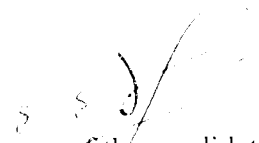


Declaration

I certify that this dissertation does not incorporate without acknowledgement any material previously submitted for Degree or Diploma in any university and to the best of my knowledge and belief it does not contain any material previously published or written or orally communicated by another person except where due reference is made in the text.

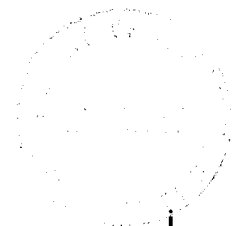

Signature of the candidate

To the best of my knowledge the above particulars are correct



University of Moratuwa, Sri Lanka
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

Prof. (Mrs.) N. Ratnayake



Acknowledgement

I am thankful to The University of Moratuwa for providing me with the training and education required for my post graduate studies. I gained a valuable knowledge under a devoted staff and access to facilities available at the University of Moratuwa. It has provided me an insight to Environmental Engineering and Management. Further I use this opportunity to convey my deepest thanks to Vice Chancellor, Prof. K.M.A.K. Ranasinghe and Dean of the Faculty of Engineering, Prof A.K.W. Jayawardane and Head of the Department of Civil Engineering, Prof. W.P.S. Dias for providing me this great opportunity to follow this course to obtain this achievement.

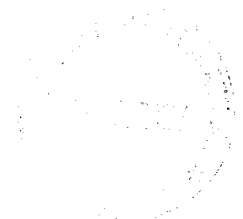
I acknowledge my sincere gratitude to my mentor and research supervisor, Professor (Mrs.) N. Ratnayake for her patient guidance, comments, regular encouragement and faith in my ability throughout this study.

I would like to thank Dr. J. Manathunge my course coordinator and Dr. Mahesh Jayaweera for their guidance for the research.

I would like thank all members of National Water Supply & Drainage Board for having guided me to develop my career. Further I would like to thank all Heads of Departments of NWS&DB for having placed their trust and assigned me with a work load that provided me with the opportunity to obtain a wealth of knowledge on Non Revenue Water reduction in the Colombo water distribution system.

I would like to thank officers of the NWSDB, Eng. A.V.P. Dhammika (Area Engineers Colombo City South), Eng. Kumudu Wijegunawardene (Senior Engineer -NRW) and Eng. S. Sumnaweera (Assistant General Manager -R&D) and the leaders of the two teams Mr. N.G. Ariyathilaka and Mr. M.S.C. Perera, who were involved in conducting comprehensive water loss management studies in the pilot zone.

S. S. Devaraja



Contents

Declaration.....	i
Acknowledgement	ii
Abstract.....	iii
1 Chapter One: Introduction.....	1
1.1. Background	1
1.2. Previous Studies Done by the University of Moratuwa	4
1.3. Problem Identification	5
1.4. Objectives of Study	5
1.5. Description of Study Area	6
1.5.1. Background of Colombo City Water Supply :.....	6
1.5.2. Water Sources.....	6
1.5.3. Water Distribution in Colombo City.....	7
1.5.4. Present Service Status.....	7
2 Chapter Two: Theoretical Framework and Literature Review.....	8
2.1. Water Loss Management.....	8
2.1.1. Definition of NRW & UFW.....	8
2.1.2. NRW in Developed Countries	10
2.1.3. NRW in Developing Countries.....	10
2.2. Causes for Water Losses	12
2.2.1. Apparent Losses (Non Physical Losses).....	13
2.2.2. Real Losses (Physical Losses).....	13
2.3. Water Loss Reduction Techniques.....	16
2.3.1. Water Audit.....	16
2.3.2. Meter Management.....	17
2.3.2.1. Meter Selection.....	17
2.3.2.2. Meter Installation	17
2.3.2.3. Meter Testing and Maintenance	17
2.3.2.4. Meter Replacement	17
2.3.2.5. Type of Meter Usage in Water Distribution.....	18
2.3.2.5.1. Production or Bulk Meter	18
2.3.3. District Meter Areas (DMAs) (Zonal Metering).....	19
2.3.4. Pressure Management.....	20
2.3.5. Leakage Monitoring and Control Methods.....	20

