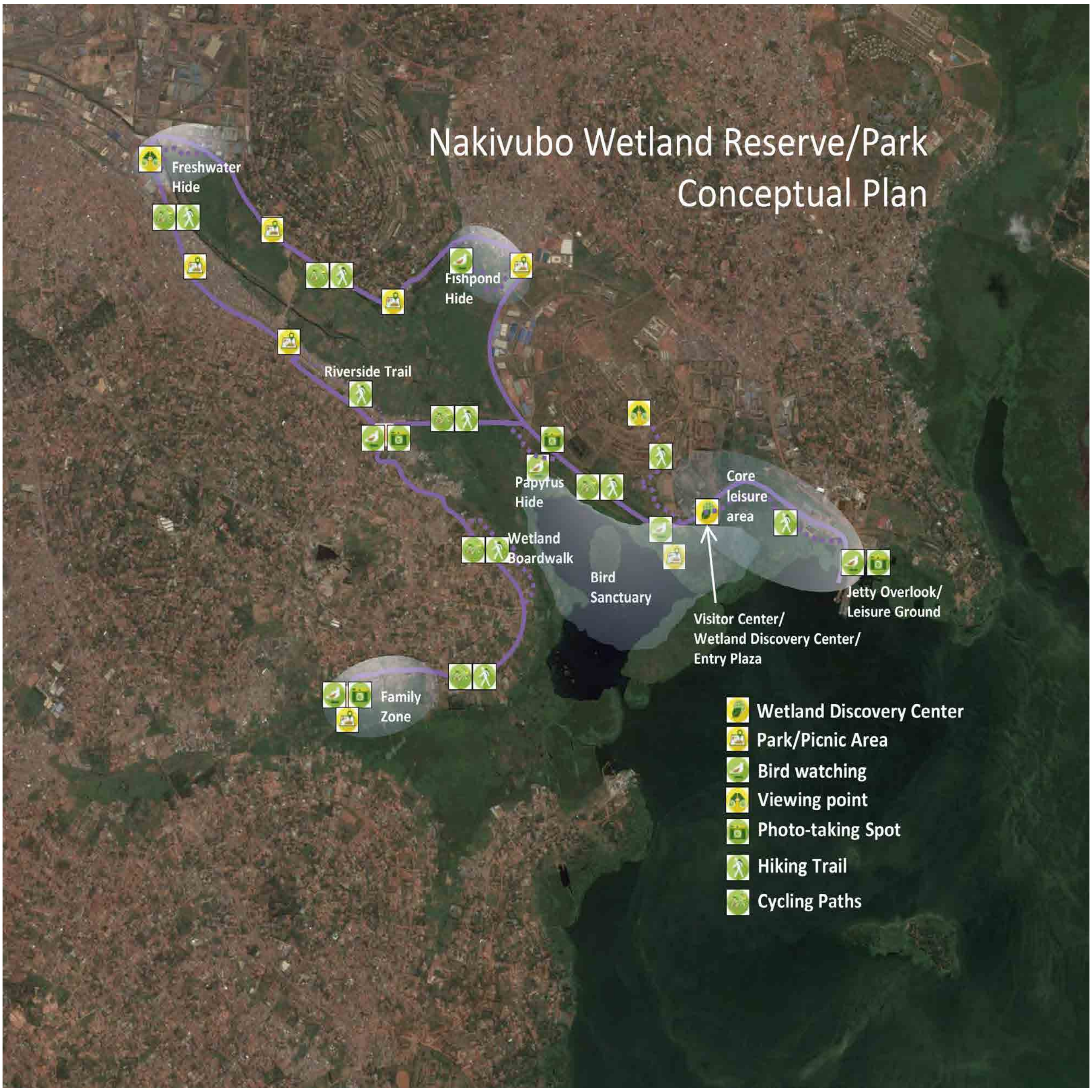


Figure A6.10 Concept vision for the Nakivubo Wetland Park used in this study

Appendix 7: Impacts of water quality changes on water treatment costs

A7.1 Introduction

In the context of treating water the biggest effects of increased sediment and nutrient loads on the cost of treating water are as follows: (Source: Graham 2004, McDonald & Shemie 2014, Rangeti 2014):

- Increased usage of coagulants;
- Increased amount of time water spends in settling ponds;
- Increased waste water sludge (costly to treat and transport);
- Increased sediment loads preventing adequate filtration and disinfection of other pathogens and algae;
- Increased occurrence of algal blooms and toxic algae;
- Increased dominance by blue-green algae;
- Clogging of reticulation systems by filamentous algae;
- Increased occurrence of taste and odour issues in potable water and the need for activated carbon usage to eliminate these;
- Wasted water on more frequent backwashing to clean clogged filters; and
- Increased nutrients require the use of more complex and costly treatment technologies.

Ggaba Water Treatment Works is made up of three treatment plants. Ggaba I has been operational since 1930, Ggaba II since 1992 and Ggaba III since 2007, and they have a total water supply capacity of approximately 170,000 m3 per day (NWSC pers. comm. 2015). In 1992 the plant was upgraded to include clarification stages of the treatment process and in 2007 the system was upgraded again to become fully automated (Ooyo 2009). In doing so the process became more accurate in terms of chemical dosages during the various treatment stages. From Ggaba the water is pumped to reservoirs at Muyenga, Gunhill and Naguru Hills which have a total storage capacity of 65 220 m3 (NWSC 2014). In 2010 the intake pipeline at Ggaba III was extended further into Lake Victoria in an effort to extract higher quality water for treatment. From October 2010 the new pipeline was in operation (NWSC pers. comm.).

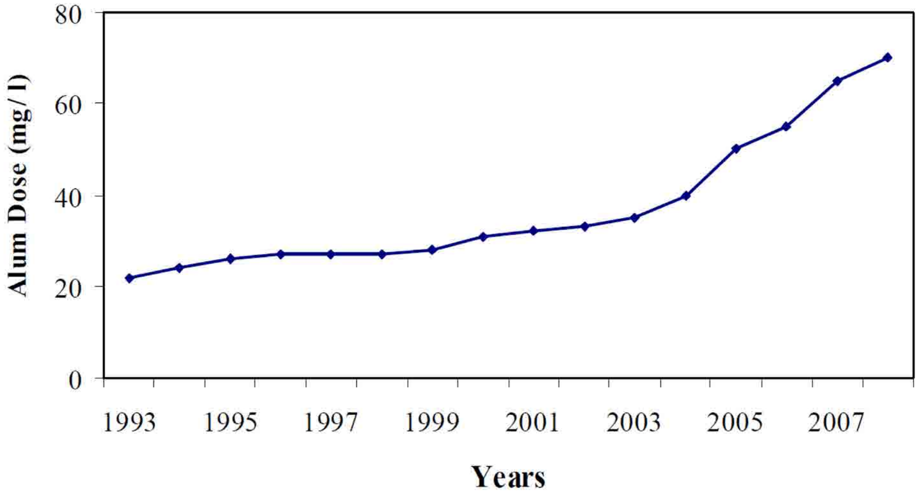


Figure A7.1 Rising aluminium sulphate dosage at Ggaba WTW 1993 – 2007
Source: Ooyo 2009

A7.2 Water treatment pre-2007

Previous studies have shown that one of the major economic benefits of the Nakivubo wetland has been its ability and function in treating pollution so as to maintain a certain standard of water in Inner Murchison Bay which influences water treatment at Ggaba only 3 km away (Emerton *et al*. 1998). However, over the years the ability of the wetland to maintain this function has decreased and the water quality entering Murchison Bay has deteriorated significantly thereby increasing water treatment costs at the Ggaba WTW. In 1998, COWI reported that the Inner Murchison Bay had medium to high levels of eutrophication with Total Phosphorous loads of 183 kg/day and Total Nitrogen loads of 1125 kg/day entering the lake. Of this it was determined that 85% of the phosphorous and 75% of the nitrogen entering the inner bay was from the Nakivubo wetland (COWI 1998). Ooyo (2009) found that the water quality in the Inner Murchison Bay was poor but improved as one moved further out from the Nakivubo channel to the outer bay. Phosphorous levels were particularly high, being above the recommended maximum level for surface water of 0.1 mg.l-1, ranging from 1 – 4 mg.l-1 across the monitoring stations (Ooyo 2009). Ooyo (2009) determined that the high levels of phosphorous caused intensive algal blooms in the inner bay and as a result influenced the amount of aluminium sulphate needed during the treatment process to adequately remove algae and associated odour and taste problems. The aluminium sulphate dosage increased significantly from approximately 20 mg/l in 1993 to almost 70 mg/l in 2007 (Figure A7. 1, Ooyo 2009). The level of aluminium residue remaining in treated water can pose a threat to human health and during the period 1993 - 2007 the residue increased in Kampala's drinking water from 0.01 to 0.16 mg.l-1, only slightly less than the maximum permissible level of 0.20 mg.l-1 (Ooyo 2009).

A7.3 Water treatment post-2007 (empirical data)

Water treatment data from Ggaba WTW was analysed for the period February 2007 – May 2015. These data were supplied by the NWSC and included monthly volumes of raw and treated water, monthly chemical usage and costs and water quality data for the raw and treated water. From the chemical cost data spreadsheets provided by the NWSC it was noted that the overall usage of each chemical (kilograms) had been multiplied by current costs for each chemical (shillings per kg) (i.e. they multiplied the amount of chemical used in 2007 by the current day cost of the chemical). Therefore all costs are assumed to be in present-day Shillings (2015).

