

DECLARATION

I declare that this research report is my own unaided work. It is being submitted for the degree of Master of Science in Engineering to the University of Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

.....

John Wilson

.....day of year.....

ABSTRACT

Gaborone, Botswana is currently exploring the option of direct potable reuse of wastewater to augment its drinking water supply. A feasibility study has already been undertaken assessing this option and has concluded that direct potable reuse is feasible. Based on this report and an assessment of the possible options for reuse, an alternative design has been developed integrating all levels of wastewater treatment.

The design integrates the different levels of wastewater treatment compared to the existing proposed design and is based the following points:

- Reuse will commence once the influent flows to the sewage treatment works reach 65 000 m³/day, expected to be in 2012
- The future expansion of the sewage plant will provide two separate treatment process trains, the existing conventional activated sludge (CAS), and a new Membrane Biological Reactor (MBR).
- CAS will treat waste generated from the water reclamation plant, whilst MBR treats screened raw sewage and provides disinfected feed water to the plant
- The reclamation plant is comprised of 6 unit processes; cartridge filtration, nanofiltration, reverse osmosis, UV disinfection, stabilisation, and chlorination.
- Final product water will be blended with conventionally treated surface waters from the Gaborone water works, with a maximum 35% of the blended water being reclaimed.

The report concludes that this design is more cost effective resulting in an approximate saving of 15% on the overall costs over an 11-year period.

ACKNOWLEDGEMENTS

The author would like to thank the Gaborone City Council staff at the Glen Valley wastewater treatment plant, Botswana Water Utilities Corporation, Orange County Water Board and Sanitation Board, and Singapore PUB for tours of the facilities, data and countless questions.

Contents

DECLARATION	I
ABSTRACT	II
ACKNOWLEDGEMENTS	III
CHAPTER 1 – INTRODUCTION	1
Introduction	1
General Overview of Water, and Wastewater Treatment	1
Wastewater Treatment - Overview	4
Water Treatment for Drinking Water	10
Treatment and Reuse	16
Reuse Options	19
Concerns for Reuse	22
CHAPTER 2: EXISTING SITUATION IN BOTSWANA	25
Location, Climatic, Geographic and Demographic context	25
Existing Planning and Institutional Details – Water Resources and Wastewater Treatment	26
Over view of Existing Infrastructure	26
Water Treatment Works	27
Storage and Supply	29
Distribution Networks	31
Sewage Infrastructure	33
Wastewater Treatment	33
Wastewater Characterisation	38
Treatment Standards	44
Existing Reuse	49
Future Planning and Development	50
CHAPTER 3: EXISTING SITUATION IN THE WORLD - LITERATURE REVIEW	51
Case Studies	51
Indirect Potable Reuse – California (United States of America), Orange County	52
Direct reuse non-potable – Singapore, NEWater	62
Direct Potable Reuse - Namibia, Windhoek	70

Comparison of Wastewater Effluent Agreements	77
CHAPTER 4: OPTIONS SELECTION	80
Selection Process for the Development of Options	80
Option 1 – Indirect potable reuse – Surface Storage	83
Option 2 – Indirect potable reuse – Groundwater recharge	84
Option 3 - Direct Re-use Option adopted by WUC	85
Locations and Layouts	87
Overview of the process train	88
Waste handling	91
Option 4 – Direct reuse - Modified Option 3	93
Selected Option	95
CHAPTER 5 – OPTION 4 DESIGN	96
Background to the Design	96
Overview	98
Detailed conceptual design	100
Wastewater Treatment	101
Water Reclamation/Advanced water treatment	109
Summary of Barriers	115
Waste Streams and Downstream Impacts	117
Location	121
Capacity	122
Cost Comparison	125
CONCLUSION	129
REFERENCES	131