2.3.5.1.	Passive Leakage Control.....	21
2.3.5.2.	Active Direct Leakage Control.....	21
2.3.6.	Deteriorated Smaller Pipe Line Replacement.....	22
2.3.7.	Rehabilitation of Distribution Network.....	22
2.3.8.	Part to Whole System	23
2.3.9.	Asset Management and Ownership Concept	23
2.3.10.	Incentive Based Management	23
2.4.	Performance measures for water loss and leakage.....	23
2.4.1.	Measuring and Evaluating the Water Loss and Leakages.....	24
2.4.2.	Current Annual Real Losses (CARL).....	24
2.4.3.	Unavoidable Annual Real Losses (UARL).....	25
2.4.4.	Infrastructure Leakage Index (ILI)	25
2.4.5.	Theoretical Analysis of Water Leaks in Distribution System.....	27
2.4.6.	Quantification of Leakage	28
2.4.7.	Benefits of Reduction of Leakage	29
2.4.8.	Economical Analysis of Leak Repairs.....	29
2.5.	Present Development in NRW Management in the World.....	30
2.5.1.	Water Loss Reduction Strategies.....	30
2.5.2.	Water Loss Strategy Development	30
2.5.3.	Water Loss Interventions	31
2.6.	Case Studies	33
2.6.1.	Case Studies in Developed Countries	34
2.6.1.1.	Case Study in Geneva Water.....	34
2.6.1.2.	South Africa Experience	35
2.6.1.3.	Water Supply System Budapest.....	36
2.6.1.4.	Water Supply System Vienna	36
2.6.1.5.	Case Study in Singapore	37
2.6.2.	Case Studies in Developing Countries.....	38
2.6.2.1.	Case Study in Sandakan, Sabah, Malaysia.....	38
2.6.2.2.	Reducing leakage in Jakarta, Indonesia	40
2.6.2.3.	Case Study in Manila Water in the Philippines	41
2.7.	Typical Problems in NRW Management in Developing Countries.....	44

3	Chapter Three: Research Methodology.....	45
3.1.	Study approach	45
3.1.1	Literature Review.....	45
3.1.2	Estimation of Water Loss Using the Standard IWA Water Audit.....	45
3.1.3	Calculation of Performance Indicators	45
3.1.4	Determination of the ELL.....	45
3.1.5	Review of Existing Network	45
3.1.6	UFW Reduction Management.....	46
3.1.7	Development of Short and Long Term Strategies for Colombo City	46
3.1.8	Development of the Strategic Approach for Water Loss Management	46
3.2.	Method for Data Assembly.....	48
3.2.1.	Type and Method of Data Collation.....	48
3.2.2.	Desktop Studies	48
3.2.3.	Role of Operational Staff	49
3.2.4.	Pilot Scale Studies	49
3.2.5.	Field Observations	49
3.3.	Methods of Data Analysis.....	50
4	Chapter four: Observation and Data Analysis.....	51
4.1	Analysis of Colombo City Water Distribution System.....	51
4.1.1	Water Pipes and Accessories	51
4.1.2	System Pressures	54
4.1.3	Bulk and Domestic Water Management.....	54
4.1.4	Statistics and Status of Domestic Meters	56
4.1.4.1.	The Main Problems Identified in Domestic Metering in Colombo City,	58
4.1.4.2.	Impact of Domestic Water Meters on NRW	59
4.2.	Review of Activities for Sections Dealing with Water Loss Management	59
4.2.1.	Management Structure & Effectiveness.....	60
4.2.2.	Inputs of Information Technology	60
4.3.	Performance Indicators for Colombo City Water Supply	61
4.3.1.	Water Demand and Supply	61
4.3.2.	NRW in Colombo City and Water Balance	64
4.3.3.	Unavoidable Real Losses	67
4.3.4.	Economic Level of Leakage (ELL).....	70
4.3.5.	Colombo City Revenue Analysis.....	71

