

Table of Contents

Acknowledgment	I
Dedication	III
Summary	IV
Zusammenfassung	VIII
Table of Contents	XIII
List of Figures	XVI
List of Tables	XIX
List of Abbreviations	XX
1.0 Introduction	1
1.1 The Challenge of Reducing Leakage in Water Networks	1
1.2 The Necessity of Reducing Leakage in Water Networks.....	2
1.3 Successful Water Loss Projects and the Lessons Learnt.....	3
1.4 Water Situation in Ghana	5
1.4.1 Background of the Water Sector in Ghana.....	6
1.4.2 The Non-Revenue-Water (NRW) Situation in Ghana	9
1.5 Tools for Water Loss Management.....	10
1.6 Research Objectives	11
1.7 Outline of the Dissertation	12
2 Theoretical Background	14
2.1 Introduction.....	14
2.1.1 The Standard Water Balance	14
2.1.2 Overview of Leakage Management.....	15
2.1.3 Leakage Awareness, Location and Repair.....	16
2.1.4 Pillars of Leakage Management	17
2.1.5 Hydraulic Zoning of Network Area.....	21
2.2 Principles of Leakage Detection in Water Networks	22
2.2.1 Acoustic Techniques	22
2.2.2 Non-acoustic Techniques	24
2.3 Leakage Estimation in Water Networks.....	24
2.3.1 Tools and Software for Leakage Estimation.....	25
2.3.2 Methods of Leakage Estimation	29
2.4 Sensitivity and Uncertainty Analysis	35
2.4.1 Uncertainty in NRW Estimation	36
2.4.2 Sensitivity Analysis in Leakage Estimation.....	38
2.4.3 Complementarity of the Leak Estimation Methods	39
2.4.4 Parameters for Leakage Estimation	40
2.5 Performance Indicators for Urban Water Networks	46
2.5.1 IWA Key Performance indicators.....	47

Table of Content

2.5.2 Additional Key Performance indicators.....	49
2.5.3 Benchmarking of Water Utilities	51
2.6 Leakage Detection Modeling Methods	53
2.6.1 Direct Transient Method (DTM)	54
2.6.2 Inverse Transient Analysis (ITM).....	55
2.6.3 Bayesian Identification Method (BIM).....	55
2.6.4 Pattern Recognition Methods (PRMs)	56
2.7 Leakage Estimation and Detection Modeling: Gaps Identified	59
2.8 Inverse Monte Carlo Modeling.....	61
3 Research Methodology.....	63
3.1 Introduction.....	63
3.2 Research Framework	63
3.3 Description of Case Study Water Network	65
3.4 Design and Calibration of Network Hydraulic Model (NHM).....	67
3.5 Research Design: Data Collection-Field Measurements	67
3.6 Additional Data	71
3.7 Leakage Estimation Methodology	72
3.7.1 Customer Night Use (QCNU)	73
3.7.2 Leakage Exponent N1	74
3.7.3 Hour Day Factor (HDF)	75
3.8 Uncertainty and Sensitivity Analysis	75
3.8.1 Uncertainty in NRW Estimation	76
3.8.2 Sensitivity of Leakage Estimation.....	77
3.9 Performance Assessment System for Water Utilities.....	77
3.9.1 Key Performance Indicators	77
3.9.2 Performance Assessment System (PAS)	78
3.10 Methodology: Inverse Modeling of Simulated Leaks	79
3.11 Application of Inverse Modeling to Case Study Water Network.....	82
4 Results, Analysis and Discussion	85
4.1 Introduction.....	85
4.2 Description of Measured and Obtained Data.....	86
4.2.1 Analysis of Non-Revenue Water (NRW) and Deductions.....	86
4.2.2 Uncertainty Analysis of Non-Revenue Water	89
4.2.3 Minimum Night Flow (MNF) Measurements	90
4.2.4 Leakage Exponent and Hour-Day Factor	104
4.2.5 Customer Night Use (QCNU).....	105
4.3 Estimation of Leakage in Case Study Water Network	106
4.3.1 Top-Down Water Balance	107
4.3.2 Bottom-Up Water Balance.....	111
4.3.3 Component Analysis of Leakage.....	116
4.3.4 Key Performance Indicators	118

Table of Content

4.4	Summary of Findings: Leakage Estimation Method	119
4.5	Limitations of Leakage Estimation Method	121
4.6	Modeling Leak Detection	122
4.6.1	Modeling Leak Detection of Single leaks	122
4.6.2	Leak Detection Modeling of Two Leaks	129
4.7	Summary of Findings: Leak Detection Modeling	140
4.8	Limitations of the Developed Model	142
5	Conclusion and Outlook.....	143
5.1	Introduction.....	143
5.2	Leakage Estimation.....	144
5.3	Leak Detection Modeling	146
5.4	Outlook.....	149
6	Recommendations	151
6.1	Introduction.....	151
6.2	Specific Recommendations.....	151
6.2.1	Zonal Water Balance	151
6.2.2	Leakage Management.....	151
6.2.3	Apparent Losses	152
6.3	General Recommendations for Urban Water Supply in Ghana	152
6.3.1	Policy-Driven Data Collection	152
6.3.2	Injecting Competition in GWCL Operations	153
6.3.3	Integrating Tools for Leakage Management	156
6.3.4	Moving towards Smart Water Network	158
6.4	Performance Assessment System (PAS) for Ghanaian Water Utilities.....	160
7	References.....	163
8	Appendices.....	I