During 2010 there was a period of inconsistent cost data that did not match the volume data or the water quality data and as a result was removed from the analysis. This inconsistent data occurred during the same period that the new pipeline was being constructed and it is assumed that the changeover and building of the pipeline resulted in unusual values that were significantly different to all other monthly observations. It was decided that these values should be removed from the analysis.

Data were provided on monthly measurements of TSS and turbidity as well as other parameters such as colour and E coli. Contrary to expectation, water treatment costs and TSS were negatively correlated and were not significant (Figure A7. 2 and Figure A7. 3). Previous studies and the current state of Inner Murchison Bay would suggest that TSS, a measure of algae and suspended sediments, would have a positive and significant impact on the water treatment costs at Ggaba. Other water quality variables, such as iron and colour were also negatively correlated with costs. Turbidity and E coli showed a positive relationship with costs but these relationships were weak and not significant. Multiple regression yielded a significant model but the signs were not as would be expected.

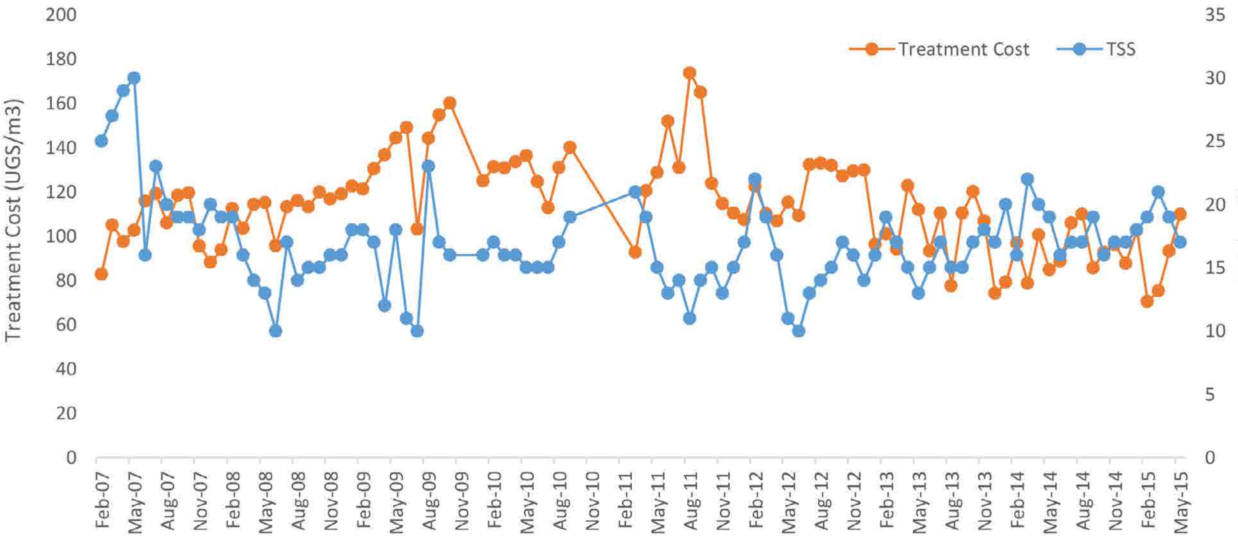


Figure A7.2 Total treatment costs (Ugandan Shillings per m3 treated water) and Total Suspended Solids (TSS, mg/l) for the period 2007 – 2015.

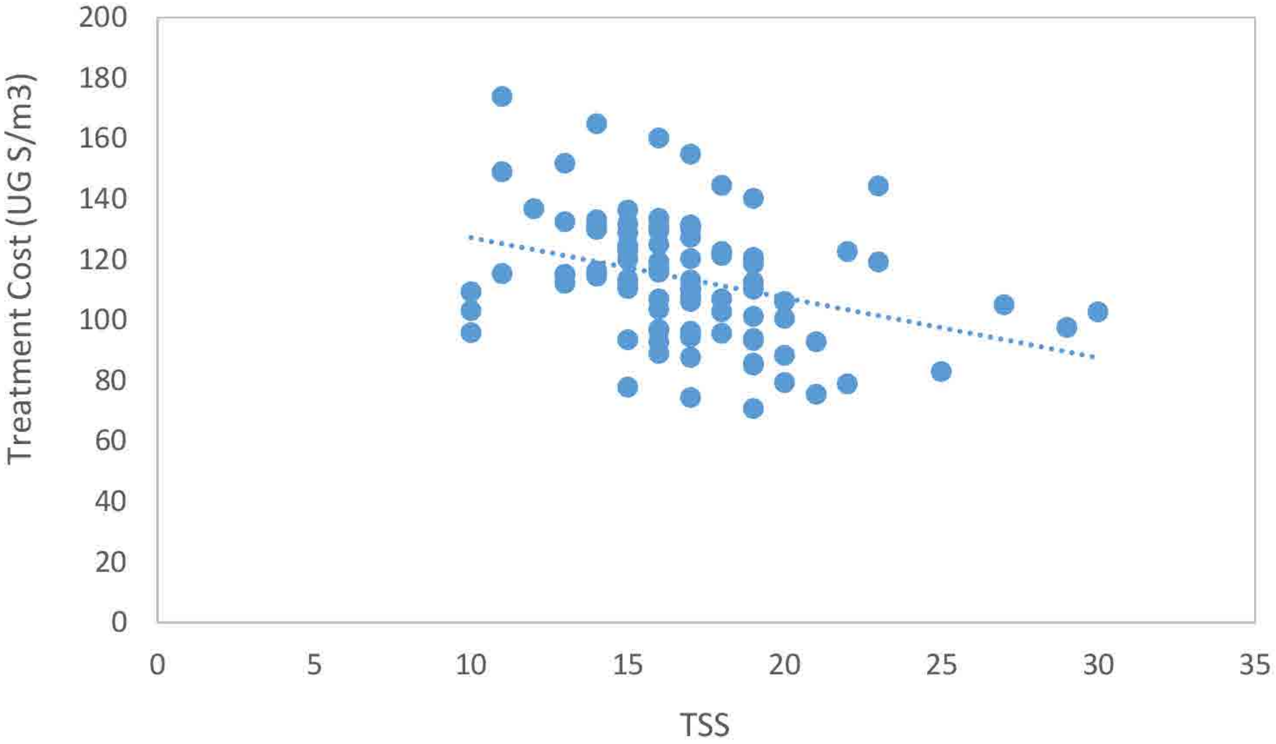


Figure A7.3 The negative relationship between treatment costs (Ugandan Shillings per m3 treated water) and TSS from 2007 – 2015.

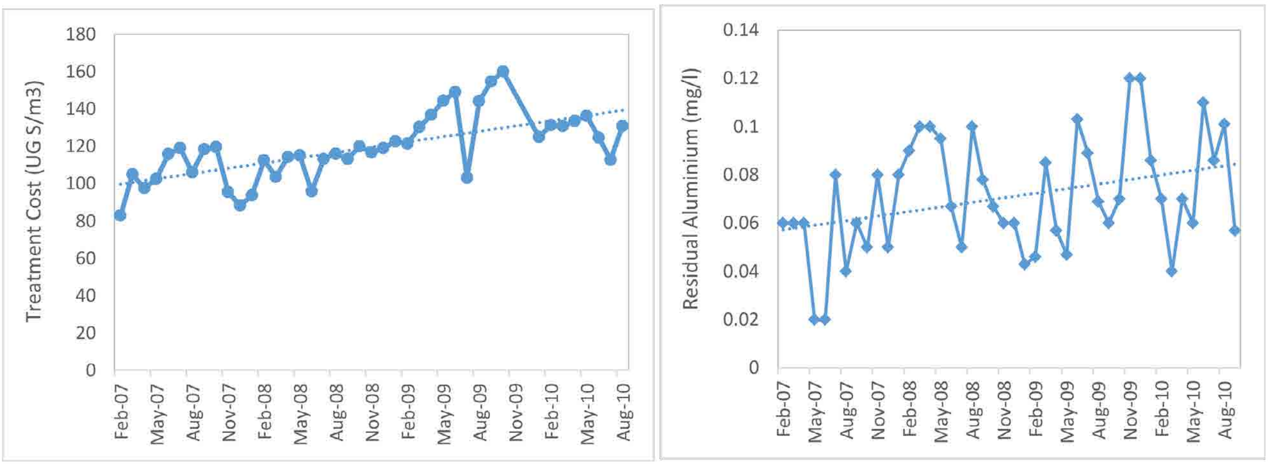


Figure A7.4 (a) Increasing water treatment costs (Ugandan Shillings per m3) over the period 2007 – 2010 and (b) increasing residual aluminium levels (mg/l) in treated water for the same period.