4.3.6.	Activities to Maintain Leakage at Different Levels in Colombo City	73
4.4.	Major Factors Contributing to NRW in Colombo City	78
4.4.1.	High Amount of Leakage	79
4.4.1.1.	Age of the Distribution System	79
4.4.1.2.	Scraping Without Lining	79
4.4.1.3.	Unnecessary Pipelines	80
4.4.1.4.	Bundle Service Pipes	80
4.4.1.5.	Active Leak Detection Programme	80
4.4.1.6.	Absence of Preventive Maintenance Programme	80
4.4.2.	Illegal Connections and Water Theft	80
4.4.3.	Free Water Supply	82
4.4.3.1.	Tenement Garden Consumption	82
4.4.3.2.	Fire Demand	84
4.4.3.3.	Bowser Supply	84
4.4.4.	Administrative Errors	85
4.4.4.1.	Estimated Bills	85
4.4.4.2.	Meter Errors	85
4.4.4.3.	Meter Readers' Malpractices and Data Entry Errors	85
4.5.	Pilot Scale Studies	85
4.5.1.	Analysis of Distribution System	86
4.5.2.	NRW in Pilot Zone and Water Balance	87
4.5.3.	Unavoidable Real Losses	88
4.5.4.	Leakage Control	89
4.5.5.	Reduce Free Water Supply	92
4.5.6.	Reduce Illegal Consumptions	92
4.5.7.	Reduce Administration Losses	93
4.5.8.	Results of Pilot Studies	94
4.5.8.1.	Result of House to House Survey	94
4.5.8.2.	Impact of Pilot Scale Study	94
4.5.8.3.	Analysis of Billed Quantity	95
4.5.8.4.	Analysis of Consumer Complaints	96
4.5.8.4.	Pressure Distribution Over Pilot Area	100
4.6.	Strategy Formulation for Water Loss Management	100
4.6.1.	Short Term Strategy	100

4.6.1.1.	Management Rearranges.....	101
4.6.1.2.	Water Audit.....	104
4.6.1.3.	Continue and Intensify House to House Survey and Leak Detection Programmes.....	104
4.6.1.4.	Meter Reader Rotation	105
4.6.1.5.	Improve Repair Techniques, Materials and Workmanship	105
4.6.1.6.	Re-train Staff in Improved and Latest Methods of Water Loss Management.....	106
4.6.1.7.	Assess and Manage Apparent Losses	106
4.6.2.	Long Term Strategy for Colombo City.....	107
4.6.2.1.	Smaller diameter Pipe replacement	108
4.6.2.2.	Hydraulic Characteristic Improvements in Large Diameter Pipes	108
4.6.2.3.	Water Meter Management.....	108
4.6.2.4.	Establishment of DMAs.....	109
4.6.2.5.	Leakage Management and Control.....	109
4.7.	Challenges Faced During Implementing of New Strategy	110
4.8.	Achievement of the Millennium Development Goals (MDGs)	112
5.	Chapter Five : Conclusion and recommendations.....	113
5.1.	Conclusions.....	113
5.2.	Recommendations.....	114
6.	Chapter Six : References	116

List of Figures

Figure 1-1:	Total Global Saltwater & Freshwater Estimates	1
Figure 1-2:	Water Stress Indicator	2
Figure 1-3:	Safe drinking Water Coverage 2006	2
Figure 1-4:	Problems with Conventional Water Distribution Management	3
Figure 1-5:	Characteristics of Sustainable Active Water Distribution Management.....	4
Figure 1-6 :	Map of Colombo City	6
Figure 1-7:	Key Map of Water Intake and Storage Reservoirs.....	6
Figure 1-8:	Water Treatment Plants feed to Colombo City	7
Figure 1-9:	Status of smaller diameter pipes in Colombo distribution system	7
Figure 2-1:	Means of Water Losses in Water Distribution Processes	8
Figure 2-2:	Features of Poor Water Loss Management Scheme.....	9
Figure 2-3:	Mean NRW in Some Cities in Asia	11

Figure 2-4: Mean UFW in Large Cities in Developing Countries.....	12
Figure 2-5: IWA Standard International Water Audit	16
Figure 2-6: Economics of Meter Exchanges.....	18
Figure 2-7: Water Saving due to Pressure Management.....	20
Figure 2-8 : Relationship between pressure and leakage rate for different “N” values...28	
Figure 2-9 : Relationship between UARL and ELL	29
Figure 2-10: Water loss management process	31
Figure 2-11 : Four basic methods of managing real losses.....	32
Figure 0-1: Four basic methods of managing apparent losses.....	33
Figure 2-13 IWA’s water balance results for Geneva – Year 2004.....	34
Figure 2-14 : Evaluation of the Non Revenue Water (% of Production)	35
Figure 2-15 : Deteriorated Pipe Rehabilitation with Inner Liner.....	36
Figure 2-16 : NRW reduction in Sandakan.....	39
Figure 2-17 : Variation in leakage level over time	41
Figure 3-1 : Flow Chart of Research Methodology	47
Figure 4-1 : Pipe Material Composition by Percentage.....	53
Figure 4-2 : Leaking Cast Iron pipe and Scaled Cast Iron pipe.....	53
Figure 4-3: % of Revenue in Colombo City in Each Category of Consumption.....	55
Figure 4-4 : % of Connections in Colombo City in Each Category.....	56
Figure 4-5 : % No of Connections Vs % of Income in Each Category	56
Figure 4-6 : Reducing of Estimated Bill and Defective Meter Percentages.....	57
Figure 4-7 : Meter to Withstand Air	57
Figure 4-8 : Water Meter Blocked Incidents due to Sand and Solvent Cement.....	58
Figure 4-9 : Non Revenue Water in Colombo City from 2000 to 2008	65
Figure 4-10 : Composition of Non Revenue Water in Colombo City	65
Figure 4-11 : Water Balance Colombo City in Year 2008.....	66
Figure 4-12 : Relationship between ILI Vs Distribution Pressure Variation.....	68
Figure 4-13: ILI result for 22 systems from England and Wales.....	69
Figure 4-14 : ILI results for 20 systems from the USA and Canada.....	70
Figure 4-15 : ILI results for 27 Systems from South Africa.....	70
Figure 4-16 : Ecumenical Analysis of Leakage Control in Colombo City without Pipe Replacement.....	75
Figure 4-17 : Economical Analysis of Leakage Control in Colombo City with Pipe Replacement.....	78