List of Figures

FIGURE 1 THEORETICAL COST OF DIFFERENT TREATMENT LEVELS BASED ON THE REMOVAL OF DIFFERENT PARTICLE SIZES (MODIFIED FROM JUDD ²).	3
FIGURE 2 OUTLINE OF THE LEVELS OF TREATMENT AND PROCESS INVOLVED (MODIFIED FROM ASANO ⁵).	5
FIGURE 3. LEVELS OF WASTEWATER TREATMENT - METCALF AND EDDY ⁴	6
FIGURE 4. OUTLINE OF THE BASIC PROCESSES INVOLVED IN THE TREATMENT OF WASTEWATER (CITY OF ALBUQUERQUE ⁷).	7
FIGURE 5. OUTLINE OF THE DIFFERENT STAGES OF POTABLE WATER TREATMENT (MODIFIED FROM DRINAN ¹⁵).	12
FIGURE 6. SIMPLIFIED TREATMENT PROCESS FOR INDIRECT POTABLE RECLAMATION PLANT USING MEMBRANE TECHNOLOGY (METCALF AND EDDY ⁴).	18
FIGURE 7. EXISTING WATER INFRASTRUCTURE (INFORMATION FROM GIBB AND PULA 2007 ³¹).	27
FIGURE 8 FLOW DIAGRAM OF KEY TREATMENT PROCESSES AT THE GABORONE WATER WORKS.	29
FIGURE 10 OVERVIEW OF GABORONE WATER DISTRIBUTION NETWORKS - GIBB AND PULA 2007 ³¹	32
FIGURE 12. FLOW DIAGRAM OF EXISTING GLEN VALLEY WASTEWATER TREATMENT WORKS – SOURCE LIEBENBERG & STANDER AND RITES 2003 ³³	35
FIGURE 14. CURRENT UPGRADING OF THE GABORONE WASTEWATER TREATMENT WORKS (BASED ON INFORMATION FROM BERGSTAN AND RITES 2004 ³²).	38
FIGURE 15. PROCESS FLOW DIAGRAM OF THE ORANGE COUNTY INDIRECT POTABLE REUSE SYSTEM (MARKUS 2008 ³⁶).	54
FIGURE 16. OCSD WASTEWATER TREATMENT PROCESS (OCSD ³⁸).	57
FIGURE 17. OVERVIEW OF THE WATER CYCLE OF BEDOK, SINGAPORE.	65
FIGURE 18 SCHEMATIC DIAGRAM OF NEWATER PROCESS – LEE MUN FUNG 2008 ⁴⁶	67
FIGURE 19. WATER CYCLE OF WINDHOEK, NAMIBIA.	72
FIGURE 20 NEW GOREANGAB PROCESS FLOW DIAGRAM (LAHNSTEINER AND LEMPERT ⁴⁸).	75
FIGURE 22 SELECTION OF OPTIONS FOR REUSE KEY	82
FIGURE 24 OVERVIEW OF INDIRECT REUSE PROCESS USING SURFACE WATER.	83
FIGURE 25 OVERVIEW OF INDIRECT REUSE PROCESS USING GROUNDWATER RECHARGE.	85
FIGURE 21 SIMPLIFIED LAYOUT OF OPTION 3	88
FIGURE 27. PROCESS FLOW DIAGRAM – GIBB AND PULA ³¹	91
FIGURE 23 SCHEMATIC DIAGRAM OF FLOW VOLUMES AND TDS BALANCES – (GIBB AND PULA ³¹).	93
FIGURE 24 OVERVIEW OF OPTION 4 DIRECT POTABLE REUSE	95
FIGURE 25 MEMBRANE BIOREACTOR SCHEMATIC LAYOUT.	101
FIGURE 26. PROPOSED NEW PROCESS TRAIN FOR THE PRODUCTION OF NEWATER - LEE MUN FUNG ⁴⁶	103
FIGURE 27 BASIC OUTLINE OF TYPICAL MBR PROCESS (UNITED ENVIROTECH ⁵⁹).	106
FIGURE 28. SCHEMATIC DIAGRAM OF ENTIRE SYSTEM VOLUMES AND TDS BALANCES	118
FIGURE 29 SECONDARY EFFLUENT TOTAL DISSOLVED SOLID (TDS) CONCENTRATIONS OVER TIME.	119

List of Tables

TABLE 1. ADVANTAGES AND DISADVANTAGES OF MEMBRANE BIOREACTORS (INFORMATION TAKEN FROM HILLIS ²⁶ AND METCALF AND EDDY & AECOM ²⁴).	19
TABLE 2. DIFFERENT USES AND METHODS FOR APPLICATION OF RECLAIMED WATER BASED ON CALIFORNIA CODE OF REGULATIONS. MODIFIED FROM METCALF AND EDDY ⁴ .	22
TABLE 3. CLASSIFICATION OF CONSTITUENTS FOUND IN WASTEWATERS (MODIFIED FROM METCALF AND EDDY ⁴).	23
TABLE 4. GUIDE FOR THE INTERPRETING TDS CONCENTRATIONS FOR AGRICULTURAL REUSE (ROWE AND ABDEL-MAGID ³).	24
TABLE 5. AVERAGE DAY DEMAND PROJECTIONS FROM 2005 WATER MASTER PLAN REVIEW – GIBB AND PULA 2007 ³¹ .	29
TABLE 6. COMMON PARAMETERS FOR THE CHARACTERISATION OF WASTEWATER (MODIFIED FROM HENZE, <i>ET AL</i> ³⁴).	39
TABLE 7 DESIGN FLOWS FOR NEXT PLANNING PERIODS (MODIFIED FROM LIEBENBERG & STANDER AND RITES 2003 ³³).	41
TABLE 8 AVERAGED WATER QUALITY RESULTS – AVERAGED FROM GIBB AND PULA 2007 ³¹ .	44
TABLE 9 BOTSWANA OF BUREAU OF STANDARDS FOR THE DISCHARGE OF WASTEWATERS.	49
TABLE 10. SIMILARITIES IN ENVIRONMENTAL AND DEMOGRAPHIC ISSUES BETWEEN GABORONE AND WINDHOEK.	70
TABLE 11 SPECIFIC PARAMETERS REQUIRED TO BE MET FOR NEWATER PRODUCTION.	78
TABLE 12. EVAPORATION RATE OF THE GABORONE DAM	84
TABLE 13 MULTIPLE BARRIER APPROACH TO TREATMENT PROCESS SELECTION – MODIFIED FROM GIBB AND PULA ³¹ .	87
TABLE 14. OUTLINE OF THE DIFFERENT TREATMENT BARRIERS	116
TABLE 15 TREATMENT CAPACITIES AT THE GABORONE WATER TREATMENT WORKS (GIBB AND PULA ³¹).	123
TABLE 16 CAPACITIES AND RATIOS OF RECLAIMED WITH FOR BLENDING (INFORMATION FROM GIBB AND PULA ³¹).	124
TABLE 17 COSTS INVOLVED IN DIFFERENT UNIT PROCESSES OVER 11 YEAR PERIOD (1 YEAR PILOT TESTING AND 10 YEARS OPERATION) – INFORMATION TAKEN FROM GIBB AND PULA ³¹ .	127