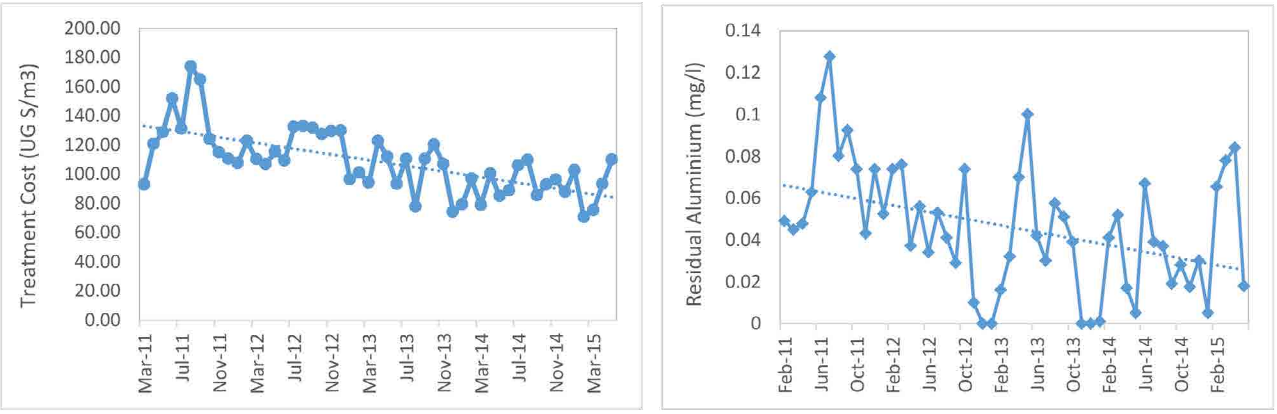


Figure A7.5 (a) Increasing water treatment costs (Ugandan Shillings per m3) over the period 2007 – 2010 and (b) increasing residual aluminium levels (mg/l) in treated water for the same period.

In 2007 Ggaba III became fully automated, making chemical dosage more accurate and the water treatment process more efficient. However, water treatment costs continued to rise from 2007 until mid-2010, as did the residual aluminium sulphate present in the treated drinking water (Figure A7. 4).

As a result of the rising residual aluminium sulphate levels in the treated drinking water, the NWSC switched to using a combination of aluminium sulphate and polyaluminium chloride (PAC) in the treatment process in 2010. PAC is a synthetic polymer that dissolves in water and is preferred to Alum because it has a lower dosage requirement, often does not require any form of neutralising agent, has a shorter flocculation time, produces less sludge and requires less backwashing (Graham 2004). The use of PAC at Ggaba III commenced at approximately the same time as the extension of the abstraction pipe further into Murchison Bay. It is assumed that these two changes had a significant impact on both the water treatment costs and the quality of the drinking water being produced as both costs and residual alum levels started to decrease towards the end of 2010 (Figure A7. 5).

The use of PAC during the treatment process resulted in a decrease in the use of Alum, thereby reducing the residual aluminium in the drinking water. The use of PAC as a flocculent also reduced the amount of backwashing needed to remove algae clogged in filters. This can be seen in Figure A7. 6 below; the difference in the volume of raw water entering the plant and the amount of treated water decreases significantly from mid-2010 when the polymer PAC was used for the first time.

It was expected that water quality would have continued to deteriorate over time, but with an abrupt change to overall better quality in late 2010 when the extended pipe came into operation, followed by a new path of deterioration. However, no such trends were observed for either turbidity or TSS (Figure A7. 7). E coli counts did increase over time, but without any improvement in 2010 (Figure A7. 7). It should be noted that water quality measurements are taken where the piped water enters the plant.

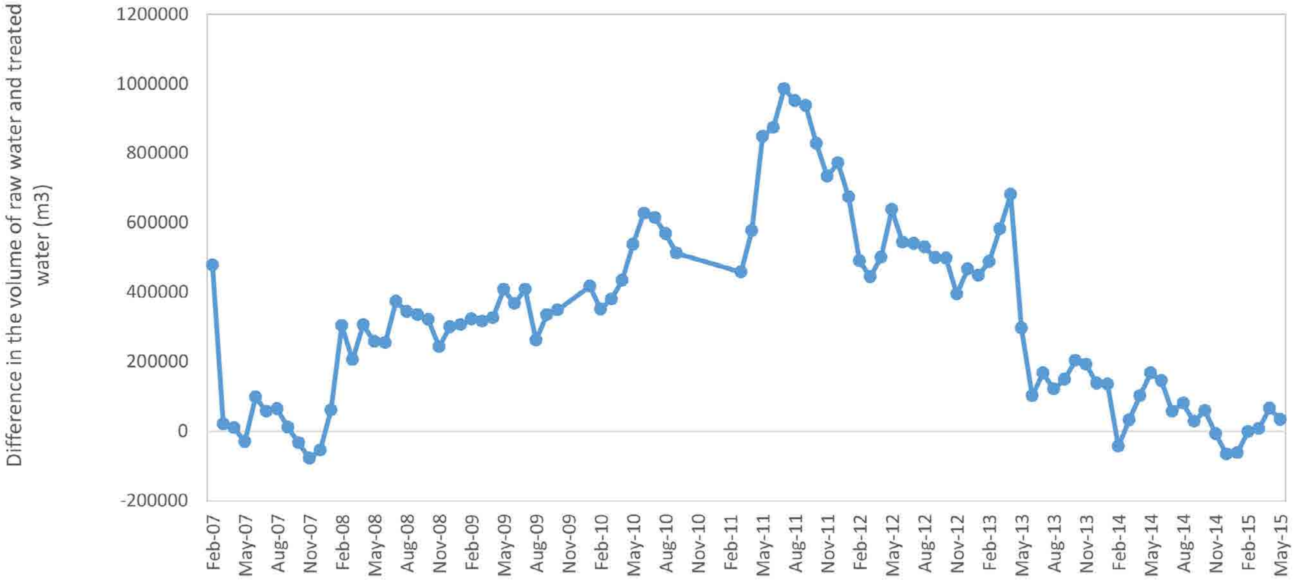


Figure A7.6 The difference in the volume of raw water and treated water at Ggaba 2007 - 2015

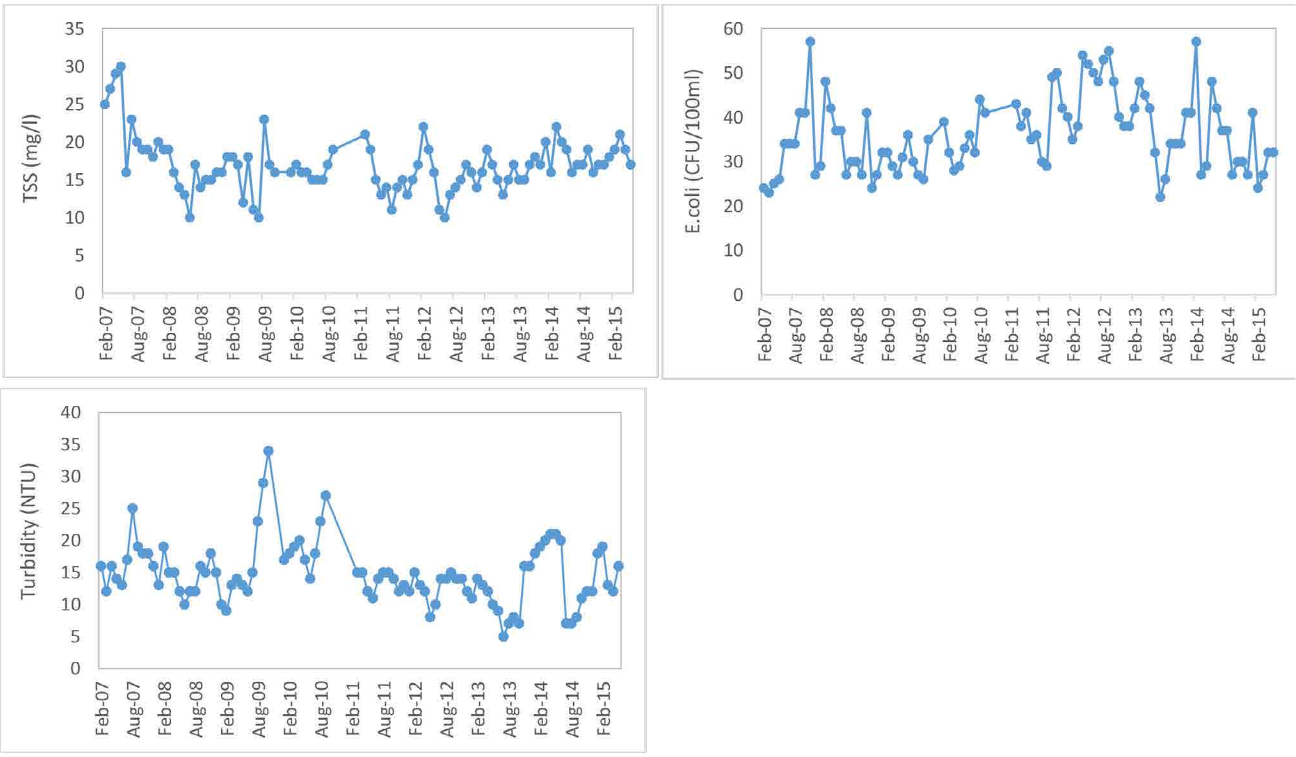


Figure A7.7 TSS, E coli and Turbidity trends over time.