Figure 4-18 : Scaled Pipe in Colombo city	79
Figure 4-19 : Bundle pipes in Colombo City	80
Figure 4-20 : Economical analysis of illegal detection in Colombo City	82
Figure 4-21 : Tenement Garden demarcated Colombo city map	82
Figure 4-22 : Illustrates Low living standards and Water wastage Hygienic Problems in Colombo City Tenement gardens.....	83
Figure 4-23 : Temporary Collecting pits in Tenement Garden due to low pressure.....	83
Figure 4-24 : Pipe material type by percentage	86
Figure 4-25 : Progress of NRW reduction in Colombo City pilot zone.....	87
Figure 4-26 Culvert Crossing Leak Investigation in two roads	90
Figure 4-27 : Results of Step Testing.....	92
Figure 4-28 : Illegal Water Meter Tampering.....	93
Figure 4-29 : Behaviors of Billed quantity in four areas in Colombo city	95
Figure 4-30 : Water Leak Complaints in Colombo City	96
Figure 4-31 : Comparison of Area that Failed in Colombo city	97
Figure 4-32 : Analysis of Reported Low Pressure in Colombo City	98
Figure 4-33 : Reported No Water Complaints	99
Figure 0-2 : Early Management System in Colombo City Water Distribution.....	101
Figure 4-35 : Proposed Colombo City Distribution Management System	103
Figure 0-3 : Propose Meter Reader Rotation in Colombo City Water Distribution.....	105

List of Tables

Table 2-1 : Relationship Between Leakages and Average System Pressures & ILI in Developed and Developing Countries	26
Table 2-2 : Improvement in 2006 Compared with 1993 in Cambodia	43
Table 4-1 : Pipe Ages of Transmission and Distribution Mains in Colombo City	52
Table 4-2 : Pipe Line Composition of Colombo City Distribution System.....	52
Table 4-3 : System Pressures in Four Areas of Colombo City	54
Table 4-4 : Impact of Average Monthly Consumption with Income Generation in Different Categories of Consumers	55
Table 4-5 : % of Estimated Bills and Defective Meters in Colombo City	57
Table 4-6 : Analysis of Water Meter Performance in Pilot Studies in Wellawatta	59
Table 4-7 : Collection Ratios 2004 to 2008	60

Table 4-8 : Performance Indicators for the Colombo City Water Distribution System ..	61
Table 4-9 : Summary of Tenement Garden Details in Colombo City	62
Table 4-10 : Summary of Pilot Scale Study to Analysis Common Outlet Consumption in Colombo 1 to 15.....	63
Table 0-1 : Summary of Pilot Scale Study for Analysis of Common Outlet Consumption in Colombo City	64
Table 4-12 : Non Revenue Water in Colombo City from 2000 to 2008.....	64
Table 4-13 : Presents Summarizes of System Data and Presents the UARL, CARL and ILI in Colombo City.....	67
Table 4-14 : Analysis of Western Central Region, Revenue Vs consumption	72
Table 4-15 : Activities to Maintain Leakage at Different Levels in Colombo City with Active Leak Reduction Programme	74
Table 4-16 : Capital Investment Needs for the Different Levels of Leakage Control.....	74
Table 4-17 : Loan Installment for Capital Investment for the Different Levels of Leakage Control.....	75
Table 4-18 : Active Leak Detection with Pipe Replacement.....	76
Table 4-19 : Capital Investment Needs for the Different Levels of Leakage Control.....	77
Table 4-20 : Leakages and Frequency of Pipe Bursts per Kilometer	79
Table 4-21 : Economical Analysis of Last Five Years Illegal Detection.....	81
Table 4-22 : Present Status of Common Outlets.....	83
Table 4-23 : Progress of Connections Provided to Tenement Gardens	84
Table 4-24 : Length and % of Pipe Composition in Pilot Project.....	86
Table 4-25 : NRW Variation in Pilot Area	87
Table 4-26 : Illustrated in the Components of the Water balance in pilot zone.....	88
Table 4-26 b : Presents Summary of System Data	89
Table 4-27 : Sequence of Valve Closed in Step testing in Pamankada Road	91
Table 4-28 : Result of House to House Survey	94
Table 4-29 : Analysis of Quantity of Billed in 4 Areas in Colombo City	95
Table 4-30 : Water Leaks Complaints	96
Table 4-31 : No of Area Failed Reported	97
Table 4-32 : No of Reported Low Pressures in Colombo City during year 2009.....	98
Table 4-33 : Reported No Water Complaints	99