After meeting with the NWSC in Kampala and discussing with them the results of the data analysis it was agreed that the main drivers of use of chemicals in water treatment are E.coli and nutrient concentrations within the raw water. Other relevant water quality data, such as chlorophyll levels were not made available in time for this study and in any case it is expected that these data are unlikely to be able to explain the decrease in treatment costs since 2010. It is expected that these decreases in costs are a result of improved human efficiency in operating the treatment process at the WTW and of the change to PAC as discussed above. Variables such as human efficiency are unobservable within the analysis and it was decided that the use of a benefit transfer approach from another water treatment plant that is not complicated by such factors would be a more beneficial approach to use here.

A7.4 Estimation using benefit transfer

Discussions with the NWSC confirmed that water quality deterioration still has an impact on costs and will continue to do so under the new plant. Therefore in the absence of a useable model for the Ggaba plant, it was decided to value the potential cost savings using a benefits transfer method. This is essentially the use of a model developed elsewhere, but with parameters adjusted as far as possible to correct for differences between the source and receiving valuation site.

A model was developed for the Durban Heights Water Treatment Works in South Africa (as part of the Durban case study), using monthly treatment cost data over a period of five years (July 2010 – June 2015), data on raw water quality and on nutrient loads entering the Nagle Dam from which the raw water is drawn. The model had to be designed in such a way that it could be applied in a situation of more limited data from Inner Murchison Bay. Thus the model was developed with treatment costs as a function of phosphorous loads, coliform counts, colour, temperature and conductivity. Using these values and a standard water treatment cost model developed for water treatment in Durban we were able to calculate the water treatment cost savings as a result of improved water quality entering Murchison Bay. The technology and chemicals used to treat water at Durban Heights and Ggaba WTW are comparable as are the dimensions of the water supply reservoir in Durban and Inner Murchison Bay.

The water treatment cost savings at Ggaba were estimated based on the assumption that total phosphorous concentrations in the wetland would improve substantially through the restoration interventions and, as a result, total phosphorous concentrations in Inner Murchison Bay would ultimately decrease to a mesotrophic condition, resulting in treatment cost savings due to fewer algal blooms. The cost saving estimate is that obtained when this level of lake condition is reached.

Table A7.1 Estimated capital and maintenance costs for the proposed Nakivubo Wetland Park based on the concept vision used for this study

	Coefficient	Std. Error	t.value	Pr(>|t|)	
Intercept	47.780	23.007	2.077	0.044	*
Phosphorous Load	0.015	0.005	3.381	0.002	**
Temperature	0.685	0.674	1.016	0.316	
Coliforms	0.006	0.003	2.261	0.029	*
Colour	0.501	0.403	1.242	0.222	
Conductivity	0.980	1.239	-0.791	0.434	
R-squared				0.481	
Adjusted R-squared				0.416	

*Notes: (1) ***p<0.001, **p<0.01, *p<0.05, .p<0.10.*

Table A7.2 Estimated capital and maintenance costs for the proposed Nakivubo Wetland Park based on the concept vision used for this study

	Pre-Restoration	Post- Restoration
Phosphorous concentration (mg/L)	2.5	0.047
Phosphorous load (kg/yr.)	8088	152
Water treatment cost ($/ML)	22.14	8.52
Saving per ML ($/ML)		13.60
Annual cost saving (US $ millions)		0.845

Data on phosphorous concentrations in the wetland and average flow data for the Nakivubo wetland were used to calculate phosphorous loads entering Inner Murchison Bay (IMB) under a pre-restoration scenario. Currently the phosphorous concentrations in the lower wetland are extremely high at around 2.5 mg/L. The restoration interventions are aimed at reducing these concentrations to ensure the wetland is in a mesotrophic state, which at the upper end of this state, has a phosphorous concentration of 0.047 mg/L. This value was used to determine the post-restoration phosphorous load using flow rates from the wetland. Based on these values, the pre-restoration annual phosphorous load entering the Lake was estimated to be 8088 kg and post- restoration 152 kg. The model was updated using average values for water quality parameters found in the raw water in Inner Murchison Bay. Average temperature, average colour and average conductivity were used based on data analysed from NWSC for the raw water at the Ggaba WTW. Because Coliform data was not available for Inner Murchison Bay or for the raw water at Ggaba, the average coliform count from Durban was applied. It was assumed that not only will phosphorous loads decrease as a result of wetland restoration but so too will the coliform counts. The decrease in coliforms and in phosphorous was then assumed to improve the colour of the water being treated as a result of fewer nutrients, bacteria and algae in the raw water. A 66% reduction in coliforms and in colour was applied to the post-restoration scenario.

The treatment cost model estimates are shown in Table A7.1. The result from the model was computed as a Rands per ML (R/ML) value. This value was then converted into US $ using current 2015 conversion rate. The results of the analysis show that the water treatment costs would decrease from $22.14 to $8.52 per ML of treated water (Table A7.2). This is a saving of $13.60 per ML which equates to $845,000 per year based on the current supply of 170 ML per day at the Ggaba WTW. Currently the average cost of treating one ML of water at Ggaba is approximately $30/ML (Figure A7. 2). Therefore the water treatment savings that would occur as a result of restoration are significant with post-restoration costs being 38% of pre-restoration costs.

The difference between the model estimate of $22.14/ML pre-restoration and the actual current cost at Ggaba of $30/ML is possibly a result of having to use average coliform data from Durban as well as external effects such as plant efficiency which are unobservable and expected to differ between the Durban Heights and Ggaba WTW.

A7.5 Conclusions

The empirical data that was provided by the NWSC produced unexpected results that differed from personal comments and understanding by the staff of the current water treatment situation at Ggaba. The general understanding is that water treatment costs are still increasing as a result of poor water quality in Inner Murchison Bay. Current pollution levels entering Inner Murchison Bay from the Nakivubo wetland are high and have been increasing consistently over the years as the wetland condition has deteriorated. It was expected therefore that the water treatment data would show deteriorating water quality in Inner Murchison Bay and related increases in water treatment costs. This, however, was not the case and the data did not conform in any way to what was expected. Although the technology at Ggaba WTW has been upgraded and the water intake pipeline has been extended further into Inner Murchison Bay, one would still expect to see increasing treatment costs as a result of the poor water quality. As a result of not being able to use the empirical data to determine a water treatment cost model the benefit transfer method was used. This proved to be relatively successful and was based on the assumption that the effect of phosphorous loads on algae and on treatment costs were similar at Durban Heights and Ggaba. The analysis showed that a reduction in phosphorous concentrations in the lower wetland as a result of the restoration interventions would have significant impacts on chemical costs and the saving per ML of treated water would be almost half of the current day cost. An annual saving of $845 000 is estimated if restoration interventions for the Nakivubo wetland are implemented.

Other associated treatment costs expected to decrease as a result of improved water quality entering Murchison Bay include sludge removal and backwashing. The reduction in phosphorous and other nutrients as a result of restoration initiatives are expected to decrease the frequency and intensity of algal blooms in the inner bay and will therefore decrease the need for continuous backwashing of the filters. Sludge dewatering and sludge removal can be very expensive and it assumed that the improved water quality will decrease the amount of sludge produced during the water treatment process and will therefore reduce the time and costs involved in having it removed.

Appendix 8. Recreational demand for open space areas in Kampala and potential benefits of restoring Nakivubo wetland

A8.1 Introduction

Urbanisation in Africa is occurring at an unprecedented rate as the rural poor move into cities in search of employment and other opportunities. This has had a significant impact on natural and semi-natural green open space areas in and around urban centres and the benefits that they provide to city inhabitants. Urban green open space not only provides opportunities for recreation and tourism, it provides a refuge from urban dis-amenities such as noise, traffic congestion and pollution (Anderson & West 2006, Kroeger 2008), helps to reduce stress (Ulrich & Addoms 1981, Kaplan 1983), and promotes emotional, psychological and physical health (Chiesura 2004, Anderson *et al*. 2013). A decrease in availability of suitable green open space can lead to increased travel costs and congestion, as well as decreased health, productivity and economic output. It can also contribute to urban sprawl, as city inhabitants move to the urban fringe in order to have access to green open space. However, investment in the maintenance of green open space areas is often given low priority due to a lack of appreciation of their value (TEEB 2010).

In Uganda, the city of Kampala has undergone a period of rapid urbanization that has significantly contributed to the degradation of the quality of the city's natural environment. The city is located on the edge of Lake Victoria, and has developed on a hilly landscape that is drained via a number of wetlands that are connected to the lake. Since terrestrial green open space areas within the city have either been lost to development or are under private ownership, the wetlands are the last publicly-accessible green open space within the urban area. However, they have been used as conduits for waste water, have been altered and encroached upon by agriculture and informal settlements, and are generally highly polluted and degraded. With few opportunities in the city, Kampala residents tend to travel to the outskirts of the city or beyond to visit outdoor recreational areas, contending with and contributing to heavy traffic congestion along the way.

One of the main wetland systems in Kampala is the Nakivubo wetland which has its source in the city centre and flows into Lake Victoria in Murchison Bay, close to the harbour area at Port Bell. While highly degraded at present, the lower part of the wetland has been recognised as a potential location for the development of a recreational park that encompasses wetland and lake shore waterfront areas. Bringing this about may require considerable investment in restoration and infrastructure which the city might be reluctant to make unless there is evidence that the benefits would outweigh the costs. This requires estimation of the potential demand for a new/improved recreational site, as well as the other co-benefits that will result from wetland restoration.

Importantly, the addition of a new recreational site close to the city centre has the possibility of generating welfare for citizens that were not able to access the currently-available sites due to the costs involved.

The demand for outdoor recreational areas is typically analysed using a random utility maximisation model framework that links the frequency of site visitation to individual attributes, the characteristics of alternative sites available, and the travel costs required to reach each site (Babatunde *et al*. 2012). The models are then used to infer the value that households place on access to sites and/or changes to site characteristics. Such information is very useful to managers of these public open space areas.

Recreational demand studies that involve multiple sites have been dominated by studies of angler site choice (Hunt 2006). Although one has to take care to minimise issues of endogenous stratification and truncation, studies of user groups such as anglers are probably best carried out using on-site survey methods, because the proportion of anglers in any population is usually fairly low. Some of these studies have explored the implications of a reduction in the number of quality of angling sites (Provencher & Bishop 1997). Few, if any studies have been carried out on site choice for general outdoor recreation by urban residents, or have investigated the potential gains in welfare associated with the restoration or addition of recreational sites. Unlike angling, general recreation (e.g. swimming, picnicking, and walking) is likely to have a very high level of participation among urban households, and whereas a loss of a site may simply reduce the welfare in an existing user group, in a case where opportunities may be increased, this may induce the participation of new households. Therefore it was considered more appropriate to gather our data from a general household survey.

Recreational studies typically employ revealed or stated preference methods or some combination thereof. While stated preference methods are usually regarded as less reliable than revealed preference methods, which model actual behaviour, they may provide important validation where the situation involves introduction of a new choice that may be outside the current set of experiences and thus simulation of the new situation may involve extrapolation beyond the range of parameters used to estimate the model. In this study, we used revealed preference data on frequency of travel to a number of sites in and around Kampala, and augmented this with data from the same respondents on their interest in utilising and their willingness to pay for access to the proposed Nakivubo Wetland Park.

A8.2 Conceptual Framework

A8.2.1 Multi-site choice model of revealed preference

Our econometric framework of modelling multi-site choice of outdoor recreation is informed by a random utility framework. In the latter, individual choices aren't completely deterministic, instead, choices are affected by alternatives that are not included in the survey and other unobservable individual's and site characteristics (Hannemann & Kanninen 1996). McFadden (1974) made use of this intuition in developing the random utility model, which was accomplished through the inclusion of an error term in (1).

$$V_{iqt} = \alpha_{iq} + \gamma_i s_q + \beta_q x_{iqt} + \varepsilon_{iqt} \qquad (1)$$

In this specification, we assume a linear-in-parameters specification for indirect utility, where we denote the individual with subscript q, the choice with i, and choice alternative with t. Note also that α_iq is the individual alternative-specific intercept that captures the intrinsic preference for the alternative, γ_i captures systematic preference heterogeneity related to socioeconomic characteristics, where s_q is a vector of socio-economic characteristics; β_q captures systematic preference heterogeneity related to program attributes, x_iqt is the vector of attributes (including costs) for alternative and ε_iqt is stochastic and accounts for observational deficiencies due to unobservable components in the model that are assumed to be uncorrelated with the observed components.

The above functional specification leads to a conditional logit model, which is often used to model discrete choice behaviour under the random utility framework (Greene & Hensher 2003, Train 1998). However CL suffers from restrictive assumption of IIA, and, therefore, fails to account for unobserved heterogeneity (parameter variation) and potential correlation between available choices. In light of this limitation recourse to more flexible approaches are desirable. One such o is the RPL. In this study, in addition to the base CL model, we applied RPL model preferences for outdoor recreation sites. The RPL generalizes the CL by allowing coefficients to vary randomly over individuals, rather than being fixed (Train 1998), and, therefore, it relaxes IIA and can represent any substitution pattern. Furthermore, the RPL explicitly accounts for unobserved heterogeneity (Train 1998, Carlsson *et al*. 2003).

Conditional Logit

In general, (1) is a logit model with both alternative-varying and alternative-invariant regressors. As such, it constitutes a mixed logit model. However, following the literature, we restrict γ_i=γ and α_iq=α, since the real interest is in attribute preferences, rather than alternative-specific effects. Assuming β_q=β and that each of the errors is identically and independently distributed (IID) type 1 extreme value, a CL can be estimated based on the following probability model.

$$P_q(i) = \frac{\exp\left(\beta x_{iqt} + \alpha + \gamma s_q\right)}{\sum_{l=1}^{N} \exp\left(\beta x_{lqt} + \alpha + \gamma s_q\right)} \qquad (2)$$

Estimation can proceed with data that is pooled over all of the choice experiments.

Finally, using parameter estimates from either model, we calculate both marginal WTP for a change in each of selected attributes of recreations sites and total WTP for a joint change in these attributes. By restricting total WTP to a joint change of attributes that matches with improvement in Nakivubo wetland as specified in CVM, we estimate the welfare impact of developing the wetland park via revealed preference approach.

Random Parameters Logit and Latent Class Logit Models

The RPL, on the other hand, extends the CL, by allowing the coefficient vectorβ_q, to vary across the population according to the densityf(β|θ), where θ is a vector of the parameters of the distribution, while the CL assumes that the preceding density is degenerate. Assuming the error terms are IID type 1 extreme value, an RPL or mixed logit model (Train 1998) can be specified. Following Carlsson *et al*. (2003), the conditional probability of alternative i for individual q in choice situation t can be specified.

$$P_q\left(it|s_q, x_{iqt}, \beta_q\right) = \frac{\exp\left(\beta_q x_{iqt} + \alpha + \gamma s_q\right)}{\sum_{l=1}^{N} \exp\left(\beta_q x_{lqt} + \alpha + \gamma s_q\right)} \qquad (6)$$

One of the maintained assumptions in the RPL inherent in (6) is that individual utilities vary, but are stable across the different choice experiments (Train 1999).

Given (6), the conditional probability of observing a sequence of choices is simply the product of the individual choice probabilities for each choice set. Denoting j(q,t) as the sequence of choices from all of the experiments, the conditional probability can be written,

$$\pi_q\left(j(q,t)|s_q, x_{iqt}, \beta_q\right) = \prod_{t=1}^{T} P_q\left(it|s_q, x_{iqt}, \beta_q\right) \qquad (7)$$

Due to the variation in the β_q parameter vector, the preceding conditional probability needs to be integrated over the assumed density, in order to arrive at the unconditional probability in (8).

$$P_q\left(\theta|s_q, x_{iqt}\right) = \int \pi_q\left(j(q,t)|s_q, x_{iqt}, \beta_q\right) f(\beta|\theta)\, d\beta \qquad (8)$$

However, the integral in (8) does not have an exact solution. Therefore, we estimate via simulated maximum likelihood (Revelt & Train 1998, Train 1999). Furthermore, it is assumed that there is correlation between the randomly distributed parameters, and, therefore, we estimate the full variance-covariance matrix of the parameter vector, Σ_β, assuming a normal distribution, i.e., β_q~N(β̅,Σ_β). Given the Cholesky decomposition of the variance-covariance matrix, β_q=β̅+Cη_q, where η_q is a vector of standard normals. In other words, we estimate both β̅ and C, such that CC^’=Σ_β.

Despite the desirable properties of RPL, allowing for individual heterogeneity and correlation across alternatives, it is subject to restrictive assumptions. In this case, those assumptions are based on the assumed distribution of the coefficient vector. The two most common are: (a) the log-normal distribution, which restricts all individuals to have positive coefficients for the variable, and (b) the normal distribution, which allows for both positive and negative values. However, there is no rule of thumb to select the distribution. As with any sort of model misspecification, the estimated results could be biased if the distribution is misspecified (Carlsson *et al*. 2003).

An alternative to resolve the problem is a recourse to non-parametric or semi-parametric models that requires no or few assumptions about the parameters distribution. Latent Class model (LCM) provides the remedy to distributional problem as it is semi-parametric model. Latent class model largely resemble RPL by way of accounting for preferences heterogeneity, albeit the heterogeneity is modelled as discrete parameter variation (Greene & Hensher 2003). In this study, we will also estimate LCM in addition to RPL estimation to compare welfare estimates of the program change. In LCM, individual are sorted into set of class or segments of the population which is not observed by the analyst. Assume that there exist segments in the study population that individual belongs to segment . The utility function in (1) can thus, be re-specified as

$$U_{iqt|s} = \alpha_{iq|s} + \gamma_i s_{q|s} + \beta_q x_{iqt|s} + \varepsilon_{iqt|s} \qquad (9)$$

Utility parameters are now segment specific (Boxall & Adamowicz 2002) and equation (2) becomes

$$P_{q|s}(i) = \frac{\exp(\mu_s)(\alpha_{iq|s} + \gamma_i s_{q|s} + \beta_q x_{iqt|s})}{\sum \exp(\mu_s)(\alpha_{iq|s} + \gamma_i s_{q|s} + \beta_q x_{iqt|s})}, \qquad (10)$$

Where and are segment specific utility and scale parameters respectively.