List of Annexes

- Annex I : Proposed Restructure for Management of Colombo City
- Annex II : New Tariff Structure of NWS&DB
- Annex III : Format of House to House Survey
- Annex IV : Pilot Area Key Map
- Annex V : Pressure Measurement on 03.02.2010 at Havelock Bridge
- Annex VI : Pressure Measurement on 03.02.2010 at Pamankada Bridge
- Annex VII : Pressure Measurement on 03.02.2010 at Kirulapana Bridge
- Annex VIII : Pressure Measurement on 10.12.2009 at Anula Road
- Annex IX : Pressure Measurement on 10.12..2009 at 191/4 Galle Road
- Annex X : Pressure Measurement on 10.12.2009 at Gregory Place
- Annex XI : Pressure Measurement on 20.11.2009 at Hames Avenue
- Annex XII : Pressure Measurement on 20.11.2009 at 506, Galle Road
- Annex XIII : Pressure Measurement on 20.11.2009 at W.A. Silwa Road
- Annex XIV : Pressure Measurement on 20.11.2009 at Hamdan Lane
- Annex XV : Pressure Measurement on 20.11.2009 at Arthusa Road
- Annex XVI : Pressure Measurement on 06.11.2009 - 09.11.2009 at Pamankada Bridge
- Annex XVII : Pressure Measurement on 29.10.2009 at Kirulapana Bridge
- Annex XVIII : Pressure Measurement on 04.04.2009 at Mayura Place
- Annex XIX : Pressure Measurement on 26.03.2008 at 191/4, Galle Road
- Annex XX : Pressure Measurement on 26.03.2008 at Havelock Bridge
- Annex XXI : Pressure Measurement on 26.03.2008 at Pamankada Bridge
- Annex XXII : Pressure Measurement on 26.03.2008 at W. A. Silva Mawatha
- Annex XXIII : Pressure Measurement on 26.03.2008 at Gregory Place
- Annex XXIV : Pressure Measurement on 26.03.2008 at Anula Road

Abbreviations

- AE - Area Engineer
- AWWA - American Water Works Association
- BS - British Standards
- CARL - Current Annual Real Losses
- CC - Colombo City
- CI - Cast Iron

CMC	- Colombo Municipal Council
CV	- Circulation Valve
DMA	- District Metering Area
EAA	- Engineering Assistants
ELI	- Economical Leak Index
GIS	- Global Information System
HDPE	- High Density Poly Ethylene
IBNET	-International Benchmarking Network
ILI	- Infrastructure Leak Index
IWA	- International Water Association
JICA	- Japan International Cooperation Agency
km	- Kilo meters
l/sec	- Liters / second
m ³	- Cubic Meter
MDGs	- Millennium Development Goals
mgd	- Million Gallon per Day
MIS	- Management Information System
Mm ³	- Million Meter Cubes
MNF	- Minimum Night Flow
NNF	- Net Night Flow
NRW	- Non Revenue Water
NWS&DB	- National Water Supply & Drainage Board
OIC	- Officer In Charge
OPD	- Operation and Development
PVC	- Poly Vinyl chloride
SLS	- Sri Lankan Standards
SV	- Sluice Valve
TG	- Tenement Garden
UARL	- Unavoidable Annual Real Losses
UFW	- Unaccounted For Water
UN	- United Nation
UNESCO	- United Nations Educational, Scientific and Cultural Organization
UNICEF	- United Nations Children's Fund
WHO	- World Health Organization