Following Swait (1994), we specify that the probability that an individual be in segment is given as;

$$\Phi_{qs} = \frac{\exp(\alpha\lambda_s Z_q)}{\sum_s \exp(\alpha\lambda_s Z_q)} \tag{11}$$

Where a vector of socio-economic and psychometric variables, is a vector of parameters and is a scale factor (Boxall & Adamowicz 2002). The joint probability of a randomly chosen individual chooses alternative and be in segment is given as

$$\Phi_q(i) = \sum_{s=1}^{S} \Phi_{qs} P_{q|s}(it) \tag{12}$$

Substituting this for choice equation (6) and membership equation (7) probabilities yields

$$P_q(i) = \sum_{s=1}^{S} \left[\frac{\exp(\delta\lambda_s Z_q)}{\sum \exp(\delta\lambda_s Z_q)} \right] \left[\frac{\exp(\mu_s)(\alpha_{iqjs} + \gamma_i s_{qjs} + \beta_q x_{iqjts})}{\sum \exp(\mu_s)(\alpha_{iqjs} + \gamma_i s_{qjs} + \beta_q x_{iqjts})} \right] \tag{13}$$

A8.2.2 Contingent valuation

In the second part of the study, we estimate WTP for use of the proposed Nakivubo Wetland Park in a referendum-style contingent valuation study. We estimate a simple spike model to analyse closed-ended responses and allow respondents to be indifferent about the project (Kriström 1997). Zero responses are common in open-ended valuation studies and the spike model specification allows us to take zero-bids into account. For public goods, closed-ended styled contingent valuation studies often assume that all respondents are "in-the-market". Popular distributional assumptions (e.g. log-logistic, lognormal, or Weibull) together with other popular models using continuous distributions (e.g. logit, probit models) imply that all respondents have positive WTP (Kriström 1997). These assumptions exclude respondents who have zero WTP for the good in question.

Respondents may select not to reveal their true WTP for using Nakivubo Wetland Park. They may find that the Wetland Park doesn't contribute positively to their welfare. One obvious reason being availability of alternative substitute outdoor recreation sites, which may be better and cheaper in terms travel cost of visit. Another reason has to do with sentiment, as has been voiced during the survey, that displacing poor people who are currently living around the proposed wetland Park without compensation is not morally supported. The simple spike model allows us to split the sample into two categories: respondents with zero WTP and positive WTP for the establishment of Nakivubo Wetland Park. To determine if the respondent is indifferent or not (i.e. if the respondent has a zero WTP) we use the answer to the follow-up open-ended question.

The closed-ended question asks the respondent whether he/she will accept or reject the Nakivubo Wetland Park for a given bid T. The project is represented as the change of environmental and physical qualities (infrastructure, environmental amenity etc.). We define WTP for this change as:

$$V(y - WTP, z^1) = V(y, z^0) \tag{1}$$

where $V(y,z)$ is an individual's indirect utility function and y is income. Assuming respondents value the Wetland Park differently, the probability that an individual's WTP does not exceed a given bid amount T is given by:

$$prob(WTP \le T) = F_{wtp}(T) \tag{2}$$

where $F_{wtp}(T)$ is a right, continuous, non-decreasing function. The expected WTP is given by:

$$E(WTP) = \int_0^{\infty} 1 - F_{wtp}(T)dT - \int_{-\infty}^{0} F_{wtp}(T)dT \tag{3}$$

The distribution function of WTP is assumed to take the following form:

$$F_{wtp} = \begin{array}{ll} 0 & \text{if } T < 0 \\ p & \text{if } T = 0 \\ G_{wtp}(T) & \text{if } T > 0 \end{array} \tag{4}$$

where T is the bid offered to the respondent, belongs to and is a continuous and increasing function such that there is a spike (discontinuity) at zero. The spike model uses two basic valuation questions (a) whether or not the respondent has non-zero WTP and (b) whether or not the respondent would want to pay the price, T suggested in the dichotomous choice question. Define an indicator that indicates if the respondent has nonzero WTP or not: . Similarly, let indicate if the respondent is willing to pay the suggested bid price, T: .The log-likelihood for the sub-sample is then given by:

$$l = \sum_1^N \{S_i A_i \ln(1 - F_{wtp}(T)) + S_i(1 - A_i)\ln(F_{wtp}(T) - F_{wtp}(0)) + (1 - S_i)\ln(F_{wtp}(0))\}$$

Assuming that WTP has a logistic distribution and the WTP function is linear in the parameters, the response function is given by:

$$F_{wtp} = \begin{array}{ll} 0 & \text{if T} < 0 \\ (1 + \exp(\beta z))^{-1} & \text{if } T = 0 \\ (1 + \exp(\beta z - \lambda T))^{-1} & \text{if } T > 0 \end{array} \tag{5}$$

where Z the vector of socio-economic characteristics of the respondents is, β is the corresponding parameter vector and λ is the marginal utility of income. The mean WTP is then given by $\frac{1}{\lambda}\ln(1 + \exp(\beta z))$ and the median WTP is given by $\frac{\beta z}{\lambda}$ (Kriström, 1997).

where the vector of socio-economic characteristics of the respondents is, is the corresponding parameter vector and is the marginal utility of income. The mean WTP is then given by and the median WTP is given by (Kriström, 1997).

A8.3 Data collection

A8.3.1 Recreational sites and attributes

Prior to the household survey, we used the help of local experts to compile a list of outdoor recreational sites, and to create a map of these sites. Data were then collected on 10 purposely selected major outdoor recreation sites in Kampala. The site attributes chosen were presence of natural amenities; forest, wildlife, water view and facilities; paved walkway, parking lot, restroom, playground and picnic tables and boats. These attributes were expected to be salient attractions of the sites to drive outdoor recreation demand.

A8.3.2 Survey design

A survey was conducted in Kampala, Uganda over the period of 20 - 28 July 2015. A two stage sampling design method was used, in which a set of parishes (an administrative unit equivalent to a suburb) was selected, and then households were selected within each of these parishes. In the first stage, parishes were randomly selected from all five divisions of Kampala (Central, Kawempe, Lubaga, Makindye and Nakawa). In the second stage, drawing on the 2014 Ugandan census data, we randomly selected households within each Parish. A total of 644 households were interviewed, with interviews being conducted with an adult member of the household (aged 20 or more). The survey was conducted by 11 trained and experienced enumerators, and was closely supervised by one of the authors.

The survey instrument comprised three parts: socio-economic questions, revealed preference questions about household use of multiple outdoor recreational sites during the last 12 months and a contingent valuation section on the restoration of the Nakivubo wetland for its development as a recreational park. Key questions regarding multi-site choice were whether an individual had visited any outdoor recreation site during the last 12 months, how many trips they made to visit the sites during the same period and the travel cost incurred during the last visit.

In the contingent valuation part of our questionnaire, we described proposed change in quality of Nakivubo wetland from its current degraded (deteriorated) state to one of being Recreation Park for Kampala public. The changed to a new state was described as improved water quality in the area, and provision of facilities such as lakefront picnic areas, and walking and cycling paths in and around the wetlands. This was followed by questions to elicit the households' willingness to pay to use the proposed area.

We chose single-bounded dichotomous (SBDC) CVM value elicitation format because of its incentive compatibility advantage compared to other formats. As SBDC is a closed-ended value elicitation format, this required the design and generation of a price vector of starting bids. The bid vector was obtained from a pilot study of 40 randomly-selected households, in which an open-ended CVM question format was used. Using the response to open-ended CVM question of the pilot study, we generated a vector of five starting bids; {2000, 6000, 12000, 14,000 and 20,000}. We used entry fees as the payment vehicle. Respondents were asked if they anticipated visiting the new Nakivubo Park after its development in the future. For each respondent who replied affirmatively, we randomly assigned an entry fee from the bid vector asked if he/she is willing to pay it as an entry to visit the new park in the future. This closed-ended question was followed by an open-ended question; "what would be the daily per-person entrance fee for which you would decide not to visit the site (assuming children pay half-price)"?

A8.3.3 Description of data

Table A8.1 presents descriptive statistics of the data used in the empirical analysis. Although the primary purpose of our analysis is to examine preferences for various types of outdoor recreation sites in Kampala, it is expected that individual, household and site level characteristics are likely to affect the demand for various recreations sites and the expressed willingness to pay for new wetland park establishment. The study included variables that vary at the individual (household) level: age, gender education and income of a respondents and household head. We also included household income range.

In terms of socio-economic covariates, we found that 52% of the respondents were male, the average age was 30, and average education was 15 years. Corresponding to this, we observed that 87% of households were headed by males, the average household head was 43 years old and has 17 years of education. About 2.3% of the households fell in the Ugandan lowest income class whereas 23.4% falls in top income class of the same. These estimates compare with Uganda National Household Survey 2012/13 estimates of 2.1% and 23.5% respectively.

On average, households visited outdoor recreation sites about 5 times within the last 12 months and paid an average of 18 744 USh as travel cost per visit. Almost all households (92%) anticipated visiting the Nakivubo Wetland Park after it is developed, and 72% of households were willing to pay at least 2000 USh as entry fee to visit the park.

We expect that household income is positively related to outdoor recreation demand as well as increase the likelihood of willingness to pay for development of new park ceteris paribus. From economic theory, travel cost is expected to be inversely related to the frequency of visits to outdoor recreation sites, but is likely to raise propensity of willingness to pay for a new recreation park as a substitute alternative. As natural beauty is critically scarce for households residing in CBD areas, respondents from such areas are expected to demand more outdoor recreation than others.

Table A8.1 Descriptive statistics used in the empirical analysis

Variable	Description	Mean	Std.Dev.	Min	Max
age	Respondent's age	29.55	9.719	19	75
qn10a der	Frequency of site visit in a year	4.689	3.119	1	9
qn2b	Respondent's gender	0.528	0.499	0	1
qn3	Respondent's education level in years	15.21	5.230	3	21
qn4a	Household head's age	43.23	12.10	23	87
qn4b	Household head's gender	0.867	0.340	0	1
qn4c	Household head's education in years	16.98	4.810	4	22
qn5	Member household earning income	1.987	1.010	1	5
qn19a1	Travel cost to a site	18744	15079	500	65000
qn24	Willing to visit Nakivubo park regardless	0.918	0.274	0	1
qn26	Willing to pay to visit Park establishment	0.718	0.450	0	1
qn27	Open-ended willingness to pay for Nakivubo park establishment	16935	13650	1000	50000
income1	Income range: 50,000 USh	0.0234	0.152	0	1
income2	Income range: 50,000-100,000 USh	0.0714	0.258	0	1
income3	Income range: 100,000-200,000 USh	0.127	0.333	0	1
income4	Income range 2000,000-300,000 USh	0.0714	0.258	0	1
income5	Income range 300,000-500,000 USh	0.206	0.405	0	1
income6	Income range: 500,000- 1,000,000 USh	0.266	0.442	0	1
income7	Income range >1,000,000 USh	0.234	0.424	0	1

A8.4 Results

A8.4.1 Revealed Preference Analysis

Utility Parameter Estimates

We estimated the utility function parameters (using conditional logit (CL), random parameter logit (RPL) model and latent class model (LCM). Table A8.2 presents the estimated utility function parameters from the standard conditional, random parameter logit model and latent class model.

In all models, we included one common alternative-specific intercept for the ten alternatives (sites). In RPL, we assumed coefficient of travel cost to be fixed and not randomly distributed for two reasons: (a) the distribution of the marginal willingness to pay for site attribute is the same as the distribution of that attribute's coefficient (b) we wish to restrict the travel cost coefficient variable to be non-positive for all individuals. All of the non-price attributes are randomly distributed with normal distribution. We also included some socio-economic variables age, income class and household head's education as fixed coefficients variables and these interact with the alternative-specific coefficient.

In comparing CL and RPL models, we observe that the latter outperformed the former for the following major preseasons: (a) the standard deviations of coefficients all site attributes attribute are statistically significant implying heterogeneity in preferences among the respondents (b) following Greene & Hensher (2003) comparing this owing to log-likelihood value shows that RPL is an improvement over CL model.

Furthermore, the result of latent class model as evidenced by statistically significant class probabilities attested the presence of discrete preference heterogeneity. Based on Bayesian information criterion (BIC) statistics, we selected three classes of study sample. The statistically significant class probabilities suggest the presence of discrete preference heterogeneity across this class, which makes LCM different from CL. As RPL is not nested within the LCM, there is no comparison test available for these two models within classical statistical/ econometric tradition. However, this limitation can be overcome by Bayesian model selection method to choose the model that best fits the data at hand. Overall, the heterogeneity in preferences for attributes among individuals in RPL and across population classes in latent class model (LCM), make us prefer these models to the conditional logit model.

Table A8.2 Estimates of utility parameters

Variables	Conditional logit	Random parameter logit		Latent class logit		
		Coefficient	Standard deviation	Class 1	Class 2	Class 3
Paved	0. 8029 (0.1479)***	1.4136 (0.6831)***	3.3428 (1.9020)***	3.6689 (13.256)	0.31107 (0.1724)**	-22.6268 (154.152)
Size in ha	-0. 0179 (0.0046)**	-0.0574 (0.0273)***	0.0523 (0.0200)***	-4.5326 (30.808)	0.01858 (0.00679)***	-0.00875 (00860)
forest	-0.9927 (0.2364)***	-1.5680 (0.46960)***	1.6301 (0.7440)***	2.7513 (28.599)	-2.3348 (0.4333)***	-0.9854 (0.2803)***
Water-view	0.03310 (0.2664)	0.2919 (0.4069)	1.241 (0.5743)***	4.5326 (30.809)	-0.54090 (0.4879)	23.7677 (154.152)
Kiosk	0.9590 (0.1952)***	1.8312 (0.7498)***	1.4636 (1.2997)	13.2013 (52.259)	3.4583 (0.58710)***	1.10884 (0.2562)***
Travel Cost	-0.12260D-04 (0.7047D-05)*	-0.1662D-04 (0.1029D-04)*		-0.3713D-04 (0.146D-04)**	-0.20556D-04 (0.8119D-05)**	-0.7063D-04 (0.10287D-04)
Intercept	1.068 (0.371)***	1.536 (0.623)***		-16.3511 (30.506)	4.5816 (0.8852)	24.4192 (154.152)
Age	-0.03350* (0. 0173)	0. 03174 (0. 01689)		-0.1244 (0.0672)**	-0.10627 (0.0489)***	-0.01929 (0144)
income	0.1342 (0.0914)	0. 1291 (0.0896)		0. 3374 (.01593)***	-0.4405 (0.35424)	0.1126 (0868)
education	-0.0828** (0.0298)	-0.07945 (0.0296)		-0.33419 (0.1555)***	27.7228 (71.8976)	-0.00406 (0.00545)
Respondent size	548	548				
Observation size	5,480	5,480				
Class probability				0.3584 (0.0408)***	0.38003 (0.0388)***	0.26149 (0. 04737)***
Log- likelihood	-839.7574	-831.9344		-792.8639	-792.8639	-792.8639

*Standard error in parentheses, *** p<0.01, ** p<0.05, * p<0.1*

In all models, the estimate of travel cost parameter is negative and statistically significant, corroborating with economic theory; as travel costs rises, demand for outdoor recreations falls. Moreover, household income class coefficient has positive sign in all but class 2 of LCM. For the most part, its effect is statistically insignificant, but in class 1 of LCM, the latter of which supports our priori expectation from economic theory.

With regards to attributes, only two of five selected attributes; paved walk way and presence of kiosk and canteens, have positive and statistically significant effect on the demand for outdoor recreation. The results show that these attributes are the most attractive feature of outdoor recreation's sites in Kampala.

RPL offers more information. It shows that preferences for paved walkway are heterogeneous among visitors as suggested by standard deviation (SD) parameter of the preferences for this attribute. In fact, its SD is the highest indicating that the preferences are the most heterogeneous one for this attribute. However, SD parameter for kiosk attribute is not statistically significant suggesting that there is no individual level preference heterogeneity for this attribute. For both attributes though, we see that preferences vary a great deal across classes of LCM model.

Of the remaining attributes, the results show that water view attribute has no effect on visitor's preference in all the models. To our surprise though, results from CL and RPL show that Kampala visitors strictly prefer smaller size of recreation sites and absence of forest although these preferences are heterogeneous across individuals (see SD of RPL parameters). Results from LCM analysis also largely support these finding although we still observe class level preference heterogeneity for both of the attributes. Overall, our evidences of heterogeneous across visitors and classes of visitors are in line with general findings in related literature (see Hynes *et al*. 2008, Scarpa *et al*. 2007, Scarpa & Thiene 2005, Breffle & Morey 2000).

Table A8.3 Marginal Willingness to Pay (MWTP) and Compensating Variation for selected attributes

Variables	Conditional logit	Random parameter logit	Latent class logit		
			Class 1	Class 2	Class 3
Size	-1465.6073 (945.54723)	-3457.9932 (2732.683)	-18692.716 (183763D+12)	904.204250 (511.0674)	-1240.136 (2189.484)
Paved	65465.017 (40000)	85056.478 (61048.84)	98793.0645 (356959D+12)	15132.654 (10035.522)	-0.32037D+07 (21856D+10)
Forest	-80950.87 (49992.026)	-94353.592 (60806.33)	74086.2002 (770095D+12)	-113584.173 (51187.837)	-139530.645 (209435.16)
Water view	-2699.656 (21722.469)	-17563.4380 (25672.117)	122051.138 (829579D+12)	-26313.307 (26500.780)	-336521D+07 (218557D+10)
Kiosk	78198.6344 (45704.22)	110185.125 (71234.9460)	122051.138 (829579D+12)	168236.237 (74445.716)	156998.201 (231437.258)
CV(WTP)	145688	66034.6039	116639.845	270874.695	-0.310017D+07
	(73438.015)	(78718.58)	356959D+12	111274.775	0.218557D+10

Welfare Measures

The preceding coefficient estimates, although interesting, do not provide for straightforward interpretation, due to the differences in the estimation models and the scale factor associated with these values (Greene & Hensher 2003). In order to improve interpretability, marginal rates of substitution between the attributes were computed, using the negative of the travel cost coefficient as the denominator, and the distribution of these ratios is obtained via the Krinsky-Robb (Krinsky & Robb 1986) method. These ratios can be interpreted as the marginal WTP for a change in each attribute (Greene & Hensher 2003, Train 1998, Carlsson *et al*. 2003, Hannemann & Kanninen 1996). The calculated marginal rates of substitution or marginal willingness (MWTP) to pay between the attributes are presented in Table A8.3. Because the parameters are normally distributed, and the travel cost coefficient is fixed, the calculated marginal WTP is also normally distributed.

Marginal willingness to pay (MWTP) estimates of both CL and RPL models, consistent with utility parameter results, shows that only paved walk way and kiosk attributes offer a positive welfare gain. In either models, we see that average visitor enjoys the highest welfare gain from presence of kiosk and canteens followed by that of presence of paved walkway in a recreation site. The remaining attributes have negative but statistically insignificant welfare effects in both models.

Returning to LCM results, we see a slightly different set of results compared to the results of the two preceding models. Particularly, marginal willingness to pay of each attribute varies a great deal across population classes (segments). Paved walk way appear to have positive welfare effect in class 2, but statistically insignificant effect in rest of the classes. Likewise, we find that average individuals in class 2 and 3 derives positive welfare gain from kiosk attribute, but this effects appears to be negligible for average individual in class 1 of our study sample. In terms of remaining attributes, variation of MWTP estimates were observed across LCM classes although, for most part, they appear to be statistically insignificant as vindicated by their corresponding high standard deviation SD. For site size though, we observe a positive and statistically significant MWTP in class 2, but zero MWTP in remaining classes. Presence of forest in sites is welfare reducing in class 2, but has no welfare effects in rest of the classes. Water view attribute has no significant welfare effect in any of the classes as is the case in CL and RPL analysis.

In addition to MWTP analysis, we also estimated compensation variation (CV) or total willingness to pay (WTP) for a joint change in all selected attributes as opposed MWTP, which estimate the welfare effect of a change in a single attribute. As can be seen from last row of Table A8.3, CV estimates are positive and significant in all of our models, but it turns out to be insignificant in class 1 and 3 of LCM. The CV estimates ranged from 660 346 USh ($18.34) in RPL to 2 708 755 USh ($75.24) in class 2 of LCM. The results suggest that a simultaneous change in all of these attributes, as for example for establishment of new outdoor recreation site, is welfare improving for average visitors in Kampala.

A8.4.2 Stated preference analysis

WTP Estimates

The bid-response data conform to a priori expectations, as informed by economic theory; where quantity demanded falls with increasing price (Figure A8.1).

Mean WTP was estimated from a simple spike model as 18 077 USh ($5.64) with the ratio of the 95% confidence interval to the mean being 0.072. This result rises to 19 552 USh ($6.11) with 0.12 ratio of the 95% confidence interval to the mean when estimated from standard probit model. Although the WTP estimates are different, there is significant overlap in their confidence intervals, implying that equality of WTP cannot be rejected. Note also that both of the mean WTP estimates are larger than that obtained from an open-ended question, which was 16 935 USh ($5.29). This supports findings from previous studies in which SBDC format is followed by open-ended elicitation question (Gelo & Koch 2015).

Analysis of bid function

Table A8.3 presents the estimated results from the simple spike model and Klein & Spady (1993) semi-parametric (KSS) specification of the binary choice model. A total of 620 observations were included in the analysis. Our discussion of the bid function analysis is however, based on the results from the latter specification for the following reasons. Normally, parameters of discrete-choice models are estimated by maximum likelihood which imposes assumptions on the distribution of the underlying error terms. Under correctly-specified distributional assumptions, parametric maximum likelihood estimators such as spike and probit models are known to be consistent and asymptotically efficient. Nevertheless, departures from the distributional assumptions may lead to inconsistent estimation (De Luca 2008). In our case, the likelihood ratio test of the probit model against the KSS model rejects the Gaussianity assumption of normal distribution suggesting that ordinary probit function or simple spike specification with covariates may not be appropriate for our data. This result is also supported by estimated marginal densities of the error terms (Figure A8.2).

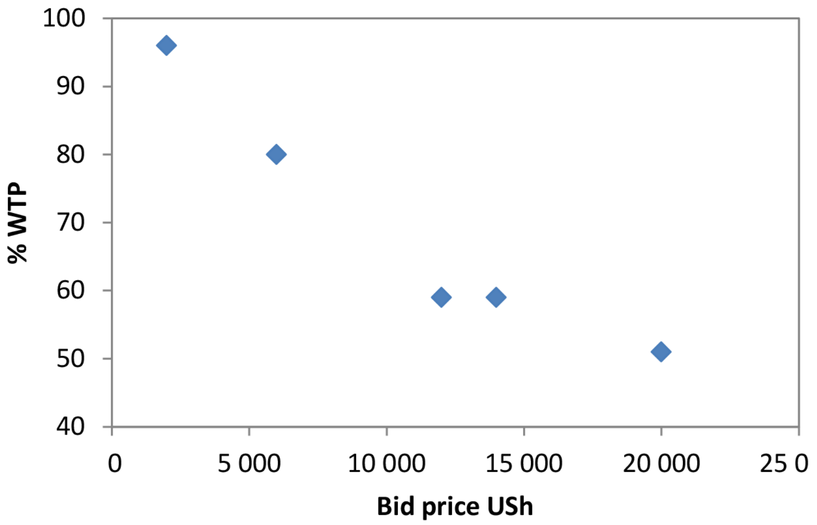


Figure A8.1 Survival function showing proportion of respondents willing to pay the suggested fee in relation to the fee posed in the questionnaire

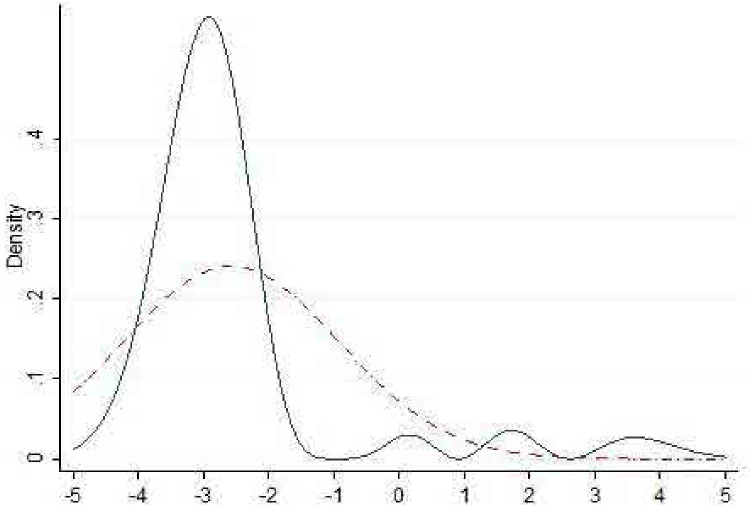


Figure A8.2 Marginal density of error terms from KSS model

In the analysis, the parameters, which capture the link between socio-economic covariates and WTP, for the most part, are consistent with our a priori expectations. The results suggested that female respondents were more likely to visit Nakivubo in the future and be willing to pay entry fees. However, education reduced willingness to pay an entry fee for visiting the park. Age of the respondent, on the other hand, did not seem to be of significance in influencing WTP for visiting the park.

Mean WTP increased with household income, but decreased with the entry fee (price) of visiting the Wetland Park. In other words, outdoor recreation services of the new park are seen as normal goods as its demand increases with income. Furthermore, the demand for this service is consistent with the law of demand: increase in entry fee (price) reduces the WTP (demand for the services). Additional significant demand shifters, other than income and respondents' characteristics, were the education and age of the household head. The results suggested that respondents from households with older and more educated household heads were more likely to visit Nakivubo Wetland Park and be willing to pay entry fees.

A8.5 Estimated aggregate recreational benefit

Based on a total of over 400 000 households in Kampala City, the results of the revealed preference analysis suggest an overall net benefit to Kampalans of some \$17.0 - \$29.4 million per annum. Using the mean household size, mean adult:child ratio, and mean expected level of use per household (2.3 times), the results of the stated preference analysis yield a slightly lower overall estimate of \$14.7 - \$15.9 million per annum. Nevertheless the estimates are relatively close.

Table A8.4 Determinants of bid function

Variable	Parametric model	KSS model
Intercept	3.928***	-1.452***
	(0.212)	(0.378)
Respondent's age	0.00961	-0.00197
	(0.00904)	(0.00802)
Respondent's education	0.0129	-0.0954***
	(0.0154)	(0.0123)
Respondent's gender	0.102	0.293*
	(0.162)	(0.155)
Household head's age	-0.00473	0.00953*
	(0.00641)	(0.00524)
Household head's education	0.0308*	0.0413***
	(0.0166)	(0.0132)
Income class	0.0923*	0.0911**
	(0.0495)	(0.0387)
Bid	-0.000128***	-0.000213***
	(1.36e-05)	(1.18e-05)
Share -zero WTP	0.282	0.282
	(13650)	(13650)
Log-likelihood	-642.961	-533.648
LR test of Probit model against SNP model		97.47***
Number of observations	620	620